Product-Service System Innovation in Urban Mining
-A case study with Volvo CE

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Abstract: Volvo Construction Equipment (Volvo CE) is one of the world's largest manufacturers of construction machines. Now they want to access a sustainability-focused mining field – urban mining. This study is to find a solution helping Volvo CE quickly access to urban mining with a Product-Service System (PSS) development concept. To do this, the authors completed surveys and several interviews with construction companies, to understand the user and customer needs. The authors also go through a functional analysis on a new prototype of their collaboration partner - Stanford University. The result of this thesis is a PSS concept for urban mining, developed with machine selection guidelines combined with Life Cycle Assessment, and Quality Function Deployment. Recommendations include: 1) Improve the communication between Volvo CE and their Customers. 2) Adding more visible services. 3) Adding multiple business solutions provide to customers. 4) Understanding relevant stakeholders in urban mining 5) Expand research on urban mining.

Keywords: Construction Equipment, Urban Mining, Product-Service System, Sustainable Development, Life Cycle Assessment, Quality Function Deployment, House of Quality
Statement of Contribution

The thesis team consists of two MSPI (Master’s in Sustainable Product-Service System Innovation) students from Blekinge Institute of Technology in Sweden. Both team members have interesting in providing a sustainable Product-Service System for construction equipment manufacturing company under a new concept-urban mining.

Each of the authors puts their efforts to contribute the final thesis document. Yi Chai mainly focuses her work on thesis structure, thesis planning and contacting with companies and Stanford students. She did great contributions in methodology and theory, Life Cycle Assessment, QFD design and initial Product-Service System Design. Zhenqing GAO main focuses on Design research methodology, urban mining background, previous needfinding arrange and new Product-Service System idea. The common works by both authors are needfinding interview, survey design, and thesis writing.

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Executive Summary

Introduction

The essential concept of urban mining is extracting valuable materials in urban area via recycling or reusing them in a proper way. In a broad sense, urban mining is the process of city recycling which includes products, building and waste. Volvo CE is one of the leading edge construction equipment manufacturers who saw the potential in urban mining market. The objective of this thesis is to research the value of urban mining, to find customer needs and requirements from different stakeholders and to find ways to increase customer value via Product-Service System Innovation.

Two universities have been involved in this urban mining topic with Volvo CE, one is Stanford University (United States) and one is Blekinge Institute of Technology (BTH, Sweden). Students in both universities are in collaboration with sharing knowledge and innovative ideas. From Stanford side, they focused on prototyping the future machine, which is suitable in the urban mining environment and in our side from BTH; we provide our contribution in sustainable Product-Service System innovation. Within the collaboration, we aim to provide a combination of tangible machine and intangible service system for Volvo CE in urban mining.

Research Design

To achieve our thesis goal, we did research design and formulated our research questions in three aspects:

1 Value aspects

What is the value in urban mining?

How can Volvo CE make a contribution towards optimizing the value of urban mining?

2 Product aspects

How can Volvo CE satisfy their client with the most suitable solution?
What will be the competitiveness if using a future prototype (i.e., the Volvo 310X)?

3 Service aspects

What business model can provide a “win-win” situation for manufacturing and recycling companies and at the same time promote sustainability?

Sub questions:

What is the current business model for urban mining business?

What factors affect value creation for recycling firms?

Which Product-Service System is suitable for Volvo CE in urban mining of demolition projects?

Methodology and Theory

To find the right answer for our research questions, we first did research to understand the concept and potential in urban mining. We did several interviews in construction companies, the construction worker union, construction equipment manufacturers, a construction recycling company and a concrete making company. Then we prepared a survey to collect useful information from a customer’s point of view. The survey consists of three parts, which are basic information of the interviewee, questions related to our research questions, and comments of our future prototype, respectively. We use Life Cycle Assessment to analyse the Volvo 310X – the future prototype from the Stanford team – versus current machines in the use phase. To translate customer requirements to technical targets, and product and service targets, we use Quality Function Deployment (QFD). Finally, we develop a Product-Service System concept in the end, based on the collected information.

Results

From interviews and survey in different companies locally, we get many relevant customer requirements in urban mining area in Sweden. The requirements we summarized are clean environment for construction workers, safety for workers doing the demolishing work, alleviate burden meaning that the worker should not need to use man power to lift and to put
down the heavy construction materials, avoid deadly dust like quartz and asbestos to workers, increase demolition efficiency, increase management and commitment during the working site, sorting and recycling the demolished concrete in a proper way, and the machine for demolition tasks could through the door and reach the required locations.

For the results of QFD, remote system, machine chassis and concrete fragment system is more attracting for customers. To reach these three technical goal, real time data tracking reporting system, site management and attachments is the back up. Three items, which are procurement or rent suitable demolition equipment, maintenance, and human resource, are more important in the product and service system planning.

From a LCA study under a boundary, which we focused on the use phase of recycling a concrete slab, we found that current solution is expensive in terms of fuel cost and total solution provided. On the other hand, the Volvo 310X, which is a future prototype designed by Stanford University, is cheaper in fuel cost but need more time to finish a certain job.

We design a use-oriented PSS model to let Volvo CE selling function of product. Logically, when urban mining environment coming, also some future market changes will appear. We consider that more special products will be designed for complicated urban construction sites; the earth’s resources scarce make people pay more attention on recycling. Our use-oriented PSS model is designed for dealing with this situation.
Glossary

IPS²: Industrial Product-Service System
ISO: International Organization for Standardization
LCA: Life Cycle Assessment
LCC: Life Cycle Cost
LCI: Life Cycle Inventory
LCIA: Life Cycle Impact Assessment
MSPD: Method for Sustainable Product Development
MSPI: Master of Science in Sustainable Product-Service System Innovation
OEM: Original Equipment Manufacturer
PD: Product Development
PSS: Product-service Systems
QFD: Quality function deployment
SPs: Sustainability Principles
Volvo CE: Volvo Construction Equipment
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1 Introduction

In this introduction, we start with introducing and defining urban mining and urbanisation background. We give an overview of urban mining market and two interesting cases about demolition market. Then we introduce our project background, which includes our challenges, thesis purpose, and team members. In addition, we provide information about our scope. After that we will draw out the purpose of this thesis.

1.1 Urban Mining and Rapid Urbanisation

Urban mining is a very broad concept, which includes almost all recycling behaviours in cities. In addition from a construction perspective, many of the demolition work also can be considered as urban mining. So we think that the most appropriate definition for urban mining is the process of reclaiming compounds and elements from products, building and waste (Stallone, 2011). With today’s increasing urbanization trend, many of the original resources being mined from the distant mining field transfer to cities, urban areas now might have a higher content of valuable material than normal mines.

Urbanisation

In 1950, about 14% of the world’s population lived in an urban environment, it increased to 50% at the beginning of the 21st century and an estimate shows 60% of the people will live in cities in 2030. Almost all materials go to urban areas and with it follows a new thinking – urban mining. The base for developing urban mining concept is: “Attention is currently moving from the limited and fixed stocks of raw materials to the increasing anthropogenic stocks of materials.” (Cossu and Bisinella 2012, 1) and “urban mining therefore provides a systematic management of anthropogenic resources stocks (products and buildings) and waste, in the view of long term environmental protection, resource conservation and economic benefits.” (Cossu and Bisinella 2012, 1). All these arguments give us a concept that present and future of centralized urbanization is an inevitable trend.

There is no doubt that increasing urban population will bring more resource requirement in city, at same time the original earth’s resources are
becoming depletion. So urban mining will gradually emerge its potential. Besides, the concentration of valuable metals from many urban mining sites often can be greater than modern mines. On the contrary, if we ignore some of urban waste we will not only lose the value of the waste itself, but also pollute the environment and society (Neville 2002). So research on the urban mining concept is necessary.

### 1.2 Urban Mining Market

In old residential areas, the ground contains a lot of metals. In fact, these areas might have a higher content of metal than normal mines. The reason that Volvo wants to get more involved in this market of urban mining is that it's an up and coming market that will be more and more relevant in the future. In today's era of shortages of raw materials, urban mining shows more and more significant hidden value and economic benefits. Urban mining is often used to describe the concept of recovering gold, silver, and a range of other metals from old electronics. It found that the annual production of electronic goods worldwide required 320 tons of gold and over 7,500 tons of silver, with a combined value of $21 billion dollars. At present, just 15% of that is recovered (Ko, 2013).

However, urban mining goes beyond electronics. With the development of civil engineering technology and city planning, many old towns need to be rebuilt or demolished. Here we introduce probably the world’s largest construction site, which is happening in Sweden, and a potentially largest demolition market, China’s metropolis.
As figure 1 show, Sweden is forced to move a whole city called Kiruna after traditional mining caused massive cracks in the ground. This is a tangible example of urban mining application. As indicated on the MailOnline’s Web site, so far it has given 3.5 billion kronor ($532 million) to the project as well as ear marking, an extra SEK7.5 billion for the remainder.

At the same time, the Chinese market itself also hides a huge demand on demolition building. The rapid development of China’s economy is old news by now. But this “China speed” not only surprised the world, but China itself as well. That means, going back thirty years in China, Chinese urban planners did not realize how valuable city centre land can be. So as a result – as with downtown Shanghai – there are many rundown low grey concrete houses between the new high-rise buildings. This illustrates how great the demand for concrete demolition is.

1.3 Project and Team Introduction

This thesis aims to explore the related factors influencing achievements of urban mining by analysing existing construction manufacturing equipment service conditions and improving the demolition system. Through the models and theories we learnt from the Master in Sustainable Product-Service Systems Innovation (MSPI) program, we utilized Product-Service System (PSS) concept to assist a construction manufacturing company build a systematic planning before they enter a new market.
The thesis team consists of two MSPI students and company we are collaborating with is Volvo Construction Equipment (Volvo CE) in Eskilstuna, Sweden. We also work in a global team that includes four mechanical engineering students who focus on product development from Stanford University and one industry economics student, also from BTH.

Our global vision is to create a business model that includes a use case scenario, which will highlight the various construction site applications. And for Stanford group, they are focusing on designing a construction machine called the ‘Volvo 310X’, which we will also use as a product case in our thesis. The complete global team envisions creating not only a product but also a sub-system within the construction industry.

Our corporate company Volvo Construction Equipment (Volvo CE) is known for their construction vehicles and equipment that are commonly found on mining or construction sites. Founded in 1832, Volvo CE is a leading developer, manufacturer, and supplier of construction equipment including but not limited to: articulated haulers, graders, compact and heavy wheeled loaders, and wheeled and tracked excavators. Volvo CE mainly distributes its machines through independent dealers to customers in more than 200 countries.

Through the cooperation with BTH and Stanford, Volvo CE wants to explore growth opportunities of urban mining both in business and technology ways.

Currently some kinds of companies, which are engaged in recycling business, are already doing the relevant work, but they lack of specific products, technology and theoretical support. For instance, people working at some sites, which can be summarized as urban mining sites, like recycling yards or house demolition sites, always work in dirty and noisy conditions. This makes their work inefficient and unsafe. By developing products that are specifically meeting the needs of urban mining, Volvo CE can get an edge to this emerging market. Volvo was beginning to feel that their machines were becoming somewhat of a commodity and so, through their ‘Emerging Technologies’-department, they want to investigate the possibility of tapping into a new sub-industry in mining, urban mining. This is what Volvo CE wants us to explore.
So the overall boundary from Volvo CE is urban mining, but at the same time we have to keep the core values of Volvo, which are safety, quality and environmental care in mind.

1.4 Introduction of Research Object

We got a task from Volvo CE to pay attention to urban mining. With the progressive elaboration of research and discussions with our Stanford team mates, we choose to focus on the demolition of buildings as a field of urban mining, and especially on the concrete part, which includes paying attention to concrete demolition machines, value of recycled concrete and designing an adaptive mechanism for recycled concrete industry. By using our background knowledge about sustainable product-service system innovation and this scientific design research method, we can make a good framework to study manufacturing areas related to design by setting up a proper scope and providing a step-by-step framework.

1.4.1 The Current State of Recycled Concrete

Nowadays, the applications of recycled aggregate concrete to use in construction activities have been practices by developed European countries and also some Asian countries. To overcome economic value and environmental issues brought by the large volumes of wastes from construction and demolition works; we analyse how to tap into the potential of recycled concrete and also focus on researching the preliminary recycling stage of concrete from demolished buildings.

Concrete consumption in the world is estimated at two and a half tons per capita per year (CAMBUREAU 2008, Mehta 2009). To make this huge volume of concrete 2.62 billion tons of cement, 13.12 billion tons of aggregate, 1.75 billion tons of water is needed. Most often, aggregates are collected from mountains or river gravels. A significant amount of natural resource can be saved if the demolished concrete is recycled for new constructions. In addition to preserving natural resources, recycling of demolished concrete will also offer additional business opportunities, saving cost of disposal, saving money for local government and other purchasers, helping local government to meet the goal of reducing disposal. (Uddin et al. 2013)
At present, the amount of global demolished concrete is estimated at 2~3 billion tons (Torring and Lauritzen 2002, 501-510). It is also estimated that in the next ten years, the amount of demolished concrete will be increased to 7.5~12.5 billion tons (Torring and Lauritzen 2002, 501-510). If technology and public acceptance of using recycled aggregate are developed and 100% of demolished concrete is recycled for new construction, there will be no requirement for normal aggregate (Thormark 2001, 2-6).

### 1.4.2 Value of Recycled Concrete

From our interviews and references, we know that “if the aggregate has higher flakiness index and used for making concrete, the developed fresh concrete will have lower workability. Meanwhile, the elongated particles also adversely affect the strength of concrete especially the durability and flexural strength because the bond between the aggregate and cement paste depends on it.” (Gambhir 2004, 6). According to our search, the size of recycled concrete was affected the strength in compressive strength, the results shows the 10 mm and 14 mm size of recycled concrete is better than 20 mm size.

Urban mining is increasingly being taken seriously by industry because it gives access to materials—such as expensive metals used in electronics—that are buried in waste tips and landfills. However, there is a new kid on the block—literally. Concrete buildings, when demolished, can serve as an excellent source of new building materials. “Instead of transporting aggregates from far away, we can use local buildings as a source for aggregates” (Francesco Di Maio 2013, 1).

In traditional ways of tearing down old buildings, that will divert tons of brick and metal from filling up landfills. Preserving and adapting older buildings for new uses will increase their energy efficiency and reduce their carbon footprint. Concrete buildings, when demolished, can serve as an excellent source of new building materials.

### 1.5 Volvo CE Expectations

The pursuit of business always is profits, how to link environmental care and sustainable development with the company’s benefits and profits should be carefully considered. After analysing scope and limitation, we
were clarifying current understanding and expectations with Volvo CE related departments.

