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Improvement Management and Predictive Volume Estimation of Plastic Waste at a Swedish Construction Company

Master's Thesis in the Master's Program Quality and Operations Management

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ABSTRACT

Limited space at construction sites is one of the most common problems leading to low levels of plastic recycling. Therefore, this study aims to identify operational solutions to improve plastic waste management at a single construction site of a Swedish construction company, while also uncovering and enhancing change and improvement processes within the wider organisation. To achieve this, the first objective is to develop a model to predictively quantify plastic waste volumes and the required storage area they occupy to improve waste management planning. The study takes a case study approach with interviews with actors from a large Swedish construction company and construction site observations. Input data required for the model was shown to be readily accessible through Environmental Product Declarations (EPD) provided by suppliers. Consultations with suppliers produced supplementary data for products where no EPD was provided or if the sought data was missing. A scenario analysis showed how choices made by management at the construction site can impact the space required to store plastic waste.

The second objective is to study change and knowledge management at the construction company to facilitate anchoring of the developed model as well as future improvement projects. It was shown that the company took an unstructured approach to most change and improvement efforts. This caused potentially beneficial changes and improvements to hardly leave their pilot project and the relevant knowledge to only be shared by a small network of management staff. Management staff could go out of their way to champion a change within the organisation, however this was mostly fuelled by intrinsic motivation and required much individual responsibility with no guarantee of success. Therefore, different management concepts and frameworks were proposed, most notably, the concept of continuous improvement. Successful use of concepts such as the PDCA-cycle could bring structure to the company's change and improvement efforts shifting their improvements from happening discreetly and disorganised to continuously and planned.

Keywords: Construction sector, change management, continuous improvement, knowledge management, plastic waste, quantification, prediction, space

Contents

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1. Introduction

The consumption of plastic has grown globally over the past decade and is not looking to slow down in the foreseeable future (*Global Plastics Outlook*, 2022a). Furthermore, plastic is contributing to environmental destruction, for example, through resource extraction, microplastics spreading into the environment and greenhouse gases being emitted into the atmosphere after incineration. With the current climate crisis and the EU vowing to be climate neutral by 2050 the greenhouse gas emissions from plastic production and incineration become a major issue (European Commission & Directorate-General for Communication, 2021). In 2019 plastics were responsible for circa 3.3% of the global greenhouse gas emissions making their sorting and recycling crucial (*Global Plastics Outlook*, 2022b).

One of the largest consumers of plastics and generators of plastic waste in Sweden is the construction sector. It is responsible for circa 152 000 tons of plastic waste accounting for 9.4% of the Swedish total (Nordin et al., 2019). Out of these 152 000 tons about 41% were sorted into mixed plastic fractions, meaning they were sorted separately from other products. However, only about 1% was recycled. There are different barriers to improving the recycling rate. For example, plastic waste needs to be sorted in terms of polymer type to make the material recyclable (Ahlm et al., 2021). Analyses of the plastic waste have shown that the main type of plastic waste at construction sites is plastic packaging made of low-density polyethylene, with smaller amounts of installation spill made from a mix of other polymers (Jansson, et al., 2019). This makes it so that while there exists a lot of plastic waste, the volume of waste for each unique polymer (except for low-density polyethylene) is low. The low volume of waste for each polymer type and the limited space for sorting on the construction site is commonly referenced as the reason why sorting is lacking (Ajayi et al., 2015; Hasan et al., 2022; Jansson et al., 2019; Oyedele et al., 2011; Yuan et al., 2011).

In cities, the problem with space is usually exacerbated even further as construction sites are limited to smaller areas and should avoid disturbing their surroundings as much as possible. Congested workspaces can also create a health hazard due to the increased risk of accidents when operating large machines in tight spaces (Kim et al., 2005). Jansson et al. (2019) also states that if congested space becomes an issue, it directly affects recycling as there might not be space for multiple different partitioned containers leading to all waste being discarded in one container. A potential way to mend the issue of limited space would be to predict waste volumes and their required storage space, thereby allowing construction site managers to act on those predictions and adapt their waste management to those space requirements. However, there seems to be limited research regarding the predictive quantification of plastic waste.

When changes need to be made in an organisation, disruption of normal operations should be avoided as much as possible. This is to avoid a potential negative image of the change and a resulting negative attitude towards it. Therefore, it is important to facilitate a smooth transition to not let the change effort fail. This is a challenge in most industries but is especially prevalent in the construction sector due to their often rigid organisational structure and the non-standardised nature of construction sites (Ahlstrand, 2022; Dubois & Gadde, 2002).

Therefore, to equip an organisation to handle changes in regulations and effectively implement improvements, concepts and frameworks from change and operational management can be applied to help the organisation's management to lead those efforts.

1.1 Aim and research questions

This study aims to identify operational solutions to improve plastic waste management at a single construction site of a Swedish construction company, while also uncovering and enhancing change and improvement processes within the wider organisation.

The aim will be reached by answering the following three questions:

RQ1: How can plastic waste volumes be predicted continuously throughout the length of a construction project?

To answer RQ1, knowledge about current structures and processes at the studied construction site must be uncovered. With that knowledge it is possible to gain an understanding of how a waste prediction method can be used at the studied construction site. After having answered how the method can be used, the next question becomes:

RQ2: How is the construction company currently working with change and improvement?

Gaining an understanding of how the construction company currently works with change and improvement will make it possible to understand how the proposed model can be implemented throughout the wider organisation. It will also uncover areas of improvement on the subject, leading us to the final question:

RQ3: Which operations management practices can help the construction company improve change and improvement efforts?

1.2 Boundaries of the study

Limiting the amount of waste generated can be done in the various stages of the lifecycle. This study focuses on the use phase, more specifically on-site sorting, making it a part of the larger product lifecycle context. The study will encompass one Swedish construction company and one construction site with the goal of identifying characteristics and solutions for the specific company and construction site. The characteristics and solutions will however be transferable to a certain extent due to the similarity between construction companies and the nature of project-based organisations.

2. Background

This chapter covers information necessary to understand in which context this study was performed. The construction sector and construction waste will be introduced in that order which should give appropriate context going forward.

2.1 The construction sector

The construction sector is a large presence in society in multiple ways. For one, people depend on it for housing and amenities and are therefore directly impacted by it. It also generates a tremendous amount of economic output, generating about 19% of Swedish GDP in 2021 (Boverket, 2024a). However, both economic output and social impact are dwarfed by the impact the construction sector has on the climate and on the environment. Boverket (2024b) approximates that 21.72% of all greenhouse gases in Sweden can traced to the construction sector, as well as 28 % of airborne particulate and 40% of all waste.

The construction sector is characterised by companies having large and rigid hierarchies, meaning that change and information flows slowly through the company (Ahlstrand, 2022). Adopting changes can often require rigorous effort and considerable time which increases with every actor involved, potentially making changes originating from the top part of the organisation the slowest (Widén & Hansson, 2007). Unlike other large, hierarchical, capital-intensive industries such as the automotive industry the construction sector is characterised by its non-standardisation (Blind, 2002; Johansson et al., 2013; Rundquist et al., 2013). This is due to the project-based nature of the construction sector where most projects are one-offs not only due to the nature of the buildings, but also the nature of the area they are built in, requiring different processes depending on the location. An example of this is how the same company responsible for the man-made island in Copenhagen was also responsible for a pre-school in the outskirts of Oslo and a college in central Stockholm (NCC, 2024).

2.2 Construction waste

The Swedish construction sector, as previously mentioned, generates approximately 40% of the total waste generated in Sweden (Boverket, 2024b). This waste consists of a large number of different more or less homogenous materials such as wood, paper packaging, and inert materials. The total amount of materials recycled from the construction sector in 2016 was around 640 000 tons, compared to the 1.2 million tons incinerated (SMED, 2018). Plastic waste is a large part of the waste generated by the Swedish construction sector, approximately 152 000 tonnes in 2016/2017. Virtually all of the plastic waste ends up incinerated and used for heat or energy (Nordin et al., 2019).

To help tackle the challenge with recycling in the construction sector, Avfallsförordning 2020:614 is an ordinance recently put into place mandating all construction waste to be sorted into at least 6 different fractions, one of which is plastic (Avfallsförordning (2020:614), 2020). This law is intended to facilitate future recycling ordinances tackling the low recycling rate of construction waste.

Furthermore, the different types of plastic waste must be received by the right handler who is able to both technically and economically receive and recover the materials. Different initiatives exist that have the sole purpose of increasing the amount of recycled plastic in the construction sector. It is already the responsibility of producers of plastic packaging to collect and handle the waste from the packaging (Förordning (2022:1274) Om Producentansvar För Förpackningar, 2022). For plastic flooring, there is a company called 'GBR Golvåtervinning' collecting installation spill from all types of floor and walls containing plastics, receiving almost 400 tons every year (Golvbranschen, 2023). With regards to packaging, Enebjörk et al. (2022) showed the feasibility of using small compactors to store plastic waste in the form of bales at the construction sites. Plastic film experiences a lot of sponging when stored as waste, so a compactor leads to reduced storage space required for the waste. The authors claim in their final conclusions that the use of a compactor is "a key factor" to enable recycling of plastics at the construction site, whilst simultaneously facilitating easier handling of the material by waste collectors.

3. Theoretical framework

The theory relevant for this study covers two areas. The first relating to quantification of plastic waste and the second relating to change management and continuous improvement concepts both in general and in the construction sector.

3.1 Approaches to quantifying construction waste

Approximating construction waste can be done through different means, ranging from national waste statistics (Boverket, 2024a), through broad generalised approximations, to, as in this study, detailed quantification for individual product categories. The two studies used for this were Solís-Guzmán et al. (2009) and Llatas (2011).

Solís-Guzmán et al. (2009) presents a model to quantify construction and demolition waste presented as volume of waste (m^3) by floor area of the building (m^2) in the Spanish construction sector. For the total construction waste (VAC_i) the volume is split up into two distinct types based on the apparent constructed volume for a construction item "i". These are the apparent wreckage waste volume (VAR_i) and the apparent packaging waste volume (VAE_i). Construction items are groups of items sharing a common characteristic. For example, there are many different types of electrical sockets, but they all share the characterization of being electrical sockets. The different items also vary in their unit of measurement. For example, concrete is defined in kilograms while hot water pipes are defined in meters.

