Manufacturing processes and materials selection for a sustainable future

Gustav Kågesson
Zainalabidin Tahir

Department of Mechanical Engineering
Blekinge Institute of Technology
Karlskrona
Sweden
2015

Master of Science thesis in Mechanical Engineering

in cooperation with
Abstract

This study focuses on different manufacturing processes and material choices for products that are designed to help the future to be more sustainable. These products were developed in a global project that explored the field and subfields of urban mining. This thesis is a part of that project and is meant to come with valuable input to the results. In this urban mining project two products were developed.

The two different products that has been developed during this project is the NIX and the UM Factory. They work together with keeping material on the construction site when space is limited in order to reduce the transportation, both for the environmental benefit and also from a cost perspective. Together they will not only keep the material on the site but also refine them so they can be used again.

This thesis will look into how these two products can be manufactured and what materials is a suitable choice for the products. These two factors were also thought about during the development of the products, both how to make it as simple design that was easy to produce while still fulfilling the requirements set. Also what materials might be a suitable choice for different parts of the products is considered, in order to be reliable, easy to work with, and relatively cheap. The study also explored some methods and materials that might be worth looking into in a few years. Methods and materials that today are undeveloped or not economically viable.
Executive summary

Background
Urban mining is the platform where processes and technology are developed in such an environment aiming to recover resources from waste produced by the urban landscape; this includes municipal-, electronic- and agricultural waste. The idea is to (re-) invent processes enabling further purpose for materials both from old deposits and new products providing secondary raw materials and energy (Cossu, 2012).

During the autumn many prototypes and ideas were pitched around and the Swedish students had a major deliverable in January. However, going into this thesis there is no product developed yet. What is known is that whatever the product is going to be there will be manufacturing of that product and this thesis will focus on how that product can be manufactured going into different manufacturing processes as well as looking further to what legislations might happen in the future and how to stay ahead of those aspects. Since the product is undefined for now this thesis will start with a broad outlook into many different manufacturing processes and be more focused the further the project goes when the product starts to be defined.

Purpose & research questions
The aim of this thesis is to study various manufacturing processes that can be appropriate for the manufacture of an environment friendly future product. In addition, other aspects that go hand in hand with the selection of manufacturing process will also be discussed - such as materials selection, economical- and environmental aspects.

The big challenge of this study is that it is unclear how the end product will look like concerning features and functions. But we do know that it should be designed for urban mining, which means that it should be sustainable from the very first step of its life cycle, extraction of materials, through production, transportation, usage and finally disposal. This leads us to focus on three research questions in this study:
What manufacturing processes are suitable for the final product of the urban mining project?
What are the appropriate material choices for the final product?
Can urban mining be a possible future business segment for Volvo CE?

Definition of Urban Mining
The idea itself questions the current consumer logic and progresses far beyond the ideas of separation and collection. As far as results it hopes to provide the society with lower costs, recovery of resources, increased produced responsibility, higher recourse quality and improved environmental protection. There is no margin or room for side steps when it comes to closing the circle in the material cycle, final disposal techniques should aim to be part of the cycle (adding value to the next step) as fully and meticulously as possible (Cossu, 2012).

Several materials such as, linear alky benzene sulfonates, cellulose, polyethylene, aluminum, cement, steel allows us to complete our daily activities. Recycling becomes a necessity in a world where material prices are ever fluctuating and heavy pollution in mass production is a factor. Urban mining, which is a new approach towards recycling, is anchored in the fact that large quantities of potential material are incorporated into urban environments. The potential material can be found in buildings, infrastructure, landscape, etc. (Brunner. 2011).

Urban mining, which does not yet have a general definition, highlights the systematic reuse of anthropogenic materials in urban and infrastructure intensive areas. To decide whether or not a certain material can be economically mined, comprehensive information about substances and materials is required. Factors that are impactful include availability, abundance, element concentration, speciation, and partner minerals. Another factor, which is important when deciding if one should recover a material from its urban material flow, is how it has been used and processed. For instance, aluminum can occur in several different forms and chemical combinations: solid metallic aluminum (Al) in a car body, kaolin (Al₂O₃ · 2SiO₂ · 2H₂O) in journals and magazines or aluminum hydroxide Al(OH)₃ in a pharmaceutical antacid. This illustrates the fact that one needs sufficient information regarding a specific materials urban flow, from the extraction of the raw material via production and utilization to disposal at the end of a
product’s lifecycle. Events during this process may come to be crucial when deciding if a material can be mined economically or if its value is non-recoverable. This information (density, speciation, locations, partner elements, dissipative loss, flows, and stock) can be seen as a regulatory framework, which forms the base for recovery priority, how to design and implement high performance reclamation systems that incorporates cutting edge logistics and recycling technologies. Additionally, it sets the rules for final disposal, a safe way to manage non-recyclables in an environmentally friendly approach. Taken such information into account is necessary when advancing from the current state of managing material flows into a future state, an “urban mining” state. In this “new” state a more precise and efficient approach is used for recovering materials, value as well as environmental risk is taken into account when managing substances from cradle to grave (Brunner. 2011).

Energy is required when transporting waste and recyclables. The same is true for recycling and refinement processing. To conduct sustainable urban mining it is hence important to incorporate short transportations and processes that are energy efficient. When developing an “urban mining” strategy a comprehensive understanding of the urban environment as a system is required. Urban areas and cities go through different development phases, which should be considered and identified (Brunner. 2011).

**Products**

During this project two products were developed. These products are the ones this thesis is based on when choosing manufacturing processes and suitable materials. The two products are called UM Factory and NIX.

**UM Factory**

UM Factory stands for "Urban Mining Factory" and is a concept that is based on what the students presented in the PSS course that was further developed with help of the modular X chart. The UM Factory is a concept that will be transported to the work site and then set up to help with handling of the material. There will be different boxes that will do different things and be helpful at different times during the demolition or rebuilding and so the boxes can be transported off site to save space when not needed. With this idea there is limitations what cannot be made with today's technology but can be developed with time. Since this is a very broad concept a narrower concept
was further developed while the broad concept remains more visionary. The narrow concept that was developed is the batch plant factory; this is a concept that will turn crushed concrete into a new mix of concrete that can be used to build parts for a new building.

Another important environmental aspect of the UM Factory concept is that it is designed to minimize the dust and noise distribution, this makes it possible for use in the urban areas without harming the environment or disturbing people.

Figure 1: Illustration of the UM Batch Plant concept.

NIX
The NIX is an idea based on the dirt mushroom but without the heavy bulb on top. This idea has had a few different versions on the way but the basic idea has looked the same the whole time. This would also store material in a vertical way with panels that will make the storage unit able to take different shapes such as square or hexagonal. The storage units would then be able to stand very close next to each other and also stacked on top of each other. The NIX should also be able to be assembled by hand with a maximum of two workers; this means lightweight parts while still able to hold the material in place. The size is variable since it is possible to make different shapes from the panels but the hexagon would be able to hold 7.5 tons of material in weight and this would mean a full NIX if the material is crushed up concrete.
Result
In this chapter the results from this master thesis is collected. Going through what materials and manufacturing methods can be used to produce the two products described in the previous chapter in order to satisfy the requirements for each of the two products.

Materials selection
For this thesis a structured selection process was picked. For this selection the first task was to list the design requirements, this was done in the large urban mining project. The second step is to pick a selection method among these four: Analysis, Synthetic, Similarity and Inspiration.

NIX
When selecting the materials for the NIX the first method was picked, the selection by analysis. The method is based on a "deductive reasoning", using precisely inputs and well-established design methods in order to provide a data based output of materials and their attributes.
A few different materials was looked into for the different parts of the NIX, it was a struggle since the total weight of the different parts was crucial in order to be able to handle it by hand. The result was to make the side panels in two parts with different materials. A frame of aluminum to support the panels from buckling, the panels inside of the frame are made out of polypropylene. This gives a total weight of about 22kg per panel and that is within the acceptable weight requirement.

There is also a bottom frame that is made out of aluminum and acts as a support for the flexible bottom that is made out of carbon fiber fabric. The reason for using fabric is the light weight and carbon fiber fabric is the way to go in order to support the weight of a filled NIX.

**UM Factory**

For the UM factory the method of choice was selection by inspiration. Since this concept was developed by being inspired by current batch plants these were also the starting point for selecting materials for our UM Batch Plant. Since the biggest requirement for this product is to be able to hold all the material in the buckets and the total weight is not that demanding. A pre-conception that steel or aluminum is the answer for most engineering products was applicable.

The UM Batch Plant is almost purely made out of weldable steel. The reason is that it is easy to work with, strong and relatively cheap. The goal was to use the same material for as much as possible in order to be able to weld the parts together and using standard pipes, beams and plate sizes to make it even cheaper. Others materials had to be used for the conveyor belt and the insulation. The conveyor belt is made out of rubber and for the insulation polyurethane was used for the prototype and this should also work well in a full scale model.

**Manufacturing processes**

**NIX**

The NIX design is simple and does not require a lot of manufacturing processes since it does not contain many components. The panels will be made of “plastic” and be put in a “hinge frame” made of aluminum.
Saw cutting will be used in order to cut U-shaped aluminum profiles into the desired length. Later, TIG spot welding method will be used in order to attach the parts together. Bending with a single die method (figure 3.9) will create the frame “hinges”. Then attached to the frame by TIG spot welding as well. A robot will be used in order to do the welds to get a precisely and high quality finishes.

**UM Factory**

For the UM Batch Plant there is a lot of manufacturing that needs to be done but since it uses more or less the same material this still is a simple job.

For the different beams and pipes saw cutting will be used. Water jet is the method of choice for making the plates. Different bending methods will be used in order to bend the plates into the right angle. Finally MIG welding will be the method to weld all the parts together since this is an easy, fast and good enough method for welding the parts of this design. The design also contains a few standard parts such as motor, cylinder and conveyor belt will need to be ordered. When all the parts are welded and painted everything will be put together by screwing the parts together in order to easy switch out part by part if they break.

**Conclusions**

The purpose of this study was to investigate what manufacturing processes in combination with suitable materials would be appropriate to use for a sustainable product. More specifically the product developed within the urban mining project. The outcome of the question: "What are the appropriate material choices for the final products?" was inter alia materials that are cheap, easy to manufacture and recyclable; such as aluminum, polypropylene and steel, and to a smaller scale carbon fiber. On the other hand the outcome of the question: "What manufacturing processes are suitable for the final products of the urban mining project?" was bending, welding, water jet cutting, CNC machining and sawing. These methods are easy methods that is widely used today and they work good for these products. They are also not harmful for the environment.

As regards the third research question “If urban mining could be a future business segment for VCE” we believe that the answer is yes it could be. During this study and project the area of urban mining have been more and
more clear as a segment. Eight months ago none of us had heard about urban mining but now we have a clear understanding of what it is and how it will affect the future. With all the different site visits that have been conducted a lot of insights have emerged within the different segments of urban mining. We found that the different segments correlate to each other in many aspects. For example a lot of the waste travels through the municipal solid waste management plants at some point in the process. We see urban mining as a part of the coming future, now it is just to get onboard the train and for someone to take the roll as captain to lead the way. We believe that Volvo CE could be that captain. We see this is a great way for Volvo to be the leader in this field both to help develop the recycling area for a better world and also help the company to take the next necessary step to stay ahead of the competition. Therefore we recommend Volvo to take urban mining as their new business segment.

**Future work**

Some work for the future after this thesis is to look into the economical aspects and comparing the different manufacturing processes but also the different materials for the two products. Especially for the materials this is something that needs to be done since there are so many materials out there and new are developed all the time. Combining this with looking into how the products can be redesigned in order to be 3D printed is something that will be beneficial, not that the design is poor but 3D printing opens up for a whole new area of design freedom.

For the UM Factory the other concepts will need to be developed, such as crusher and sorting containers. Also building the UM Batch Plant in full scale to try if the capacity and functions will work as intended needs to be done. For the NIX the problem with material getting stuck in the corners needs to be addressed. Also trying to stacking NIX`s to the full capacity needs to be tried, there might be some issues doing this since the NIX is designed to be lifted in wires from the top. Might be a problem to stack them high in the air.
Acknowledgements

We would like to thank Volvo CE for the opportunity to do this project and more specifically Jenny Elfsberg that was our final customer in this project. We would also like to thank Martin Frank and Michael Stec from Volvo CE for being our corporate coaches during this time and contributing with a lot of useful feedback. We would also like to thank Volvo CE for the opportunity to go to Stanford and present our Urban Mining project. As well as the staff at Volvo CE for the inspiring site visits.

We would like to thank Tobias Larsson who has been the coordinator between BTH, Volvo CE and Stanford from the BTH side. We would also like to thank Tobias Larsson and Christian Johansson for both supporting and pushing us during this project, it has been great to just be able to come up to them and discussing the problems we have encountered. It always felt like they supported us and had time for us.

We would like to thank Sebastian Sjöberg for being our culture coach and helping us with the global teamwork as well as facilitating some very interesting and inspiring workshops. He also brought some students from Hyper Island during one workshop which was very fun to get a more outside spacey view of the project and solutions.