We found some comparative advantages of Volvo CE in the urban environment. Firstly, what Volvo CE seeking is long-standing customers and flexibility of the machine above the cost optimization? This can be reflected in their safety, environmental care and use friendly machines. For example like their machinery’s cab, Volvo CE cab is counted worthy of more comfortable than other companies’ cab because it has lower interior sound levels, hydraulic angular variation for high building and air-condition etc. (If Metall 2013)

Apart from advanced technologies and good products, they also want to become globalized. Volvo CE with their BRIC (Brazil, Russia, India and China) strategic plan has made a great opportunity for them. Especially in the Chinese market, Volvo CE’s ongoing efforts to enter the Chinese construction market since 2002 bring their considerable achievements, even bigger than Caterpillar, which is the biggest construction manufacturer in world with nearly 70% market share (Sabertec 2014). These achievements give them an edge on further business like urban mining. (Caterpillar 2014)

1.6 Thesis Purpose

Our thesis purpose is to help Volvo CE to serve their concrete demolition market’s customer better; assist and add value around Stanford’s Volvo 310X by design a product-service system.

In particular, we will embarks on the background, status and trend of urban mining industry; doing needfinding in concrete demolition market and analysing existing construction manufacturing equipment service conditions, research the characteristics in the future city concrete demolition market

1.7 Thesis Structure

The thesis report consists of eight parts. Chapter 1 is the introduction of the project and urban mining concept. Chapter 2 is our research design and Methodology. Follow up is Theory in Chapter 3. Needfinding is in Chapter 4. After the needfinding, a QFD design and an analysis with Stanford’s new designed machine of product functions is in Chapter 5. Then a new PSS
design related to urban mining is in Chapter 6. After that is our lesson achieve, interviews and discussion with construction companies and Volvo CE in Chapter 7. The Conclusions and Future Work is presented at the last part.

1.8 Key Points

Our thesis team work in a global multidisciplinary team and cooperate with Volvo CE.

Urban mining is the process of reclaiming compounds and elements from products, building and waste (Stallone 2011, 1).

In today's era of shortages of raw materials, urban mining shows more and more significant hidden value and economic benefits. The concentration of valuable metals from many urban mining sites often can be greater than modern mines

Concrete consumption in the world is estimated at two and a half tons per capita per year (Cambureau 2008; Mehta 2009).
2 Research Design

In the early part of our thesis project, we clarify our research questions with a currently understanding of urban mining review, interviews with our Collaboration Company, local demolishing companies and construction union. The scope of our research is also present in this section.

2.1 Research Expectation

Through our research, the thesis team want to find out the status quo of stakeholders in demolition system, help Volvo CE improve their service with customer through the models and theories we have learned from PSS programme and cooperate with Stanford to design a future Product-Service System for urban mining

Figure below is a flow chart of our thesis. We started Design Research to form our research design. Followed is Needfinding, which we use methods like local interviews and survey to dig out customer and company requirements from various biases of people. The two main methodologies and theories in our analysis are Quality function deployment and Life Cycle Assessment. Detail explanations of these two will be presented later in this section. At last we came out our results: LCA in two case studies and a Product-Service System Innovation for giving a sustainable and strategic system to Volvo CE which can be involved in urban mining market and product development.
2.2 Research Questions

As described above, our thesis topic is Product-Service System Innovation in urban mining – A case study with Volvo CE. Some relevant research questions surfaced and classified as below:

1 Value aspects

What is the value in urban mining?

How can Volvo CE make a contribution towards optimizing the value of urban mining?

2 Product aspects

How can Volvo CE Satisfy their client with the most suitable solution?
What will be the competitiveness if using a future prototype (i.e., the Volvo 310X)?

3 Service aspects

What business model can provide a “win-win” situation for manufacturing and recycling companies and at the same time promote sustainability?

Sub questions:

What is the current business model for urban mining business?

What factors affect value creation for recycling firms?

Which Product-Service System is suitable for Volvo CE in urban mining of demolition projects?

2.3 Scope and Limitations

Recently, urban mining can be divided into three areas: recycle buildings, recycle products and recycle waste. Due to the limitation of land resources, a number of old buildings will be demolished. These overloaded tangible assets also may contain lots of resources and materials. Thinking about how to recycle it effectively and efficiently will not only save the waste but also bring profits. Since Volvo CE who is our collaboration company have most markets on big construction equipment, we narrow our scope into recycling buildings, which is more relevant to Volvo CE’s current business.
Figure 4 Scope

Figure 4 shows the scope of this thesis. Our scope is focused on one area of urban mining, which is recycle buildings in concrete, brick, block and debris. As Stanford University is focus on prototype a new concept of concrete demolishing machine, we will analyse the characteristics as a study case in later sections. The whole thesis is limited to this scope, in order to design a sustainable Product-Service System concept for Volvo CE.

2.4 Methodology

There are three main methods we used in this thesis to try to answer related to our research questions. We did several interviews with local companies and union in Sweden and our study focus is in Sweden. Then we designed a survey as our second method to get useful opinions from different people and get their requirements in machine operation and future desire. We chose to use Quality Function Deployment as the third method to analyse customer requirements and transfer them to a product and service target to formulize our final PSS innovation.

2.4.1 Interviews

As urban mining is a new concept, there are still unclear researches in this area. Interview is the method we use to collect information from machine users, officers, and manufacturing companies. They received us to visit their company and answer our questions. Usually, we sat down and talked
to them in one or two hours with our questions or survey. After we collected the materials from them, we then put them into documents and summarized the information.

A detailed list of needs from them will be presented in the needfinding part.

1. **Volvo Construction Equipment** is a manufacturing company that design and manufacture construction equipment for different users mainly in construction areas. We did two interviews with them and try to operate their excavators in their demo centre. After visited their assembling and design sector, we have a general understanding in the process they design and build the machine. Currently, they are looking into a new area, urban mining, for enlarge their business and get answers for how a future machine can fulfil the specific environment. We also did an interview online with service expert who worked in customer solution sector and discussed with the service they have now and what will be their future goal.

2. **Byggnads** is a union represented construction workers and negotiation with construction companies like NCC, PEAB and Skanska in Sweden. They are the experts who familiar with the workers needs and we got useful information from them. What they concerned is the safety both in work environment and human health and also the remuneration. They point out that there exists misunderstanding and less communication between workers and the boss. They eager to improve the working environment and regulation for workers.

3. **Strängbetong** is a concrete test and manufacture company in Sweden. The interview aims to understand the recycling environment currently in Sweden. It shows increasing demands in recycling concrete and new regulation allow up to 30% recycle concrete. The interview confirmed the recycling demand as we expected.

4. **Globax** is a company deal with construction and demolition business in various areas. They know the process of demolition buildings and they have many years’ experiences in operating Volvo construction equipment. From their opinion, we got some hit requirements from a user perspective.
5. **Stena** is a recycle business company; they are the expert in recycling method and process. We did an interview with them and collect the requirements from a recycling company perspective.

### 2.4.2 Survey

We create a survey to collect information related to our research questions in three aspects, which are value, product and service. The survey contained 17 questions.

The survey consisted of three parts:

- **Part 1**: Basic information is about who is doing the survey and what kind of machine he/she experienced. Do they know what urban mining means?
- **Part 2**: Question areas are listed mixed with our research questions to find out what is the most important consideration for the respondent when working in an urban mining environment.
- **Part 3**: New concrete demolishing machines, we integrated Stanford the future prototype Volvo 310X as a future machine to collect the opinion and prudential functions they think could be added in the design process.

We did our survey during our interview and put the results combined with the needfinding in later parts.

### 2.4.3 Quality Function Deployment

Quality function deployment (QFD) is a “*method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process.*” (Akao and Mizuno1994, 339), as described by Dr. Yoji Akao, who originally developed QFD in Japan in 1966, when the author combined his work in quality assurance and quality control points with function deployment used in value engineering.

Patial also claimed in his paper about using QFD in product design, he said “*It is a disciplined approach to product development*” (Patial 2010, 457) and he conclude the value of QFD to be; “*Every QFD chart is a result of the original customer requirements that are not lost through misinterpretations of lack of communication*” (Patial 2010, 460).
In QFD methodology, a primary tool is House of Quality (HoQ). Figure below shows the structure of HoQ. There are six parts in HoQ structure.

1. Customer Requirements – A listed requirements from the voice of the customer was sorted out.

2. Planning Matrix – Quantifies the customers’ requirement priorities and their perceptions of the performance of existing products, allows these priorities to be adjusted based on the issues that concern the design team by weighting.

3. Technical Requirements – A listed of measurable technical characteristics of the product, which meet the specified customer requirements.

4. Interrelationships – A two dimensional matrix related to combinations of individual customer and technical requirements in designed scale and level.

5. Roof – Identify the influence between different technical requirements.

6. Targets – A conclusion from the entire matrix with technical priorities, competitive benchmarks and targets.

*Figure 5 Structure of HoQ*
Using the basic structure of HoQ is a beginning of QFD process; there is a Clausing Four-Phase Model in QFD to translation process using linked HoQ type matrices until production planning targets as shown in the figure 6. As indicated on the DRM Associates’ web site, Crow presented a basic QFD methodology flow with four-phase QFD approach figure which contains product planning, assemble/part deployment, process planning and process/quality Control.

The needs from the customer in this process can let the product development process into later parts of the strategic plan. That’s the reason we use this linked HoQ in our thesis work. Figure below shows the entire structure of the design. We use a three-linked HoQ. The first HoQ conclude the product target and this is the requirements of the second HoQ, after analysis the second HoQ, a Product and service target will be linked to the requirement in third HoQ and finalize all the requirements into a Product and service planning. Our linked HoQ is inspired by different QFD examples. The general QFD is a four phase model to formulate the manufacturing process from customer requirements. In our HoQ design, we aim for achieving the final product and service plan in urban mining. The first of HoQ is acquired “Voice of Customer” and conclude a Product targets. Then we have a second HoQ to analyse the requirement of the
product and conclude the Product and Service target. The third HoQ did a further discuss and shaped a process of PSS.

**Figure 7 HoQ design**

The usage of HoQ provided a bridge between Customer requirements and engineer requirements. We also enlarge the concept of HoQ to combine the product and service ranking even a planning strategy in linked HoQ. Our goal is to find the stronger impact in technical requirements, product-service requirements and strategy requirements. Help to answer “What business model can provide a “win-win” situation for manufacturing and recycling companies and at the same time promote sustainability?” and “Which Product-Service System is suitable for Volvo CE in urban mining of demolition projects?” as two of our research questions in service aspects.
3 Theory

Three theories we used in our thesis are presented here with Life Cycle Assessment (LCA) and Life Cycle Cost (LCC); Sustainability; Product-Service System (PSS) and Industrial Product-Service System (IPS²).

3.1 Life Cycle Assessment and Life Cycle Cost

Life Cycle Assessment (LCA) is a method for assessing environmental impacts of products, processes or services cradle to grave. LCA is now recognized as part of a category of tools providing quantitative and scientific analyses on some environmental impacts of industrial systems and it is a technique to assess environmental impacts associated with all the stages of a product's life. To be specific, from raw material extraction through materials processing, produce, manufacturing, distribution, use, repair and maintenance, and disposal or recycling. Currently LCA also related in the study of indirect land use, rebound effects, market mechanisms and so on thanks to all of them play a role in a large system in the society.

This kind of methodology was shown in 1960s for prioritizing better products. In 1980s and 1990s more documents shown to analyse not only the product itself but also the whole life stages of the product like production, transportation, or disposal. SETAC (Society of Environmental Toxicology and Chemistry), 1990, coined the term “Life Cycle Assessment” After that people through 10 years to standardize LCA methodology and Handbooks published. Organization as International Organization for Standardization (ISO) developed the standards – ISO’s 14000 series of environmental management standards. Two international standards related to LCA are ISO 14040: ‘Environmental management – Life cycle assessment - Principles and framework’ and ISO 14044 (2006E): ‘Environmental management – Life cycle assessment - Requirements and guidelines’. (Guinee et al. 2011, 90-92).

The figure 8 is the framework of LCA.
Figure 8 General framework for LCA (ISO 14040 2006)

The four parts are:

1. Goal and scope definition

   In goal and scope definition the product to be studied, the aim of the study and a functional unit are defined. In our thesis, we estimated recycling 1 ton of concrete as a function unit in urban mining environment. Energy cost is using the current energy cost rate in Sweden and all the research in needfinding part is done in Sweden. Furthermore, this part also shows an overview of the product’s life cycle. In our case studies we did later, we mainly focus on the use phase of the machine.

2. Inventory analysis

   It is a section to build a systems model according to the requirements of the goal and scope definition. A function unit is defined and each process in the process tree is on the basis of this function unit and product data. Estimates during the study are also included in this stage.

   An example in figure 9 of LCA inventory data for recycling one ton of concrete is presented here.
Figure 9 Example of LCA inventory data for urban mining industry

The environmental impacts are mainly from energy consumption, raw material consumption and outputs of the process in emissions, debris and wastes. The Economy impacts are in a Life Cycle Cost (LCC) with all the costs during this process and revenue get from the process. The social impacts we main consider here are the working conditions.

3. Impact assessment- Eco-indicator 99

It aims to describe, or at least to indicate, the impacts of the environmental loads quantified in the inventory analysis. The goal for impact assessment is to describe the environmental consequences from the data in the inventory analysis. We choose to use Eco-indicator 99 methodology in this phase.

Eco-indicator 99 is a tool, which can help the designers in product development with the collection of the environmental data in a product life cycle and it provides a way to interpret LCA. In Eco-indicator 99 three type of damage including in the defined the term “environment”, which are human health includes the number and duration of diseases and life years lost due to premature death from environmental causes, ecosystem quality includes the effect on species diversity, especially for
vascular plants and lower organisms, and resources include the surplus energy needed in future to extract lower quality mineral and fossil resources (Eco-indicator 99 Manual for Designers 2000, 7). We choose this tool as a guide in the life cycle assessment of new prototypes and existing machines in later part.

4. Interpretation

It is a process of assessing results in order to draw conclusions. In this part, we calculate and collect the data in two case studies. It combines conclusion with the results, explains the effect of assumptions and uncertainties and checks whether the purpose of the calculation has been met. We use the results we get from Impact assessment and explain how this data will influence the environmental, social and economy.

During the product development and innovation, LCA stands in an unignorable status. “For product development, process improvement and comparative studies, LCA is already a useful tool. The method outlined fills a gap between traditional LCA and the Socio-Ecological Principles.” (Andersson et al. 1998, 296). Life Cycle Assessment in Product innovation is presented as a method to support the product innovation, LCA aims to support, achieve two objectives which are improve the top line-Increase revenue and improve bottom line-Decrease costs, while at the same time reducing the environmental and social burden associated with the innovations (Curran 2012).