To then reach the total material volume per area (m^3/m^2), equation (1) is used.

$$VAC_i = Q_i \cdot CC_i \tag{1}$$

Where Q_i represents the quantity of an item "i" in its specific unit (m, m^2, m^3, kg, u) by area (m^2). This variable was obtained by conducting surveys at the construction site by measuring how much of an item is used per m^2. For example, hot water pipes which are measured in meters (m) have a Q_i of 0.21. To convert quantities of an item "i" into volume the conversion coefficient CC_i is used. CC_i is a coefficient that changes depending on which item is being converted and which unit of measurement that item has. The values of CC_i were obtained by estimating a conversion coefficient based on general characteristics for a given item. For example, wooden doors are counted in m^2 with the value of Q_i being 0.15 m^2/m^2. The conversion coefficient then becomes 0.05 m^3/m^2 as the width of a typical door is 0.05 m.

To calculate the apparent wreckage waste volume from the apparent construction volume, equation (2) is used.

$$VAR_i = VAC_i \cdot CR_i \tag{2}$$

Where CR_i is a conversion coefficient to estimate how much of the volume for an item *"i"* ends up as wreckage (breakings, spills, cut-offs or damage). This coefficient was acquired through an Andalusian construction cost database which estimates material loses for the different items observed.

To calculate the apparent packaging waste volume from the apparent construction volume, equation (3) is used.

$$VAE_i = VAC_i \cdot CE_i \quad (3)$$

Where CE_i is a conversion coefficient that states how much of an items volume is packaging. The article does not state how it acquires this coefficient.

While the article by Solís-Guzmán et al. (2009) presents a reasonable model for estimating construction waste, the coefficients used are a bit unclear in the methodology of their acquisition. Firstly, CC_i does have a reasonable method of acquisition for items given with the unit of m^2, however units which are stated in the unit u, meaning that they are simply counted in the number of units, have no explanation for how their conversion coefficient is estimated. Secondly, CR_i is acquired through a Spanish database which may not contain data relevant for the Swedish construction sector. Therefore, a Swedish variant of such a database should be applied or if none such exists then surveys and observations must be used to acquire the coefficient for each individual item studied (see section 4.4). Finally, the article does not state how CE_i was acquired. However, a study by Llatas (2011) applies a similar model for quantification of waste and states that their coefficient for determining packaging waste is acquired by asking the suppliers for a given item how much of it is packaging.

The article by Llatas (2011) also states an additional factor which should be considered when calculating waste volumes, this being the increased volume factor. Most materials undergo some kind of sponging or compression when transformed from the state delivered by the supplier. For example, plastic wrapping used in packaging takes up less volume when being laid out flat compared to if it is scrounged up into a ball. The data for this factor is however also acquired through Spanish construction databases and therefore might not be accurate in a Swedish context.

3.2 Change management, continuous improvement and organisational learning

This subchapter will present concepts connected to change management, continuous improvement (CI) of operations and processes, and organisational learning, both in a general context and a construction industry context. These concepts will be applied in the discussion to strengthen arguments and explain the findings of the study.

3.2.1 General theories

Change management is often viewed as a process where different event, actions and decisions are connected to create and visualise an understanding of how change takes place in an organisation (van de Ven & Poole, 1995). However, as explained by Burnes (2004) there is no clear and applicable approach to change management. Rather, different approaches to change management act more as guidelines that change depending on the context of the change and organisation.

Four general change management approaches

Higgs & Rowland (2005) present four general approaches to change which form two axes (see Figure 1).

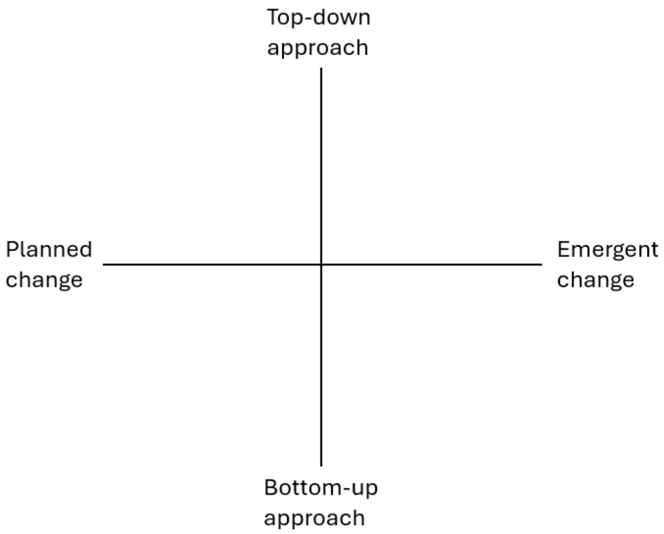

Figure 1: Four general approaches to change (adapted from Higgs & Rowland (2005))

The first axis has the top-down approach on one end and the bottom-up approach on the other (Higgs & Rowland, 2005). A top-down approach entails that initiatives and directives for change come from the top of an organisation, usually the executive branch, and move down through the organisation to the desired department. On the other hand, a bottom-up approach entails that change initiatives come from parts further down in the organisational hierarchy and when effective diffuse to the rest of the organisation (Higgs & Rowland, 2005).

The second axis has the planned approach on one end and the emergent approach on the other (Higgs & Rowland, 2005). The planned approach is characterised by predictability and views the change initiative as a clear process with well-defined steps. It is usually paired with the top-down approach where executives have a clear view of the organisation and define steps in the change process based on that view. On the other side of the axis is the emergent approach, which has emerged as a critique of the planned approached. Critiques of the planned approach have been its focus on small incremental changes and thereby making assumptions such as the organisation always being in a stable and predictive condition ignoring situations such as crises where larger and faster changes are required (By, 2005). This approach is usually paired with the bottom-up approach as workers and team-leaders are often more grounded in their work and are more aware of the problems plaguing their part of the organisation than the higher-up executives. The emergent approach does, however, not have to be of a large and transformative nature but can be used in a continuous process of change and improvement. Thereby, small changes that are deemed worthwhile by workers and team-leaders can be made for a continuous, but unpredictable improvement process, provided they have the autonomy. This phenomenon is also supported by Maslow (1943) in his theory of the self-actualizing man.

Continuous Improvement

These smaller changes, be it from any of the mentioned approaches, often take the role of CI. CI covers a variety of methods and techniques to apply continuous incremental innovation in a focused way (Singh & Singh, 2015). One of the main philosophies of CI is Kaizen, which consists of many different tools and techniques that focus on continually and incrementally improving resource efficiency, improving lead times, and reducing waste. However, this philosophy is mostly used in manufacturing and, while some parts of it can be transferred to other industries not all techniques are generally applicable (Langstrand & Drotz, 2016).

A CI framework that can be applied in a general fashion is the plan-do-check-act (PDCA) cycle (Singh & Singh, 2015). The first step of PDCA, is to create a clear "plan" for an improvement. The second step, "do" is to follow and implement the priorly created plan. The third step is to "check" for deviations from the expected results of the plan. The final step is to "act" on the findings from "check", whether by standardising the improvement, if it gave intended or better results, or by remaking the "plan" if deviations occurred. Afterwards, the cycle starts over by devising a new plan, often based on the results from prior cycles. Important to note is that standardisation does not have to be the end goal. It could also be spreading the results from "check" through to other parts of the organisation.

Continuous learning and Nonaka and Takeuchi's knowledge management model

This segways CI into continuous learning. Continuous learning pertains to continuous gathering of knowledge through for example improvement processes and anchoring these findings into the organisation (Slack & Lewis, 2019). This is a part of knowledge management, and the PDCA-cycle is a form of continuous learning. However, to convert findings from, for example the PDCA-cycle to organisational learning knowledge must be shared and converted. This process is best described by the Nonaka and Takeuchi knowledge model, which introduces tacit and explicit knowledge, and how these knowledge types are shared and converted between each other.

Tacit knowledge is knowledge in peoples' heads, often stemming from experiences rather than text and is usually difficult to describe to another person (Slack & Lewis, 2019). An example of tacit knowledge is explaining to someone how to ride a bike. For someone who knows how to ride a bike it seems obvious but explaining it to someone who does not know is very difficult without a demonstration. On the other hand, explicit knowledge is quite easy to explain and communicate between people. In industry it is often found in the forms of manuals or records.

The process of then sharing and transferring tacit to explicit knowledge, as explained by the model created by Nonaka and Takeuchi, is often seen as a continuous spiral consisting of four steps described below. In this spiral tacit knowledge gathered from experiences is transferred to explicit knowledge for someone else to absorb and thereby gain tacit knowledge (Slack & Lewis, 2019).

- "Socialisation" involves the sharing of tacit knowledge (Slack & Lewis, 2019). Here tacit knowledge is shared through often informal social encounters, usually with colleagues, where knowledge is demonstrated and discussed often creating new insights and complementary knowledge between the people partaking in the discussion.
- "Externalisation" involves the transfer of tacit to explicit knowledge (Slack & Lewis, 2019). This can be done by formalising experiences through turning them into models, metaphors, analogies, concepts, or hypotheses.
- "Combination" constitutes the organising of different sources of explicit knowledge (Slack & Lewis, 2019). This does not involve creation of new knowledge, but rather facilitates a way of absorbing different sources that are similar in content to each other. These collections are then usually shared through databases, blogs, emails, meetings, and similar.
- "Internalisation" is the transfer of explicit to tacit knowledge (Slack & Lewis, 2019). This is the application of the knowledge a person has absorbed after for example reading the priorly mentioned emails or attending the meetings. The knowledge should then be internalised through practice gaining new insights and understandings in the process by creating new tacit knowledge.

Kotter's eight steps

A framework used to describe the steps needed to implement successful change in an organisation is Kotter's eight steps (Kotter, 1995). These eight steps present a general guideline for an organisation to follow and while deviation from them is fine, ignoring steps completely drastically decreases the chance for a successful change effort. The steps are the following:

- "Establishing a sense of urgency". If a potential problem has been examined, its importance and potential for crises should be made clear to the relevant people, thereby establish a fitting sense urgency. The relevant people are traditionally managers, due to Kotter's often top-down approach. These people are then, through their sense of urgency, motivated to bring change and give their support.