We would also like to thank our teammates from both this side of the pond and at Stanford for the shared experience in this exciting project. To read more about the project and the three other master theses that were done during this project here are some references to them:

Urban Mining (Bunker et al, 2015)

Designing for the Unknown - Exploring Urban Mining as a case study (Dahlqvist & Erlingsson, 2015)

How to future proof a Business Model Capture and capitalize in the field of Urban Mining (Nilsson & Söderberg, 2015)

Construction industry market segmentation: Foresight of needs and priorities of the urban mining segment (Ha, 2015)

Gustav Kågesson
Zainalabidin Tahir
# Contents

Abstract ......................................................................................................................... 2

Executive summary ........................................................................................................ 3
  Background .................................................................................................................. 3
  Purpose & research questions ...................................................................................... 3
  Definition of Urban Mining .......................................................................................... 4

Products .......................................................................................................................... 5
  UM Factory .................................................................................................................. 5
  NIX 6

Result ............................................................................................................................ 7
  Materials selection ...................................................................................................... 7
    NIX 7
    UM Factory .............................................................................................................. 8
  Manufacturing processes ........................................................................................... 8
    NIX 8
    UM Factory .............................................................................................................. 9

Conclusions .................................................................................................................. 9
  Future work ................................................................................................................. 10

Acknowledgements .................................................................................................... 11

Notation ....................................................................................................................... 16

1 Introduction .............................................................................................................. 17
  1.1 Background .......................................................................................................... 17
  1.1.1 Volvo Construction Equipment ......................................................................... 18
  1.2 Purpose & research questions .............................................................................. 19
  1.3 Delimitations ......................................................................................................... 19
  1.4 Report layout ........................................................................................................ 20

2 Methodology ............................................................................................................ 21
  2.1 Research approach – Concurrent engineering .................................................... 21
  2.1.1 Implementation of the concurrent engineering approach .................................. 22
  2.2 Data source and data collection .......................................................................... 23
  2.2.1 Primary data .................................................................................................... 23
  2.2.2 Secondary data ............................................................................................... 24
  2.3 Validity and reliability ......................................................................................... 24

3 Theory ....................................................................................................................... 26
  3.1 Definition of Urban Mining .................................................................................. 26
3.1.1 Urban mining subfields ......................................................... 28
  3.1.1.1 Construction & demolition materials .................................. 28
  3.1.1.2 Municipal Solid Waste ..................................................... 29
  3.1.1.3 Electronic waste ............................................................... 30
  3.1.1.4 Tires ................................................................................. 31
3.2 Lean thinking .......................................................................... 31
3.3 Robotic technology ................................................................. 33
3.4 3D printing ............................................................................. 34
  3.4.1 Benefits ............................................................................... 34
  3.4.2 Drawbacks ......................................................................... 35
3.5 Numerical controlled machines ............................................. 36
  3.5.1 Numerical control ................................................................. 36
  3.5.2 CNC machining ................................................................. 37
3.6 Cutting table methods ............................................................ 38
  3.6.1 Laser .................................................................................. 39
  3.6.2 Plasma ................................................................................. 40
  3.6.3 Water .................................................................................. 40
3.7 Bending .................................................................................. 40
3.8 Welding .................................................................................. 42
  3.8.1 MIG- and MAG welding ....................................................... 43
  3.8.2 TIG welding ........................................................................ 43
  3.8.3 MAA welding (Stud welding) ............................................... 43
3.9 Selection of manufacturing processes .................................... 43
3.10 Materials selection ............................................................... 44
  3.10.1 Aspects that influence the materials selection .................. 45
    3.10.1.1 Cost Aspects ................................................................. 46
    3.10.1.2 The environmental aspect ............................................ 48
  3.10.2 A structure for material choices ....................................... 50
    3.10.2.1 Selection by Analysis .................................................... 50
    3.10.2.2 Selection by Synthesis .................................................. 51
    3.10.2.3 Selection by similarity .................................................. 51
    3.10.2.4 Selection by Inspiration ................................................. 52
4 Execution of the Urban Mining project ................................. 53
4.1 Preface (PSS course) ............................................................... 53
  4.1.1 Site visits ............................................................................ 53
  4.1.2 Need statement ................................................................. 54
    4.1.2.1 Relieve labour workers from manual handling of waste ...... 54
    4.1.2.2 Optimize transportation solutions .................................... 55
    4.1.2.3 Prevent exposure to danger, noise disturbance or nuisance... 56
    4.1.2.4 Design to consider the product lifecycle ......................... 57

13
8 References .............................................................................. 91
  8.1 Figures .................................................................................. 95
9 Appendix ................................................................................ 96
  9.1 Prototype testing ................................................................. 96
  9.1.1 Test info ........................................................................... 96
  9.1.2 Test results ......................................................................... 96
  9.2 NIX calculations ................................................................. 98
    9.2.1 Bottom clothes .............................................................. 98
  9.3 Modular X chart ................................................................. 99
Notation

Abbreviations:

Volvo CE   Volvo Construction Equipment
C&D        Construction and Demolition
BTH        Blekinge Tekniska Högskola
MSW        Municipal Solid Waste
JIT        Just in time
NC         Numerical control
CNC        Computer numerical control
E-waste    Electronic waste
PSS        Product Service System
RPM        Revolutions per minute
1 Introduction

Here in the introduction chapter background, purpose, research questions, and delimitations will be described in order for the reader to get a good understanding of what the project will be about, why it is done and what questions will be answered. This chapter will end with a report layout.

1.1 Background

Today, large cities incorporate large stocks of secondary materials that are considered as waste. These materials are valuable and need to be handled and taken care of in a way that is economically accepted and does not harm the environment. By recycling and recovering these materials we reduce both the energy consumption and the released emissions from the extraction as well as transportation of new raw materials. The challenge is to develop and implement new processes, tools and mindsets to ensure a successful transfer towards urban mining.

Urban mining is the platform where processes and technology are developed in such an environment aiming to recover resources from waste produced by the urban landscape; this includes municipal-, electronic- and agricultural waste. The idea is to (re-) invent processes enabling further purpose for materials both from old deposits and new products providing secondary raw materials and energy (Cossu, 2012).

The start of this thesis started in a larger project in collaboration with Volvo Construction Equipment and also Stanford University in USA. That project started as a course at BTH called "Product Service Systems Extreme Innovation" and a course called ME310\(^1\) at Stanford, where the task was to explore urban mining as a future business segment for Volvo CE. After the course at BTH the project turned into four different master theses with all focusing on different parts of the project while still working in the larger group. The group consists of 7 students at BTH and 4 students at Stanford.

During the autumn many prototypes and ideas were pitched around and the Swedish students had a major deliverable in January. However, going into this

\(^1\) http://me310.stanford.edu
thesis there is no product developed yet. What is known is that whatever the product is going to be there will be manufacturing of that product and this thesis will focus on how that product can be manufactured going into different manufacturing processes as well as looking further to what legislations might happen in the future and how to stay ahead of those aspects. Since the product is undefined for now this thesis will start with a broad outlook into many different manufacturing processes and be more focused the further the project goes when the product starts to be defined.

1.1.1 Volvo Construction Equipment

Volvo Construction Equipment (Volvo CE) is a part of Volvo group. Volvo CE manufactures and distributes construction equipment worldwide. Their products can be found in quarries, oil and gas fields, road construction projects, recycling plants, waste facilities and demolition sites in as many as 125 countries. Their products range includes excavators, dump trucks, haulers, wheel loaders, demolition equipment, waste handlers, graders, pavers, compactors, milling equipment, and a range of compact equipment such as mini excavators and backhoes.

![Segment picture of Volvo CEs production line.](image)

Volvo CEs core values, Safety, Quality and Environmental care is incorporated in everything they do. They seek to have a net positive environmental impact on the world and this is one reason why they show
interest in the urban mining sector. They also look into this sector since it is likely to be the future and Volvo CE would like to be the leader in this.

1.2 Purpose & research questions

The aim of this thesis is to study various manufacturing processes that can be appropriate for the manufacture of an environment friendly future product. In addition, other aspects that go hand in hand with the selection of manufacturing process will also be discussed - such as materials selection, economical- and environmental aspects.

The big challenge of this study is that it is unclear how the end product will look like concerning features and functions. But we do know that it should be designed for urban mining, which means that it should be sustainable from the very first step of its life cycle, extraction of materials, through production, transportation, usage and finally disposal. This leads us to focus on three research questions in this study:

- What manufacturing processes are suitable for the final product of the urban mining project?
- What are the appropriate material choices for the final product?
- Can urban mining be a possible future business segment for Volvo CE?

1.3 Delimitations

This thesis will not be concentrated on one or two manufacturing processes, but rather, various manufacturing processes will be investigated in order to choose the most suitable process, in combination with a suitable material. The selection of a manufacturing process depends on several aspects as materials selection, dimensions and tolerances, surface finish, environmental impact etc. In this study only the materials selection as well as a basic of cost- and environmental aspects will be incorporated.
1.4 Report layout

This report consists of seven chapters. The first one is introduction of the study done. Chapter 2 describes the method utilized in order to execute this research, in addition to what tools have been used for data collection. Chapter 3 begins with a definition of what urban mining is, then more about the theory behind materials selection and the various manufacturing processes investigated within this thesis, where some environmental and cost aspects has been incorporated as well. Chapter 4 is more specifically about the urban mining project, what ideas and concepts were generated and how they were developed into final products. Furthermore, the results achieved from this work are brought up in chapter 5, where an analysis of the results has been made also. In chapter 6 there is a discussion about the outcome of this project and if it would look different if other methods would be used, some future speculations are brought up there as well. And finally, in the last chapter number 7, a short conclusion is made about the results that have been achieved and what future work is recommended to proceed with.
2 Methodology

This chapter will explain the general approach of conducting this study and which methods were used to collect data for the research. There are several methods to choose from when conducting a thesis work, but no method is perfect or fits in all cases; all have their advantages and disadvantages. The selection of the right method is important in order to achieve the best outcome (Cohen et al, 2007). In this case, since the desired outcome is vague at the beginning, but will continuously be developed over time there is a need for a methodology that “help us to understand, in the broadest possible terms, not the products of scientific inquiry but the process itself” (Cohen et al, 2007, page 47).

2.1 Research approach – Concurrent engineering

Product development has always been a part of companies and the methods for how to do it in the most effective way constantly change. Back in the day all product development was sequential meaning that development for a new product would be handled one area at the time, for example one team working with the idea, the next team make it into reality and a third team that decide material and how to manufacture the product. This means that when the new team get the previous teams work they had to familiarize themselves with and interpret what the previous team had done. This means a lot of extra time to simply understand the problem at hand and consequently also a lot of misunderstandings and mistakes. An easy way to look at this is the whispering game children play where the message is almost never correct when it comes to the last person (Wallin, 2007).

Because of the competitive market and need to reduce costs there was a need to make product development more effective. So in the late 1960s companies started to integrate the different areas so they became more involved earlier in the project. The idea behind this was to have better communication between the teams and in this way reduce the development time for a new product. This was called integrated product development and last few years the idea has been refined to what is called concurrent engineering. In concurrent engineering the production team is also integrated with the development teams. The aim with this is to have none or at least minimum changes to the product after product launch. There is also a goal to make as many big
decisions as possible in the beginning of the project in order to lower the cost and lead time. However this means a potential huge economical risk since the cost will be high if the decisions have to be changed later in the process (Wallin, 2007).

What everyone is after is a product development process that shortens lead times but at the same time increase the customer focus. A process that focuses on this and has become more popular lately is lean thinking (Read more about this under chapter 3.2 Lean thinking). To be successful it is very important to identify needs, thoughts and preferences in an early stage of the development process. The early stages of the development refer to the planning and concept development parts of the project. The biggest part is the planning where the groundwork is done; the conditions are decided in order to come up with a desired product that will increase the profits (Wallin, 2007).

2.1.1 Implementation of the concurrent engineering approach

Concurrent engineering is not a research method but rather a way for engineers to develop new products and we liked the way of thinking so we did a version of this where we saw ourselves as experts in manufacturing and how we could influence the end design with our knowledge and this way of thinking.

Since there were no concrete product to work with in the beginning of this thesis and the product was developed alongside the thesis work so this approach felt like a good choice. The theory above states that the development process focuses on developing all areas within one team instead of different teams that pass the information along to the next team. The large project has one big group while this thesis has a small one. Using this approach for this master thesis opened up the possibility not only to be a part of the developing process as the manufacturing experts of the team but also to see if the theory was applicable and easy to use. This approach made it possible to explore the manufacturing theory and processes alongside developing the product. This also helped the larger urban mining project by contributing with the knowledge from manufacturing, and therefore developing a product that is sustainable and is relatively easy to manufacture without any special designed tools or machines.
The thought behind the approach is to get different people with different expertise to help each other to develop a new product or service. As a part of this thesis the goal was to be the ones with the expertise in manufacturing and material selection that are both sustainable and economically accepted. In order to get this expertise some knowledge needed to be collected first before the concurrent engineering approach could be practiced. A lot of data and knowledge were collected and this was then used as input to the large project when developing and refining the ideas. This meant that the manufacturing and material selection processes incorporated with environmental- and cost aspects was always a part of the development. There was a focus in designing the product in a way that it does not require specially made tools to manufacture, since this would add extra costs for the company. The idea was also to avoid making big changes at the end phase of the design process since it would cost both time and money, which maybe could make the whole concept fail in terms of a non-achievable requirement.

2.2 Data source and data collection

How data was collected and from where are two important aspects that impact the validity and reliability of the done research, since if a piece of research is invalid then the research is worthless (Cohen et al, 2007). In this study, and since it was run in parallel with a larger project, data has been collected either by own hand or from the larger project.

2.2.1 Primary data

The collection of primary data is important in order to be able to answer the research questions within this study. The main purpose behind this thesis was to investigate sustainable manufacturing processes. A literature research was made at the beginning of the project to understand what various manufacturing processes are obtainable, and what could affect the choice of a certain manufacturing process. As a start here, the book “Tillverkningssystem, länken mellan teknik och ekonomi” (Ståhl 2012) was advantageous to understand that factors as materials selection, environmental as well as cost aspects are crucial when determining an appropriate manufacturing process. Thereafter, more quantitative research about several manufacturing processes is done, this in parallel with in deep study about materials selection, cost and environmental aspects. Here, sources as articles, online-data from websites of
firms and organizations have been of great help to investigate various manufacturing processes, while two additional literatures was utilized to gather knowledge and theory behind materials selection, more specific “Materials And Design” (Ashby & Johansson, 2010), as well as “Selection And Use Of Engineering materials” (Charles, J. A, 1997).

A lot of information and data was collected from these different sources. In order to analyze and summarize those and selects what is most appropriate; a combination between simple pros and cons method was used as well as deduction reasoning where conclusions are based on logical reasoning from the theory.