Followed with LCA, Life Cycle Cost (LCC) is in an advanced step we used in both of our cases study. “LCA, in which a decision is based on the environmental benefits of a system or design. LCC provides a basis for contrasting initial investments with future costs over a specified period of time” (Bayer et al. 2010, 19). We choose to use LCC as part of study to find the economic impact in both cases study. As the words from Bayer et al. shows that LCA has its own points of focus. LCC study has benefits in realizing the cost in life cycle we defined. That’s why we use LCA and LCC to answer our product aspects research questions, which are

“How can Volvo CE Satisfy their client with the most suitable solution?” and “What will be the competitiveness if using a future prototype, called the Volvo 310X?”
3.2 Sustainability

The understanding of sustainability is a mind-set changing. The resources we extracting from the earth is limited. To understanding sustainable and move organizations towards a sustainable future, the framework for strategic sustainable development is published years ago by TNS (The Natural Step). Inside the framework following sustainability principles are basic conditions, underpinned by scientific knowledge, for the successful continuation of the socio-ecological system (Robèrt et al. 2010). The four sustainability principles as shown below is a based thinking in our LCA study, QFD categories part and also involved in our Product-Service System Innovation.

Four Sustainability Principles

The four sustainability principles (4SPs) for a sustainable society state that, in a sustainable society, nature is not subject to systematically increasing…

SP1 …concentrations of substances extracted from the Earth’s crust

SP2 …concentrations of substances produced by society

SP3 …degradation by physical means

SP4 in that society, people are not subject to conditions that systematically undermine their capacity to meet their needs. (Robèrt et al. 2010, 39)

3.3 Product-Service System Design and Innovation

The formal definition of the terminology, Product-Service System (PSS), was first determined by Goedkoop et al. in 1999 and has developed by researchers in this field since that time (Baines et al 2007). “A Product Service system (PS system) is a marketable set of products and services capable of jointly fulfilling a user’s need. The PS system is provided by either a single company or by an alliance of companies. It can enclose products (or just one) plus additional services. It can enclose a service plus an additional product. And product and service can be equally important for the function fulfilment.” (Goedkoop et al. 1999, 18).
The eight types of the PSS are presented in the picture below. The evolution of the product-service system is from the pure product or services to a mixed product and service. And the existing types of the PSS are Product-oriented PSS, Use-oriented PSS and Result-oriented PSS.

Figure 10 Eight types of the PSS (Tukker & Tischner 2006, 27)

An industrial PSS is occurred in the developing flow of PSS. The abbreviation researchers usually call industrial Product-Service System as IPS². “An Industrial Product-Service System is characterized by the integrated and mutually determined planning, development, provision and use of product and service shares including its immanent software components in Business-to-Business applications and represents a knowledge-intensive socio-technical system” (Meier 2005, 529). “IPS² are forcing a new understanding for business relationship within the Business-to-Business market” (Meier, Roy and Seliger 2010, 607). “Meier et al. provided a wider insight of research scenarios across the PSS research areas. They argued that PSS enable innovative function-, availability- or result-oriented business models.” (Lelah et al. 2012, 636)

The picture shows the main stakeholder of the relationship. The general stakeholder of IPS² is the customer, the original equipment manufacturer
(OEM, the IPS² Provider) and the suppliers and all the activity within the Society, which includes government, competitors etc. “An IPS² provider has to cope with different expectations of different stakeholders for the provision of a service in a defined quality and time schedule” (Meier, Roy and Seliger 2010, 607).

Since the tartarisation of the industrial sector, which is the service part capture the both customer and industries eye, the stakeholder of the IPS² involved in and affect the whole system. The new service based businesses need to avoid dissatisfaction of the customer by a not controllable level of technological complexity, the customer can focus on core competences, reduction of capital lock-up and the access to new technologies. The original equipment manufacturer can raise customer loyalty, open new business fields, develop marker shares and provide the customer with information about the use of their products to create innovations, but challenges still exist. Meier also sum the challenges of the OEM as:

According to Meier, Roy and Seliger (2010), people need to

• identify the important stakeholders and understand their demands,

• create proper business models,

• identify involved chances and risks,
• develop and deliver IPS$^2$ processes,
• set up IPS$^2$ oriented organization,
• qualify the staff (empowerment),
• industrialize and automate his IPS$^2$ processes and
• adapt his product understanding and business culture.

Compare the Product-Service System, IPS2 has essential elements, which are the integrated development of the mutually determined product and service shares and there is no demarcation line between product and service. OEMs in IPS2 have to be linked to the demands of the customers by seen the effects of flexibility, quality, delivery dates and prices in global markets; the customer can achieve a higher productivity thanks to a better utilization of the machine performance and the longer operation possibility and the benefit for the OEM is getting more revenue out of the additional service business with the customer and the longer business relationship by taking the whole life cycle and sustainability, eco-efficiency thinking into consideration, companies combined product and service offers lead to much higher revenue (Meier, Roy and Seliger 2010). “Industrial Product-Service Systems represent a paradigm shift in the definition of service performance in mechanical engineering by considering tangible and intangible goods in an integrated way” (Meier, Roy and Seliger 2010, 610).

Volvo CE as one of the OEM has the same status as in the IPS$^2$ stakeholder map. The customer, the supplier (Swecon) and own manufacturing factory companies. The reason we focus on the PSS in industries instead of other case study of the PSS in agriculture or pure service companies is we combine the situation and business environment of Volvo CE to fulfil the needs from the customer, the construction companies or future customers of the expectation of benefits.
4 Needfinding

Needfinding is important for our further analysis and design. Only by meeting the essence of each stakeholder demand can we achieve what we want, an improved demolition system.

4.1 Stakeholders in Urban Mining

This section we defined the stakeholders in our study of urban mining in Sweden. The results are from the online research and local people from unions and industries interview. The relation between stakeholders in urban mining is shown below. In Sweden, there are 2 parts in the labour market, which are Sveriges Byggindustrier (B-I) that represents construction companies (Skanska, PEAB, NCC), and Byggnads that represents workers in the construction industry. Also there are different unions like SEKO that focuses on the worker in road construction. To thinking the whole stakeholders in urban mining, in general, there are five parts mainly involved in the urban mining, which are unions, industries, equipment manufacturing, government and workers. As figure 12 show below, arrows point the flow of different position between these five parts. The government provide regulations for union, industries, manufacturers and workers. The union can supervise the industries and the manufacturing companies provide different construction machines to industries and the union monitors the rights of the worker when they do the job in the urban mining area.
4.2 Interviews

Interview is one of the ways to obtained information directly. Here we introduce details and content from four representative organisations. They are Byggnads, a Swedish construction worker union; Stena, a Swedish recycling company; Globax, a demolition company and Strängbetong, a concrete manufacturing company.

4.2.1 Byggnads

Our Interviewee in Byggnads is a union trade officer. His earlier career was as a construction worker for ten years. We got lots of information from him during our face-to-face interview. It gave depth to our needfinding about urban mining and small machine operation to demolish the concrete in buildings. Here we sum up the needfinding in table 1.
Table 1. Needfinding in Byggnads’ interview.

<table>
<thead>
<tr>
<th>Needs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean environment</td>
<td>Construction workers usually work in the dusty and noisy place and the dust is harmful to their health.</td>
</tr>
<tr>
<td>Safety</td>
<td>Construction is a deadly job; in an average data shows one of the construction worker die every month (112,000 people work in construction area in Sweden).</td>
</tr>
<tr>
<td>Alleviate burden</td>
<td>Worker in demolition project need to lift pieces of the concrete by manpower, which is harmful to their backs and arms.</td>
</tr>
<tr>
<td>Remove deadly dust</td>
<td>Two types of the material in the concrete are deadly to workers; asbestos (outlawed, but still found in old buildings) and quartz (found in all cement).</td>
</tr>
<tr>
<td>Demolition efficiency</td>
<td>Ordinary house can be demolished in one day via big machine. Worker is allowed use jackhammer below 30 minutes to rest. Robot is used in some demolition project (can enter in the indoor area and workers can use joysticks 3-4 meters away covered by month and nose).</td>
</tr>
<tr>
<td>Avoid risk of mis-communication at work site</td>
<td>Accident could happen because of the lack of communication between workers and boss (it happened last year in Skåne that a worker demolished the wrong wall, which caused a building to collapse).</td>
</tr>
<tr>
<td>Recycle construction material</td>
<td>People recycle the debris from the concrete to road constructions. The debris is sent to recycle companies or send to construction companies or even manage in own company. There is a large amount of money to be gained from the “wastes”.</td>
</tr>
</tbody>
</table>

Summary:

After talking with the union trade officer, we summarized some important understanding and ideas about actual deconstruction situation.

The first important information is about indoor demolition workers work environment. It mainly includes the following several aspects: toxic substances from demolition objects, dust and noise pollution, potential falling and physical effects by long-term work. For example the officer mentions that frequently using a drill over 30 minutes will increase the risk of trembling hand disorder when they get older. We think that our product-service design should pay attentions to alleviating these problems, by
choose a more human friendly solution and to train workers to recognise these risks.

In addition, we get confirmation from this experienced officer that the recycled concrete contains much more valuable content than what is recycled at present. However, after taking manual sorting and transportation cost into account, the value of it is too small. So solutions for minimizing the transportation cost and maximizing the efficiency will be important for increasing the value of the recycled concrete. We will also focus on this part in the design.

The final problem is a little beyond the scope of our thesis, but some of system knowledge about demolition stakeholders can help us design our product-service system. Multilayer contracting project should be strictly regulated; our respondent had mentioned this several times that current construction projects are usually performed by several sub-contractors. These situations cause a lot of management chaos and “blind spots” at construction sites. Front-line worker safety is thus often threatened by potential dangers due to supervisors missing out on information because of this multilayer contracting.

4.2.2 Stena

We visited the company Stena Recycling AB, located near Lyckeby in Karlskrona. It is one of the companies in Stena Metal Group who offers recycling services in five geographical markets. We visited their company in both November 8th and November 13th and had a tour of their recycling site.

Their general business is to sort waste, which is bought from different places, mostly from other manufacturing companies. They reprocess the valuable waste into new materials and metals and finally sell them to their customers.

They also have a big part within guiding companies and households. For example how you should handle toxic waste. In Karlskrona, they have a large business within old ships.

Also we were asked not to take pictures because of the valuable materials that they have on the site, because it attracts the attention of thieves. This
have led to that they keep the valuable material indoor and only “garbage” material outdoors.

Table 2. Needfinding in Stena’s interview.

<table>
<thead>
<tr>
<th>Needs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean electric scrap</td>
<td>The material needs to be free from mercury and beryllium.</td>
</tr>
<tr>
<td>Processed scrap</td>
<td>The material needs to be processed, which means that it's free from iron, aluminium and glass.</td>
</tr>
<tr>
<td>The material may not</td>
<td>The material is not allowed to dust, as this will mean problems in the different process stages.</td>
</tr>
<tr>
<td>dust</td>
<td></td>
</tr>
<tr>
<td>Sorted</td>
<td>The material needs to be properly sorted to ensure the right quality of the end product.</td>
</tr>
</tbody>
</table>
4.2.3 Globax

We had visited a company called Globax that demolishes buildings in an environmentally friendly way. The company is located in Helsingborg, Sweden but has operations all the way up to Stockholm, Sweden.

Table 3. Needfinding in Globax’s interview.

<table>
<thead>
<tr>
<th>Needs</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorting</td>
<td>This is the main thing they do; still they sometimes put materials that can be sorted in the combustible waste, mostly because of time.</td>
</tr>
<tr>
<td>Reach parts</td>
<td>1. Sometimes parts are out of reach then the user has to make the building fall a little bit in order to be able to pick things. 2. Another solution is to grab a pipe that makes the reach 2-3m longer and the user can hit down the part that he needs to take down like a chimney for example.</td>
</tr>
<tr>
<td>Collaborate</td>
<td>When working with other users involved communication needs to be done in order not to make accidents.</td>
</tr>
<tr>
<td>Communication</td>
<td>1. Communication is done in order to make each part aware of what needs to be done during the demolition. Almost no communication is done thru words during the demolition, this is decided before.</td>
</tr>
<tr>
<td>Good line of sight</td>
<td>Needs to see in order to tear down parts</td>
</tr>
<tr>
<td>Possible outcomes</td>
<td>It is good to know how they want the house to react when they tear down a part but it is also good to know about the possible worst-case scenario.</td>
</tr>
<tr>
<td>Possible changes of user</td>
<td>Very rarely they change machines with each other. But sometimes it happens and the control boards are all personally made so it can be hard to move the machine as wanted if a new user is driving the machine.</td>
</tr>
</tbody>
</table>

Summary:

Stena and Globax have a very important position in our system. Stena, as one of largest recycling companies, has been engaged in similar urban mining work for decades. Their business model to make profit from waste is great help to inspire us in designing a future urban demolition system. Globax, as a demolition company, is the direct customer of Volvo CE. Although Volvo CE already has its professional team to do customer
investigation and collects market research from their retailers every two years (talked by Volvo CE customer department), our needfinding also get some interesting harvest and new information. Some of the obstruction people usually try to solve by themselves, and if the problem is resolved, sometimes the customer will not tell this to the manufacturer. For instance, from our interview, we found that drivers sometimes will use the excavator to grab a random wall from site to do the cleaning job. This is not a correct method but it works, and driver will not let Volvo CE know this, because maybe they thought this is not a big problem or do not want buy extra tools. But if Volvo CE can find these small details, maybe the customers can be more satisfied.

4.2.4 Visit to Strängbetong

Strängbetong is a concrete manufacturing company in Sweden. An interview with an engineer was undertaken at the on-site laboratory on the 3 April. The site manufactures prefabricated concrete for walls, ceilings and railways. They are mixing the concrete indoors and are then able to reach a consistent result with high quality concrete.

Figure 13 A views in Strängbetong

Figure 13 shows production of cement. Strängbetong are using newly crushed mountain rock from a nearby quarry. They said that the factory currently was not equipped for salvaging the remaining concrete but instead it was being sent to landfill. In the concrete that does not have tension they
are using around 5% of recycled concrete as ballast. The different sizes of concrete that they are using today in their products are: gravel uncrushed 0-4mm, crushed mountain 2-8mm, crushed mountain 8-11mm, crushed mountain 11-16mm. They are also having requirements related to water absorption in the material, meaning that they have to be able to regulate the optimal amount of water added later on in the process. They are also requiring a petrographic analysis of the material to make sure it has the quality required and not too much fluoride in it to avoid corrosion on the iron.

![Figure 14 Strängbetong needfinding](image)

The two most useful pieces of information we got from Strängbetong are the requirements of recycled concrete and the market prospect of recycled concrete. The quantities of the materials that are used are: 0-4mm 35 000 tons, 2-8mm 16 500 tons, 8-11mm 20 000 tons, 11-16mm 21 500 tons for the year 2013. The different types of concrete that they produce are in the hundreds and because they have 32 different “pockets” where they could load the material into the mixer they can make almost any kind of concrete. They also said that next year’s regulations of material could be changed substantially for some concrete types, and for four types of concrete (the ones not used with added tension) the new regulation could allow to use up to 30% recycled concrete material in the new concrete.

### 4.3 Comparative Advantages of Volvo CE in Urban Environment

In this chapter, we analyse the advantages of Volvo CE by comparing with their main competitor in existing construction market. Based on these comparative advantages, we explore the opportunity for Volvo CE to gain an edge in urban mining.
Volvo CE has many competitors that are located all over the world. The biggest one is Caterpillar that has 70% of the market. Volvo CE has 6-7% of the market today and their main competitors are those that are around the same level of ownership of the market (Caterpillar 2013).