- “Forming a powerful guiding coalition”. It entails assembling a powerful group to lead the change effort. Usually this involves some person with power, for example a senior manager, and people with high operational knowledge of the change. The size of the group usually varies depending on the size of the organisation as well as the size of the change.
- “Creating a vision”. It involves creating an image of how the organisation should look after the change has taken place and develop a plan and strategies to achieve that vision.
- “Communicating the vision”. It entails using multiple vehicles to continuously communicate the new vision and plan for achieving it. This can be through meetings, newsletters, workshops, and so on. The guiding coalition should also teach new behaviours through example.
- “Empowering others to act on the vision”. It entails removing obstacles standing in the way for change and empowering people facilitating change. This can involve changing systems and structures in the organisation and thereby encouraging risk taking and new ideas.
- “Planning for and creating short-term wins”, i.e., creating smaller iterative steps for achieving the change and create recognition when these steps are successfully met.
- “Consolidating further improvements”. Wherein declaring victory too soon is described as one of the biggest mistakes. Success should be celebrated, but the vision should always draw on more improvements, especially when the organisation has gotten used to change. Here new changes can also be proposed.
- “Institutionalizing new approaches”. The knowledge and experienced gained should be internalised into the organisation and the means used to achieve success should become the new norm to facilitate future improvements.

3.2.2 Change in the construction sector

Construction projects are characterised by their non-standardised nature, making them diverse and requiring high flexibility to deal with uncertainty and different constructions methods between projects (Dubois & Gadde, 2002). CI is traditionally applied in a manufacturing context where processes are standardised and repetitive (Gieskes & Broeke, 2000). The construction sector is project based by nature where a multitude of stakeholders collaborate throughout the life of the project (Dave & Koskela, 2009). Knowledge can be transferred within and between projects through reassignment of people, using standards, frameworks and reviews after completion of projects (Kamara & Carrillo, 2002). These are generally not part of a dedicated knowledge transfer initiative and do not sufficiently capture or transfer knowledge from the project. Furthermore, assumption that people will transfer learning between projects and that these lessons will organically diffuse to the rest of the organisation leaves the company vulnerable (Kamara & Carrillo, 2002). Generic management methodologies such as just-in-time, lean production and kaizen might require different approaches to be successful in a construction context (Rundquist et al., 2013).

Managers at construction companies are shown to be interested in the concept of CI, but in general do not make use of the tools enabling it (Gieskes & Broeke, 2000). Furthermore, the prevalence of engineers who are more interested in problem solving than “soft” skills such as “improvement” limits the effort put in. An example of a tool enabling CI in the construction industry is that of Serpell & Fernando (1998) *Construction process improvement methodology for construction projects.* They present a methodology for improvement for construction successfully trialled at multiple construction projects. The methodology is an extension of the classical learning cycles with more precise steps and actions that are to be taken. The focus is primarily placed on intra-project learning (i.e., learning within a project) as opposed to inter-project learning (i.e., transfer of knowledge between projects). However, having a structured method for knowledge transfer between projects is paramount for efforts in CI.

4. Methodology

The study consists of five different data collection methods that produce both quantitative and qualitative data. With the qualitative data a quantification model was developed. Furthermore, two different analyses were performed with the aid of both data types and the quantification model, answering the research questions. The analyses are the scenario and implementation analysis and the analysis of change and improvement aspects of the construction company. The connection between the different analyses and the data types are shown in Figure 2.

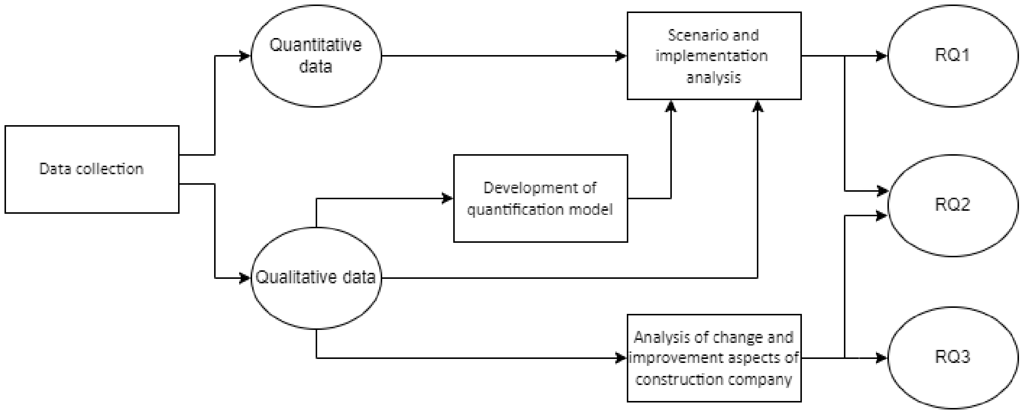

Figure 2: Methodological framework of this study

4.1 Research strategy and design

This study utilises a mixed method research approach using both quantitative and qualitative strategies to reach the objectives.

A quantitative strategy was utilised due to its emphasis on measurement of objective numbers (Bell et al., 2019). This study applied an inductive approach as the data used was of proprietary nature, meaning the structure and contents of the data was unknown beforehand. Therefore, the theoretical framework was developed to fit the data after scrutinisation.

A qualitative strategy was utilised due to its emphasis on words and observations rather than numbers (Bell et al., 2019). Here an abductive approach was taken due to the puzzling nature of the objective. While some parts of the objective can be reached through a deductive approach, a lot of the theory associated with it was an outcome of the research. Therefore, an abductive approach which combines the elements of induction and deduction was utilised.

The research design of this project involved a case study of a single construction site located in Gothenburg, belonging to a large Swedish construction company. As defined by Bell et al. (2019) "The basic case study entails the detailed and intensive analysis of a single case".

4.2 Data collection methods

This section covers the methods used for data collection.

4.2.1 Interviews

Interviews are one of the most common forms of empirical data collection and were the project's main source of qualitative data (Bell et al., 2019). The interviewees were found through snowball sampling which is a sampling method where an interviewee suggests one or multiple new people to interviewee based on the questions of the interviewers (Goodman, 1961). This is beneficial when the population being studied is difficult to access.

Due to the abductive nature of this study, a large knowledge gap initially existed between the interviewers and the interviewees regarding the culture and nature of the studied organisation. Therefore, the interviews were held in a semi-structured approach to offer a guideline from pre-established literature while at the same time being flexible by allowing development of the questions giving more elaborate responses (Bell et al., 2019).

The interviews were conducted either in person face-to-face or through software such as Microsoft teams, depending on the preference of the interviewees. A general interview guide was made and expanded throughout the interview process (see Appendix B). For each interview, a subset of questions were chosen based on the interviewees role in the company and the current status of the study. Furthermore, the guide served as a general outline and starting of point, with more detailed questions as follow up based on the initial answer from the interviewee.

4.2.2 Observations

A visit to the construction site was conducted to observe the operation and question managers on site. People from multiple research projects were present, and the time for the visit was limited to two hours. No full interview was conducted, but the site manager of the project held a thorough review of the project and answered various questions from the participants. A guided walk around the site allowed all participants to observe the construction site and the ongoing operations.

4.2.3 Literature studies

A comprehensive literature review was conducted during the research as is essential to any study (Bell et al., 2019). By studying past literature, it allowed the study to avoid pitfalls as well as inspire ideas for both the methods used and sense making of the collected data and problem.

Mixed literature review methods were adopted throughout the study. At the genesis of the study a systematic approach was adopted to make sense of a few key questions that the project held to get an understanding of the topic (Bell et al., 2019). This was performed by using keywords such as: waste management, quantifying waste, construction, change management, continuous improvement, plastic. The keywords were combined in different ways depending on what literature was sought. The search was performed in various bibliographic databases such as *Scopus, Web of Science and Science Direct*. The literature that was found went through a screening process where at first only title and abstract were scrutinised and if considered relevant the literature was read critically to make sense of the contents and assess the quality.

Critical analysis also often led to snowballing as many relevant references were identified during reading and were used to deepen the background and theoretical framework. This was, however, not always the case due to the limited research on predictive quantification of plastic construction waste.

Further into the project the literature review approach changed from systematic to narrative. The narrative approach works more iteratively where new literature is created through the project narrative (Bell et al., 2019). For example, when conducting interviews, the view on the relevance of already gathered literature may change and require new or a change in keywords. Furthermore, in some cases studies done at the company would be provided by the interviewees if they deemed it to be relevant to the study. Important to note is that this approach is subjective in nature as much of the understanding of the project narrative is based on the perspective of the authors. However, adopting this kind of approach was fitting due to continuous sense making of the project.

4.2.4 Top-down data collection

Product and material consumption data was retrieved from the greenhouse gas emission document provided by the construction company. This was done in a top-down manner by requesting the data from a high part of the hierarchy. The data received were calculations in the form of an excel sheet containing building products for different construction phases, their quantities, the unit of their quantities, the name of their Environmental Product Declaration (EPD) and their total greenhouse gas emissions. However, for one data point the quantity showed two contradictory quantifications for the same product and for some entries their respective EPDs were missing. The contradiction was cleared after speaking with a supplier. How the missing data was acquired is further explained in 4.2.5.

A work disposition plan (WDP) was provided by the construction company, which is a topographical map showing the available areas of the construction-site. This was used in combination with observations to get an understanding of the available space at the site for waste management.

4.2.5 Bottom-up data collection

A bottom-up data collection method entailed searching for sub-contractors and suppliers of the studied construction site. They were sought out regarding missing or unclear data of some materials and products as well as potential contacts at the construction site. This was done by using search engines such as *Google* deploying search terms that were affiliated with the construction company, the construction-site, suppliers, and sub-contractors. The results were mostly articles and blog posts from newspapers, magazines, and companies from the construction sector, which sometimes contained the name of a sub-contractor or supplier. These sub-contractors and suppliers where then contacted by calling their front-desk and being forwarded until a person knowledgeable in the needed data points was reached. The data-points were the amount of packaging per amount of supplied product, knowledge of break-off waste for some plastic materials, dimensions of the product and consumption rates.

Two factors motivated the use of the bottom up approach. Firstly, there was data missing regarding the products such as the amount of plastic packaging in their EPD's. Secondly, contacting suppliers directly gave the benefit of immediate delivery of data as well as potential referral to contractors who might be more familiar with the installation process.

4.3 Qualitative analysis of interviews and observations

The most challenging aspect of qualitative data is its complexity and nature of quickly growing into large amounts (Bell et al., 2019). To approach this rich and complex data the project adapts a thematic analysis to categorise data through coding depending on the aspects of the data. Bell et al. (2019) suggests considering the following aspects: *repetition, indigenous typologies or categories, metaphors and analogies, similarities and differences, and missing data.* Taking these considerations in mind during the qualitative data analysis allows differentiation between relevant and irrelevant information.