### 2.2.2 Secondary data

Other data that has been useful during this study was taken from the urban mining project as regards customer needs and design requirements. The data here was collected by observations, experiments (prototyping) and structured interviews with field workers from several site visits during the project.

The interviews and observations were interpreted into needs that then were made into requirements for the two products; these requirements affected the material choices directly. Requirements regarding weight, easy to handle and robustness is directly connected to the different materials there is to choose from. The secondary data that was collected through the urban mining project was also a big help in order to answer our third research question regarding if urban mining can be a future business segment for Volvo CE.

### 2.3 Validity and reliability

To make the study more validate and reliable it is important to choose the right approach in order to investigate and answer the research questions. In addition, a suitable method has to be used and data has to be collected in the right way, from reliable sources so that if the study is repeated the same outcome is achieved. Nevertheless, “Threats to validity and reliability can never be erased completely; rather the effects of these threats can be attenuated by attention to validity and reliability throughout a piece of research” (Cohen et al, 2007, page 133).
The theory behind materials selection, as well as environmental- and cost aspects is qualitative and reliable since it was gathered from reliable authors that have many years’ experience within this field and has published books that are used within education. In terms of electronic sources, the validity and reliability can be evaluated with help of these criteria; purpose of the site, authority and authenticity of the material, content of the material, credibility and legitimacy of the material, correctness, accuracy (Cohen et al, 2007). The secondary data in contrast was mainly collected by observations, experiments and several interviews from the urban mining project. The data from observations and interviews may not be correctly to one hundred percent, but still shows great reliability since it is collected mainly from workers within the investigated field. The interviews and observations might have shown a more complete picture if more interviews would have been done at many different locations both in Sweden and the rest of the world. However since it was not possible to travel around the world to get these interviews we had to settle from interviews around the southern part of Sweden as well as the San Francisco area in the US.
3 Theory

In this chapter all necessary theory is collected, the theory that this thesis is based on. The theory consists of everything from explaining what the field of Urban Mining is to different manufacturing processes and how to choose a suitable material for the end product.

3.1 Definition of Urban Mining

The urban areas around the world should be viewed as a physical, or virtual, environment, which by nature is intended for collective use. In this environment the rights and obligations of residents, social information, education, political- and economic actions are all executed at a highly satisfactory level (Cossu, 2012).

The idea itself questions the current consumer logic and progresses far beyond the ideas of separation and collection. As far as results it hopes to provide the society with lower costs, recovery of resources, increased produced responsibility, higher recourse quality and improved environmental protection. There is no margin or room for side steps when it comes to closing the circle in the material cycle, final disposal techniques should aim to be part of the cycle (adding value to the next step) as fully and meticulously as possible (Cossu, 2012).

Several materials such as, linear alky benzene sulfonates, cellulose, polyethylene, aluminum, cement, steel allows us to complete our daily activities. Recycling becomes a necessity in a world where material prices are ever fluctuating and heavy pollution in mass production is a factor. Urban mining, which is a new approach towards recycling, is anchored in the fact that large quantities of potential material are incorporated into urban environments. The potential material can be found in buildings, infrastructure, landscape, etc. (Brunner. 2011).

Urban mining, which does not yet have a general definition, highlights the systematic reuse of anthropogenic materials in urban and infrastructure intensive areas. To decide whether or not a certain material can be economically mined, comprehensive information about substances and materials is required. Factors that are impactful include availability,
abundance, element concentration, speciation, and partner minerals. Another factor, which is important when deciding if one should recover a material from its urban material flow, is how it has been used and processed. For instance, aluminum can occur in several different forms and chemical combinations: solid metallic aluminum (Al) in a car body, kaolin (Al₂O₃ · 2SiO₂ · 2H₂O) in journals and magazines or aluminum hydroxide Al(OH)₃ in a pharmaceutical antacid. This illustrates the fact that one needs sufficient information regarding a specific materials urban flow, from the extraction of the raw material via production and utilization to disposal at the end of a product’s lifecycle. Events during this process may come to be crucial when deciding if a material can be mined economically or if its value is non-recoverable. This information (density, speciation, locations, partner elements, dissipative loss, flows, and stock) can be seen as a regulatory framework, which forms the base for recovery priority, how to design and implement high performance reclamation systems that incorporates cutting edge logistics and recycling technologies. Additionally, it sets the rules for final disposal, a safe way to manage non-recyclables in an environmentally friendly approach. Taken such information into account is necessary when advancing from the current state of managing material flows into a future state, an “urban mining” state. In this “new” state a more precise and efficient approach is used for recovering materials, value as well as environmental risk is taken into account when managing substances from cradle to grave (Brunner. 2011).

Energy is required when transporting waste and recyclables. The same is true for recycling and refinement processing. To conduct sustainable urban mining it is hence important to incorporate short transportations and processes that are energy efficient. When developing an “urban mining” strategy a comprehensive understanding of the urban environment as a system is required. Urban areas and cities go through different development phases, which should be considered and identified (Brunner. 2011).

There are more benefits than energy saving and shorter transport distances in bringing the industrial processes back into cities via an applied comprehensive urban mining strategy. (1) Having recycling facilities within the cities will increase the potential pollution within the urban areas. Hence, the demand for best available technology will increase. When several million inhabitants can watch the potential pollution processes on a daily basis the chance that environmental standards will be thoroughly investigated increases. (2) The approach of today has resulted in an imbalance of pollution
distribution between the cities and its hinterlands. The hinterlands receive waste and pollution both from primary production and recycling at the same time as the cities exploit the advantages of the primary resources. Hence, applying such “urban mining” approach will create a better balance of intangible advantages between the two. (3) Today the public have little chance to become fully aware of the ever-scaling material flow associated with modern life. Applying such “urban mining” approach will provide the public with the opportunity to become aware of this and increase their knowledge. (4) Finally, the cities will become less dependent on primary resources through using their own secondary resources (Brunner. 2011).

3.1.1 Urban mining subfields

Following subsections provides a background to the different urban mining subfields that is studied in the project. The literature is used as an input to the project scope, context of the design development and business planning.

3.1.1.1 Construction & demolition materials

Construction and demolition (C&D) waste is generally defined as waste that arises from construction, renovation and demolition activities. Land and excavation or formation, civil and building construction, site clearance, and roadwork are also activities that are considered to generate C&D waste (Shen et al, 2004).

Statistics from various studies have reported that C&D waste constitutes the largest volume of all solid waste. The U.S. construction industry generated more than 100 million tons of C&D waste year (Mills et al, 1999), and represents approximately 29 % of total solid waste streams in the U.S (Rogo & Williams, 1994). C&D waste contributed to more than 50 % of all landfill volume in the UK (Ferguson et al, 1995), and 70 million tons of C&D waste was discarded in UK (Sealey et al, 2001). Similar extents of C&D waste percentages in proportion to total solid waste have been identified globally (Arslan et al, 2012).
Figure 3.1 Summary of the waste composition in C&D. Percentages based on volume from San Mateo Country, CA (RecycleWorks, 2008).

According to a recent study, “World cement & concrete additives” (Freedonia, 2012), by industry market research firm Freedonia - the global demand for cement and concrete additives is projected to increase 8.3% annually to $15.8 billion in 2015.

3.1.1.2 Municipal Solid Waste

Municipal waste covers waste from households, buildings, institutions, businesses and street sweepings. According to Hoornweg & Bhada-Tata (2012) the volume of Municipal Solid Waste (MSW) is expected to almost double by 2025. This is likely to open up new business opportunities. MSW represent a significant proportion of the total waste that is generated worldwide, making MSW an important urban mining subfield to study. The process of collection for MSW can be done in a number of ways (Hoornweg & Bhada-Tata, 2012):
- House-to-house: company collects waste from each house individually. Usually, the user pays for this service.
- Community Bins: Users throw their garbage in fixed bins that are placed in a neighborhood or locality. MSW is picked up by the municipality, according to a schedule.
- Curbside Pick-Up: Users leave their garbage directly outside their homes. Local authorities collect the garbage according to a set schedule.
- Self-Delivered: individuals deliver the waste directly to disposal locations or transfer stations.
- Contracted or Delegated Services: Businesses hire firms or municipality with municipal facilities which arrange collection schedules and charges their customers.

3.1.1.3 Electronic waste

Electronic waste represents great amounts of accumulated materials, containing various precious metals like gold, silver, copper and platinum, making “mining” E-waste a growing opportunity.

![E-Waste Generated by Country](image)

*Figure 3.2 Graphic illustration of the E-waste generated by countries worldwide by LiveScience (2013).*
StEP (2013) (a partnership of United Nations organizations, industry, governments and non-governmental organizations) predicted that the total annual volume of E-waste will be 33 percent higher than 2013 at 65.4 million tons of waste by 2017. In the US, approximately 1.6 million tons of used electronics (computers, monitors, mobile phones and TVs) were generated 2010. 56% was collected for reuse or recycling while 3.1% were exported (Duan et al, 2013). Latin America and the Caribbean are common destinations and Asia representing the next largest destination for exported E-waste (Duan et al, 2013).

3.1.1.4 Tires

The tire industry is economically a giant in the market. The port of global industry analysts (GIA) predicts that the shipments of tires are going to reach 1.72 billion units by 2015 (Kannan et al, 2014). Tire production is annually growing with an increase of 5% over 2011-2015 due to higher demands and shorter life spans (Kannan et al, 2014). This will ultimately result in a greater amount of end-of-life tires (Maderuelo-Sanz et al, 2012). WBSCD (2010) estimates that there are 1 billion end-of-life tires generated globally every year. These numbers suggests the business opportunities of end-of-life tires, hence making it an interesting urban mining subfield to study.

3.2 Lean thinking

The overall objective of lean thinking is to avoid and eliminate all kind of waste as well as creating value for the customer. In lean, value is measured from the customer’s point of view. Hence, the first fundamental principle of lean is to address the following question: Does a certain activity in a product's lifecycle directly contribute to make the product becoming more complete, and is this customer paying for this activity to occur? The second principle of lean is evaluating your business from an overall system wide view; considering the whole cycle of activities, from initial customer order through receiving payment for delivering the final product. Next is the principle of flow and pull. Flow, is the ideal sequence of activities throughout a process, where no stalls, disruptions, and disconnection or backtrack loops occurs. While pull means that things are done in the right moment, when they are required to be done, not before. "It implies a consumption-driven or customer demand-driven system" (Carreira, 2005, page 3) – unlike the traditional
forecast-driven system. The pull principle also tends to be described as Just In Time (JIT), which in turn means that the correct parts arrives in the exactly number requested, in the exact moment the need for them arises, at the desired location. JIT is used to reduce the direct costs of interlayer's, as well as reducing the lead time so that the company is able to respond quickly to the market needs (Carreira, 2005).

The fourth and most essential principle of lean mindset is elimination of waste, and the importance of defining what is considered as waste. The object is to eliminate wasteful activities and free up time and resources for more value-added activities instead. This will in turn increase customer satisfaction, growth of market share, greater profitability for the company, as well as increased opportunity and stability for the employees (Carreira, 2005).

Waste can be defined within seven different categories. These categories all have one important character in common; they add cost and reduce the profitability of the operation (Bergman, Klefsjö, 2007).

- Overproduction: Products that lie and wait for customers is a waste, and does not create value.
- The wait: A machine or operator that waits for resources of various kinds, such as tools or materials is a waste and does not create value.
- Transports and unnecessary movements: Transportations create no value. Should be eliminated if it does not cause other problems to the operation.
- Inaccurate processes: A process that creates faulty products must be corrected immediately, so that no more waste is created.
- Storage: Materials and products that are in stock and waiting create no value.
- Production and rework of detective units is a waste.
- Safety: lack of safety cause damage and creates insecure and less efficient working environment.

So in conclusion, Lean does not work as a planning unit which has previously specified production volumes, but more according to orders of production coming from the customer side, where all products and services follow standardized, simple and direct flows (Carreira, 2005).
3.3 Robotic technology

A robot is a multi-functional machine of great advantages; it can be used both in manufacturing and in assembly as well. The development of a robot has gone from a simple machine with only a few movements to a multi-axis machine for different purposes. It can be designed to handle materials, parts, tools or special equipment by programmed motions in a 3-dimensional space without continuous monitoring. The degrees of freedom are often used in robot contexts (fig 3.3), which refer to the amount of movements in different axes (Hågerryd et al, 2002).

![Figure 3.3 Four different types of robots with different degrees of freedom](Hågerryd et al, 2002)

Robots are used today mainly due to higher productivity and quality. Other reasons for the success of the robots are (Hågerryd et al, 2002):

- Smoother flow through the workshop
- Higher utilization of machinery
- Improved working environment
- Shorter setup time
- High flexibility
- Ability to synchronize with CNC machines, conveyor belts, etc.

The load capacity a robot can handle varies between about 100 grams up to 150 kg, with an arm length between 1.5-3m. Robots are divided into three types, depending on the application (Hågerryd et al, 2002):
3.4 3D printing

3D printing – also known as additive manufacturing – is a manufacturing method that has grown very popular the last few years. The basic idea is to have a computer model of whatever you would like to manufacture. The 3D printer will then start building that model from the ground up in thin layers until the product is finished. The areas of use are constantly increasing since the printers can handle more and more materials. Some 3D printers can even copy existing products. There also comes the possibility for regular people to manufacture small useful things at home if they have their own 3D printer (Lewis, 2013).

3.4.1 Benefits

Some of the benefits of 3D printing:

Design:
With 3D printing a big benefit are the complex geometries that can be made. This opens up a whole new area of designing products that previously was too expensive or even impossible to produce. This also opens up the possibility to reduce the number of parts by integrating multiple parts into one. This brings different positive effect such as lower weight, higher strength etc. (Lewis, 2013).