From our research, we found that Volvo CE produce more flexible construction machines for their customers. Which we think is one of the advantages compared with other companies.

From Volvo CE feedback, they felt Volvo CE standard demolition excavator had more power and better heat-sinking capability. The operators feel very comfortable because of a nice clean cab, with air conditioning or heat.

From a professional demolition website D&RI description, Volvo CE’s newest demolition excavator engine provides lower emissions and increased horsepower and engine torque. Operator comfort is improved with lower interior sound levels and a hydraulic cabin that tilts up to 30 degrees, reducing operator neck strain and fatigue when working on high-reach jobs. The Volvo telematics system - CareTrack – comes as a standard for past three years.

### 4.4 Key Points

There are five parties mainly involved in urban mining, which are unions, industries, equipment manufacturing, government and workers.

Byggnads is a construction worker union, the main needfinding results we got from them are multilayer contracting project should be strictly regulated. Secondly important information is about indoor demolition workers work environment.

Stena as one of largest recycling company has been engaged in similar urban mining work decades. Globax as a demolition company, is the directly customer for Volvo CE.

The two most useful pieces of information we got from Strängbetong are the requirement of recycled concrete and the market prospect of recycled concrete.
In the final section of this chapter, we analyse the advantages of Volvo CE by comparing with their main competitor in existing construction market.
5 Analysis

This section we put the data, which we collected from needfinding and researches into Quality Function Deployment (QFD) and Life Cycle Assessment (LCA) to find the answer of our research questions in product aspects and service aspects.

We start with a QFD analysis to arrange customer requirements, engineer requirement and find product / service targets. Then two case studies, using Stanford’s prototype Volvo 310X and Volvo CE demolition excavator in an estimated concrete recycling scenario, based on the Eco-indicator 99 method is presented as part of the example when doing LCA. In LCA, we focus on two categories in Climate Change and Human Toxic. CO₂, CO and NOₓ are three main consideration elements in the Climate Change while particulate matter (PM10) is the main elements in Human Toxic.

How do we consider service around technical equipment? The QFD analysis is presented in chapter 5.1. This method we used aims to get quick and clear product and service development targets based on customer requirements and engineers’ requirements. The QFD results also contain the prototype-Volvo 310X specifications which we will use in our LCA study.

Furthermore, we did a simple Life Cycle Cost (LCC) based on fuel consumption and machine cost both in using the future prototype Volvo 310X and using current machinery when recycling a certain volume of concrete. The data we collected is from the interviews and researches. Since the boundary of the life cycle we defined is the usage phase of machinery in recycling concrete, the life cycle cost is also within the boundary which is part of LCA study in recycling a 10 x 10 x 0.8 m³ concrete slab as case studies.

5.1 Quality Function Deployment

The Quality Function Deployment (QFD) study as mentioned before is a method transfer customer requirements to technical targets and manufacturing process. In our thesis, we aim to find the impact from customer requirements to machine technologies and services we need to
consider involving in this urban mining environment. How Volvo 310X related to PSS creates a competitive value in urban mining?

We did three linked Houses of Quality (HoQ) to analyse the customer requirements and get the target results in machine design and product-service targets. The mapped process in figure 15 shows how we did this analysis. In first HoQ, we started from the basic customer requirements, the results we got is the technical product targets considered in designing the Volvo 310X. The second HoQ is start from the results we got from the first HoQ - the consideration in designing as the requirements and we add product and service categories in technical requirements of the HoQ. The result we got is Product and Service Targets. After that, a third HoQ is to form the Product-Service System (PSS) plan.

![Figure 15 QFD analysis of the Volvo 310X](image)

From the research and interviews, we collected a large number of customer requirements. Ten customer requirements we summarized were put in the first HoQ in the customer requirements part at the left side of the HoQ and weighted the importance of them in customer aspects. Here we listed ten customer requirements in Table 4 and 11 technical requirements in Table 5.
Table 4. Customer Requirements in First HoQ.

<table>
<thead>
<tr>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>The machine shall have cleaning function to decrease dirt to the environment.</td>
</tr>
<tr>
<td>The machine shall have protection function to keep safety of the workers if accident happened.</td>
</tr>
<tr>
<td>The machine shall alleviate burden for the workers.</td>
</tr>
<tr>
<td>The machine shall have a dust mitigation function to avoid deadly dust to workers.</td>
</tr>
<tr>
<td>The machine shall increase demolition efficiency.</td>
</tr>
<tr>
<td>The machine shall have platform to increase management and commitment.</td>
</tr>
<tr>
<td>The machine shall have sorting and recycling functions.</td>
</tr>
<tr>
<td>The machine shall have functions to demolish the concrete within specific concrete size requirements from the users.</td>
</tr>
<tr>
<td>The machine shall have function to recycle concrete ingredient.</td>
</tr>
<tr>
<td>The machine shall be through the door (width of the machine is over 76 cm) and reach the required location.</td>
</tr>
</tbody>
</table>

Table 5. Technical Requirements in First HoQ.

<table>
<thead>
<tr>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>The machine shall have standard power.</td>
</tr>
<tr>
<td>The machine shall have moving function.</td>
</tr>
<tr>
<td>The machine shall have different circuit for control and power.</td>
</tr>
<tr>
<td>The machine shall have a suitable weight between 181kg to 363 kg.</td>
</tr>
<tr>
<td>The machine shall have a standard drive system power.</td>
</tr>
<tr>
<td>The machine shall have a concrete fragment system.</td>
</tr>
<tr>
<td>The chassis of the machine shall fit the urban or indoor area.</td>
</tr>
<tr>
<td>The outside dimensions of the machine shall fit the chassis.</td>
</tr>
<tr>
<td>Structural hard points and tie down points of the machine shall design to prevent falling down if the ground is not flat.</td>
</tr>
<tr>
<td>The machine shall energy by electricity.</td>
</tr>
<tr>
<td>The machine shall have a remote system and good interface for workers.</td>
</tr>
</tbody>
</table>

Figure 16 is the first HoQ matrix with the customer requirements in the left side and technical requirements on the top. More detail explanation will present with an example start with our first customer requirement ‘The machine shall have cleaning function to decrease dirt to the environment.’
Figure 16 First HoQ matrix with symbols
The symbol we used in our HoQ design is shown in Figure 17, Legend of HoQ. The first three is the option we select in the Interrelationships part of HoQ. Each of them represents a certain weighting importance. The calculation for deciding which technology is most important will combine the importance level we did in customer requirements parts and together with this relationship indicator.

For example, the first customer requirement we collected is ‘The machine shall have cleaning function to decrease dirt to the environment’, we weight the importance is 3 (Scale is 1-5, and 5 stands for a strong importance). The interrelationship between customer requirements and technical requirements is shown in the figure 15 with the symbol in the legend. ‘The machine shall have cleaning function to decrease dirt to the environment’ has one moderate relationship with ‘The chassis of the machine shall fit the urban or indoor area’, and three weak relationship with ‘The machine shall have different circuit for control and power’, ‘Structural hard points and tie down points of the machine shall design to prevent falling down if the ground is not flat’ and ‘The machine shall have a remote system and good
interface for workers’. And there is no relationship with other technical requirements in the list.

From the needfinding parts, it confirmed that in demolishing jobs, workers usually suffer the dusty, noisy working conditions. ‘The machine shall have cleaning function to decrease dirt to the environment’ is one of customer requirements. Since the Volvo 310X is designed to relieve dust and noise as the goal, the chassis of the machine, which contains a skirt to prevent the dust in the operation. The relationship of this requirement is also related to circuit which used to control the operation power, structural hard points and tie down points which need to consider if the concrete items is not flat, remote system which can release the worker away from the dirty environment. We then use the same method to analyse other requirements in this HoQ and two linked HoQ subsequently.

Total structure of HoQ shows in figure 14. In the first HoQ, 10 summarized customer requirements is transferred to product targets which we discussed with the Stanford students and got the product targets like the specifications of the machine and functions in the machine from customer requirements. Then we added a product and service technology as our second HoQ technology requirements. The product and service requirements are combined with customer requirements and services suitable for product targets we got from the first HoQ. For example, in bellowing table 6 shown, “Real time data tracking reporting system shall be contained in the machine.” is part of services from product targets in “The machine shall have a remote system and good interface for workers”, and service targets like “The machine shall have a remanufacturing service”, “Financial Guidance Service shall provide as a selection service for customers” etc. are based from customer requirements. And the results of second HoQ we got are product and service targets. Then for third HoQ, we put planning requirements as technical requirements in and get Product-Service System targets in the end.

Here we list the technical parts we designed in last two HoQ (Figure 18 and 19) and last two HoQ matrixes with symbols. (Detailed figures of HOQ is presented in appendix.)
### Table 6. Service Requirements in Second HoQ.

<table>
<thead>
<tr>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>The machine shall have a remanufacturing service.</td>
</tr>
<tr>
<td>The machine shall have attachments.</td>
</tr>
<tr>
<td>The machine shall have maintenance solutions.</td>
</tr>
<tr>
<td>The machine shall contain customer support agreements.</td>
</tr>
<tr>
<td>Financial Guidance Service shall provide as a selection service for customers.</td>
</tr>
<tr>
<td>Rental service shall be covered by business.</td>
</tr>
<tr>
<td>Site Management service shall be developed with customers.</td>
</tr>
<tr>
<td>Training shall be provided to customers to reduce the fuel consumption and to increase safety.</td>
</tr>
<tr>
<td>Real time data tracking reporting system shall be contained in the machine.</td>
</tr>
</tbody>
</table>

### Table 7. Planning Requirements in Third HoQ.

<table>
<thead>
<tr>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demolition market investigation shall be done before the purchase.</td>
</tr>
<tr>
<td>Human resource shall be matched with different conditions in service part.</td>
</tr>
<tr>
<td>The service system shall have selection between procurement or rent suitable demolition equipment.</td>
</tr>
<tr>
<td>The service system shall have Urban mining site planning.</td>
</tr>
<tr>
<td>Noise emission shall be reduced.</td>
</tr>
<tr>
<td>Indoor dust shall be reduced.</td>
</tr>
<tr>
<td>Wireless internet System shall be contained in the machine together with the services.</td>
</tr>
<tr>
<td>Transportation service shall be developed with customer.</td>
</tr>
<tr>
<td>Demolishing management shall be developed with customer.</td>
</tr>
<tr>
<td>Recycling construction materials shall be contained in the machine and provide solution to customers.</td>
</tr>
<tr>
<td>Emergency plan and protective measures services shall be informed to customers.</td>
</tr>
<tr>
<td>Machinery cleaning and storing shall be contained in the service if the machine is rented.</td>
</tr>
</tbody>
</table>
Figure 18 Second HoQ matrix with symbols
Figure 19 Third HoQ matrix with symbols
After ranking and weighting by discussing in our thesis group under a common understanding based on needfinding, engineering requirements and research in urban mining, we got three conclusions in each HoQ in the target part. Here we choose top three targets of each HoQ to present our analysis results.

**HoQ 1: Customer Requirements » Product Targets**

**Top 1:** The machine shall have a remote system and good interface for workers.

During the weighting, we found most customer requirements have more or less interrelationship in this technical requirement. The remote system should be added to support and restraint customer needs.

**Top 2:** The chassis of the machine shall fit the urban or indoor area.

This technical requirement has most interrelationships in environment, safety, human health and location limitation of customer requirements. The size of chassis should be 152 cm x 76 cm x 64 cm (60” x 30” x 25”), which can pass the width of two single doors in an indoor room site.

**Top 3:** The machine shall have a concrete fragment system.

The competitive edge of the Volvo 310X is the combination of demolishing and crushing functions. It also involved in most customer requirements. During the concrete recycling interview, 8 mm concrete debris is suitable for the recycling process. So the target for this concrete fragment system is to demolish the concrete and fragment them in to the right size.

**HoQ 2: Product and Service Requirements » Product and Service Targets**

**Top 1:** Real time data tracking reporting system shall be contained in the machine.

This service technical requirement in our analysis has strong relationship with ‘Remote System’ and ‘On-board battery’ and it also have moderate and weak relationship with ‘Standard power’, ‘circuit provided’, ‘drive system power’, ‘concrete fragment system’ and ‘structural hard points and
tie down points’. And the target for this service technical is it should contain real time tracking system in the Volvo 310X.

**Top 2: Site Management service shall be developed with customers.**

In this service requirement, it involves much weak relationship with product requirements. And it contains a strong relationship with remote system. A remote system significantly increases the convenience and value in site management. And the target is to develop an optimized site management for different site.

**Top 3: The machine shall have attachments.**

The attachment has a strong relationship with ‘Concrete fragment system’. And it also has weak impact in machine ‘weight’, ‘structural hard points and tie down points’, ‘on-board battery’ and ‘remote system’. The target for this service is to provider customer attachments fitting the working condition.

**HoQ 3: Product and Service Requirements » PSS Planning Targets**

In table 7, we list all the planning requirements in an ordered way. It was following a planning process. Start from a demolition market investigation, understanding human resource, procurement, site planning, operation and maintenance. The top three planning requirements are shown below.

**Top 1: The service system shall have selection between procurement or rent suitable demolition equipment.**

This planning requirement has all strong relationship impact of all product and service requirements. It is because all factors in the product and service requirements need to be considered. The target is to maximize the value in this planning stage from economic point of view.

**Top 2: Machinery cleaning and storing shall be contained in the service if the machine is rented.**

This is related in maintenance process, except training and site management, it involved all other product and service requirements. And the target is to maximize product lifetime and achieve a high value of using the machine.
Top 3: Human resource shall be matched with different conditions in service part.

The human resource is the top three we need to consider when develop the PSS planning. It has a strong relationship with site management and training, moderate relationship with maintenance solution and weak relationship with attachments, customer support agreements and financial guidance service. The target is to recruit and use qualified personnel in urban mining environment.

These top 9 targets we get from the three HoQ is an initial thinking when we design the industrial product-service system (IPS²) in next chapter 6. And the key results in QFD section is summarized below in table 8.

Table 8. Key results of the HoQ.