This approach is similar to the affinity-interrelationship method which is a workshop approach constructed in a manner to categorise key takeaways into the identified themes (Alänge, 2009). These themes are checked iteratively for whether the takeaways align with them, facilitating the creation of new themes when they misalign and conclusions when they align. The advantage of this method is its comprehensiveness as key takeaways and themes are visualised on a board allowing for clear visibility. The approach took the following form: First, the uncertainties of the collected qualitative data was discussed between the authors based on notes and recordings. Second, the thematic analysis was conducted to categorise the qualitative data. These two steps were iterative and were repeated for each time new data was gathered. This led to that for each iteration, new themes were identified and old themes were altered based on the data. When the data gathering was completed, the identified themes were discussed at length and compared to each other as well as the gathered literature to create conclusions.

The utilisation of the qualitative analysis consists of two parts. First, an analysis on the implementation of the quantification model (presented in 4.4) on the construction site. Furthermore, current structures and processes, enablers and obstacles for implementation and required process changes were identified. Second, an analysis with a companywide context to identify how operational and continuous improvement, and organisational learning takes place at the construction company. By understanding current practices, potential improvements to their processes with regards to organisational learning could be devised.

4.4 Quantification of plastic waste

This chapter describes the model developed to predict space requirements, how the coefficients used in the model can be acquired and how the model will be applied to the scenario analysis. Information and understandings gained throughout the data collection process were used to ensure the model achieves fidelity.

4.4.1 Development of quantification model

The purpose of the model is to approximate the space needed for plastic waste. The model is developed based on the models presented in Llatas (2011) and Solís-Guzmán et al. (2009) and is expanded to allow for different timeframes of a construction project instead of the entire process. It also outputs the total storage area required for the plastic waste. Several data sets are needed for the model development. First, the quantities of products (Q_i) for a defined period of construction, which is used for the calculation of the total volume V_i of the product i used in a defined period (see equation 4).

$$V_i = Q_i \cdot CC_i \tag{4}$$

CC_i is a volume conversion coefficient.

The plastic waste can be split into two types, packaging waste and installation spill. BV_i is the expected volume of installation spill caused by inefficiencies in construction such as spill and form fitting. PV_i, is the packaging waste volume generated by the product i.

$$BV_i = V_i \cdot BC_i \cdot MSC_i \tag{5}$$

$$PV_i = V_i \cdot PC_i \cdot PUVC_i \tag{6}$$

BC_i and PC_i are coefficients which represent how much installation spill and packaging waste (in this case plastic packaging) is generated in terms of the total volume V_i respectively, identically to how the coefficients are presented in Llatas (2011) and Solís-Guzmán et al. (2009). MSC_i and $PUVC_i$ are sponging coefficients for the installation spill and packaging material respectively. These are given due to plastics tendency to take up more space as waste than in its original state. To achieve lower amounts of sponging, construction sites can use compactors to bale plastic packaging to ease storage and transport of the waste, which creates a new sponging coefficient that regards the compacted packaging waste as $PCVC_i$ (Enebjörk et al., 2022). PVC_i is therefore the compacted packaging volume.

$$PVC_i = V_i \cdot PC_i \cdot PCVC_i \tag{7}$$

To then calculate the maximum volume required for the plastic waste storage, a few contingencies were considered. Firstly, during the planning horizon, the waste will be emptied by a waste management company. In other words, the volume is dependent on the planning horizon PH (weeks) and the container emptying interval EI (times emptied/week). Multiplying PH and EI will then give the total amount of times the waste containers will be emptied for the planning horizon.

With the coefficients BV, PV, PVC, PH and EI the maximum volume of uncompressed waste (MVUW) and the maximum volume of compressed waste (MVCW) present during the planning horizon can be calculated using the following two equations:

$$\boldsymbol{MVUW_i = \frac{BV_i + PV_i \cdot (1 - CE)}{PH \cdot EI}} \tag{8}$$

$$MVCW_i = \frac{PVC_i \cdot CE}{PH \cdot EI} \tag{9}$$

The variable CE is a boolean that describes whether a compactor has been used or not. With the two volumes the total surface area required (SR) for plastic waste storage can be calculated using the following equation:

$$SR = \left(\sum_{i=1}^{k} MVUW_i + MVCW_i \right) \cdot SRR + SFC \cdot CE \tag{10}$$

SRR is the surface requirement ratio and represents the surface area required per cubic meter of waste stored. This varies depending on storage unit used and is the ratio between the storage unit's required space in square meters and its total available volume in cubic meters. SFC is the space required for the compactor in square meters.

The calculations for surface area required for plastic waste storage (SR) are summarised as a flowchart in Figure 3

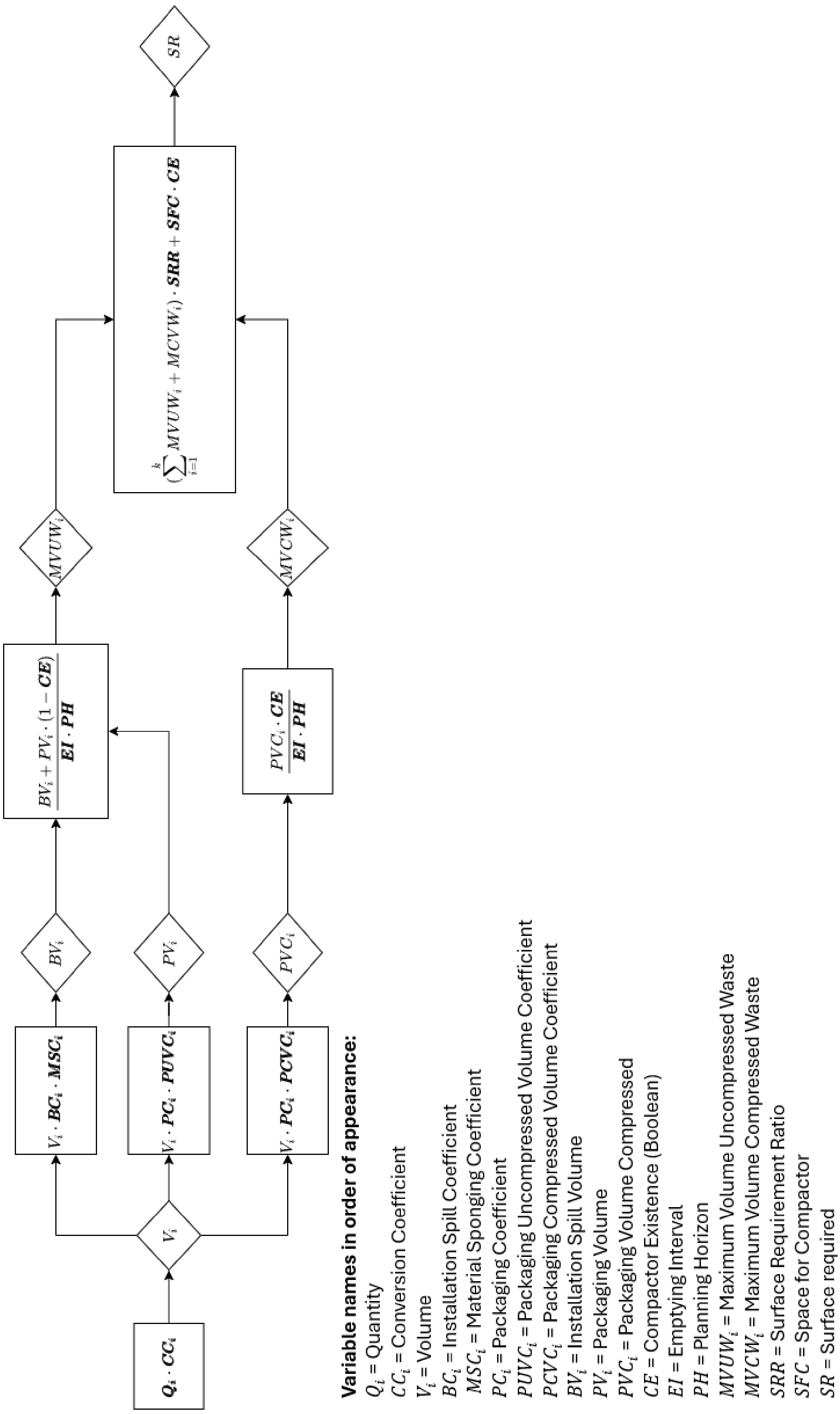

Figure 3: Flowchart describing calculation for SR, input variables are bolded

4.4.2 Determination of coefficients

The goal of the model is to be easily applied at current or near future projects, meaning that the input data must be easily acquired and easily applied to the model. Determining the constants CC, BC and PC is done by turning to and asking the people supplying these products or reading product specifications sheets, varying depending on the product and constant.

Determining CC varies highly depending on which unit the constant is supposed to convert to cubic meters. For example, if a product is given in square meters then converting it to cubic meters just requires the thickness. However, if a material is given in units, such as electrical outlets, then converting it to cubic meters becomes more difficult. In those cases, one can usually approximate a size for one such unit or find the information in product specifications. The following table presents some methods to find CC depending on the given unit of the material or product.

Table 1: Methods of finding conversion coefficient (CC)

Unit	Volume Conversion Data	Method of Acquiring Missing Data
m^3	None	-
m^2	Thickness	Product specification, Consult supplier
m	Cross section	Product specification, Consult supplier
kg	Density	Product specification, Table of densities
unit	Physical dimensions	Product specification, Consult suppliers

BC and PC were determined through consultation with contractors and suppliers, and through data supplied in the EPD for a given product. The EPDs did not contain installation spill and packaging numbers for all products, requiring different approaches for different products.

$PUVC$, $PCVC$ and MSC was approximated from relevant authorities on the subject such as the Swedish waste trade association (Avfall Sverige), suppliers of compactors and from the study by Llatas (2011). PH, EI, SFC and SRR were determined based on waste statistics, interviews and product specifications.

4.4.3 Scenario analysis

Based on the model presented in 4.4.1 a scenario analysis was performed to determine the usability of the model and the impact of different choices done by the construction site. The variables planning horizon *(PH),* emptying interval (EI), space requirement ratio *(SRR)* and space for compactor *(SFC, CE)* are varied to show the impact on the space required to store the plastic waste. The intervals for the variables are based on interviews, supplier data and observations.