Flexibility:
It is very easy to produce different kinds of products from the same 3-D printer with no need of changing the tools like most other manufacturing processes. The only thing you need to do is change the computer model. However switching between different materials is a bit more complicated (Phil for Humanity, 2013).
Product development:
Since it so easy to make products in a 3D printer it is very easy to make fast prototypes early in the development process. This means that problems or faults in the design will be uncovered early on and therefore the product development will be faster (Phil for Humanity, 2013).

Less waste:
The waste material will be much less since the method is based on building the material from the ground up instead of removing material as most other methods do, like cutting. The only waste material from a 3D printer is potential support structures from the printing. This material can be melted down and used again (Weston, 2013).

Smaller stocks:
Since the 3-D printer is very flexible the need for mass production will decrease and this leads to less need for storage (Phil for Humanity, 2013).

Less transport:
The possibility to manufacture basically everything the need for suppliers will decrease so the transport from supplier to end manufacturer will decrease (Phil for Humanity, 2013).

Cheap:
A 3-D printer or multiple 3-D printers might be a big initial cost for a company but the need for manual labor will decrease so the long term cost will be lower, the designers in the company can operate the 3-D printers easily from their work stations (Phil for Humanity, 2013).

3.4.2 Drawbacks

Some of the cons with 3D printing:

Copyright:
Since 3D printing is so easy it will be harder for manufacturers to control copyright problems. It will be close to impossible to determine if a product is counterfeit or not (Phil for Humanity, 2013).
Dangerous items:
The possibility to print dangerous items will make the work for law enforcement much harder since criminals can print out guns and knives (Phil for Humanity, 2013).

Useless things:
The possibility for the regular person to print out whatever they feel like will open up for the possibility that people will print out useless stuff that will just lay around (i.e., creates more waste) (Phil for Humanity, 2013).

Limited size and strength:
3D printers are often limited in size, at least right now and this makes it harder to make bigger items. Also the strength of the product is less than traditional manufacturing processes because the layer-by-layer technology. This means that the products might need some hardening process when the product is done. So some finishing work might be needed, not only for strength but also for surface finish since the layers can create an uneven finish (Phil for Humanity, 2013), (Lewis, 2013).

3.5 Numerical controlled machines

3.5.1 Numerical control

The most basic automated manufacturing technique is called numerical control (NC). This means that the machine can execute the operation fully or partially automatic and a program controls this. The use of numerical controlled machines started back in the 1960s and is used in most areas of production today (Ståhl, 2012).

The first ever numerical controlled machine was shown in USA 1952. The drive behind the development of this technology was the lack of manpower in the early 1950s. Another reason was that the aircraft industry needed to handle complex surfaces (Ståhl, 2012).

A numerical controlled machine can be moved in or around many different axles this is usually the three axes X, Y, Z, and the rotation around these. The rotation is often labeled A, B, C this is shown in figure 3.4. There are different machines that uses different amount of axis depending on what is needed. The most common choices are 3 or 5 axis (Ståhl, 2012).
The NC technology is old but is still very much in use with the same fundamental functions. The big difference from the beginning of numerical controlled machines to now is that the machines follow a computer program and are then called computer numerical control (CNC). With CNC it is much easier to change a small part of the program without having to rework the whole process. Another benefit is that it is easy to preview the process in a simulated view in the computer instead of trying it on an actual piece of material. From the beginning punch cards were used to control the machine, the machine would read row by row during the machining process. The CNC technology started to be developed during the 1970s (Ståhl, 2012).

3.5.2 CNC machining

The first thing that is needed when working with a CNC machine is a 3D model of what is to be produced. When the 3D model has been created the next step is to program the machine. This means deciding what operations to do (i.e., drilling, milling, etc.), the order of each operation needs to be decided as well as revolutions per minute (rpm) and feeding speed. Also what tool is needed for each operation is decided. The machine has a "tool belt" and the tools have a number assigned to them so that the machine can change the tools automatically. When everything is done a visual simulation is done to see what will happen - a verification that everything works as intended. The program will show a virtual animation of the operations and the order. If everything is in order the program is translated into code that the machine
understands and is uploaded to the machine. The next step in the process is to actually set up the machine; the tools need to be in the right pocket and the protrusion for drills need to be correct. If the drill does not stick out more than the depth of the drill holes this will hurt the tool and the product. The same applies for the milling tools. The number of tools varies from machine to machine but if possible it is best if you never or very rarely need to change the tools back and forth. There are machines that can hold up to hundreds of tools, which mean that you have the same toolset for many different products without the need of changing them all the time. The material has to be mounted in the machine and the edges (X, Y and Z) need to be specified. The final step is to let the machine do its job and control the part after it is done (Automill AB, 2015).

### 3.6 Cutting table methods

A cutting table is most often used to cut out 2D shapes from a material that is fixed on the table. What materials that can be cut out depend on the cutting method also the thickness of the material that can be handled depends on the method. What is the same for all method is that the material is fixed on a table and a nozzle will trace and cut out a certain shape. In the beginning of cutting tables there was an eye that would trace a thick line on a paper, the eye was attached to an arm that would have a nozzle and would move in the same shape and thus make the correct product.

![Old school cutting machine with eye tracer on the left.](image)

*Figure 3.5 Old school cutting machine with eye tracer on the left.*
Nowadays CAD-drawings are used and uploaded into a computer where you then place the drawings in a pattern to minimize the waste of material. There are also many different methods for cutting. Laser and plasma both uses gas and heat to cut out the shapes. Then there is water cutting that uses compressed water to cut, sometimes sand is added to make it cut through thicker or harder materials. There are also more advanced machines that use for example 5 axles to make 3D shapes, commonly used in the aircraft industry to make the complex parts in an aircraft engine (Kågesson & Holmberg, 2014).

![Figure 3.6 a 5-axis water jet cutter](image)

### 3.6.1 Laser

A laser cutter is most often used to cut regular steel or stainless steel. The laser cutter can also cut in aluminum or other softer metals but the laser needs to be powerful enough to handle this materials, a more powerful laser is required since these metals has the ability to reflect the light and conduct the heat. Heat treated materials can also be cut but the cut edges will be hardened, this might be a good feature if this is the finished product but if any machining is required after the cutting process the hardened edges becomes a problem (Efunda, Laser cutting, 2015).

There are some limitations when it comes to thicknesses for laser cutting, the thicker the material is the lower tolerance is manageable. For example 10mm
3.6.2 Plasma

Plasma uses gas just like laser cutting do. It is the cheapest of the three both in initial cost and operating cost. This method is also fast but has bad precision, the worst of the three. Since the plasma gas is very hot there will often be rough edges afterwards. Because of the heat the area of use is limited to some of the most common metals. It can cut in metals from 1 to 100mm (Kågesson & Holmberg, 2014).

3.6.3 Water

Water jet cutting is the only method of the three that does not require heat. The method uses pressurized water to cut in materials and often some kind of abrasive material is used to cut it thicker or harder materials. Water cutting has the highest operating cost of the three and are number two when it comes to initial investment. Water cutting can be used for a lot of different materials and thicknesses up to 300mm depending on the material (Kågesson & Holmberg, 2014).

One big environmental advantage of using water jet cutting to the other is that no noxious gases is produces when using it. Both laser and plasma will emit gases when in use in some cases from the generation of the laser itself and also in all cases fumes from melted metal (Milco waterjet, 2015).

3.7 Bending

Bending is a common manufacturing process by which metal can be deformed plastically, creating a change in the material’s shape. The material is exposed to stress beyond the yield strength but below the ultimate tensile strength. The
surface thickness and volume of the material usually remains the same, while
the shape changes, by a deformation in one axis (Efunda, Bending, 2015).

The bending process is flexible and can be used to create many different
shapes. Important factors that have to be considered when deciding which
type of metal bending process are; work piece material, size and thickness. As
well as size of the bend, bend radius, angle of bend, curvature of bend and
coordination of bend in the work piece (The library of manufacturing,
Bending, 2015).

The V bending is one of the most common types of sheet metal manufacturing
processes. It is done by using a V shaped punch that forces the working piece
into a V shaped die as well. This can be used to obtain anything between very
acute and obtuse angles, including 90 degrees (The library of manufacturing,
Bending, 2015).

A Press Brakes is used to perform the bending. Normally, it has a capacity of
20 to 200 tons to accommodate stock from 1m to 4m. There are several types
of bending processes; other common ones are Air bending & Edge bending,
last one performed with a wiping die (Efunda, Bending, 2015).

1.

2.

*Figure 3.7 Metal bending with a V die.* (The library of manufacturing,
Bending, 2015)
3.8 Welding

Welding is a process of joining two or more metal parts by heating up both materials to their melting point. After the molten materials cool, the two metals are permanently bonded. The joining can be done with or without additives, where the required energy to melt the base materials can inter alia be provided by electricity, gas flame, friction, laser or high pressure (Svetsarrätt, 2015) (Efunda, Welding, 2015).

There are several welding methods, but most common, at fixed workstations are MIG, MAG and TIG welding. MMA (“stud welding”) was common before but is currently being replaced by the other methods. Gas welding can also occur, but mostly at temporary workplaces (Svetsarätt, 2015).
3.8.1 MIG- and MAG welding

MIG welding stands for "Metal Inert Gas" and MAG stands for "Metal Active Gas". Both methods are fast and require minimum post-processing. The disadvantage with those methods is that they not suitable for outdoor work because they are both sensitive to rust and impurities, which cause pore formation in the weld (Steelex, 2015).

3.8.2 TIG welding

TIG welding stands for “Tungsten Inert Gas”, unlike the MIG and MAG welding the electrode is not consumed during welding, but only the work piece and possibly additive material melts. In order to protect the weld joint, a shielding gas is supplied (helium, argon or a mixture of both). Generally, TIG provides better quality than MIG or MAG welding; the weld looks better and contains less defects. Only disadvantage is that the process is more time consuming compared to the other methods (Steelex. 2015).

3.8.3 MAA welding (Stud welding)

MAA stands for Manual metal arc welding, and is usually called the stud welding. It is widely used to join most steels, stainless steels, cast irons and many non-ferrous materials. The density of the weld is low and the quality is highly dependent on the skills of the welder (Twi-global, 2015).

3.9 Selection of manufacturing processes

The choice of manufacturing processes depends on several crucial factors. The material choices are extremely important, but in addition there are another series of factors that can be crucial (Ståhl, 2012):

- Material selection
- Dimensions and tolerances
- Surface finish and character
- Spill of materials and needs of process additives
- The total environmental impact
- The total size of the batch and lot size
- Machine and manufacturing costs
- Set times and maintenance costs
- Flexibility and the possibility of automation
- Company-specific conditions

The environmental impacts from manufacturing processes can be reduced by taking into account the following aspects (Ståhl, 2012):

- Minimize energy consumption.
- Reduce scrap rate.
- Minimize and recycle waste materials and residues.
- Reuse and minimize processing additives as lubricating oil, coolants, etc.
- Substitute hazardous substances in the process.

### 3.10 Materials selection

Already in the initial phase of a product’s development the importance of the materials selection and the structural design will play a key role that will highly affect both manufacturability and the possibility of an effective and economically viable recycling of the end product. The decision in the past was simply based on criteria regarding the availability of the basic materials, as well as the skills of the chemist, metallurgist or the engineer in converting them into useful products at acceptable costs (Ståhl, 2012).

At present, concrete and timber are the most important materials regarding the market size, but are being supplemented by a constantly increasing range of other materials; metals (as copper, aluminum, zinc, magnesium and titanium), plastics (thermoplastics and thermosets), ceramics, and composites (based on plastics, metals and ceramics) (Charles et al, 1997).

However, two additional and very important criteria regarding materials selection have also to be considered nowadays, namely; the total energy consumption of a given material as well as the ease with which it may be recycled. Those criteria have arose out of the concept "Spaceship Earth"
which means that planet we live on has a limitation of resources (Charles et al, 1997).

A likely trend that will facilitate recycling is that future products will contain fewer types of materials, increased use of recyclable materials in addition to increased use of standard materials due to cost considerations (Ståhl, 2012).

### 3.10.1 Aspects that influence the materials selection

The choice of materials plays a crucial role regarding the safety of production as well as the recyclability of the end product. It has been estimated that there are more than 100,000 materials available for the designer to choose from, each with certain specific characteristics that differ it from other materials (Charles et al, 1997). In addition to the wide range of different materials to choose from there are several factors (figure 3.10) that need to be considered, what makes the materials selection process a challenging task (Ståhl, 2012).

![Figure 3.10 Aspects, demands and requirements that impact the choice of materials. (Adapted from Ståhl, 2012, page 303)](image)

Sometimes the material may be selected mainly because it satisfies a specific high-prioritized design requirement for one property above all others, still, a useful material must possess a combination of properties. And the exact combination required for a given application depends on the desired cluster of properties (Not necessarily a wide-range) – (Charles et al, 1997).

Different types of materials, which possess a certain combination of properties are presented in table 3.1 (Charles et al, 1997).
Table 3.1 Showing different types of materials and a combination of properties they possess

<table>
<thead>
<tr>
<th>Plastics</th>
<th>Metals</th>
<th>Ceramics</th>
<th>Composites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>Compliant</td>
<td>Stiff</td>
<td>Brittle</td>
<td>Stiff</td>
</tr>
<tr>
<td>Durable</td>
<td>Tough</td>
<td>Durable</td>
<td>Low density</td>
</tr>
<tr>
<td>Temperature-sensitive</td>
<td>Electrically conducting</td>
<td>refractory</td>
<td>Anisotropic</td>
</tr>
<tr>
<td>Electrically insulating</td>
<td>High thermal conductivity</td>
<td>Electrically insulating</td>
<td>Low thermal conductivity</td>
</tr>
</tbody>
</table>

The clusters (Table 3.1) contain a wide-range of different materials and there are always exceptions to these generalizations. Plastics for example are commonly durable, but some plastics cannot withstand stress corrosion. Metals are generally tough, this in combination with the strength property, which appears in most metals as well, makes the metallic materials used widespread for engineering purposes (Charles et al, 1997).