<table>
<thead>
<tr>
<th>Nine high important impacts in HoQ</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HoQ 1 (Product)</td>
<td></td>
</tr>
<tr>
<td>Remote system</td>
<td>A remote system has a high demand to protect workers release from dirt working place.</td>
</tr>
<tr>
<td>Chassis</td>
<td>Classis need to fit into indoor environment which is 152 cm x 76 cm x 64 cm in future prototype.</td>
</tr>
<tr>
<td>Concrete fragment system</td>
<td>A competitive system for future prototype adding multi-function in the machine.</td>
</tr>
<tr>
<td>HoQ 2 (Product and Service)</td>
<td></td>
</tr>
<tr>
<td>Real time Data tracking reporting system</td>
<td>Data sent to maintenance centre for solving the problem before it comes out.</td>
</tr>
<tr>
<td>Site Management</td>
<td>Adding value to increase management in urban mining site.</td>
</tr>
<tr>
<td>Attachments</td>
<td>Attachments to suit different working environment and be efficient.</td>
</tr>
<tr>
<td>HoQ 3 (Planning)</td>
<td></td>
</tr>
<tr>
<td>Procurement or rent suitable demolition equipment</td>
<td>The early stage in PSS planning to select suitable demolition equipment and purchase ways.</td>
</tr>
<tr>
<td>Machinery cleaning and storing</td>
<td>In the relation of maintenance to maximize machine lifetime and achieve a high value of using the machine.</td>
</tr>
<tr>
<td>Human resource</td>
<td>Recruit and use qualified personnel in urban mining projects.</td>
</tr>
</tbody>
</table>

5.2 Case Study 1 - Volvo 310X Analysis

This is one of the case studies we did as a calculation example in LCA and LCC study. The case study shows how and what impacts people need to consider when selecting a machine. First we assumed a situation for case studies which is to recycle a 10 x 10 x 0.8 m³ concrete slab. In the study,
we choose a function unit as recycling one ton of concrete. The energy consumption, environmental, and economic results will be calculated and used to compare the results with case study 2 in later parts of the report.

The structure of case studies is following our theory part of LCA theory and Eco-indicator 99 methodology (Eco-indicator 99 Manual for Designers, 2000) we use as our key method. Since the Volvo 310X is a future prototype, we start with an introduction of the Volvo 310X. Then we follow four of the four stages in LCA: (1) Goal and scope definition. (2) Inventory analysis. (3) Impact assessment. (4) Interpretation. The results in two case studies will be compared in Chapter 5.4.

5.2.1 About Volvo 310X

As the potential of recycling concrete market growing, we can see there is an increasing demand for demolishes concrete in construction areas in urban environment. To engage in such a big future, new product-service systems need to be considered to suit this new challenge.

As we are in collaboration with Stanford University, we are working as a team together to design and actualize a render for Volvo CE. This render is called the Volvo 310X, which focuses on recycling concrete. The idea of the Volvo 310X is a machine, which can demolish and crush the concrete as well as transport the debris in a remote control system. The picture below shows renders of the Volvo 310X.

![Renders of the Volvo 310X](image)

*Figure 20 Renders of the Volvo 310X*

Here we listed the function of the product:

1. Break concrete (pneumatic chippers)
2. Crush concrete (pneumatic hammers)
3. Remove debris (vacuum system)
4. Mitigate dust (skirt and watering system)
5. Dampen noise (vibration)
6. Control machine (remote control)
7. Detect process (sensor)

Figure 21 shows an input and output flow of the concrete breaker. The inputs of the machine are energy, materials and signals. The output is crushed concrete. To see detailed inside, the details of the functions of the concrete breaker is shown below.

In Figure 21, the concrete breaker is further analysed. Suppose now we are in a construction site, this picture tells how this machine works. Firstly, sensors will collect the information of the items to analyse the structure of the concrete. For example, to see what is in the concrete and if there is a reinforcing bar inside the concrete, a signal will alert the driver to tell him/her to be careful. The driver can then change the settings on the machine to change the degree of depth of the drill and protect the head of the drill. At the same time the machine is ready to give power to the drill. After the concrete is fully checked, energy goes into the drill to drive it and crush the concrete.
From the functional analysis, the benefit of this machine is it can work remotely and it can demolish and remove materials at the same time. As the needfinding has shown before, the construction workers are working in an unpleasant environment, which is dusty and noisy. They usually need to lift the amount of hundreds of kilos concrete during the work and stay in a dusty area, which you cannot see objects in arm's length. That is the purpose behind the design of the new Volvo 310X.

We estimated that this Volvo 310X can be used in:

Demolish concrete, demolish brick and block since the materials and demolishing method is relatively similar between them.

This prototype could meet the needs of being able to demolish concrete materials in an environment with less dusts, less noise, remote control and re-designable (can add or erase the electrical drills as need and reshape the whole product).

Thanks to the changing performance of concrete breaker, Volvo 310X can work in an indoor environment to demolish concrete layer by layer and with less noise and less dust around. Thus the use area could be enlarged to decoration companies or people whom want to demolish concrete.

Together with different types of Product-Service System and development of technology, we believe Volvo 310X could suit different working domains in the future.

5.2.2 Goal and Scope Definition

The purpose of doing this study is to quantify environmental impacts when using future prototype Volvo 310X. As we mentioned in theory part, this
study also include analyses in environmental (LCA), economy (LCC) and social impacts.

How to find the answer about environmental impacts? The common way to find environmental impacts is doing a LCA. Mostly LCA needs to study whole life cycle of the product from cradle to grave, from material extracted from the earth crust, production, usage and end of life. But in our case study we only focus on the use phase. We narrowed our scope to use phase since it is the phase mostly concerned by customers. Secondly, we chose use phase is because the limited resources we can found during our study. We need to narrow it down to a more reliable analysis based on the data we could found. During the study, we used Eco-indicator 99 (Eco-indicator 99 Manual for Designers, 2000) as a method in our case study.

Mostly in use phase, environmental impacts came from the operation of the machine. It still contains damage like wear and tear of the roads or machines which also can emit substances to the environment. According to the interview of truck driver, compare to the energy consumption, emissions in operation and transportation, the wear and tear is not in a significant position in the results of environmental impacts, that’s why we only choose the most high impact ones into our consideration. After an environmental impact study, a Life Cycle Cost will be calculated in the end.

Since the parameters of the Volvo 310X are assumed, we here present an example to general understanding the impact of using the machine. The uncertainty of the study also will be presented in discussing chapter.

**About Function Unit**

In our case study, the specified purpose was to compare two different ways of recycling concrete in use phase and identify the activities in the life cycle making the largest contributions to the environmental impact. To reach the goal we need to identify a modelling specification which is choose a function unit. A defined function unit can have equivalent concerning function when we did a comparison in later section. Since there is no former study about recycle concrete in urban mining, we here defined our function unit as recycling one tonne of concrete.
Life Cycle of Recycling Concrete with Volvo 310X

We focus on the use phase of the Volvo 310X in the assessment. The life cycle is shown in figure 23.

Figure 23 Life Cycle of the use phase of the Volvo 310X

In general there are five parts in this use phase, it starts at the transport of the Volvo 310X to the urban mining site, further to demolishing and remove the concrete, then to collecting the debris and transporting it, clean the machine and maintaining the machine, and at last the transport back to the company’s storage facilities for preparing for another mining project.

A detailed inputs and outputs in each part are shown in pictures below. In figure 24 the inputs we consider are machines and energy. The outputs we defined is the state that the machine is transported to the site and during the transportation, emissions from the transportation is created to the open air and wastes like wear and tear in transportation equipment and energy loss. Since our study is main focus on the emissions and energy in the use phase, we do not take the wastes parts into account in our later calculation parts but the outputs is there which can show the whole picture of this study.
In figure 25, it shows the inputs and outputs of demolishing concrete parts as one stage of the life cycle. Since Volvo 310X can directly demolish and crush the concrete, the inputs should be concrete, machines like Volvo 301X and energy use and the outputs are debris from the concrete, emission from the demolishing process, wastes of wear and tear of the machine, wastes of demolishing the concrete.

Figure 25 Inputs and outputs in demolishing concrete
Then after demolishing, figure 26 shows the next stage, debris collection and transportation. The collection process is still included the operation of the Volvo 310X since it was designed with the function to collect the debris. The inputs of this activity part are debris, machines like Volvo 310X, transportation machines and energy consumption. The outputs are the state that all the concrete debris is put in the demolition company, emissions form machines operation and wastes from wear and tear of machines, roads.

![Diagram: Inputs and outputs in debris collection and transportation](image)

*Figure 26 Inputs and outputs in debris collection and transportation*

Then, in figure 27, a cleaning and maintenance are also included in the life cycle of use phase. The inputs are machines and energy or materials need to be used in cleaning process. The outputs are the cleaned and checked machines, emissions from cleaning, wastes from cleaning. This life cycle part is existed but we do not include in the later calculation because what we try to find is focus on the costs, energy consumption of Volvo 310X and transportation machines. Here we put here is to give the full understanding of the life cycle in recycling concrete.
The last stage of life cycle part of this study is transportation machines back to company. Shown in figure 28, the process includes inputs like machines, energy which is only in transportation. The outputs are the state that machines are laid in Demolition Company, emissions from transportation, wastes from wear and tear the transportation machine and roads. But in later calculation part, we only focus on the energy consumption and emissions from transportation, which is in our study boundary.
Table 9 is the summary of the inputs and outputs, which we showed in above pictures in our case study 1. Then a detailed calculation section of the emissions, costs and energy consumption are presented based on this life cycle in next section.

Table 9. Summary of case study 1 inputs and outputs in each life cycle part.

<table>
<thead>
<tr>
<th>Parts</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation to mining site</td>
<td>Machines, Energy</td>
<td>Machines on the site, Emissions, Wastes</td>
</tr>
<tr>
<td>Demolishing concrete</td>
<td>Concrete, Machines, Energy</td>
<td>Debris, Emissions, Wastes</td>
</tr>
<tr>
<td>Debris collection and</td>
<td>Debris, Machines, Energy</td>
<td>Debris in demolition company, Emissions, Wastes</td>
</tr>
<tr>
<td>transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning and maintenance</td>
<td>Machines, Energy</td>
<td>Cleaned machines and site, Emissions, Wastes</td>
</tr>
<tr>
<td>Transportation machines back to company</td>
<td>Machines, Energy</td>
<td>Machines in demolition company, Emissions, Wastes</td>
</tr>
</tbody>
</table>

5.2.3 Inventory Analysis

This section is for determining the functional unit in life cycle. We first collect the basic technical parameters of our future prototype Volvo 310X from Stanford engineers, technical parameters of Volvo A30F articulated truck, which we selected for transport the debris and demolition machines. All relevant data are shown in tables.
Table 10. Data of the Volvo 310X.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>272.2</td>
<td>Kg</td>
</tr>
<tr>
<td>Power</td>
<td>Around 20</td>
<td>Kw</td>
</tr>
<tr>
<td>Length</td>
<td>152.4</td>
<td>Cm</td>
</tr>
<tr>
<td>Width</td>
<td>76.2</td>
<td>Cm</td>
</tr>
<tr>
<td>Height</td>
<td>63.5</td>
<td>Cm</td>
</tr>
<tr>
<td>Removal rate</td>
<td>2</td>
<td>m²/h</td>
</tr>
<tr>
<td>Air usage</td>
<td>0.566</td>
<td>m³/min</td>
</tr>
</tbody>
</table>

Table 11. Data of defined case.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation distance (From company to site)</td>
<td>5</td>
<td>km</td>
</tr>
<tr>
<td>Power of truck (Volvo A30F articulated truck)</td>
<td>266</td>
<td>kw</td>
</tr>
<tr>
<td>Load capacity (Volvo A30F articulated truck)</td>
<td>28000</td>
<td>kg</td>
</tr>
<tr>
<td>Speed (Volvo A30F articulated truck)</td>
<td>50</td>
<td>km/h</td>
</tr>
<tr>
<td>Concrete length</td>
<td>10</td>
<td>m</td>
</tr>
<tr>
<td>Concrete width</td>
<td>10</td>
<td>m</td>
</tr>
<tr>
<td>Concrete height</td>
<td>0.8</td>
<td>m</td>
</tr>
<tr>
<td>Concrete density</td>
<td>2800</td>
<td>kg/m³</td>
</tr>
</tbody>
</table>

In case study 1, we assumed that the distance between the company and urban mining site is 5 km, the task we need to do is demolishing a 10 x 10 x 0.8 m³ concrete slab. From operation experience, the fuel consumption of a heavy duty truck engine is 15.2 MPG (6.5 km per litre) with a speed of 37MPH (60 km per hour) (Freight Best Practice 2009). In our case, the speed of Volvo A30F transportation truck we assumed is 50 km per hour, thus, the fuel consumption of this is 5.4 km per litre. Since the total distance of the case is 90 km which consumes 16.6 litres of diesel.

The detailed equations, calculations and results are shown in table 12.
Table 12. Calculation results of case 1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Equation</th>
<th>Calculation</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to demolish concrete</td>
<td>$T_d = \frac{\text{Concrete Volume}}{\text{Removal rate}}$</td>
<td>$T_d = \frac{80 \text{ m}^3}{2 \text{ m}^2/\text{h}}$</td>
<td>40 h</td>
</tr>
<tr>
<td>Mass of recycling concrete</td>
<td>$M = V \times \rho$</td>
<td>$M = 80 \text{ m}^3 \times 2800 \text{ kg/m}^3$</td>
<td>224 tons</td>
</tr>
<tr>
<td>Energy density (Diesel)</td>
<td>$D$</td>
<td>$D$</td>
<td>36 MJ/L</td>
</tr>
<tr>
<td>Energy consumption of Volvo 310X</td>
<td>$W_1$</td>
<td>$W_1$</td>
<td>570MJ Assumed</td>
</tr>
<tr>
<td>Transportation distance</td>
<td>$n = \frac{S}{M \text{MAXF capacity}} \times 2 + 2$</td>
<td>$S = 5\text{km} \times \left(\frac{224\text{t}}{28\text{t}} \times 2 + 2\right)$</td>
<td>90km</td>
</tr>
<tr>
<td>Fuel consumption of Volvo A30F</td>
<td>$C_{A30F}$</td>
<td>$C_{A30F}$</td>
<td>5.4 km/l (reference from Freight Best Practice 2009)</td>
</tr>
<tr>
<td>Diesel used by Volvo A30F</td>
<td>$D_{A30F} = \frac{S}{C_{A30F}}$</td>
<td>$D_{A30F} = \frac{90\text{km}}{5.4 \text{ km/l}}$</td>
<td>16.6 l</td>
</tr>
<tr>
<td>Energy of transportation</td>
<td>$W_e = D \times D_{A30F}$</td>
<td>$W_e = 36\text{MJ/l} \times 16.6\text{l}$</td>
<td>597.6 MJ</td>
</tr>
<tr>
<td>Total energy</td>
<td>$W_{\text{total}} = W_1 + W_2$</td>
<td>$W_{\text{total}} = 570\text{MJ} + 597.6\text{MJ}$</td>
<td>1167.6 MJ</td>
</tr>
<tr>
<td>Energy consumption (Function Unit)</td>
<td>$W_{\text{function unit}} = \frac{W_{\text{total}}}{M}$</td>
<td>$W_{\text{function unit}} = \frac{1167.6\text{MJ}}{224\text{t}}$</td>
<td>5.2MJ/t</td>
</tr>
<tr>
<td>Time (Function Unit)</td>
<td>$\frac{T_{\text{function unit}}}{M} = \frac{T_{\text{total}}}{M}$</td>
<td>$\frac{T_{\text{function unit}}}{M} = \frac{40\text{h} + 1.8\text{h}}{224\text{t}}$</td>
<td>12 minutes</td>
</tr>
</tbody>
</table>

The number of transportation times include extra 2 times for transporting the Volvo 310X to the mining site and back to the company.