4.5 Ethical considerations

To minimise ethical risks and conform to ethical standards, ethical principles have been considered with great care throughout the project. The principles considered are of four areas as presented by Bell et al. (2019): *avoidance of harm, informed consent, privacy, and prevention of deception*.

- Avoidance of harm. As the project involves work with humans, directly interviewing humans, and has results that could impact humans, precautions were taken to avoid all harm. Such precautions include, for example, avoiding disruption or disturbing workers in a potentially hazardous work environment, but also taking care that the potential change proposals do not contain any recklessness and would not put workers in any potentially harmful situations.
- Informed consent. As the project contains data gathering through interviews, all interviewees were informed about the purpose of the study and what their contribution would be before the interview started. They were then asked for consent on whether their given information could be used in this study. Interviewees could also at any time withdraw their consent leading to deletion of any notes or recordings of the interview and that information would not be used in the paper. Furthermore, interviewees could at any time ask to pause a recording of an interview if they wanted to share information, but not have it be a part of the paper.
- Privacy. All interviews were performed anonymously and no person was ever referenced directly. Furthermore, the anonymity extended past the paper, meaning that if a reference to another person was made in an interview this reference was always made anonymously.
- Prevention of deception. To avoid deception, every interaction has been kept truthful, sharing all information that would be ethically correct to share. Furthermore, the identities and roles of the authors were shared to all participants to keep it transparent and be presented as the responsible figures of the project.

5. Results

The results of the study are split into three distinct categories. The case description, describing the practices for waste management at the construction site; change management, describing how change works in relation to waste management efforts; and finally, the quantification of plastic waste, where data for the different products are presented along with the surface required *(SR)* to store the plastic waste as output of the model.

5.1 Structures and practices of the construction company

The investigated construction project is a multi-story wooden building, currently being constructed by a large Swedish construction company. As of this report, the construction is in its later stages working on interior.

5.1.1 Flow and organisation of waste at the construction site

Plastic and other materials enter the construction site on delivery from the respective suppliers, and waste leaves the site with the waste management company. Plastic waste is generated on delivery of materials and products in the form of packaging and later inside the construction site in the form of both installation and packaging waste. The waste generated during the construction is gathered by the respective workers and transported to a central waste collection area for on-site sorting. There are six containers for different types of waste in accordance with Avfallsförordning (2020:614), (2020), one of which is plastic. The space allocated for each container is given in the WPD. Ensuring the workers compliance with the sorting requirements is up to the respective team leaders.

The construction site made use of a compactor to compact plastic film used to protect wooden beams. However, the compactor used was deemed too small and the waste management company was unable to provide a larger machine, leading to low use and subsequent removal of the compactor.

The separation of plastic waste at the construction sites has gone through changes recently. Plastic film was previously sorted separately from other plastics due to the sorted material being valuable and recyclable. Now, however, the construction company only mandate the separate collection of all plastic waste as a single mixed fraction in accordance with Avfallsförordning (2020:614) (2020). The mixed plastic waste is then further sorted by the waste management company. The construction company has a framework agreement with the waste management company, making use of their services on most or all projects. The waste containers are emptied by the waste management company upon request of the manager responsible for waste at the construction site.

5.1.2 Company organisation

The nature of the construction sector is to be project based, and the construction company does not break the mould in this regard. The project has a project leader who is responsible for all operational aspects of the construction, including waste management, and is working with a high degree of autonomy. The project leader can delegate the responsibility for waste management to subordinates, and there are experts assigned to each project whom the project leader can consult regarding quality and sustainability (KM). However, the project leader keeps ultimate authority on the subject. Meetings about waste takes place every second week with relevant managers present.

The construction company hires subcontractors to do the actual construction at the construction site. The subcontractors have their own team leaders whom they report to and build only a specific part of the whole structure. Different subcontractors are used for different aspects of construction, and employees from the subcontractors far outnumber the employees from the construction company at the construction site.

The project follows a process chart containing guides, steps and traffic lights (points where certain criteria need to be fulfilled before proceeding). The project gets requirements from the construction company, the customer and the project definition/guidelines. Requirements related to waste management from the construction company take different forms and are generally effort based rather than result based. For example, the requirement to sort a single plastic fraction does not come with goals for how much should be sorted. There are also semi-mandatory requirements the project must adopt a certain number of, called “responsible workplace”. These are not only related to waste management, but also other responsible practices. Goals for what percentage of waste is allowed to be mixed, combustible, inert, and landfill are set by the construction company, with follow ups quarterly to ensure compliance by the different projects. Statistics on responsible workplace and waste for the different projects is used to try and inspire competition among the projects.

5.2 Change management and organisational learning in the company

The construction company takes initiatives to improve the operations at their construction sites. However, these are met with multiple challenges which will be presented in this subchapter.

5.2.1 Pilot projects

The company has ongoing improvement initiatives related to waste at multiple sites. These initiatives are usually in the form of pilot studies initiated by Quality and Environment specialists (KM) or by project leaders for their respective projects. There is currently an ongoing initiative at the studied construction site where the construction company has made an agreement with a local wood supplier. Through this agreement, the wood supplier has committed to take back wood used in temporary constructions at the construction site. The wood supplier then sorts the collected wood themselves and place it back in the market. The construction company has a dedicated bin where wood from the temporary constructions should be placed. New temporary constructions should then be built from the wood of old temporary constructions if the required material is available. Another change/improvement tried on the construction site is the use of compactors for plastic packaging used to cover wooden beams. The results from these types of pilot projects are then evaluated by the KM and the network of KMs, or by the project leaders depending on where the initiative started.

The diffusion or spreading of learnings throughout the organisation gathered from pilot projects is usually minimal or bound to only certain groups. This is partly due to different construction projects being unique or not relevant to each other, making a lot of improvements and learnings case specific to their respective construction site. The organisation, therefore, partly mirrors these aspects and lets most learning take place organically, by letting results and conclusions from changes and improvement efforts spread through word of mouth. For example, if a KM conducts a pilot project and attains some learning after evaluating the results they would discuss these learnings with their colleagues. Some of these colleagues would also be KMs and might then apply these learnings to their own projects if they seem fitting. This could lead to valuable learnings snowballing and spreading through the organisation, however reality shows that they are usually kept within a small bubble of different managers and KMs.

5.2.2 Championing

A way learning is spread throughout the construction company is through championing. If a person at the organisation believes that an improvement would be applicable to multiple construction projects this person could champion this idea. However, this requires a lot of initiative and personal commitment, as well as no guarantee that it is going to be implemented.

Furthermore, there is no clear incentive for the person doing this other than intrinsic motivation. For example, there could exist a great improvement for sustainability, but if no one has intrinsic motivation for it, it might fall through the cracks as explained by the following quote from a sustainability coordinator:

"It is very much up to personality, some project leaders care little for sustainability whilst others believe it to be very important and have a passion for it".

If the championing is successful, then the learning from the improvement could be added as or change a guideline in a "master" document similar to a process chart that is used and followed by all projects in the organisation. The improvement could also be implemented into responsible workplace as an elective practice for construction projects.

5.2.3 Executive change efforts

Efforts to implement change taken from the top of the organisation have been present at the construction company. Primarily there are two examples. One successful and one less successful. The successful change involved a change in the Swedish law, requiring construction companies to sort their plastics into one fraction. Adherence to this law was performed quickly by the construction company by emphasising high urgency. The less successful change involved standardisation of concrete to reduce the number of different types of concrete used in the company's construction of standardised housing. This change effort did not display the same level of urgency as the first case, and while the company did force their managers to present their progress for this effort the number of different concrete types did not get reduced at the expected speed. It is still believed that the change effort will eventually be "successful", however when that will be is not clear. The difference between the two cases has been described as a difference in required effort. Where the first case was a comparatively "easy" change to implement while the second case was more difficult and offered a hard challenge for managers.

5.2.4 Challenges in the workforce

Issues exist with implementation of new practices due to the nature of the workforce. The construction sites employ many different subcontractors with different nationalities and language knowledge. Getting all of the workers from all the subcontractors to know how to follow each procedure and sort each thing correctly with the current scheme is difficult.

"There are a lot of people working on a construction site. Not all of them speak Swedish and it is difficult to communicate what is to be sorted where."

"It is difficult to reach out with information just with text or a start meeting considering how many subcontractors are working at the construction site"

A further example is the limited buy-in during the scheme to reuse wood for temporary structures. Even when the scheme was known at the site, it still saw limited application by the relevant contractors leading to no wood being sent back to the supplier.

Important to note however, is the flexibility of the on-site workforce. If problems arise, someone does not know how to proceed with their work, or something just "feels" inefficient workers try to come up with solutions themselves or save that work for later.

5.3 Quantification of plastic waste and space requirements

This chapter presents the application of the model introduced in 4.4, presents the input data gathered during the study and shows how coefficients can be calculated/found for two different products. Finally, scenarios are presented that show how different choices available to the construction site impacts the space required for plastic waste.

5.3.1 Product coefficients

The coefficients for 17 different products used in the façade stage of construction were identified in this study as a proof of concept (see Table 2).

Two example products and how their respective coefficients *(CC, BC* and *PC)* were gathered is presented below. Important to note is that while the coefficients are unique, the product itself is not, meaning that these coefficients can be applied to multiple projects, provided the product is the same. The metadata for theses coefficients can be found in Appendix A.

The first product, *Glass*, is a product provided in prefabricated units. The amount of used plastic packaging is provided in the form of square meters of plastic film per installed square meters of product. The shipping was done in batches of 4 units at 18 m^2 each, with a total amount of packaging at 42 m^2 for the units. As is presented in Table 2, CC_1 is 0.4 as the thickness of one prefabricated unit is 40 cm. BC is in this case 0 as the product is made from glass and steel and therefore does not have any plastic installation spill.

The product *Bricks* comes covered in plastic film, similarly to *Glass*, and is declared at 0.4872 kg/tonne of shipped goods in its EPD. With a density of 1662.5 kg/m^3 for these clay bricks and a density of 925 kg/m^3 for low-density polyethylene a PC of $9.61 \cdot 10^{-4}$ can be derived. As is presented in table 2, CC is 0.0006 which is derived from its density as the product is given in kg. BC is 0 as the product is made of clay.