The selection of materials usually requires extensive compromises when it comes to requirement for material properties and behavior during processing. And even more compromises needs to be made if environmental and recycling properties have to be considered (Ståhl, 2012).

Additional specific aspects that have to be considered, is regarding merging and combination of two different types of materials; the two different types of materials must be primary separated after disposal, with a competitive cost. The combined materials should not contaminate each other either, which requires that materials are "wholly incompatible" with each other regarding solubility and adhesiveness or have the opposite properties, i.e. they have good compatibility so that these can get mixed to form a new material (Ståhl, 2012).

3.10.1.1 Cost Aspects

The main challenge in materials selection is to achieve satisfaction in terms of the required properties for a specific product design. Nevertheless, cost considerations will always be involved in the final decision, and in many
cases it may be the dominant criterion. A competition between materials or components where similar performance is obtainable may be finally decided with regarding to costs. But the precise cost and performance ratio depends usually on the type of application involved. Usually, when weighing performance in relation to costs, we divide products in two categories; performance-oriented, which demand the maximum achievement of performance – Or cost-oriented, in which considerations of cost must be predominant (Charles et al, 1997).

Spaceships for example, or certain military equipment/devices are performance-oriented products, where the requirements regarding safety, power source and so on are of high priority in comparison to costs. While a vehicle for example, or other daily-use products can be considered as cost-oriented products (Charles et al, 1997).

The mass-production industries must adjust their prices according to what the customer can or is willing to pay, so once an acceptable performance is achieved, the product is ready to be released to the market. This means that the manufacturer does not have to offer the maximum level of performance that he is technologically capable of. But still, he has to make sure that his "value-for-money" parameter is not lower, but rather better than what his competitors offer. Thus, he has to provide the optimum rather than the best performance, which of course, has to be acceptable by the customer also.

It is not so easy to measure the “value-for-money” parameter, but nowadays the current trend is to provide customized products that meet the needs of the individual than volume manufacturing of uniform products. (Charles et al, 1997).

“In the present context it is convenient to give special meaning to the term value and cost:

1. Value is the extent to which the appropriate performance criteria are satisfied.
2. Cost is what has to be paid to achieve a particular level of value.”
   (Charles et al, 1997).

The properties for a specific design and material may be compromised in terms of cost-reduction, where some properties may be excluded in order to reduce the final costs. Obviously, this does not always apply; sometimes the designer is prepared to fulfill a certain property at any cost, since the absence
of this specific property would make the whole design fail. As an example, the designer of a bridge will not regard toughness as a cost-effective property. While the automobile manufacturer for example has traditionally treated corrosion resistance in an average car as a very cost-effective property, since they assume that the bodywork does not reach a critical rusting stage until the car has reached second or third-time buyers. Therefore, cost-effective decisions should only be made with full knowledge relating to (Charles et al, 1997):

1. “The special requirement of anticipated service.
2. The properties of all available materials and their relationship to those requirements”. (Charles et al, 1997)

3.10.1.2 The environmental aspect

Nowadays, awareness of environmental and recycling requirements is very important to be implemented at the earliest possible phase during the development of a new product.

Usually, a product developer is expert at developing products that fulfill the desired requirements and preferences in terms of shape, size and color, as well as specific manufacturing requirements as production capacity and production cost etc. (Ståhl, 2012).

Rarely has he, at least until a few years ago faced specific environmental requirements. The two main reasons for implementation of the environmental requirements are (Ståhl, 2012):

- Laws that force or will enforce environmental and recycling requirements in the future.
- Usually, environmentally friendly changes go hand-in-hand with purely technical cost reduction as well as competitive advantage for the company.

Minimization of environmental impact does not apply by absolute standards or rules. But a list of activities and advices that emerged from discussion with various stakeholders could provide great support in the product developments process (Ståhl, 2012):

- Materials selection:
- Use of recycled materials, or a mix of both new and recycled.
- Use recyclable materials

**Materials Optimization:**
- Reduce the size of the components and the product (less materials needed)
- Minimize number of different materials
- Minimize the number of components
- Design for the same life time of the different components
- Do not oversize
- Design for minimum waste during manufacturing

**Design for disassembly:**
- Use of compatible materials; two or more materials that can turn into a new material when recycling, if not achievable; select materials with different densities or other characteristic properties that makes it easy to separate.

**Composition and assembly:**
- Work with modular principles
- Avoid separated attachments
- Simplify and standardize the attachment of the recyclable components

**Surfaces:**
- Use finishes that are compatible with the base material
- Design the surfaces for easy cleaning

**Labeling:**
- Use standard material labels.

**Packaging:**
- Avoid packaging, or minimize the amount packaging materials.
- Use recyclable packaging

**Product information:**
- Attach detailed instructions with the finished product regarding the use, repair, recycling opportunities and disassembly
3.10.2 A structure for material choices

The materials selection process within a new product design can be done in four different methods namely; Selection by analysis, by synthesis, by similarity and by inspiration (Table 3.2), where the basis of those methods involves “converting a set of inputs – the design requirements – into a set of outputs- a list of viable materials and process” (Ashby, Johnson, 2010).

Table 3.2 A structure for materials selection; Depending on the requirements and the desired results a certain selection method is used.

<table>
<thead>
<tr>
<th>1. Design Requirements</th>
<th>2. Selection Methods</th>
<th>3. Possible materials processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>Analysis</td>
<td>Databases of materials and products</td>
</tr>
<tr>
<td>Economical</td>
<td>Synthetic</td>
<td></td>
</tr>
<tr>
<td>Sustainability</td>
<td>Similarity</td>
<td></td>
</tr>
<tr>
<td>Aesthetic</td>
<td>Inspiration</td>
<td></td>
</tr>
<tr>
<td>Perceptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intentions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.10.2.1 Selection by Analysis

The method is based on a "deductive reasoning", using precisely inputs and well-established design methods in order to provide a data based output of materials and their attributes. The process of analysis is divided in four sub-steps; where the inputs here are the technical requirements (Ashby, Johnson, 2010).

- Translation of the requirements: Usually begins by expressing the requirements in non-technical terms, and then translated further into a statement of the objectives and constraints the design must meet.
- Analysis: of the component for which a material needs to be selected. The analyze expresses identified performance metrics as equations that measure performance.
- Identification; identify the material properties that will determine performance, from the equations above.
- Screening: Go through the database of materials and their properties; eliminate those that do not fulfill the design constraints, and rank the materials that remain by their ability to maximize the performance metrics.
The analysis method has great advantages; it is systematic, based on a deep understanding of the underlying phenomena and it is robust due to the qualitative defined inputs (Ashby, Johnson, 2010). On the other hand the drawback of this method is that it limits the approach to a subset of a well-specified problems and well-established rules, which make the process difficult to apply if decisions need to be based on imprecisely specified inputs and imperfectly formulated rules (Ashby, Johnson, 2012).

3.10.2.2 Selection by Synthesis

The synthetic method is considered as an "inductive method" that has its foundations in previous experiences. The inputs here are the design requirements expressed as a set of features describing intentions, aesthetics and perceptions (Ashby, Johnson, 2010).

The material selection process is done by seeking a match between the desired features, intentions, perception or aesthetics, with previous solved problems ("product cases") that have one or more features in common with the new problem. The advantage of using this method is that it encourages developments in one field to be adapted for use in another previously unknown field. While the main drawback is the opportunity to suggest radically new solutions, since this method depend on past experience and designs (Ashby, Johnson, 2010).

3.10.2.3 Selection by similarity

The process of materials selection within this method is done by searching for materials with desired properties that match those of an existing material, in a way that can ensure success of the new design, without a deep understanding of why these materials have certain values/properties (Ashby, Johnson, 2010).

The main reason why designers select "similar" materials is in case a need of substitution occurs. A certain material needs to be substituted when that material ceases to be available or fails to meet a changed design requirement, for example because of new environmental legislation (Ashby, Johnson, 2010). Another reason why designers may wish to consider similar materials is to break pre-conceptions; "That polycarbonate, ABS or a blend of the two are the best choices for product bodies and shells; that polyethylene, polypropylene or PET can solve most packaging problems; or that aluminum
or steel are the answer for most “engineering” products” (Ashby, Johnson, 2010, page 131).

Designers often have pre-conception, and those may be good as a quick solution but in the same time they constrain innovation. Thus, a search for similar material will break pre-conceptions and bring creativity or novelty in design solution (Ashby, Johnson, 2010).

One way to approach the similarity method can be done in three steps (Ashby, Johnson, 2010):

- **Capture**: first, capture the attribute profile of the incumbent. This should be easy with present-day data sources.
- **Edit**: In order to avoid retrieving the materials we started with, this step involves relaxing the constraints on non-critical attributes. Thus, expanding the range of candidates and tightening the constraints on the one attribute, which causes the problem.
- **Search**: search and find substitutes that satisfy the essential qualities of the incumbent, without its weaknesses.

**3.10.2.4 Selection by Inspiration**

Designers usually get most of their ideas by inspirations from other designers, both from the past and from present as well. Still, the scientific method is of no help here, since many good ideas are triggered by accident. Inspiration of this sort comes by exploring ideas almost at random (Ashby, Johnson, 2010).

Interaction with materials through a material collection or – less good – through images is a good way to gain inspiration. Browsing in stores and interact with products is another way to gain inspiration. A web-based viewer of images of materials, linked to some technical information and supplier contact can also be used as an inspiration method (Ashby, Johnson, 2010).
4 Execution of the Urban Mining project

In this chapter the reader will get an insight how the larger project was conducted and also what the results and finding from it was. Since our thesis is based on the products that was the result of this larger project this is a necessary chapter to read in order to understand how these products was developed.

4.1 Preface (PSS course)

This section of the report will start with what happened in the beginning of the project before it went over to a thesis. This to make sure that the reader will follow the work since many decisions and the base knowledge was made during this period of time. The first natural step was to look into the different subfields of urban mining, which are "Construction & Demolition" (C&D), "Municipal Solid Waste" (MSW), "Electronic waste" (E-waste) and "Tires/Rubber". Read more about this under chapter 3.1 Urban mining.

4.1.1 Site visits

Site visits was conducted in all subfields of urban mining in order to find out the different opportunities and how the different fields interact with each other. Site visits were conducted in both Sweden and USA in order to get some international knowledge without having to travel the world to observe different cultures.

In America, site visits were conducted at "Transform Urban - The Kirkham Project", "Stanford: Construction and Renovations - Meyer Library demolition" and "Building ReSources". These all fall under the subfield of C&D, the students at Stanford found that they had good availability to this subfield and chose early on to focus on this.

In Sweden site visits were conducted at "Globax - IKEA", "Bredemads Recycling and waste management facility", "Affärsvärkets Recycling and waste management facility", "Stena Techoworld", "Sims Recycling" and "Ekeby waste water treatment plant and wetland". Since the students at
Stanford looked deeper into C&D the Swedish students took a broader approach and looking more into the three other subfields. At "Ragn-Sells" a phone interview was conducted since a visit was not possible.

4.1.2 Need statement

As a result from the site visits and interviews five primary needs was identified.

- Relieve labor workers from manual handling of waste
- Optimize transportation solutions
- Prevent exposure to danger, disturbance or nuisance
- Design to consider the product lifecycle
- Make better use of waste

The five primary and general needs are further elaborated in the following subsections. Detailed table of interpreted needs from statements and identified problems is referred to the appendix.

4.1.2.1 Relieve labour workers from manual handling of waste

Manual handling of waste is a consistent activity throughout multiple urban mining material streams. Waste management processes usually involves disassembly, “cherry-picking” or separating materials that is desired for reusing or recycling, and what is not. The main observed method doing this is doing it manually, either by the aid of construction equipment such as a wheel loaders, or completely by hand.
Figure 4.1 Manual handling and sorting of waste is a repetitive and recurring task within urban mining. These tasks commonly involve human and environmental exposure to hazardous waste.

The challenge lies in knowing what type of waste materials that you are dealing with -- “Stuff you've never seen arrives” or “You might believe that some waste is recyclable but is apparently only trash. Everything that glimmers are not gold.” is quoted from a worker at Stena Technoworld. This suggests that the individuals experience-based judgment skills are important, which is also complex to develop an automate solution for.

4.1.2.2 Optimize transportation solutions

Transportations of materials are another issue that was found significantly reflecting on costs and environmental impacts. The materials streams involve high volume of waste that is daily transported for different purposes. Data findings highlights that a lot of transportation can be reduced or eliminated if materials can be reused or recycled on the site it was mined from, for instance by using the demolition waste as material input to a another construction project.

Another side of the issue is that machines and equipment can be hard to utilize in demolition site with limited space -- “In general it is better with small machines or equipment to be able to work in a small workspaces.” -- for
instance in deconstruction projects (inward demolition). Separated and stored materials, labor worker, and machines usually have to share the same working space.

Figure 4.2 Machines and equipment can be hard to utilize in most demolition sites where construction materials, machines, equipment and labor workers shares the same working space. Limited space on construction or demolition sites is a common issue.

4.1.2.3 Prevent exposure to danger, noise disturbance or nuisance

“Most often, it could be that you feel a very strong scent or something chemically that nobody recognizes. This forces us to go away for a while before we know what it is” is quoted from a demolition worker at Globax. Manual handling of waste materials commonly involves human and environmental exposure to hazardous waste like asbestos or mercury, either directly or indirectly.

The construction industry is generally known for its high rate of accidents, health issues and environmental impact. It was stated from a demolition worker at Globax that “demolishing buildings with nearby houses around is hard” and “a lot of dust is released into the air when demolishing”, which implies on the environmental and health issues that C&D projects generates. The quote “Dislikes that it is never calm and quiet” further highlights the significance of noise disturbance.
4.1.2.4 Design to consider the product lifecycle

Since most products usually contain different materials it is inevitable that they need to be disassembled in one or another way in its end-of-life phase. This makes reusing or recycling more difficult. As products become more complex in their technology and design, they have recently become more difficult to disassemble as well.