The function unit we assumed is a unit that is equal to recycling one ton concrete, at a distance length of 5 km between the factory and the urban mining site. In our estimated case 1, to demolish one ton of concrete (function unit) costs 12 minutes and the average energy consumption is 5.2 MJ including the energy of transportation via a Volvo A30F articulated truck.

5.2.4 Impact Assessment

We use Eco-indicator 99 to calculate the impact in of the use phase of the Volvo 310X. We focused on human toxic and climate change. As a tool, Eco-indicator 99 has its own unit – the Eco-indicator point (Pt). Milli-point (mPt) is usually used in different studies. The value of 1 Pt (1000 mPt)
represents one thousand of the yearly environmental load (damage) of one average European inhabitant (Eco-indicator 99 Manual for Designers, 2000). The calculation data we used is from Ecoindicator' 99 based on Goedkoop and Spriensma in 1999 in the book The Hitch Hiker’s Guide to LCA. (Baumann & Tillman 2004)

**Human Toxic**

The most impact of human toxicity in demolishing process is the dust emission. For the particulate matter in the demolishing phase, 1 kg particulates <10 um responds to 3.98 mPt\(^1\). Data in Construction and Demolition Emissions and Impact Analysis shows it create 26.5 pounds PM10 of fugitive dust daily (California energy commission n.d.). We assume that the Volvo 310X can relieve the dust by 95 %. Then around 1.33 pounds (0.6 kg) of fugitive dust will be emitted in the air, which is harmful to the workers. For Volvo 310X, the time to demolish concrete (224 tons) in this case is in 40 hours.

Time for demolishing one ton of concrete,

\[
T_{\text{One ton of concrete}} = \frac{\text{Total time}}{\text{Mass of concrete}}
\]

Then,

\[
T_{\text{One ton of concrete}} = \frac{40h}{224} \approx 0.17 h
\]

For each ton of concrete, it needs about 0.17 h to recycle. If we consider 8 h for daily working time, then the total emission of the dust to recycle one ton of concrete is

\[
Emission_{\text{one ton of concrete}} = \frac{T_{\text{one ton of concrete}}}{8h} \times \text{Daily emissions}
\]

Then,

\[\text{Equation}\]

\(^1\text{The indicator of human toxic we select here is from Ecoindicator’ 99 based on Goedkoop and Spriensma in 1999 in the book The Hitch Hiker’s Guide to LCA (Baumann & Tillman 2004). A detail data format is shown in Appendices 4.}\]
\[
Emission_{\text{one ton of concrete}} = \frac{0.17 \text{ h}}{8 \text{ h}} \times 0.6 \text{ kg} \approx 0.013 \text{ kg}
\]

So the results of PM10 emissions when use Volvo 310X is around 0.013 kg per ton of concrete.

The Eco-indicator 99 results of human toxic is

\[
\text{Human toxic} = Emission_{\text{one ton of concrete}} \times \text{Indicator}_{\text{PM10}}
\]

Then,

\[
\text{Human toxic} = 0.013 \text{ kg} \times 3.98 \text{ mPt}^* \approx 0.052 \text{ mPt}
\]

**Climate Change**

The three main emissions from a gasoline engine are carbon monoxide (CO), hydrocarbons and nitrogen oxides (NO\textsubscript{x}). Diesel usually pollutes the air with particulates and nitrogen oxides (Greiner 1998).

Data we use in climate change is from Ecoindicator’ 99 based on Goedkoop and Spriensma in 1999 in the book The Hitch Hiker’s Guide to LCA (Baumann & Tillman 2004). And 1 kg carbon dioxide responds to 0.0297 mPt\textsuperscript{2}. 1 kg carbon oxide responds to 0 mPt\textsuperscript{2}. 1 kg NO\textsubscript{x} responds to 0.941 mPt\textsuperscript{2}.

---

\textsuperscript{2} The indicator of climate change we select here is from Ecoindicator’ 99 based on Goedkoop and Spriensma in 1999 in the book The Hitch Hiker’s Guide to LCA (Baumann & Tillman 2004). A detail data format is shown in Appendices 4.
Table 13. Emissions from transportation (Hsu and Mulen 2007, 33).

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (Emission)</td>
<td>212.2</td>
<td>g/km</td>
</tr>
<tr>
<td>CO (Emission)</td>
<td>0.3</td>
<td>g/km</td>
</tr>
<tr>
<td>NOₓ (Emission)</td>
<td>3.17</td>
<td>g/km</td>
</tr>
</tbody>
</table>

Since there is no data about CO₂ emission in the future prototype, we estimated the emission, which related to the transportation emissions. For the transportation of 5 km, it needs 6 minutes for Volvo A30F and the CO₂ emission is

\[
CO_{2_{\text{emission}}} = Emission \ of \ CO_{2g/km} \times Distance \\
= 212.2 \ (g/km) \times 5 \ km = 1.1 \ kg
\]

To demolish one tonne of concrete, it needs 12 minutes. Since Volvo 310X is powered by electricity, thus, there is zero emission from operating the machine. So the total Carbon dioxide amount is 1.1kg.

\[
CO_{\text{emission}} = Emission \ of \ CO_{g/km} \times Distance = 0.3 \ (g/km) \times 5km \\
= 1.5 \ g
\]

\[
NO_{x_{\text{emission}}} = Emission \ of \ NO_{xg/km} \times Distance \\
= 3.17 \ (g/km) \times 5 \ km = 15.9g
\]

The Eco-indicator 99 results of climate change is

\[
\text{Climate change} = CO_{2_{\text{emission}}} \times \text{Indicator}_{CO2} + CO_{\text{emission}} \times \text{Indicator}_{CO} \\
+ NO_{x_{\text{emission}}} \times \text{Indicator}_{NOx}
\]

Then,

\[
\text{Climate change} = 1.1 \ kg \times 0.0297 \ mPt^* + 1.5g \times 0 \ mPt^* + 15.9g \\
\times 0.941 \ mPt^* \approx 0.048 \ mPt
\]
Table 14 shows three results in Climate change, Human toxic we use Eco-indicator 99 method. The function unit we use is recycling one tonne of concrete and in a transportation of 5km in distance. From a board view in the whole Urban Mining process, this is a tiny part of the process. So we can see the results in this table have a small number in these two areas. For climate change, the result 0.048 mPt stands for $0.048 \times 10^{-3}$ of the yearly environmental load (damage) of one average European inhabitant. $0.052 \times 10^{-3}$ of the yearly environmental load of one average European inhabitant is the result for human toxic. The summation of two impacts is 0.1 mPt, which stands for $0.1 \times 10^{-3}$ of the yearly environmental load of one average European inhabitant.

\[ \text{Table 14. Case 1 of Eco-indicator 99 completed form (function unit in recycling one ton of concrete, 5km distance).} \]

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount</th>
<th>Indicator</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change</td>
<td></td>
<td></td>
<td>0.048 mPt</td>
</tr>
<tr>
<td>CO₂</td>
<td>1.1 kg</td>
<td>0.0297</td>
<td>0.033 mPt</td>
</tr>
<tr>
<td>CO</td>
<td>1.5 g</td>
<td>0</td>
<td>0 mPt</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>15.9 g</td>
<td>0.941</td>
<td>0.015 mPt</td>
</tr>
<tr>
<td>Human toxic</td>
<td>0.013 kg</td>
<td>3.98</td>
<td>0.052 mPt</td>
</tr>
<tr>
<td>(Particulate matter)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total [mPt]</td>
<td></td>
<td></td>
<td>0.1 mPt</td>
</tr>
</tbody>
</table>

5.2.5 Life Cycle Cost

In the using phase, Volvo 310X is in a combination function of concrete crusher and assimilate the concrete debris. The main cost of this case is the energy cost including the machine and the transportation fuel cost in recycling $10 \times 10 \times 0.8 \text{ m}^3$ concrete. “The energy density for diesel fuel ranges from 32 to 40 megajoules per liter (MJ/L)” (Nektalova 2008). We choose 36 MJ/L as the unit for calculate the cost during the use phase. Electricity cost in Sweden is around 1.82 SEK/kwh.

Electricity cost for Volvo 310X is

\[ \text{Electricity cost}_{\text{Volvo 310X}} = \text{Electricity cost}_{\text{unit}} \times \text{Energy}_{\text{Volvo 310X}} \]

\[ = 1.82 \text{ SEK/kwh} \times 160\text{kwh} \approx 291 \text{ SEK} \]

The diesel prise for one litre costs around 14.22 SEK. In this case, the transportation needs 16.6 litres of diesel so the fuel costs are around 236 SEK. The total cost for energy use is
The above cost is for recycling 224 ton of concrete. For recycling one tone of the concrete the fuel costs are around 2.3 SEK. Since the impact for fuel costs is related to real situation and how you use the equipment, to find an accurate result, a real test is needed. Here, we got the results from estimation.

For the machines costs, we get inspiration from the current prototype costs and existing Volvo equipment market. From our study, pure real prototype cost from Stanford engineer is around 95,000 SEK. (Detailed costs for prototype you can find in our appendix 3). There are lots of extra costs need to add on the machine price like the development cost, manufacturing cost etc. then, we estimated the pure machine cost for each machine is around 95,000 SEK (same as we get from Stanford University as they spent in their prototype), the human resource cost is around 700,000 SEK and the market development cost around 400,000 SEK and the profit is the rest which is around 300,000 SEK. If we add up to the cost of the machine, the price of Volvo 310X is around 1,500,000 SEK. And in the market, Volvo A30F cost around 2,600,000 SEK per truck.

During the life cycle we defined, we here put a life cycle cost of the machine in this life cycle. We found a renting cost for Volvo A30F is around 100,000 SEK / Month. In this case, the machine occupation time is around one week since it needs 40 hours to demolish all the concrete by Volvo 310X. We assumed the renting price for Volvo 310X is around 60,000 SEK / Month according to the renting price of Volvo A30F. Then we calculate the total machine cost for this life cycle is:

\[
    \text{Machines Costs}_{\text{Case Study 1}} \approx \text{Price}_{\text{Volvo 310X}} + \text{Price}_{\text{Volvo A30F}} + \text{Energy cost}
\]

Then,

\[
    \text{Machines Costs}_{\text{Case Study 1}} \approx 60,000 \text{ SEK} \times (1/4)(\text{month}) + 100,000 \text{ SEK} \times (1/4)(\text{month}) \approx 40,000 \text{ SEK}
\]
The total costs in our case study 1 during the determined life time (one week time frame) which includes machine costs, fuel costs are around 40,500 SEK.

**5.2.6 Interpretation**

Interpret the Results

The results we get from case study 1 shows the impact of climate change, human toxic and the life cycle cost shows the cost for the case. The total environmental impact we got base on the Eco-indicator 99 is 0.1 mPt with a function unit which is recycling one ton of concrete of a 10 x 10 x 0.8 m³ concrete slab and the total life cycle cost for this case is 40,500 SEK which include the machine renting cost, fuel cost. The result is based on an assumed case when recycle one ton of concrete of a 10 x 10 x 0.8 m³ concrete slab. We choose this kind of concrete slab is for better understanding the impacts of using machines in a certain case. In this case study, we give out an example when doing a LCA and a LCC. If in a real situation, the results need to be recalculated.

**Verification**

Since Volvo 310X is a future prototype, we put lots of assumption in this prototype. The estimated data is based on the results of the early trials by the Stanford University mechanical engineering students. The electricity consumption and diesel consumption is based on the energy calculation. The cost of the energy is based on the current unit cost in Sweden and the costs of the machines are in a web research in an appraised price.

In this case, we focus on only the use phase of the machine, to study a large scale of the life cycle of the machine is also interested in the future work.

**5.3 Case Study 2-Volvo CE Demolition Excavator Analysis**

In case study 2, the boundary of life cycle is the same as in case study 1. We estimated that the condition is recycling 10 x 10 x 0.8 m³ concrete slab and recycling one ton of concrete as our function unit during the use phase. This case study is based on a common understanding in recycling concrete currently. To accomplish recycling concrete in a demolishing project,
excavator and crusher usually be used. The collaboration between demolish company and recycle company is often in the process. Following the Eco-indicator 99 method, case study 2 also starts with the four stages of the LCA theory, which are the same as in case study 1. The steps are: (1) Goal and scope definition. (2) Inventory analysis. (3) Impact assessment. (4) Interpretation. Then follow up with a LCC study and in chapter 5.4 we compare the results with case study 1’s.

### 5.3.1 Goal and Scope Definition

We use Eco-indicator 99 (Eco-indicator 99 Manual for Designers, 2000) to analyse the current recycling process using a Volvo CE demolition excavator. This work is also to find the environmental, economy and social impact. To compare both case studies in a relevant way, we use the same indicator as we did in case study 1. Following case study 1 analysis, recycling one ton of concrete was chosen as our functional units.

**Life Cycle of Recycling Concrete with Volvo Excavator**

The second case study is to conduct a Life Cycle Assessment of the demolition of a concrete building by using current Volvo CE equipment, which includes the EC460CLD demolition excavator, an articulated truck A30F and an on-site concrete crusher Nordberg HP400 SX. But since we focus on Volvo CE’s product-service system and to increase their customer value, we limited the LCA scope to the use phases. The way to achieve this goal was to quantitatively assess the environmental trade-offs of the life cycle of the three construction machines, including the use phase, the end of life phase, and transportation. We pay more attention to the influences of production and its impact on the environment and personal health. A schematic overview of the product’s life cycle is shown in figure 28. In general, there are seven parts in this life cycle. It starts with transporting the excavator and crusher to the urban mining site, further to demolish the concrete. After a manually sorting and transport the debris to an on-site crusher, the crusher will turn large concrete wastes to small pieces. The next step is to refine the debris to be able to transport it to a recycling company to resize the concrete. The last two steps are clean the machine and maintain the machine as well as transport back to the company preparing for another mining project. This life cycle is more complicated than the one in case 1.
A detailed inputs and outputs in each part are shown in pictures below. In figure 30, the inputs we consider mainly in machines and energy. In this stage, only transportation activity is involved. The outputs we defined is the state that the machine is transported to the site and during the transportation, emissions from the transportation is created to the open air and wastes like wear and tear in transportation equipment and energy loss which is the same consideration as case study 1. Since our study is mainly focused on the emissions and energy in the use phase, we also do not take the wastes parts into account in our later calculation parts but the outputs is there which can show the whole picture of this study.
In figure 31, it shows the inputs and outputs of demolishing concrete part. The inputs are the machine Volvo EC460 CLD, concrete and energy. Since the operation way of Volvo EC460 does not like the same as future prototype Volvo 310X (Volvo 310X can directly demolish and crush the concrete), the outputs are scraps from the concrete (large piece of the concrete), emission from the demolishing process, wastes of wear and tear of the machine, wastes of demolishing the concrete.