$PUVC$, $PCVC$ and MSC are coefficients that are not unique to any one product. The sponging for packaging $(PUVC)$ was taken from Avfall Sverige (RVF Utveckling, 2000). Its value is the same for all soft plastic packaging (including plastic film) in closed medium sized containers. The sponging coefficient for soft plastic packaging processed with a compactor ($PCVC$) is measured by weighing and measuring a compacted plastic bale but was here approximated to have a value of $PCVC$=7.7 based on one manufacturers product specification (Wastecare Corporation, n.d.).

As for the sponging coefficient of materials that are not packaging (MSC), values have been taken from Llatas (2011).

*Table 2: Products and Variables. * Indicates missing, incomplete, or low-resolution data*

Product	Unit	Q	CC	BC	PC	$PUVC$	$PCVC$	MSC
1 Glass	m^2	2400	0.4	0	0.00182	37	7.7	-
2 Plastic film	m^2	19897	0.0002	0*	0.06595*	37	7.7	2
3 Brick	kg	67950	0.0006	0	0.00088	37	7.7	-
4 Glass wool	m^3	636	1	0	0.00057	37	7.7	-
5 Steel	kg	1272	0.00012	0	0.00052	37	7.7	-
6 Wood	m^2	315	0.016	0	0.00011	37	7.7	-
7 Fire retardant cladding	m^3	82	1	0	0.00046	37	7.7	-
8 Wood	m^3	455	1	0	0*	-	-	-
9 Steel	kg	23803	0.000127	0	0	-	-	-
10 XPS insulation	m^2	337	0.0033	0*	0*	-	-	2
11 Gypsum	m^2	3447	0.0095	0	0.00414*	37	7.7	-

12 Glass wool	m^2	2979	0.034	0	0.00103	37	7.7	-
13 Gypsum	m^2	1089	0.0125	0	0.00388*	37	7.7	-
14 Plastic film	m^2	630	0.003	0*	0*	-	-	2
15 Wood	m^2	195	0.023	0	0.00147*	37	7.7	-
16 Stone	m^2	49	0.01	0	0*	-	-	-
17 Wood	m^2	315	0.015	0	0.00011	37	7.7	-

5.3.2 Scenario presentation

The scenarios that are applied to the model vary depending on the following variables: The dimensions of the container giving the space requirement ratio *(SRR),* planning horizon *(PH)* and emptying intervals *(EI).* These variables are based on realistic figures and will serve as basis for the scenario analysis to show how different choices made by the construction site can impact the required space.

For this case, which will be called the "default case", a planning horizon *(PH)* of five weeks has been used with an emptying interval *(EI)* of 2. The waste container is a standard 10 m^3 waste container with a surface area of 6.27 m^2 giving an *SRR* of 0.69. This is the type of container used at the construction site for plastic waste. Q_i for each product is provided by the construction company, totalling products used for the construction of the façade. In this case the use is assumed to be linear over the planning horizon of five weeks. Finally, the compactor takes up 13 m^2. With all the data gathered in table 2, the model generates the output presented in Table 3 below:

Table 3 Maximum volume of waste generated and surface required (SR). MVUW: maximum volume of uncompressed waste, MVCW: maximum volume of compressed waste.

	With compactor	Without compactor
MVUW (m3)	0	10.16
MVCW (m3)	2.11	0
SR (m3)	14.82	7.01

Furthermore, to study the potential effect of different choices available to managers at the construction site, outputs have been generated for varying values of the constants *PH, EI* and *SRR* with and without using a compactor. Only one constant is being varied at a time with all other constants staying the same as in the example case above.

With *PH* varying between 1 to 7 weeks, *SR* varies as shown in Figure 4. The difference in *PH* has a much higher impact on *SR* when not using a compactor versus when using one. When *PH* is more than two, using a compactor becomes less favourable than not using one. Furthermore, when a compactor is in use changes to *PH* barely have an effect as *SR* quickly becomes asymptotic, moving towards 13 m^2 which is the space allocated for the compactor.

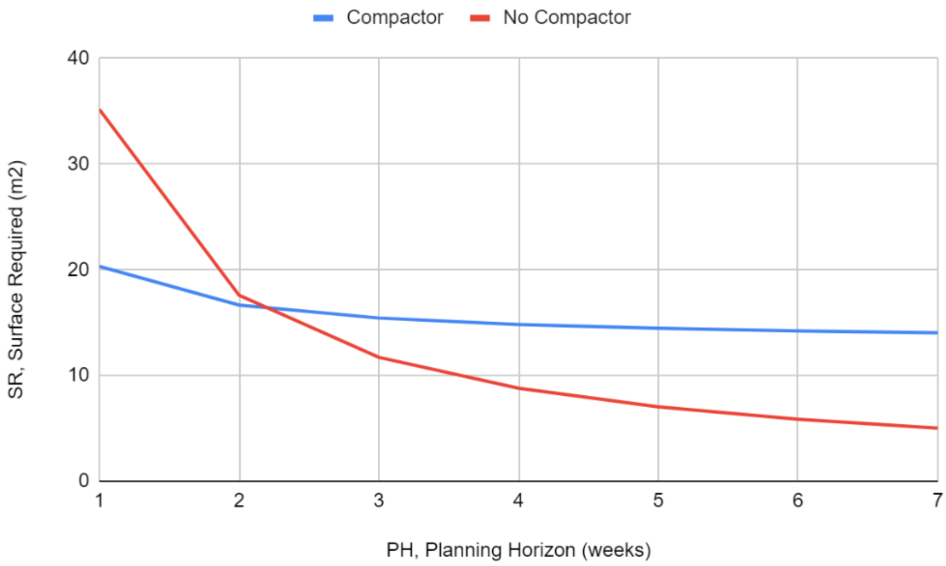

Figure 4: Surface required (m^2) depending on length of planning horizon (weeks) with and without the use of a compactor

For *EI* varying between 0.5 and 3 times per week *SR* varies according to Figure 5. Similarly to Figure 4, the intersection between compactor and no compactor happens early in the interval, with an asymptote in *SR=13* when a compactor is used.

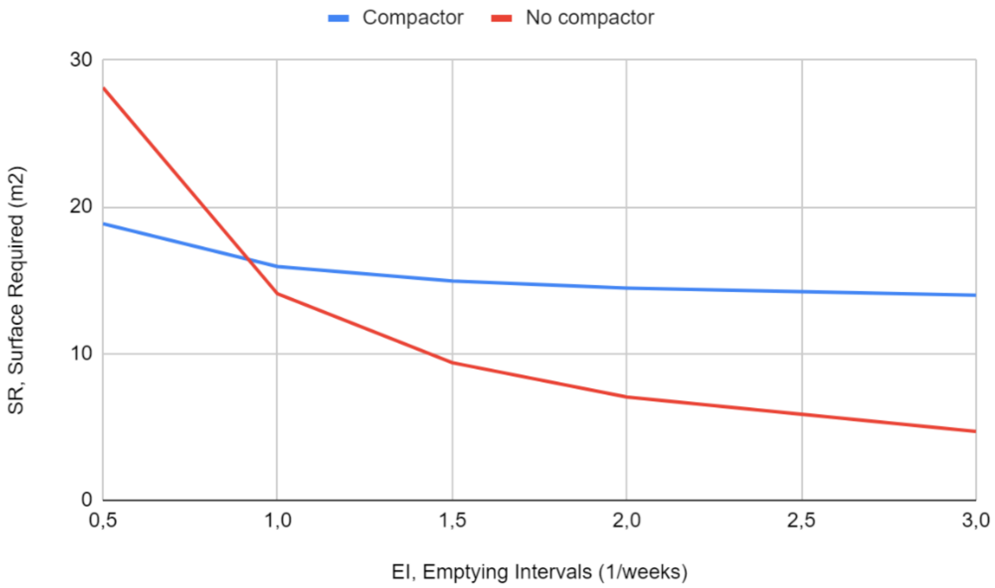

Figure 5: Surface required (m^2) depending on frequency of emptying intervals (1/weeks) with and without a compactor

For an *SRR* varying between 1.47 and 0.47 m^2/m^3, SR varies according to Figure 6. The waste management company can provide 0.66 and 1 m^3 bins as well as 3, 10, 20 and 35 m^3 containers. These container sizes are marked in Figure 6. *SR* varies linearly depending on the size of the container and, for the default case, using a compactor always has a higher *SR* than not using one.

However, this would not be the case for all values of *PH* and *EI* since decreasing *PH* or *EI* would lead to an intersection appearing. As can be observed in Figure 6, larger containers have a lower *SRR* than smaller ones. However, it is important to note that the containers themselves take up space, meaning that a container with a volume matching *MVUW* or *MVCW* should be used instead of choosing one with the lowest *SRR*. In the default case this would be a 10 m^3 container for *MVUW* and a 3 m^3 container for *MVCW*. Therefore, the *SRR* is not the only variable to consider when making decisions regarding which container to use.

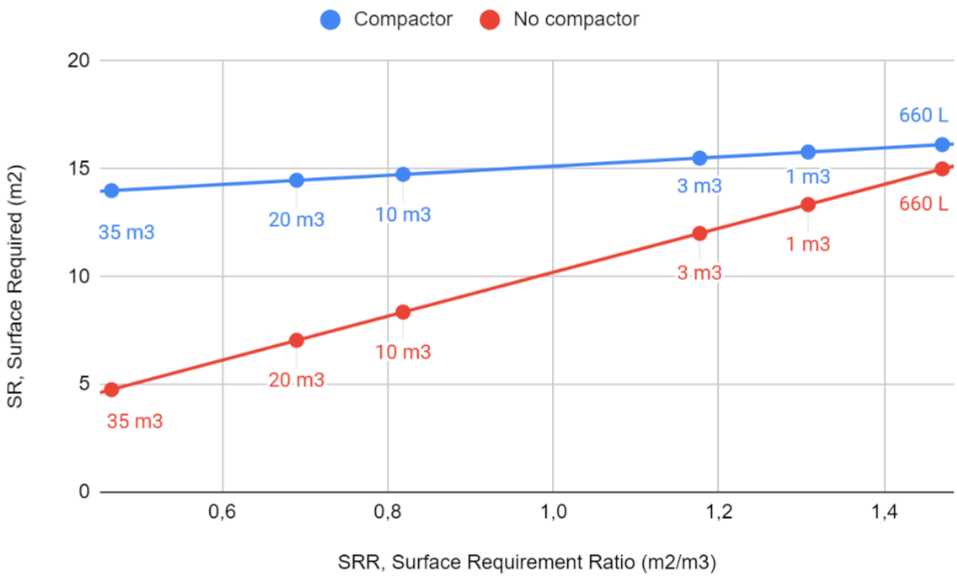

Figure 6: Surface required (m^2) depending on the surface requirement ratio (m^2/m^3) with and without a compactor. Dot indicates available size of container from waste management company.