Many of those interviewed proposed that a greater focus on the product’s lifecycle should be put initially in the design development process. Design decisions can determine a product’s life cycle considerably in terms of for instance recyclability, reusability and environmental impact.

“These machines are extreme, they come in here done but we change almost everything. All the work lamps on the machine for instance. It is already in place but we take it off and put another lamp there. The regular lamps are not good enough, everything is expected to be LED now. So everything is exchanged to LED” is quoted from a service technician. This somewhat suggests that a product’s lifecycle and user’s needs is not always considered in the design development or manufacturing phase. “These parts takes long time to weld and to make it fit the machines”, “Everything is so big and unwieldy to work with. That is why it is so time consuming”. The cost optimization and choice of production process may prioritize a firm’s manufacturing costs rather than the products total life cycle cost, as implied by these quotes.

4.1.2.5 Make better use of waste

The C&D sub-field generates various waste materials such as concrete, window glass, plastic and insulation materials. Many types of materials, especially plastics and old insulation cannot be recycled, usually ends up in the landfill. Due to the issue of lack of space on C&D sites, the waste is usually either crushed on site or transported away. Crushed concrete and window glass, which is common in modern buildings, was for instance found being used as infill in construction projects to save costs on transportations. However, this depends a lot on different factors, whether if it can be reused on site or in nearby ones. Noise disruption during crushing is another factor that can be regulated depending on the location.
Cost and time are other factors that are considered important by many projects since it is usually a matter of making profit. The reason why C&D projects do not put much effort into reusing or recycling waste is due to lack of benefits. If cost savings can be done without taking further responsibility of the waste (for reusing or recycling etc.), and if it is completely legal, then it is likely to become more viable. Finding better and more innovative uses of waste is the challenge that is raised from here. “Better local collaboration” and “The waste that we can’t use anymore is put on landfill” are quotes from a worker at Building ReSources that suggest there is a potential need for a circular economy and preventing landfills.

4.1.3 Idea generation and prototyping

After the site visits, observations and defining the needs, the group made the decision to go into the C&D subfield since this sector is a very large sector that affects all the other subfields with the waste that is produced. This is also a field where Volvo is already a major actor and a customer base exists. When
developing the ideas, the group still has all the knowledge from the other subfields. The interaction from C&D to the other subfields is shown in the figure below.

Figure 4.4 The “current” flow of materials that was identified. C&D waste undergoes most of the waste management processes on other places, which requires transportation.

When the needs had been defined, idea generation was conducted in order to find a solution to solve these with a product. The idea generation was conducted in several ways ranging from brainstorming to more controlled/formal brainstorms and idea generation based on system/function decomposition. From these ideas a few different prototypes or mockups were created to test different functions.

It became clear that the process of going from a worn out building to a new building was long – containing many different steps and in reality many different companies. The idea to make this loop tighter was brought up in the group. At the end of the PSS course the concept that was generated focused on this idea by bringing the factory to the construction site instead of moving the waste back and forth over large distances with trucks. The concept got the
name on-site concrete recycling plant and the idea was to put everything that is needed to make new concrete out of old concrete in a container that could be put on site.

![CAD-model of the system and its different main components.](image)

**Figure 4.5 CAD-model of the system and its different main components.**

### 4.2 Concept Generation

After the completion of the PSS course the Swedish students chose to follow the ME310 deadlines. These deadlines were for the most part prototyping deadlines where the team prototyped different ideas and showed at biweekly reviews at Stanford. This both because there were no formal deadlines in the master thesis and in order to get some structure and good collaboration. What was done and presented during the autumn were put aside and the knowledge was used to explore new areas and ideas. However the focus was still the construction and demolition area.
4.2.1 Dark Horse

The spring started with exploring something called a dark horse prototype. This means to first form an idea that is a bit out of the box and something that probably will not work but that seems interesting to try and make it work. Even if the idea will not work there is something to learn about it and probably there is a way to make it work or at least part of it. For this process the group started with discussing different ideas and opportunities on each side of the Atlantic, before having a brain writing session over Google hangout. After this the ideas were discussed and the group settled on looking into smart ways to store material at the limited sized worksites. It was also decided that what the idea and prototype was going to be was up to the two parts of the group to get two ideas instead of just one. This was also an easy way to do it since the time difference is so big and also it is a waste to build two prototypes that both looks exactly the same.

4.2.1.1 Dirt Mushroom

This idea was inspired by a water tower were the material was stored in a vertical way with a bulb on top. The idea was that the material that would be stored in this would have a very small footprint in relations to the amount. The full-scale model would be 7 meters tall and 6 meters in diameter. The footprint of this version of the dirt mushroom would be 1/6 of a regular pile of material. This idea was made into a prototype to see how it worked but it was soon realized that this would not work, the solution was too top heavy.
4.2.1.2 Hammock

Another idea that built on reducing the footprint while storing material was the hammock. This idea built on three telescopic legs and a hammock between them and the idea here was to fill the hammock with material then raise it up in order to be able to use the area under it for other things, such as storing machines or even drive underneath it.
4.2.2 Final Design

After the dark horse prototyping the project went into the next phase, the functional prototyping. The functional prototyping was a phase that focused more on trying to make prototypes that could show certain key functions. This was in order to nail down the final designs and prototypes. The different key functions were developed and the good ones added to the final design.

4.2.2.1 NIX

The NIX is an idea based on the dirt mushroom but without the heavy bulb on top. This idea has had a few different versions on the way but the basic idea has looked the same the whole time. This would also store material in a vertical way with panels that will make the storage unit able to take different shapes such as square or hexagonal. The storage units would then be able to stand very close next to each other and also stacked on top of each other. The NIX should also be able to be assembled by hand with a maximum of two workers; this means lightweight parts while still able to hold the material in place. The size is variable since it is possible to make different shapes from the panels but the hexagon would be able to hold 7.5 tons of material in weight and this would mean a full NIX if the material is crushed up concrete.
4.2.2.2 Modular X

Modular X is not a product idea as the others but rather a collection of the different processes that is needed in order to convert waste material into new material that can be used to build a new building. So basically what is needed in order to recycle the materials. The idea is then to take these different processes and move them to the site instead of shipping the material to the different factories. This was named modular X because the vision was to make the different processes work with each other without a lot of middle handling of the material. A figure of the modular X chart can be found under appendix.

4.2.2.3 UM Factory

UM Factory stands for "Urban Mining Factory" and is a concept that is based on what the students presented in the PSS course that was further developed with help of the modular X chart. The UM Factory is a concept that will be transported to the work site and then set up to help with handling of the material. There will be different boxes that will do different things and be helpful at different times during the demolition or rebuilding and so the boxes can be transported off site to save space when not needed. With this idea there is limitations what cannot be made with today's technology but can be
developed with time. Since this is a very broad concept a narrower concept was further developed while the broad concept remains more visionary. The narrow concept that was developed is the batch plant factory; this is a concept that will turn crushed concrete into a new mix of concrete that can be used to build parts for a new building.

Another important environmental aspect of the UM Factory concept is that it is designed to minimize the dust and noise distribution, this makes it possible for use in the urban areas without harming the environment or disturbing people.

Figure 4.9: Illustration of the UM Batch Plant concept.

4.3 Concept Selection

The different concepts build on each other or are a support function/product for another concept. The concept selection was made continuously and the concepts were often built on in order to improve them. The dirt mushroom lead to the current NIX idea while the hammock was disregarded quite quickly since it used advanced technology that would cost a lot so there would be no business case for it. The NIX solution was the concept that was chosen to continue on. The NIX was looked at into detail and the different parts were looked at separately in order to improve on the overall concept. The NIX was
refined but the group felt that it was lacking a system to be put in, the NIX on its own was not enough. This is why modular X was developed. Modular X has a lot of potential and in order to make this concept into something feasible the UM Factory concept was developed. Here the focus was put on the batch plant idea to make it into something tangible this is then called "UM Batch Plant".

The two concept that was picked was the NIX and the UM Factory. The group found that both of these concepts have great potential and complement each other in a great way.

4.4 Concept Evaluation

The NIX concept was picked because it filled a lot of the requirements that the project group generated. For example the NIX is a modular storage unit that can be used both for smaller jobs at private homes or in huge projects. It is also a light design that can be manually handled and this will reduce the machine cost. The NIX also fills the need for storing material on site when the space is limited. However the NIX need support functions both before and after its use. The material need to be crushed down to a manageable size for the NIX to be at its maximum capacity and not store a lot of unnecessary air. It also needs some process afterwards when the stored material will be used again. This is where the concept of UM Factory comes in; the vision is to use different UM Factories for different times in the job process. For example a UM Crusher before the material is stored in the NIX, the advantages of having a crusher in a box is the possibilities to reduce the noise level and also the dust that is generated. Both of these disturbances are a problem in urban environments where there are a lot of peoples that will be bothered with these things.

4.4.1 Prototypes

The two concepts that was picked to be prototyped is the NIX and the UM Batch Plant. The NIX design was nailed down sooner than the UM Batch Plant so the NIX will be a visually good looking prototype in full scale while the UM Batch Plant was designed later on and will be a prototype that focus more on the testing of features. The visual look of the UM Batch Plant will be a bit more rugged and in quarter scale.
4.4.1.1 NIX

The NIX prototype was built as both a visual good looking prototype that will get some good attention during the Expe at Stanford University but also a prototype that can show on the modularity of the concept. The prototype is in full scale and built in materials that is the same or close to the material that is planned for the final product. For example the fabric bottom was hard to get in the final material since it is expensive and have very long delivery time.

![Figure 4.10: Two NIX prototypes stacked.](image)

4.4.1.1.1 NIX improvement possibilities

When testing the NIX prototype a problem that was found was the fact that a lot of material stayed in the corner when the NIX was going to be emptied this is a problem that will need to be addressed for future development of the product. The reason for material getting stuck here is that the opening is rectangular in the middle while the NIX is a hexagon. One solution to this
might be angled edges in these two corners just to make the material slide down to the center. Folding the fabric in another way so that it goes more into the corners could also solve this. Other than this, the NIX prototype worked as intended when it was tested, the opening lets the material be emptied in a trench looking way in a controlled manner.

4.4.1.2 UM Factory

The UM Batch plant was built in scale 1:4 in order to be in a manageable size and with less focus on the visual since that prototype was built in Sweden and there was no money or time to ship it to the Expe. This prototype was built to see how good noise reduction possibilities a container or walls around the batch plant but this prototype also showed on noise reduction possibilities for other versions of the UM Factory. For more data on the results of this test see appendix.
4.4.1.2.1 UM Factory improvement possibilities

For the noise reduction on the UM Factory there are many possibilities for future development. The results from testing with the polyurethane foam plates showed good potential and this should work well for the full-scale model as well. There are a few tweaks that can be made in order to make it reduce the noise even better. From the prototype testing it was found that most of the noise leaked out in the corners of the container since they were not welded together and also in the space between the bins. Since a full-scale container is welded together in the corners there will be a bit less noise that leak already here. Another possibility is to make the walls look and work like a sandwich material. With foam plastic in between the inner and outer wall.
This could possibly reduce the leakage even more. By also putting foam plastic around the bins and seal the bins to the roof even further noise leakage might be prevented. There might be some gains in making the bins with an inner and outer wall as well. However this might cost more than it is worth.

There could be some benefits of making the container from scratch instead of buying a standard one. First of all the sandwich walls can be made already from the start and also all the holes, openings and lids can be made from the start instead of modifying something that is already done. This is good for the environment since modifying something will waste more material. There might also be some savings in time and cost if doing them in house instead of buying from a supplier.
5 Results

In this chapter the results from this master thesis is collected. Going through what materials and manufacturing methods can be used to produce the two products described in the previous chapter in order to satisfy the requirements for each of the two products.

5.1 Materials selection

The choice of materials for a product depends on the requirements that it should fulfill. From the theory chapter, we know that there are four methods – Selection by Analysis, Synthetic, Similarity and Inspiration – to apply in order to select the appropriate materials for this product. But it is not clear which method would be paramount in this case; all methods have their advantages and disadvantages.

Comparison of the selection methods:

<table>
<thead>
<tr>
<th>Table 5.1: Comparison between different material selection methods.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Systematic.</td>
</tr>
<tr>
<td>Deep understanding behind the specific material selected.</td>
</tr>
<tr>
<td>Robust due to precisely inputs.</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
</tbody>
</table>
imprecisely inputs or imperfectly formulated rules. | radically new solutions (Depends on past experience) | materials have certain values /properties. | depends on ideas discovered almost randomly.

5.1.1 Materials selection – NIX

All four methods are based on conversion of the design requirements into a list of viable materials. In this case, there are different requirements and properties that the NIX design should be able to achieve. Some of them have a great impact on the choice of materials while other requirements are of less importance.

The NIX is considered as an “engineering” product, and its most important function is to hold a given mass of a certain material. This requires both strength and durability. If the NIX design fails to withstand the forces it is exposed to, then it does not matter how elegant the design is or how simple it is to setup and neither if it is recyclable or not. Dissatisfaction of the strength requirement will make the whole design fail.

Therefore, strength and durability of the selected material will be prioritized in this case. This goes hand-in-hand with the requirement of lightweight, since heavy components will eliminate the simplicity of the design setup. Another important requirement is the environmental aspect – as recyclability and minimizing hazardous waste.

The NIX consists of three main parts: a bottom, a frame and the panels, which are the biggest part. The challenge is to design strong panels, which are light enough to be handled manually (maximum weight 22kg). Later, the same or similar materials can be chosen for the bottom and frame. Here, the Analytical method would be advantageous. It is robust and based on a deep understanding of how the chosen materials will satisfy the set requirements.

The analytical method is done in four steps that will be walked through shortly:

1. First step is translation of the design requirements into clear statement of function, constraints, objective and free variables:
Table 5.2: Translation of design requirements into statements.