Figure 30 Inputs and outputs in transportation to mining site

Figure 31 Inputs and outputs in demolishing concrete
Then after demolishing, figure 32 shows the next stage, manual sort and transportation. The collection process need to be done by using grabs of the excavator and put the concrete scraps close to the on-site crusher. Since the crusher is in the urban mining site, we ignore the transportation between concrete demolish to the location of the crusher. We only focus on calculate the operation costs of the machine and emissions in this activity. The outputs is the state that all the concrete scraps are put in the crusher, emissions from machines operation and wastes from wear and tear of machines, roads.

**Figure 32 Inputs and outputs in manual sort and transportation**

Next part of the life cycle is on-site crusher operation, which shows the inputs and outputs in figure 33. In this activity, we main focus on calculate the operation costs and energy consumptions during the crush. The inputs are the crusher, scraps from the concrete (large pieces) and the energy. The outputs are debris from the scraps (small pieces), emissions from the crush process, wastes from the crush and wear and tear of the machines. According to our case boundary, we will not calculate the wastes part in our later calculation but focus on the energy consumption, energy costs, emissions and machine costs.
Since current situation in demolish business, all construction wastes will be sent to the recycling company to be refined and recycled. So for the next stage of life cycle in case study 2 are debris reefing and transportation. Figure 34 shows the inputs and outputs of this activity. The inputs are the prepared debris, machines and energy. The outputs are the state that the debris is transported to the recycling company, emission from the transportation, wastes of wear and tear of the machine and roads. For later calculation parts, we still focus on the energy consumption, machine costs and emissions in our later calculation section.
Then, in figure 35, cleaning and maintenance is also included in the life cycle of use phase, which is the same as in Case Study 1. The inputs are machines and energy or materials need to be used in cleaning process. The outputs are the cleaned and checked machines, emissions from cleaning, wastes from cleaning. This life cycle part is existed but we also do not include in the later calculation because what we try to find is focus on the costs, energy consumption of Volvo EC460, Volvo A30F and Crusher. Here we put here is to give the full understanding of the life cycle in recycling concrete.

\[\text{Figure 35 Inputs and outputs in cleaning and maintenance}\]

The last stage of life cycle part of this study is transportation machines back to company. Shown in figure 36, the process includes inputs like machines, energy which is only in transportation. The outputs are the state that machines are laid in the demolition company, emissions from transportation, wastes from wear and tear the transportation machine and roads. But in later calculation part, we still only focus on the energy consumption and emissions from transportation, which is in our study boundary.
Figure 36 Inputs and outputs in transportation machines back to company
Table 15 is the summary of the inputs and outputs, which we showed in above pictures in our Case Study 2. A detailed calculation section of the emissions, costs and energy consumption are presented based on this life cycle in next section.

Table 15. Summary of case study 2 inputs and outputs in each life cycle part.

<table>
<thead>
<tr>
<th>Parts</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation to mining site</td>
<td>Machines</td>
<td>Machines on the site</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>Emissions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wastes</td>
</tr>
<tr>
<td>Demolishing concrete</td>
<td>Concrete</td>
<td>Concrete scraps</td>
</tr>
<tr>
<td></td>
<td>Machines</td>
<td>Emissions</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>Wastes</td>
</tr>
<tr>
<td>Manual sort and transportation</td>
<td>Concrete scraps</td>
<td>Scraps prepared</td>
</tr>
<tr>
<td></td>
<td>Machines</td>
<td>Emissions</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>Wastes</td>
</tr>
<tr>
<td>On-site crusher operation</td>
<td>Scraps prepared</td>
<td>Debris prepared</td>
</tr>
<tr>
<td></td>
<td>Machines</td>
<td>Emissions</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>Wastes</td>
</tr>
<tr>
<td>Debris refining and transportation</td>
<td>Debris prepared</td>
<td>Debris in recycling company</td>
</tr>
<tr>
<td></td>
<td>Machines</td>
<td>Emissions</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>Wastes</td>
</tr>
<tr>
<td>Cleaning and maintenance</td>
<td>Machines</td>
<td>Cleaned machines and site</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>Emissions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wastes</td>
</tr>
<tr>
<td>Transportation machines back to company</td>
<td>Machines</td>
<td>Machines in demolition company</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>Emissions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wastes</td>
</tr>
</tbody>
</table>

5.3.2 Inventory Analysis

This case is also to demolish, transport and recycle a 10 x 10 x 0.8m$^3$ volume of concrete. And we simulate to use three existing common equipment at the demolition site. They are a standard Volvo CE demolition excavator EC460CLD, an on-site work concrete crusher Nordberg HP400 SX and a Volvo A30F articulated truck, which is mainly the implementation of transport tasks. Their specifications are shown below (tables 16, 17, and 18).
Table 16. Data of Volvo CE demolition excavator EC460CLD.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated output</td>
<td>1800</td>
<td>r/min</td>
</tr>
<tr>
<td>Power</td>
<td>235</td>
<td>kw</td>
</tr>
<tr>
<td>Bucket</td>
<td>1.7-3.3</td>
<td>m³</td>
</tr>
<tr>
<td>Pressure</td>
<td>31.4</td>
<td>MPa</td>
</tr>
<tr>
<td>Operate Weight</td>
<td>49.1</td>
<td>Ton</td>
</tr>
</tbody>
</table>

Table 17. Volvo A30F articulated truck.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation distance (From company to site)</td>
<td>5</td>
<td>km</td>
</tr>
<tr>
<td>Power</td>
<td>266</td>
<td>kw</td>
</tr>
<tr>
<td>Load capacity</td>
<td>28000</td>
<td>kg</td>
</tr>
<tr>
<td>Speed</td>
<td>50</td>
<td>km/h</td>
</tr>
</tbody>
</table>

Table 18. Data of Nordberg HP400 SX Crusher (Landfield and Karra 2000, 212).

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crusher discharge</td>
<td>3.2*0</td>
<td>cm</td>
</tr>
<tr>
<td>Production</td>
<td>5000</td>
<td>h/year</td>
</tr>
<tr>
<td>Electricity</td>
<td>5850000</td>
<td>MJ/year</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>568</td>
<td>litre (changed 2 ×/year)</td>
</tr>
</tbody>
</table>
According to our investigation, a standard Volvo CE demolition excavator EC460CLD will use two hour to demolish this part. So time to demolish concrete $T_d=2 \text{ h}$.

Use phase modelling includes power, oil and lubricant consumption, and parts replacement. The power consumed for a full 8-h shift was monitored to obtain the total quantity of electricity consumed during 1 day. The power consumption of the rock crusher, normalized to the functional unit of 1 short tons of crushed rock, was $W_{\text{unit}}=2.34 \text{ MJ/t}$ (Landfield and Karra 2000).

Volvo L50E that contains D4D engine and it is almost the same engine type as in our study machine, Volvo EC460CLD. From Owning and Operating Cost Template version 1.1, the fuel consumption is 1.3 gallons/h (5 L/h) (Volvo Construction Equipment 2006). In this case, we need 2 hours to demolishing total concrete. So for fuel consumption in EC460CLD, 10 L diesel fuel is needed.

An on-site work concrete crusher and A30F, which is mainly the implement of transport tasks. And here we set that the distance from recycling company to work site is 10 km and distance from Demolition Company to work site is 5 km.

The detail equation, calculation and results are shown in table 19.
Table 19. Calculation results of case 2.

<table>
<thead>
<tr>
<th>Category</th>
<th>Equation</th>
<th>Calculation</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to demolish concrete</td>
<td>( T_d )</td>
<td>( T_d )</td>
<td>2 h</td>
</tr>
<tr>
<td>Mass of recycling concrete</td>
<td>( M = V \times \rho )</td>
<td>( M = 80 \text{m}^2 \times 2800 \text{kg/m}^2 )</td>
<td>224 t</td>
</tr>
<tr>
<td>Energy density (Diesel)</td>
<td>( D )</td>
<td>( D )</td>
<td>36 MJ/L</td>
</tr>
<tr>
<td>Fuel consumption of Volvo EC460CLD</td>
<td>( C_{EC460CLD} )</td>
<td>( C_{EC460CLD} )</td>
<td>5 L/h</td>
</tr>
<tr>
<td>Fuel consumption of Volvo A30F</td>
<td>( C_{A30F} )</td>
<td>( C_{A30F} )</td>
<td>5.4 km/L</td>
</tr>
<tr>
<td>Energy of using Volvo EC460CLD</td>
<td>( W_1 = C_{EC460CLD} \times D )</td>
<td>( W_1 = 5L/h \times 2h \times 36MJ/L )</td>
<td>360 MJ</td>
</tr>
<tr>
<td>Energy of using Nordberg HP400 SX</td>
<td>( W_2 = W_{unit} \times M )</td>
<td>( W_2 = 2.34MJ/t \times 224t )</td>
<td>524 MJ</td>
</tr>
<tr>
<td>Transportation distance</td>
<td>( S = \frac{S_{unit1} \times n_1 + S_{unit2} \times n_2}{M} \times 2 ) ( n_1 = \frac{M_{A30F \ capacity}}{M} \times 2 - 1 ) ( n_2 = \frac{M_{A30F \ capacity}}{S_{unit2 \ capacity}} \times 5 \text{km} ) ( S_{unit2 = 10 \text{km}} )</td>
<td>( S = 5 \text{km} \times \frac{224t}{28t} \times 2 ) ( +10 \text{km} \times \left( \frac{224t}{28t} \times 2 - 1 \right) )</td>
<td>230 km</td>
</tr>
<tr>
<td>Diesel used by Volvo A30F</td>
<td>( D_{A30F} = \frac{S}{C_{A30F}} )</td>
<td>( D_{A30F} = 230 \text{km} \times 5.4 \text{km/L} )</td>
<td>42.6 L</td>
</tr>
<tr>
<td>Energy of transportation</td>
<td>( W_3 = D \times D_{A30F} )</td>
<td>( W_3 = 36 \text{MJ/L} \times 42.6L )</td>
<td>1533 MJ</td>
</tr>
<tr>
<td>Total energy</td>
<td>( W_4 = W_1 + W_2 + W_3 )</td>
<td>( W_4 = 360 \text{MJ} + 524 \text{MJ} + 1533 \text{MJ} )</td>
<td>2417 MJ</td>
</tr>
<tr>
<td>Energy consumption (Function Unit)</td>
<td>( W_{function \ unit} = \frac{W_{total}}{M} )</td>
<td>( W_{function \ unit} = \frac{2417 \text{MJ}}{224t} )</td>
<td>10.8 MJ/t</td>
</tr>
<tr>
<td>Time (Function Unit)</td>
<td>( \frac{Time_{function \ unit}}{Time_{total}} = \frac{Time_{total}}{M} )</td>
<td>( \frac{Time_{total}}{Time_{total} + T_1} = \frac{2h + 4.6k}{224t} )</td>
<td>2 minutes</td>
</tr>
</tbody>
</table>

\* The number of transportation times includes distance between urban mining site to Demolition Company and Recycling Company as well as the distance for transporting excavator and crusher to the mining site and back to the company. We assume the location of site, Demolition Company and Recycling Company is in a line and that both Demolition Company and Recycling Company are in the same side away from the site.
5.3.3 Impact Assessment

We apply Eco-indicator 99 (Eco-indicator 99 Manual for Designers, 2000) to calculate the impact in the use phase of case study 2. We focused on human toxic and climate change, which is the same as in case study 1. All the indicators and methods in calculation are the same as in case study 1.

Human Toxic

For the particulate matter in demolishing phase, 1 kg particulates <10um responds to 3.98 mPt*. Data in Construction and Demolition Emissions and Impact Analysis shows it create 26.5 pounds PM10 of fugitive dust daily (California energy commission 2014). We assume that the Volvo EC460CLD will create 26.5 pounds (12020.2 g) PM10 daily which is harmful to the workers. If we consider the time we use the machine for this case is

\[ Time_{Volvo\ EC460CLD} = \frac{T_d}{M} \]

\[ T_d, \ \text{Time to demolish concrete; } M, \ \text{Mass of concrete.} \]

Then, we get,

\[ Time_{Volvo\ EC460CLD} = \frac{2h}{224t} = 0.54 \text{ min/t} \]

So it needs 0.54 minutes to recycle one ton of concrete. If we consider 8 h for daily working time, then the total emission of the dust to recycle one ton of concrete is

\[ PM10\ Emission_{Volvo\ EC460CLD} = \frac{Time_{Volvo\ EC460CLD}}{8h} \times \text{Density}_{PM10} \]

Then,

\[ PM10\ Emission_{Volvo\ EC460CLD} = \frac{0.54 \text{ min/t}}{8h} \times 12020.2g \approx 14g/t \]

Volvo EC460CLD creates around 14g PM10 during the operation phase when demolish 1 ton of concrete. And the research shows that 1.2 g of particulate matter (PM10) will be created by Nordberg HP400 SX Crusher.
per short ton (Landfield and Karra, 2000). Total particulate matter in this case is 15.2g. The Eco-indicator 99 results of human toxic is

\[ \text{Human toxic} = Emission_{\text{one ton of concrete}} \times \text{Indicator}_{PM10} \]

Then,

\[ \text{Human toxic} = 15.2 \, g \times 3.98 \, mPt^* = 0.06 \, mPt \]


**Climate Change**

Data for climate change calculations is under 100-time horizon indicator midpoint of Eco-indicator 99 based on Goedkoop and Spriensma in 1999 in the book The Hitch Hiker’s Guide to LCA (Baumann & Tillman 2004). And 1 kg carbon dioxide responds to 0.0297 mPt*. 1 kg carbon oxide responds to 0 mPt*. 1 kg NOx responds to 0.941 mPt*.

*Table 20. Emissions from transportation (Hsu and Mulen 2007,33).*

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (Emission)</td>
<td>212.2</td>
<td>g/km</td>
</tr>
<tr>
<td>CO (Emission)</td>
<td>0.3</td>
<td>g/km</td>
</tr>
<tr>
<td>NOx (Emission)</td>
<td>3.17</td>
<td>g/km</td>
</tr>
</tbody>
</table>

Since the transportation distance we chose is the same in case 1 (5 km), So CO₂ emission in transportation is also the same as case 1, which is 1.1kg. To demolish one ton of concrete, EC460CLD needs 2 minutes and we estimated Nordberg HP400 SX Crusher needs 20 minutes. CO₂ emission of these two machines we estimated is around 4 kg based on the emissions from transportation (Hsu and Mulen 2007,33). Total CO₂ emission in this case is 5.1 kg. Total CO emission we estimated is around 2 kg and total NOx emission is around 1 kg.