6. Analysis and discussion

This chapter will discuss the characteristics of operational improvement and organisational learning present within the construction company. Furthermore, implementation of the model will be discussed to gain an understanding of how the construction company could go about implementing the model at the studied construction site and how they could anchor it within the larger organisation. Finally, the methods deployed during the study will be discussed along with the potential for further studies.

6.1 Operational improvement and organisational learning

Continuous improvement (CI) and organisational learning are concepts presented in 3.2, and will serve as a basis for discussion within this subchapter. Change can originate from different parts of the organisation and are here split up into bottom-up and top-down.

6.1.1 Bottom up

The literature review showed the limited application of CI and organisational learning practises in the construction sector. Similarly, the studied construction company has practices that align with certain aspects of the practices presented in the literature, but fails to adopt them as a whole.

One way in which the construction company complies with the concepts of CI is giving a lot of autonomy to its workers and subcontractors to allow for flexibility and on-site problem solving. This is one of the first prerequisites for concepts such as Kaizen and takes a bottom-up approach for emergent change. Workers at the operational level encounter a problem, solve the problem, and thereby gain tacit knowledge of how to solve a similar problem in the future. Furthermore, this tacit knowledge gets enhanced further due to socialisation from the team-oriented work at the construction site, described as intra-project learning by Serpell & Fernando (1998). This lays great groundwork for CI; however, the tacit knowledge is never converted to explicit knowledge due to a lack of knowledge management. Subcontractors come and go from construction sites on a regular basis and there is no evidence of them sharing their knowledge with staff from the construction company such as site managers and KMs. This also presents a problem for knowledge transfer to subcontractors as their sporadic nature and potential language barriers make processes such as internalisation inconsistent and maybe even a waste of time. An example of difficulty with guiding the subcontractors would be the scheme of reusing wood from temporary structures. Furthermore, use of subcontractors hinders knowledge transfer through staff reassignment between projects due to the workers not being directly employed by the construction company. Nevertheless, tacit knowledge could still be transferred to the construction company staff through socialisation. However, even then there are no protocols facilitating externalisation of this tacit knowledge as required by CI. The lack of structure ends the cycle of improvement prematurely, losing the company valuable learnings. An unstructured exception to the premature end of the improvement cycle is the use of championing to externalise knowledge.

For example, if a site manager comes across knowledge they would find very useful, they could champion it within the organisation by externalising, combining and finally diffusing the knowledge through internalisation with tools such as responsible workplace. However, due to this process being unstructured it has no guarantees of being successful. Therefore, while this process takes an emergent bottom-up approach, it is not continuous nor planned. Rather it is discreet and disorganised.

6.1.2 Pilot projects and top down

A different way the construction company works with operational improvement is through their pilot projects. These pilot projects are similar in structure to the PDCA-cycle which should facilitate both CI and organisational learning but differs slightly leading to them not fully realising those concepts.

Firstly, the plan step is compliant with the PDCA-cycle as presented by Singh & Singh (2015), with directives for the plan coming from either the construction company, the client, or a KM. Secondly and thirdly, both the do and check steps are compliant, with the KM taking the responsibility to make sure that the plan is followed and that continuous efforts are made to check whether goals are met. Finally, the act step is where the approach of the pilot projects falls short of the PDCA-cycle. For this step, the KM records the results of the project and makes notes of whether it was successful or not. In the unsuccessful case an analysis of why the results did not meet the goal is performed. However, there is often no new plan created from these results, handicapping the CI. This can be due to the client's construction project being finished, and therefore not gaining further directives. It can also be due to the construction company simply not giving further directives as well as the KM not wanting or not being able to continue the cycle. Furthermore, it is not only the aspect of CI which differs in the act step, but also the continuous learning. Like the case of knowledge transfer of subcontractors, the tacit knowledge gathered through the pilot projects is only shared within a bubble of KMs and site managers with it rarely being externalised and thereby not anchoring the findings of the pilot projects in the organisation. However, for longer projects, the PDCA-cycle might be effective to facilitate intra-project learning where flexibility is a lot higher allowing the act step to be used effectively. It could also be tailored more towards the specific project like how Serpell & Fernando (1998) present their tools for CI at construction sites. Important to note however, is that as previously mentioned, subcontractors make up a majority of the workforce, meaning that there is no guarantee that learnings will stay for future projects, nor even the whole project they were conceived in.

Top-down approaches for change have also taken place through the executive efforts. While one effort was successful, and one was less successful seemingly due to the effort required to make the changes some change management insights can be made by applying Kotter's eight steps (Kotter, 1995). For example, the sense of urgency might not have been the same for the two cases. A change in the law where the construction company can become liable to fines if the law is not followed naturally establishes a strong sense of urgency, while standardisation of concrete might require a lot more convincing to start the change effort. A further aspect which created urgency in the first case was the competitive use of waste statistics leaderboards. Different construction sites were pitted against each other to lower their mixed, landfill and inert waste. The second change effort had not facilitated short-term wins through for example a checkpoint system where progress is checked regularly to see if the plan is staying on track or if it needs revisions. Thereby, the slow progress was noticed quite late. If this had been noticed earlier perhaps the change would have been delayed less. This can also be compared to the first case where waste fraction statistics are checked regularly by management both on-site and executively to be compliant with the law.

6.2 Model implementation.

Several aspects are of interest when the implementation and use of the quantification model is to be considered. This chapter covers the practicalities of implementation on the given construction site, how it can be adopted by the whole organisation, what benefits using such a tool could bring to the organisation, and an analysis of the scenarios presented in 5.3.2.

6.2.1 Usability/ease of use

The application of the model has shown that the needed input data for the model exists and can be collected by the construction company with the same methods as in this study. Furthermore, these methods should be more easily applicable by the construction company due to easy access to their own data as well as their connected network of suppliers and subcontractors.

To begin with, EPDs are a great tool and could function as the foundation for the data needed to implement the quantification model. Data on packaging existed for most products in their respective EPDs, but installation spill was missing for a lot of the products. Acquiring data that is missing or inaccurate in the EPD can be done through consultations with subcontractors or suppliers of the products or materials, which was done for a several of the data points in this study. Identifying the percentage of installation spill requires input from subcontractors who are closely familiar with the installation process whilst packaging can be identified through suppliers or subcontractors. CC_i must also be identified for each product but exists outside the confines of the EDPs since CC_i is a construct of the model. The acquisition of CC_i proved simple for all products using the methods shown in Table 1.

When the input data has been acquired for all the products it should remain constant due to the standardised nature of a lot of construction materials and products. Efforts to maintain a database with the coefficients for each product should therefore decrease as time goes on and more projects implement the tool due to reoccurrence of products. This data could be acquired by letting a KM take a central role in data gathering during trial runs or pilot projects. However, since the KM is only loosely attached to the construction sites, processes for data gathering should be implemented within the project organisations to ensure longevity.

Application of the model in the study was done using Q_i from past consumption instead of predicted future consumption as is intended in the model. Instead, *PH* of different lengths were used to account for different consumption rates. For practical implementation, methods of predicting future consumption needs to be developed and used alongside the model for efficient use. These predictions could possibly be performed by permanent construction site staff supported by the subcontractors.

As for the usability of the model at the studied construction site, the model could certainly be applied. However, the situation on the site is deemed not to be space limited or produce waste in volumes large enough. Therefore, the implementation of the quantification model is not warranted in its current form at the studied site. However, this does not diminish the potential impact of the model in its current form on sites with more plastic waste or less space.

6.2.2 Anchoring in the organisation

In this study, multiple avenues for how new practices can make their way onto projects within the company have been identified. These are mandates, semi-mandatory guidelines (Responsible Workplace), organic diffusion by KM and project leaders, and customer demands. New practices can be trialled with for example a pilot project and then be pushed out through one or multiple of these avenues.

The necessity to predict plastic waste volumes is dependent on the situation at the given projects, as construction sites with plentiful space naturally are not concerned with it. Therefore, criteria for the project size or waste storage space should accompany mandates to ensure the practice is only applied in situations where the benefits outweigh the burden. Placing the practice within *Responsible Workplace* would similarly lower the risk of overuse since each project can choose what practices to adopt. It would however run the risk of getting ignored by the projects due to its voluntary nature.

Organic diffusion is something the company seemingly favours, although it appears to be limited outside of the networks of KMs when it comes to waste management related improvements. The motivation to improve waste management practices is currently connected to the overarching goal to limit the mixed/landfill fraction, and improvements initiatives usually depend on the initiative and intrinsic motivation of the project leader. Increased external motivation could be achieved by including stricter waste related goals in project guides or customer demands. However, including the use of the quantification model in project guides or customer demands is not realistic. Therefore, the model should be provided as a tool for projects in their attempts to reach the waste related goals originating from these project guides, customer demands or both.

For the first practical use of the model, conducting a pilot project is probably the best course of action. It can thereby be applied to a fitting project, for example one where space is supposed to be very limited, and have its usefulness evaluated. Using a change concept or framework such as the PDCA-cycle or Kotter's eight steps would be beneficial as well. The PDCA-cycle could be used to evaluate and make changes to the model and some variation of Kotter could be used to correctly implement the model. For example, Kotter's first step of convincing the relevant people of the use of the model should be the start of the project's primary effort. Furthermore, creating a vision and clearly communicating that vision is important to build trust and facilitate use of the model. Finally, a focus on short-term wins with regular checks on if the model is achieving its goals cannot be ignored to know if it is performing as expected and if not, quickly find out why.

6.2.3 Impact of scenario choices

The scenarios presented in 5.3.2 show how different choices of factors can impact the required space and thereby how different solutions might be preferable depending on the situation.

PH and *EI* impact *SR* in a similar way due to them being the factors in the denominator for *MVUW* and *MVCW* (see Figure 3). Therefore, if for example *PH* is lowered by half the resulting higher *SR* can be compensated for by doubling *EI*. This approach does, however, have its limits. This is due to *PH* in the scenario analysis being directly tied to consumption rates. *PH* would in reality not impact consumption rates as Q_i would most likely increase in line with *PH*. Consumption rates are therefore quite inflexible since keeping the construction on schedule takes precedence over waste planning. *EI*, on the other hand, offers more flexibility but has an upper limit where containers cannot realistically be emptied more often.