<table>
<thead>
<tr>
<th>Function</th>
<th>Contain and store a pressure/load of 7.5 ton crushed concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraints</td>
<td>Non-negotiable constraints:</td>
</tr>
<tr>
<td></td>
<td>- The storage unit must be impact resistant; must support</td>
</tr>
<tr>
<td></td>
<td>axial the tensile load from the contained material &amp; vertical</td>
</tr>
<tr>
<td></td>
<td>load 707 040 kN without failing.</td>
</tr>
<tr>
<td></td>
<td>- The material of storage unit must be recyclable</td>
</tr>
<tr>
<td></td>
<td>- The storage unit must be RoHs approved</td>
</tr>
<tr>
<td></td>
<td>- The storage unit must be safe during operation</td>
</tr>
<tr>
<td></td>
<td>Negotiable constraints:</td>
</tr>
<tr>
<td></td>
<td>- The storage unit shall be easy to repair</td>
</tr>
<tr>
<td></td>
<td>- The storage unit shall be sealed to dust and water</td>
</tr>
<tr>
<td></td>
<td>- The storage unit shall be able to store bulky materials</td>
</tr>
<tr>
<td></td>
<td>- The storage unit shall contain few moving parts</td>
</tr>
<tr>
<td></td>
<td>- The storage unit shall be able to stack ten units high</td>
</tr>
<tr>
<td></td>
<td>- The storage unit shall be simple to set up</td>
</tr>
<tr>
<td>Objective</td>
<td>To be maximized:</td>
</tr>
<tr>
<td></td>
<td>- Toughness</td>
</tr>
<tr>
<td></td>
<td>- Stiffness</td>
</tr>
<tr>
<td></td>
<td>- Durability</td>
</tr>
<tr>
<td></td>
<td>- Strength</td>
</tr>
<tr>
<td></td>
<td>To be minimized:</td>
</tr>
<tr>
<td></td>
<td>- Weight</td>
</tr>
<tr>
<td></td>
<td>- Costs</td>
</tr>
<tr>
<td>Free variables</td>
<td>- Cross section area</td>
</tr>
<tr>
<td></td>
<td>- Choice of material</td>
</tr>
</tbody>
</table>

2. Second step is analysis of the component for which a material needs to be selected. The analysis expresses identified performance metrics as equations that measure performance:

The NIX components for which a material needs to be selected is the panel; it should be light enough to be carried by one worker, about 22 kg. While in the same time must be able to withstand the horizontal and vertical (from stacking on each other) forces. The measure of performance is the mass, \( m \) - it is what we wish to minimize. The performance equation describes this objective:

\[
m = A \cdot L \cdot \rho \quad (1) \quad \text{// } \rho = \text{density}, L = \text{panel length}
\]
Reducing the section area $A$ will reduce the mass; $L$ is fixed to 1.07 m. But if it is reduced too much it will no longer carry the load $F$ and this constrains the section area. Requiring that;

$$F/A > \sigma_y/S \quad (2)$$

Where $\sigma_y$ is the yield strength of the material of the panel, and $S$ is a safety factor. Using this to replace $A$ in equation (2):

$$F*S/\sigma_y > A \quad (3)$$

This will be used back in the mass equation (1), which gives:

$$m > S*F*L*[\rho/\sigma_y]$$

All variables here are specified except the one in the square brackets - and it depends only on the choice of material. The mass is minimized and performance maximized by choosing materials with the smallest value of $\rho/\sigma_y$, which is called a material index.

3. Third step is identification of the material properties that will determine performance, from the equations above:

The material properties that we search for here are stiffness, durability and strength and most important is light density. Another aspect that should be considered here is cost, since the chosen material has to provide the desired properties at the lowest cost. The cost factor will determine the choice of materials in case two or more materials can provide desired performance but have various purchase as well as processing prices.

4. Finally, go through a database of materials and their properties; eliminate those that do not fulfill the design constraints, and rank the materials that remain by their ability to maximize the performance metrics:

This is done by studying a diagram of the relationship between the yield strength (MPa) and the density (Mg/m$^3$) (Figure 5.2). The materials with low density and high yield strength are put in equation (4). If the right side of the
equation becomes lower than or equal to the total acceptable mass (22kg), it means that the material is suitable for the design.

Table 5.3: A list of possible materials for the NIX design.

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield strength (MPa)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>275</td>
<td>2.7</td>
</tr>
<tr>
<td>ABS</td>
<td>20</td>
<td>1.060</td>
</tr>
<tr>
<td>PET</td>
<td>54.4</td>
<td>1.541</td>
</tr>
<tr>
<td>Composite</td>
<td>300</td>
<td>1.430</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>30.3</td>
<td>0.899</td>
</tr>
<tr>
<td>DCPD</td>
<td>43</td>
<td>1.03</td>
</tr>
</tbody>
</table>

Looking at table (5.3), we see a list of materials that could be a possible solution for the NIX design. According to quick Autodesk Inventor /FEM tests, we get a total panel weight lower than 22 kg if we use composite, DCPD or polypropylene. Other materials would be either too heavy to carry or too weak to withstand the applied forces.

In order to select the optimum material those materials are compared to each other by using another diagram that shows the relationship between strength in correlation to cost (figure 5.3). The outcome of this is that composite materials and DCPD cost much more than polypropylene. In addition, the composite is not recyclable, what makes it a less viable material.

This makes polypropylene the optimal choice for this design since it is cheap, light and strong enough to carry the applied weight, held by aluminum frame that support the panel from buckling. As well as an aluminum bottom frame to make it more stable when stacking storages on top of each other (fig 5.1).
The material for the bottom we chose carbon fiber fabric since it is very light, and strong to carry the applied weight (calculation in appendix), besides it is easier to transport. Only disadvantage is that is not recyclable, but here the mass and strength requirements are higher prioritized than the requirements of cost and recyclability.

Figure 5.2 A diagram used for materials selection, showing the correlation between yield strength (MPa) and Density ρ(Mg/m³) (Materials; strength – density, 2015)
As mentioned before the reason behind the choice of polypropylene as a material for the panels in terms of light density, easy to manufacture and is considered as environmental friendly since the plastic can be recycled after end of use. Another aspect that affected the choice of material was the cost aspect. Even though the strength was a more important property for the final product, some cost consideration was made in order to select the optimal material instead of a material that provides high performance.

Since the purpose of the NIX design is not only to reduce the environmental impact from the construction and demolition field, but also to make economical savings in order to be attractive to buyers. The other possible
materials, DCPD and composite were excluded because they would increase the purchasing price for the NIX. The total price of the NIX should not exceed the cost of hauling materials off site.

The material for the flexible bottom was chosen to be carbon fiber fabric, this is not recyclable but the importance of light weight and minimum space utilization during transportations was crucial. Selection of another material such as plastic fabric would not withstand the force. A rigid aluminum bottom would not only be too heavy to handle but also take up more space during transport.

5.1.1.1 Environmental aspects - NIX

From the theory chapter we have a list of advices and activities (Sven 1995) more as “requirements” for an environmental friendly product. Comparing the NIX design to these requirement, it shows that the design fulfill almost all of them. It can be made of recycled materials, and the materials used are 100% recyclable. The sizes of the components are optimal, while the number of different component types is three and the number of different materials is just the same. What is not fulfilled within the material optimization is that the different components are not designed for the same lifetime, since the panels’ material is not really robust. But the simplicity of the design allows easy change of a broken panel, instead of disposal of the whole product.

Another advantage with the design is that it is modular and easy to disassemble, and the three different component types are easy to separate when recycling. The only disadvantage of the design is that the panel frame is not a standardized profile; it is specially designed, and need to be processed to get the desired shape.

5.1.2 Materials selection – UM Factory

Selection of materials for the UM Batch Plant, is less exhausting than the selection of materials for the NIX design. The requirements differ and there are no specified constraints regarding weight and simplicity of the design. The only weight to take into consideration is the maximum allowed weight for a truck or the maximum load capacity of a container. This weight differs from country to country. The total weight of a UM Factory is also easy to regulate
by how much material is stored in it (water, sand, cement or crushed concrete) during transportation.

The main function of the UM Batch Plant is not really dependent on which materials is used, except that the materials should be strong enough to withstand the inside forces of the loads. Here, the selection method was done by using the inspiration method in combination with a traditionally “pre-conception”; that steel or aluminium is the answer for most "engineering" products.

![Figure 5.4: Inspiration sources for the UM Factory.](image)

The inspiration method was simply made by researching how a concrete batch plant works today; how the design looks like and what the different main components are. Both how the parts are designed and what material they are made of. We also looked into similar "new" materials if there were any better options with the same basic functions and strengths. See figure 5.4 for examples of inspiration sources.
The UM Batch Plant is surrounded by a standard container that is acting as a shield so no unwanted disturbances is released to the surroundings, such as dust and noise but also material that might fall out during the process. This will then be contained to keep a clean environment at the urban site. The reason for the container is also the easy transport that it brings, which can easily be transported by train, truck, or ship. The container that will be used is needs to be modified with openings so material can be loaded into the UM Batch Plant but also there needs to be a way to close these openings when transported. The inside of the container will also need to be fitted with insulation material. For the prototype that was built polyurethane foam plates was mounted on the inside of the sides, doors and lid. The results were promising and the same material could work in the full-scale model but with thicker plates.

The UM Batch Plant contains four different bins for the different materials that is needed for the concrete manufacturing. These will contain water, cement, sand, and crushed up concrete. The sand and crushed concrete bins will be open when the UM Batch Plant is set up on a site in order for these materials to be filled up when needed. The cement and water bins need to be closed at all time, the water bin to not leak water and the cement bin to not let out any dust. This means that these two bins need to have a closed system
inlet to fill them up. All four containers are made out of regular weldable steel for example S355J2 in order for easy manufacturing and high strength.

The sand, crushed concrete, and cement bins are held up by legs in order to have the outlet over the conveyor belt. The legs are fitted with plates in both ends. The plates are made out of the same material as the bins and the legs are made out of quadratic beams that also are made out of weldable steel. The beams will be cut in angle in one end to fit with the angled sides of the bins. The plates will be welded to the beams and the bottom plate will have holes in it in order to mount it into the floor of the container but the plates in the top end of the beams will be welded into the bins. The plates will be there in order to divide the force over a larger area in order to be able to have a thinner material in the containers. Legs will also be used for the slides for the screw. These legs will have the same set up in the bottom end with a plate that is screwed into the floor. On the top end however there is no need for a plate and the legs will be welded directly into the slides.

Legs will also be needed for the conveyor belt but these will instead be made out of U-beams with plates in the bottom as well like the others but the reason for the U-beams is in the top end where these will contribute to easily screw these into the conveyor belt.

The legs for the conveyor belt will be screwed into the sides of the gutter that surrounds the conveyor belt. The gutter will be made out of two parts, one plate that is bent in an L-shape and one plate that will act as a side to the L-
plate. The reason for making it into two parts is if there is a need to service the conveyor belt there is only the need to remove side. In the back of the gutter there will be another lid that is welded into the L-shaped plate. On the other side there will be a similar lid. In the front there will also be a small hole in the floor with angled plates in order to let the material from the conveyor belt down to the screw. The gutter will have legs that is screwed in, the same screws will be used attach the side to the L-plate by two U-beams that have a plate on each side. These U-beams will also be used to hold up the plate that the rubber belt will slide on. See figure 5.6 for a better understanding, in the figure the large side plate is hidden for better internal view.

The conveyor belt will be made out of a rubber belt that will be moved around with the help of an electric motor. The belt will be stretched around two rolls, one in each end. One of these rolls will be connected to the motor that will rotate it. In between the rolls there will be a plate that the belt will slide on just to keep it from sagging in the middle.

In the bottom of the standard container there will be two slides for the screw. These slides will let the screw slide in under the conveyor belt when the UM Batch Plant is in transport mode. These slides will be made out of U-beams with a plate in each end to not let the screw move to far back or fourth. The slides will be fitted with the aforementioned legs. Both the U-beams and plates will be made out of weldable steel.

A pipe that keeps the concrete mix in place will surround the screw. The pipe will be open in the bottom end in order to let the materials fall down into the screw. In this opening there will be edges that will make the inlet a bit wider than the pipe. In this end there will also be two pins that will slide in the slides in order to keep the screw in place. In the other end of the screw there will be an outlet on the underside of the pipe. The pipe will be able to be moved into different angels up and down. Therefore there will be a bracket on the upper side of the pipe that will be connected to a hydraulic cylinder that will move the pipe up and down. All these parts will be made out of weldable steel in order to weld them together. The hydraulic cylinder will be a standard part in a suitable size. The screw will also be made out of weldable steel. The screw will have a steel core with a thin plate that will be twisted around the core and welded in place. The other end of the cylinder will be mounted into a bracket that is welded onto a beam that is screwed in place between the insides of the large container.
5.1.2.1 UM Factory material selection - analysis

For the UM Batch Plant there might be some advantages in changing the material of the bins into a lighter material such as carbon fiber. However using steel is not that bad, it is easy to weld together and since pretty much the whole UM Batch Plant is made out of steel it is easy to recycle. If the UM Batch Plant is made into many different materials that will lead to more work in order to recycle it. The materials might need to change in the future depending on regulations, prices and availability but from the knowledge of today steel is a good choice.

5.1.2.1.1 Environmental aspects - UM Factory

For the UM Batch Plant, the design is almost 100% recyclable. With exception for the conveyor belt and the insulation materials, which depends on how they are taken care of when disposed. However, the development within this field is growing and those materials can be down cycled and used for other purposes.

Since the design consists of pretty much just steel, the components will have a similar lifespan. The only disadvantage is that the components are pretty large and therefore heavy, which might make the disassembly of the product a bit difficult and heavy equipment is needed. Minimum waste during manufacturing is easy to achieve, as long as materials are ordered at the desired amount, shape and size. The design is not really modular, but it is possible to change / repair components if they break down, and all profiles are standardized so it is just a matter of cutting them in the right way.

5.2 Manufacturing processes

5.2.1 Manufacturing processes – NIX

The NIX design is simple and does not require a lot of manufacturing processes since it does not contain many components. The panels will be made of “plastic” and be put in a “hinge frame” made of aluminum.
Saw cutting will be used in order to cut U-shaped aluminum profiles into the desired length. Later, TIG spot welding method will be used in order to attach the parts together. Bending with a single die method (figure 3.9) will create the frame “hinges”. Then attached to the frame by TIG spot welding as well. A robot will be used in order to do the welds to get a precisely and high quality finishes.

5.2.2 Manufacturing processes - UM Batch Plant

For the UM Batch Plant there is a lot of manufacturing processes that is needed in order to build the whole product but since most parts are made from the same material it will still be a pretty simple job.

In this product there is a lot of different plates that is used in different sizes and shapes. In order to get them in the correct size and shape different tools will be used. For the more advanced or complicated plates a water jet cutter is a good choice. For the easier plates that is rectangular or square without holes a sheet metal cutting machine is a better choice.

When the different plates have the correct size some of them need to be bent in a certain angle, an appropriate bending method will be used depending on angle. An edge-bending machine with a wiping die is the best choice (figure 3.8) for the L-plate on the conveyor belt gutter while a metal bending with a V die (Figure 3.7) is the best choice for the bins where a smaller angle is needed.

For the beams that will be cut up in different lengths and with some angels a metal saw is used this is a fast and easy way to cut up these kinds of materials.

For welding everything together the MIG is the best option, it is a fast method for welding steel. Since there is a lot of welding that needs to be done this method is a good choice, it would take too long and cost too much with TIG. After welding the different parts together some kind of seal is needed to prevent rust, for example painting everything.

A CNC machine will make the openings that need to be done in the pipe for the inlet to the screw as well as the outlet. A CNC machine is a good choice here since it is easy to cut out a portion of the pipe and also to make holes in
the pipe. Since a pipe has a bent surface a regular drill is hard to use while milling the hole is much easier.

The electrical motor, hydraulic cylinder and the conveyor belt will all be bought as standard parts. There is no need to reinvent these.

When all the different parts are cut up, welded and painted the next step is to assemble everything together with screws.

5.2.3 Manufacturing processes - analysis

3D printing is a very good manufacturing process that reduces the waste material during manufacturing. However for now it is a slow and expensive process that is unnecessary to use for the UM factory since it has very basic parts. There is no part that is very complex here. There might be some gain in combining the implementation of 3D printing with the change of material of the different parts. For example making the bins and their legs in one part in a material such as carbon fiber. This will reduce the number of parts and the assembly will be easier as well as quicker for the workers. We see this is a future possibility if 3D printing will be cheaper and faster but also the material will need to be cheap, easy to recycle and with good strength. There might be some strength benefits with combining many parts into one in order to remove weak spots in the design where the welding takes place.

3D printing might also be a good choice for the NIX by making the panel frames in one single piece and thus skip out on a lot of welding and making the individual parts. As it is now the panel frame is made out of aluminum, which is possible to weld, but it takes time and a skilled welder. If the frame instead were 3D printed into one piece this would lower the manual labor needed as well as making sure that the construction is strong. There might also be some benefits in making this in some kind of strong, light material such as carbon fiber. For the same reason here the as with the UM Factory the cost and time for 3D printing as well as the material makes this a less desired choice as of right now.
6 Discussion

In this chapter we will discuss if the outcome would have looked different if we would have chosen other methods to work with, if the starting point would have been different. We will also bring up some speculations we have for the future.

6.1 Methodology

To execute this thesis project the method used in general was concurrent engineering, where different “phases” of a new product development such as materials selection, manufacturing possibilities, environmental- and cost aspects were investigated in parallel, rather than sequentially. Now after the project has reached its end the question is if we could achieve a better or different outcome if we had used another method in order to execute this thesis work. We believe that there is not many other methods regarding a product development process, except for the old “over the wall” process where different phases is done in sequence, which is generally stated as not sustainable, since it’s both time and money consuming. The use of the concurrent engineering method in general was not difficult or more exhausting, even if it sounds like investigation of several “phases” in parallel would be. This instead gave us better insights early in the design process and guided the ideas generated to match several factors from the different phases so this was thought of before the design was set.

What we could have done differently is the selection of tools for data collection. A more specific method could have been chosen for the collection of primary data, either as a qualitative or quantitative method or maybe a combination of both. We believe that interviews specifically with experts in manufacturing processes or in materials selection could have been valuable to validate the final result that have been achieved, but would not make it look different, since the data was collected both by academic research as well as from companies with many years’ experience that recommended specific processes in their web pages. For example Steelex with over 40 years’ experience in welding and or Efunda’s webpage where all facts and data about various manufacturing processes is written by real engineers, according to their webpage.
6.2 Result discussion

Here we will discuss what might have been different if we would have used other methods for selecting materials as well as what might have been different if we would have started the project with a set design on a product.

6.2.1 Method for materials selection

There were four different methods for materials selection. The methods used were selection by analysis for the NIX design and selection by inspiration for the UM factory. The selection by analysis method was both time consuming to apply as well as more difficult to apply in comparison with the other selection methods, but was important to use in this case since we was restricted to certain requirements regarding the weight and the strength required to withstand the forces applied. Another useful selection method in this case was the selection by synthetic, where we tried to look for a previous case where a similar design problem has occurred and make use of the same “result”. This would save us some time and effort but no similar case was found. For the UM factory another selection methods as selection by analysis or selection by similarity could have been used. However they would require more time that we simply did not have for this project, therefore we chose to go with the most simple method, selection by inspiration, which was good enough to satisfy the design requirements.

6.2.2 Start with a designed product?

If there would have been a product or concept in the beginning of the project and this thesis would only look into what materials and processes could be used the result might have been different. First of all the different parts would already have a set design and thus the different manufacturing methods applicable to the parts would be relatively easy to find. This would mean that the process of finding theory behind the different methods would be shorter and we would have had more time to go deeper into de facts. For example with a finished product we would have had time to investigate the economical aspect further. We would also have had the time to investigate the difference in time for using different manufacturing tools. This would mean a more
thorough result however it is our belief that the result would be very similar either way.

A possible problem that might have occurred if we did start with a product that was designed and just needed materials selection and manufacturing plans is that it would not have been designed for manufacturing. In that case we would have to modify the design of the product in order to make it easy to manufacture.

6.3 Speculation for the future

We believe that in a near future, 5-10 years, 3D printing will be a big portion of manufacturing. Part will be joint together and instead of being put together one by one manually by welding or screwing for example. Already today 3D printing is used in the manufacturing of engine parts for airplanes and we think that the technology will be developed in a way that makes it useful for more common parts as well. We do think that the environmentally friendly trend will help with this. When looking at how the common manufacturing processes work today they remove material in order to get the desired product, this means that everyday companies buy material that will be removed and sent to be recycled. So in other words they produce waste. This is not sustainable from an environmental point of view and we believe that regulations will be put in place for the ratio of material in versus waste out. So the ratio between the materials a company buy versus the waste that comes directly from removing material in manufacturing processes.

Another aspect of this is big companies that live by having an environmentally friendly stamp on their product and as a core value in the business. Using 3D printing in their manufacturing chain might be a boost to this value.
7 Conclusions

The purpose of this study was to investigate what manufacturing processes in combination with suitable materials would be appropriate to use for a sustainable product. More specifically the product developed within the urban mining project. The outcome of the question: "What are the appropriate material choices for the final products?" was inter alia materials that are cheap, easy to manufacture and recyclable; such as aluminum, polypropylene and steel, and to a smaller scale carbon fiber. On the other hand the outcome of the question: "What manufacturing processes are suitable for the final products of the urban mining project?" was bending, welding, water jet cutting, CNC machining and sawing. These methods are easy methods that are widely used today and they work well for these products. They are also not harmful for the environment.

As regards the third research question “If urban mining could be a future business segment for VCE” we believe that the answer is yes it could be. During this study and project the area of urban mining have been more and more clear as a segment. Eight months ago none of us had heard about urban mining but now we have a clear understanding of what it is and how it will affect the future. With all the different site visits that have been conducted a lot of insights have emerged within the different segments of urban mining. We found that the different segments correlate to each other in many aspects. For example a lot of the waste travels through the municipal solid waste management plants at some point in the process. We see urban mining as a part of the coming future, now it is just to get onboard the train and for someone to take the roll as captain to lead the way. We believe that Volvo CE could be that captain. We see this is a great way for Volvo to be the leader in this field both to help develop the recycling area for a better world and also help the company to take the next necessary step to stay ahead of the competition. Therefore we recommend Volvo to take urban mining as their new business segment.

7.1 Future work

Some work for the future after this thesis is to look into the economical aspects and comparing the different manufacturing processes but also the different materials for the two products. Especially for the materials this is
something that needs to be done since there are so many materials out there and new are developed all the time. Combining this with looking into how the products can be redesigned in order to be 3D printed is something that will be beneficial, not that the design is poor but 3D printing opens up for a whole new area of design freedom.

For the UM Factory the other concepts will need to be developed, such as crusher and sorting containers. Also building the UM Batch Plant in full scale to try if the capacity and functions will work as intended needs to be done. For the NIX the problem with material getting stuck in the corners needs to be addressed. Also trying to stacking NIX’s to the full capacity needs to be tried, there might be some issues doing this since the NIX is designed to be lifted in wires from the top. Might be a problem to stack them high in the air.
8 References


Automill AB. *CNC; how it works*. (E-resource) Available at: <http://www.cncfräsning.se/hur_funkar_det.html> [Accessed at 2015-03-29]


Kågesson Gustav, Holmberg Daniel. 2014-06-01. Literature study, Water jet, within the course “Production system” (MT 1422)


8.1 Figures


9 Appendix

9.1 Prototype testing

9.1.1 Test info

The noise source was a portable speaker with the highest sound level and a phone also on highest sound level. The noise came from two different videos, one of a batch plant and one from a concrete crusher. The test was done in a closed room and the microphone that picked up on the noise were put 4m away from the speaker. The test had 3 different set ups, current solution, sealed in a container and a container with insulation. Current solution was the prototype without walls or roof, sealed in container was with all walls and roof and the container with insulation was after we put in the plastic foam plates on the walls and roof. Each set up was tested 3 times for each noise source.

We calculated both the actual noise reduction and the relative noise reduction. Since there is a logarithmic scale for noise level. The relative noise is the difference that humans hear. (Trafikverket, 2015)

<table>
<thead>
<tr>
<th>Noise level (dB)</th>
<th>Relative noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 dB</td>
<td>1</td>
</tr>
<tr>
<td>10 dB</td>
<td>10</td>
</tr>
<tr>
<td>30 dB</td>
<td>1 000</td>
</tr>
<tr>
<td>60 dB</td>
<td>1 000 000</td>
</tr>
<tr>
<td>100 dB</td>
<td>10 000 000 000</td>
</tr>
<tr>
<td>140 dB</td>
<td>100 000 000 000 000</td>
</tr>
</tbody>
</table>

9.1.2 Test results

<table>
<thead>
<tr>
<th>Concrete Crusher</th>
<th>Current solution</th>
<th>Sealed by container</th>
<th>Container with insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>80,9</td>
<td>72,5</td>
<td>68,5</td>
</tr>
<tr>
<td>Test 2</td>
<td>81,2</td>
<td>72,2</td>
<td>68,6</td>
</tr>
<tr>
<td>Test 3</td>
<td>81,4</td>
<td>71,9</td>
<td>68,6</td>
</tr>
<tr>
<td>Average</td>
<td>81,17</td>
<td>72,2</td>
<td>68,57</td>
</tr>
<tr>
<td>Noise</td>
<td>0%</td>
<td>11,05%</td>
<td>15,52%</td>
</tr>
<tr>
<td>Batch Plant</td>
<td>Current solution</td>
<td>Sealed by container</td>
<td>Container with insulation</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------</td>
<td>---------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Test 1</td>
<td>80,2</td>
<td>71</td>
<td>67,6</td>
</tr>
<tr>
<td>Test 2</td>
<td>80</td>
<td>70,9</td>
<td>67,7</td>
</tr>
<tr>
<td>Test 3</td>
<td>80,2</td>
<td>71</td>
<td>67,6</td>
</tr>
<tr>
<td>Average</td>
<td>80,13</td>
<td>70,97</td>
<td>67,63</td>
</tr>
<tr>
<td>Noise reduction</td>
<td>0%</td>
<td>11,44%</td>
<td>15,60%</td>
</tr>
<tr>
<td>Relative reduction</td>
<td>0%</td>
<td>87,88%</td>
<td>94,38%</td>
</tr>
</tbody>
</table>
9.2 NIX calculations

9.2.1 Bottom clothes

Cloth Bottom Calculations

Model like a thin walled pressure vessel

Hoop Stress $= \frac{pr}{2t}$
Shear Stress $= \frac{pr}{4t}$

In metric
\[ p = 7260 \text{kg} \times 9.8 \text{m/sec} = 24143 \text{Pa} \]
\[ r = 12.5' = 3.81 \text{m} \]
\[ t \sim 0.0254 \text{cm} = 2.54 \times 10^{-4} \text{m} \]

For 3.5' panels with 6'' maximum sad
\[ c = 3.5' \]
\[ h = 0.5' \]
\[ r = \frac{h}{2} + \left( \frac{2c}{h} \right)^2/8h = 12.5 \text{m} \]
Hoop Stress = 181 MPa
Shear Stress = 91 MPa

Kevlar Tensile Strength = 3620 MPa

Will have to double up to get strength in all directions
9.3 Modular X chart

**Powersource:**
- One source to power everything
- Electric
  - Self-supporting
  - Incineration
  - Solar cells
- Hydrogen
- Biofuel
- Methane
- Butanol
- Modular (one to each)

**Features (Urban mining):**
- Low noise level
- Low dust level
- Low deployment area
- Easy assembly/disassembly
- Easy transport