One way to allow even further flexibility for *EI* is the use of different containers. If for example *EI* is high a larger container could be used to decrease how often the container must be emptied. However, this requires there to be enough space to accommodate a larger container to allow ample room for trucks to pass through, both for construction equipment, but also to accommodate emptying of the containers.

In situations where *SR* is high despite the use of both high *EI* and large containers compactors become useful. This could for example be in scenarios with high Q_i. In the scenarios presented in 4.3.2 compactors were not useful except when either *PH* or *EI* were at the considerable low levels of 2 weeks for *PH* and slightly less than 1 for *EI*. However, this might not always be the case, especially for larger construction projects. In these cases, a compactor lowers the sponging factor of for example plastic film from 37 to 7.7. Then, according to the model, the only drawback would be the space required by the compactor. The space required in the model is based on the compactor being stored in a container, but different solutions requiring different amounts of space could be devised for any given construction site. It is important to note that the size of the compactor must be proportionate to the volume of waste generated, which was claimed to be the main reason for the studied construction site removing their small compactor. This creates a dilemma where the compactor cannot be too small as that diminishes its usefulness, but it can also not be too large if space is severely limited. Therefore, compactors have a strong potential to be useful, but they must fit the requirements of the construction site where they are applied.

While the different variables of the scenarios can present dilemmas, the variables can also compensate for each other's shortcomings. Therefore, understanding the impacts of these variables and how they relate to the requirements of a construction site can help site managers understand the choices they have and how they impact their operations.

6.3 Methodology and data collection

Semi-structured interviews were the right choice for this study by facilitating the flexibility to explore interesting threads during interviews making them dense and rich with information. However, when it came to the method of finding interviewees, namely snowball sampling, some issues arose. The goal was to identify and interview staff from different departments and with a mix of positions and roles. However, the snowball sampling kept leading back to the same few people working specifically with sustainability. Getting hold of operational staff who are very busy proved difficult. Due to this, insights into the operational aspects of the construction site as well as the construction company could possibly have been expanded further upon. For example, there were a lot of uncertainties regarding the operations of subcontractors, but with more efficient sampling these uncertainties could have been cleared gaining further insights. Nevertheless, a lot of rich information was still gathered, and distinct conclusions could be made.

The choice for a bottom up approach stemmed from the difficulty with getting access to operational staff. Searching the internet for suppliers and calling them to get approximations of the missing data was not the originally intended data collection method but became necessary due to the incompleteness of EPD data and delays in obtaining certain data. On a different note, contractors could have been interviewed at the construction site to get their approximations of installation spill and packaging. This would probably have been very time consuming and possibly invasive, thereby making the method in which the suppliers and subcontractors were contacted valuable. Worth noting is that not all suppliers contacted led to accurate and high-resolution data along with the process being very time consuming. Furthermore, there is no standard between the suppliers regarding how they report on the data since the data is coming from many disconnected streams. This contrasts with the top-down approach where data is presented in a clean and neat format and the information is standardised making it generally easier to work with.

6.4 Further studies

This subchapter aims to highlight some possible future studies and developments that can use this study as a springboard.

6.4.1 Reliability and testing of model

As there has not yet been a practical implementation of the model it is unclear whether it will generate an accurate output and whether the input data is reliable. Further studies where the model is applied at a construction site in tandem with sampling analyses of the mixed and plastic waste should be performed to compare the output of the model to real waste volumes. Furthermore, installation spill data could be studied through observations of workers in the early stages of, for example, a pilot study to get an understanding of how accurate the reported data in the EPDs are. Values for certain coefficients such as sponging and volume conversion (CC) are expected to be easily identified and should be measured at the actual construction site where the pilot study is performed.

As for the research strategy of such further studies a deductive strategy is highly recommended. Applying an inductive strategy for the quantification was the natural choice for this study due to limited previous knowledge, the limited literature base existing on predictive waste quantification, as well as not having product data nor knowing the structure of the data when planning the study. However, with the model now having been developed, using it as the grounds for future studies and developing deductive methods around it should enable accurate testing of the model as well as greatly expanding the quantitative findings.

6.4.2 Expansion of quantification model

The developed model has been used to quantify plastic waste as one mixed fraction. However, it would be possible to adapt the model to accommodate for different plastic types without much difficulty. This was not done in this study due to the construction site sorting all its plastic as one fraction. If a construction site desires to sort plastic in multiple fractions, data for the different plastic types could be found in a similar manner as how it is presented in the methodology, namely through EPDs or direct contact with suppliers.

Furthermore, the model could be used for other types of waste than plastic. Both Llatas (2011)'s and Solís-Guzmán et al. (2009)'s models are used on different materials such as concrete, steel, soil, etc. Therefore, if the relevant data is gathered, predictive quantification of all types of waste could be done with the model developed in this report.

7. Conclusion

This study sets out to assist the construction sector with plastic waste management in space limited scenarios and examine how such an improvement could be applied to a construction company.

To do so, a plastic waste quantification model was developed based on the quantitative data that proved available during the construction project. This model can be used by the construction site management to predict plastic waste volumes and the surface required to store it from data available to the construction company. Effort required to acquire the data ranged from easy for most data points to time consuming (especially for plastic installation spill). Nevertheless, data collected in this study can be reused together with the model in later construction projects. The scenario analysis showed how choices by management can impact the space required to store plastic waste, allowing them to make educated decisions.

The potential for spreading the model through the construction company to other projects was also assessed, based on qualitative input from interviews with company staff. Results show that such spreading can be done through multiple, already existing, avenues. The most promising avenues are semi-mandatory mandates (Responsible Workplace) and organic diffusion by KMs and project leaders. Both avenues facilitate voluntary use of the model, ensuring use only when it is beneficial for a given project such as when space is limited.

The current change, improvement and knowledge management practices of the construction company were found to generally align with existing theoretical frameworks. Still, two key aspects differed from theory, namely CI and diffusion of knowledge. This is shown through their lack of converting tacit to explicit knowledge as a result of their use of subcontractors, unstructured approach to improvement and diffusion of knowledge happening within bubbles consisting of KMs and site managers. Furthermore, the nature of subcontractors and the company's reliance on championing of ideas leads to improvements taking a disorganised and discreet form unlike the continuous and planned approaches recommended by improvement literature.

To improve such aspects, a few management practices were identified as relevant. These include Kotter's eight steps, the PDCA-cycle, and Nonaka's and Takeuchi's knowledge management model. The philosophies of the mentioned practices can be applied to already established processes such as the company's pilot projects, as well as serve as basis for knowledge and improvement within the temporary construction project organisations. Thereby facilitating the diffusion of insights made during construction projects to the rest of the organisation.

This study can help the construction sector in its struggle to decrease its impact on the environment and on the climate by providing tools that improve plastic waste sorting. Furthermore, by highlighting and proposing changes to the managerial issues, change and improvement efforts can become more prevalent across the organisation thereby facilitating a more sustainable construction company. Increased sorting and recycling of plastic waste is however only one of many areas that require improvement as society tries to handle the climate challenges of today and tomorrow. Therefore, more and larger efforts towards change must be taken as soon as possible which will require not only ideas for improvement, but also the means of which to apply these ideas.

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Appendix A

Table 4: Metadata for CC & PC

Product	Unit	Width (m)	Density (kg/m³)	Packaging per product	Reference
1 Glass	m^2	0.4	-	$\frac{42\ m^2}{72\ m^2}$	Contact with supplier
2 Plastic film	m^2	0.0002	-	$\frac{1.22 \cdot 10^{-2}\ kg}{1.85 \cdot 10^{-1}\ kg}$	(Tommen Gram, 2015)
3 Brick	kg	-	1662.5	$\frac{0.4872\ kg}{1000\ kg}$	(Randers Tegl, 2018)
4 Glass wool	m^3	-	-	$0.524\ \frac{kg}{m^3}$	(ISOVER, 2020)
5 Steel	kg	-	7850	$\frac{0.38\ kg}{1000\ kg}$	(Gyproc, 2017)
6 Wood	m^2			$0.1\ \frac{kg}{m^3}$	(Moelven Wood AB, 2018)
7 Fire retardant cladding	m^3	-	508.95	$\frac{0.1\ kg}{12\ kg}$	(Moelven Industrier ASA, 2020)
8 Wood	m^3	-	-	*	(Stora Enso, 2020)
9 Steel	kg	-	7700	0	(Celsa Steel Service AB, 2021)
10 XPS insulation	m^2	0.0033	-	*	(Sundolitt, 2016)
11 Gypsum	m^2	0.0095		0.5% weight	(Gyproc, 2024)
12 Glass wool	m^2	0.034	-	$\frac{32.4\ g}{714\ g}$	(ISOVER, 2020)
13 Gypsum	m^2	0.0125	-	0.5% weight	(Gyproc, 2024)
14 Plastic film	m^2	0.003	-	-	(Nordic Waterproofing, 2016)
15 Wood	m^2	0.023		$\frac{1.1\ kg}{680\ kg}$	(UPM Plywood Oy, 2023)
16 Stone	m^2	0.01	-	0	(EURO-ROC, 2014)
17 Wood	m^2	0.015	-	$\frac{0.1\ kg}{489.7\ kg}$	(Moelven Wood AB, 2018)

Appendix B

What are your current practices when it comes to waste management, especially plastic?

What protocols are in place to assure organization of plastic waste?

How is waste space calculated and allocated currently?

What factors decide the waste space allocated?

How are the guidelines regarding waste sorting followed?

What are the main barriers for sorting plastic waste?

How is the waste sorting assured to be aligned with the requirements put forth by the construction company?

How does the waste management change between construction stages?

What are the plans for increasing waste sorting?

What is the buy-in for sustainability initiatives from team leaders/middle managers?

What are some actions of improvement you have taken recently?

What are the main barriers to improvement?

How are changes in on site protocol usually implemented?

What are the reasons for them not being followed?

What are some common barriers when implementing change?

How does one change the habits of the workers?

What are your thoughts on [POTENTIAL IMPROVEMENTS]?

What are some challenges that you have faced during earlier sustainability improvement measures?

What successes did you have during earlier sustainability improvement measures?

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