The Eco-indicator 99 results of climate change is
\[ \text{Climate change} = CO_{\text{emission}} \times \text{Indicator}_{CO2} + CO_{\text{emission}} \times \text{Indicator}_{CO} + NO_{\text{emission}} \times \text{Indicator}_{NOx} \]

Then,

\[ \text{Climate change} = 5.1 \text{ kg} \times 0.0297 \text{ mPt}^* + 2 \text{ kg} \times 0 \text{ mPt}^* + 1 \text{ kg} \times 0.941 \text{ mPt}^* \approx 1.1 \text{ mPt} \]

*The indicator of climate change we select here is from Ecoindicator’99 based on Goedkoop and Spriensma in 1999 in the book The Hitch Hiker’s Guide to LCA (Baumann & Tillman 2004). A detail data format is shown in Appendices 4.*

In table 21, we get higher number in these three categories than case study 1. In case study 2, bigger machines are used; they emit more carbon dioxide and consume higher energy during the work. Results we use Eco-indicator 99 method in climate change, human toxicity are shown in this table. The function unit we use here is the same as in case study 1, which is to recycle one ton of concrete and transport it 5 km. It is also a small part of the whole urban mining process and the results, which are related to environmental impact, are also in small amounts. For climate change, 1.1 mPt means 1.1‰ of the yearly environmental load (damage) of one average European inhabitant are created. 0.06‰ of the yearly environmental load of one average European inhabitant is in human toxic. The summation of two impacts is 1.16 mPt, which stands for 1.16‰ of the yearly environmental load of one average European inhabitant.

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount</th>
<th>Indicator</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change</td>
<td></td>
<td></td>
<td>1.1 mPt</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>5.1 kg</td>
<td>0.0297</td>
<td>0.15 mPt</td>
</tr>
<tr>
<td>CO</td>
<td>2 kg</td>
<td>0</td>
<td>0 mPt</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>1 kg</td>
<td>0.941</td>
<td>0.95 mPt</td>
</tr>
<tr>
<td>Human toxic (Particulate matter)</td>
<td>15.2 g</td>
<td>3.98</td>
<td>0.06 mPt</td>
</tr>
<tr>
<td>Total [mPt]</td>
<td></td>
<td></td>
<td>1.16 mPt</td>
</tr>
</tbody>
</table>
5.3.4 Life Cycle Cost

The current recycling method is use the excavator and crusher to demolish the concrete and transport the debris to recycling companies and construction companies. We use the same energy density, which is 36 MJ/L for diesel fuel. The prise for one litre diesel costs 14.22 SEK. Then the total diesel consumption is

\[
\text{Diesel consumption} = \frac{W_{\text{total}}}{D}
\]

\(W_{\text{total}}\), Total energy use in case study 2; \(D\), Energy density (Diesel).

Then, \(\text{Diesel consumption} = \frac{2417 \text{ MJ}}{36 \text{ MJ/L}} \approx 67 \text{ L}\)

For case study 2, it needs 67 litres of diesel. Thus, total energy cost is around 955 SEK. Then for recycling one ton of concrete the fuel cost is around 4.2 SEK. Since the study is lack of real situation test, the result of fuel in estimation. An accurate data need to be done in a real testing.

For the machine cost, Volvo A30F cost around 2,600,000 SEK per truck, Volvo EC460 excavator cost around 1,500,000 SEK and Nordberg HP400 SX cost 2,000,000 SEK.

During the life cycle we defined, we here put a life cycle cost of the machine in this life cycle. The renting cost for Volvo A30F is around 100,000 SEK / Month. In this case, the machine occupation time is around half week since it needs only two hours to demolish and around one day to transport debris when demolish all the concrete by current Volvo machines and crushers. We assumed the renting price for Nordberg HP400 SX is around 80,000 SEK / Month and 60,000 SEK / Month for Volvo EC460 according to the renting price of Volvo A30F. Then we calculate the total machine cost for this life cycle is:

Thus, the total cost of our case study 2 is

\[
\text{Costs}_{\text{Case study 2}} \approx \text{Price}_{\text{Volvo A30F}} + \text{Price}_{\text{Volvo EC460}} + \text{Price}_{\text{Nordberg HP400}} + \text{Energy cost}
\]
Then,

\[
\text{Costs}_{\text{Case study 2}} \\
\approx 100,000 \text{ SEK} \times (1/8)(\text{month}) + 60,000 \text{ SEK} \\
\times (1/8)(\text{month}) + 80,000 \text{ SEK} \times (1/8)(\text{month}) \\
+ 955 \text{ SEK} \approx 31,000 \text{ SEK}
\]

The total costs in our case study 2 which includes machine costs, fuel costs in whole life cycle are around 31,000 SEK.

**5.3.5 Interpretation**

**Interpret the results**

The results we get from case study 2 shows the impact of climate change, human toxic and the life cycle cost shows the cost for the case. The total environmental impact we got base on the Eco-indicator 99 is 1.16 mPt with a function unit which is recycling one ton of concrete of a 10 x 10 x 0.8 m³ concrete slab and the total life cycle cost for this case is 31,000 SEK which include the machine renting cost, fuel cost.

**Verification**

Since this case is based on current understanding of urban demolishing projects, the demolish time using excavator need 2 hours which is reasonably reliable from our interview. All machine specification is based on the type of the machine which is close to the data of the machine we have chosen in this case study. The cost of the energy is based on the current unit cost in Sweden and the costs of the machines are in a web research in an appraised price.

The boundary is the same in case study 1, we focus on only the use phase of the machine, to study a large scale of the life cycle of the machine is also interested in the future work.

**5.4 Comparison of Two Case Studies**

Here we compare the results from the two case studies. Three main impact areas considered are environmental impact (LCA), economic impact (LCC) and social impact. We have used Eco-indicator 99 to calculate different impacts in the use phase of demolition excavator, crusher and transport. We
focused on human toxic and climate change in use phase of the machines and make assumptions regarding the characteristics of future Volvo 310X’s.

5.4.1 Life Cycle of Two Case Studies

Figure 37 shows two life cycles in our case studies. The blue one stands for case study 1 and the purple one stands for case study 2. There are four stages both in case study 1 and case study 2 which are “Transportation to mining site”, “Demolishing concrete”, “Cleaning and maintenance” and “Transportation back to company”. The difference between two case studies in life cycle is concrete debris collection and sorting. Since case study 1 is using Volvo 310X which is a future prototype contains a 2 in 1 function – demolish concrete and refining concrete. The idea for Volvo 310X is demolishing concrete layer by layer and vacuum system in the machine can absorb the debris simultaneously. The output of the machine is the concrete debris in a demand size of recycling and they can be directly reused in other projects. That is a change of current concrete demolition process. For current demolition project, concrete can only be tear down with a large piece of shape. A manual sort and transportation process exists in current situation. If people want to recycle those concrete, the large piece of concrete need to be crushed by a crusher and transport to a recycling company to be refined. That’s why the numbers of stages in case study 2 are more than that in case stage 1 with an increasing complicity of life cycle and transportation distances.
Figure 37 Comparison of life cycle in two case studies
5.4.2 Results of Two Case Studies

Two different ways to demolish concrete are defined in our case studies as we talked in early chapters. Case study 1 use the future prototype Volvo 310X, and case study 2 use Volvo EC460 demolition excavator plus a crusher. Since we defined the scope to focus the use phase, these two solutions have the same requirement, which is to transport debris from the urban site to the company. We estimated that the same transportation truck (Volvo A30F articulated truck) is used in both cases and the estimated distance is 5 km between urban mining site and Demolition Company.

Table 22 is a summary that shows the comparison of the cases when recycling one ton of concrete.

Table 22. Comparison of two case study results within function unit.

<table>
<thead>
<tr>
<th>Concrete case</th>
<th>10 x 10 x 0.8 m$^3$ concrete ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete weight</td>
<td>224 tons (Take concrete density is 2800 kg/m$^3$)</td>
</tr>
<tr>
<td>Function unit</td>
<td>Recycling one ton of concrete and transport 5 km</td>
</tr>
<tr>
<td>Device selection</td>
<td>Case study 1</td>
</tr>
<tr>
<td></td>
<td>Volvo 310X</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Around 5.2 MJ/t</td>
</tr>
<tr>
<td>Fuel costs</td>
<td>Around 2.3 SEK</td>
</tr>
</tbody>
</table>

1. Environmental Impact (LCA)

Product life cycle contains different phases, which are raw material acquisition, processes, transports, manufacturing, use, and waste management. Those phases have more or less impact with the environment.

Raw material acquisition is one of life cycle phases. It is a foundation for manufacturing. For example, paper is made of trees; the tree is the raw material. Then one of the processes is cutting the tree. The energy and emissions from the cutting machine are parts of the environmental impact. After cutting, a transportation of wood is step into. And a manufacturing process will begin to make paper from wood using other machines. Finally, paper were made and put into a use phase. After usage, a waste
management is also involved as one part in the whole life cycle. People need to consider whether to recycle or landfill these used papers.

In general, the life cycle of a construction machine also cannot leave these six phases. From harvesting raw materials like iron, aluminium etc. to transport the raw material to manufacturing, after the manufacturing process a machine will be made. And then the machine is put into a use phase for many years. After the use, waste management also must be considered. Currently, remanufacturing processes are popular with construction equipment manufacturers for saving cost and being environmentally friendly.

In our thesis study, we choose the use phase as our focus and scope for analysing two case studies. Considering the characteristic of urban mining, we found that people more focus on human health, energy saving and cost saving when using the equipment for demolishing the building or other construction tasks. So we put our efforts on main categories of environmental impacts, which are climate change and human toxicity. We choose those two categories as our main focus because the case circumstances, the urban environment, which discussed a lot in our interviews with human health (dust emissions) and the emission of equipment to become more sustainable and do good to the environment.

Table 23 shows the results we got from calculations in the two case studies and figure 38 shows a visualization of those results.

**Table 23. Summary of environmental impact.**

<table>
<thead>
<tr>
<th>Concrete case</th>
<th>10 × 10 × 0.8 m³ concrete ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete weight</td>
<td>224 tons (Take concrete density is 2800 kg/m³ )</td>
</tr>
<tr>
<td>Function unit</td>
<td>Recycling one ton of concrete and transport 5 km</td>
</tr>
<tr>
<td>Device selection</td>
<td>Volvo 310X EC460CLD &amp; Crusher</td>
</tr>
<tr>
<td>Climate change</td>
<td>0.048 mPt 1.1 mPt</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>0.052 mPt 0.06 mPt</td>
</tr>
<tr>
<td>Eco-indicator 99 results</td>
<td>0.1 mPt 1.16 mPt</td>
</tr>
</tbody>
</table>

84
Figure 38 Environmental Impact chart of Two Case Studies

In these two case studies, we apply Eco-indicator 99 (Baumann & Tillman 2004) to calculate the environmental impacts in climate change and human toxic.

Since we focused on the use phase of the machine, the environmental impact is mainly from the energy emissions during the use phase. Numbers such as, the distance between company and urban mining site, truck speed and machine characteristics, are based on common assumptions and kept consistent throughout the calculations. The emission data and construction particulate matter data is from a normal understanding in other project reports.

Climate Change

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions. The most common discuss is the raise of CO₂ emissions increase the greenhouse effect and sea level. In the urban mining business, emissions from using mining equipment, transportation equipment are the primary sources of climate change. Therefore we choose this category in our LCSA study. The
results show Case 1 which we use Volvo 310X is much better than Case 2. The main difference between two case studies is that Volvo 310X use electricity to drive and the setup in case study 1 does not require an extra crusher.

**Human Toxicity**

From our interview, we know that in the concrete, there are two ingredients harmful to human health, which is quartz and asbestos. In a demolishing environment, dust is the major obstacle against human health. Interviews show that workers from construction companies are sick of the dust and the antiseptic mask sometimes cannot help them because it is too weak. A highly suggestion from the Byggnads we got is to separate the demolition phase and renovate phase in a project. So in our study, we choose to use particulate matter as an indicator to see the impact of human toxicity. Data in figure 38 shows both case studies have little Human Toxicity impacts. It is because we set our boundary in only focus on the use phase in recycling one ton of concrete. In the figure we can see case 1 is a bit better than case 2 (case 1 has less particulate matter impacts to the environment than case 2). It is because the case 1 is using a machine which is close to the concrete surface when cutting the concrete but in case 1 big excavator cannot avoid large emissions during the demolishing process.

2. **Economic Impact (LCC)**

Table 24 is a summary of the economic impact of two case studies. Within our assumptions of specification in Volvo 310X, the Volvo 310X has a huge benefit in the total machine cost and also has better data in energy consumption and fuel costs with our estimation. But using Volvo EC460CLD and Crusher allows to more quickly finishing the demolishing tasks. To recycle one ton of concrete, the Volvo 310X need 12 minutes but for case two it just need 2 minutes. As Case 1 is the machine combine both demolishing and crushing functions, the case 1 solution to demolish the concrete do not need an extra crusher. The total solution cost is shown the end of the table. Since the Volvo 310X is a future prototype, it designed for remote control, thus, manpower for doing demolition concrete could be reduce if the machine is automatically. But for the costs of the life cycle we defined, which we based on the rent cost, Case Study 2 (31, 000 SEK) is better than Case Study 1 (40,500 SEK). It is because the machine occupation time in case 1 is longer than case 2.
In another hand we only consider using one Volvo 310X in our assumed case study. If the construction companies choose to use more Volvo 310Xs in the same site, the efficiency could be increased during the tasks and the total life cycle cost in use phase will be reduced. But that study is out our scope but could be considered in the future work.

Table 24. Summary of Economy Impact.

<table>
<thead>
<tr>
<th>Concrete case</th>
<th>10 x 10 x 0.8 m³ concrete ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete weight</td>
<td>224 tons (Take concrete density is 2800 kg/m³)</td>
</tr>
<tr>
<td>Function unit:</td>
<td>recycling one ton of concrete and transport 5 km</td>
</tr>
<tr>
<td>Device selection</td>
<td>Volvo 310X</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Around 5.2 MJ/t</td>
</tr>
<tr>
<td>Time occupation</td>
<td>Around 12 minutes</td>
</tr>
<tr>
<td>Fuel costs</td>
<td>Around 2.3 SEK</td>
</tr>
<tr>
<td>Total costs in defined life cycle (Machines and fuel costs)</td>
<td>Around 40,500 SEK</td>
</tr>
<tr>
<td>Total machine costs</td>
<td>Around 4,100,000 SEK</td>
</tr>
</tbody>
</table>

3. Social Impact

The advantage of Volvo 310X is small, remote control or in the future could be pilotless. It helps worker relieving from the dirty working conditions and reducing the dangers in construction jobs. The company can use the machine instead of hiring workers to do the dangerous work. On the other hand, Volvo 310X provide a clean solution that is also a benefit for urban society and human health. We think in the future, people would like to be a construction worker thanks to the new technology. For example, they can control the machine by remote when siting in the office.

Discussion of this Study

This study is aimed to understand the environmental impact, economic impact and social impact of two different methods when recycle concrete in urban areas. Specifications of the future prototype Volvo 310X is estimated by Stanford mechanical engineers and the existing prototype they made
shows they can reach the specifications in the future. That’s the base when we did assumptions.

For case study 2, machine specifications are close to the real data and we also discussed with machine expert from Volvo CE. The data we used in calculate the environmental impact is from Ecoindicator’ 99 based on Goedkoop and Spriensma in 1999 in the book The Hitch Hiker’s Guide to LCA (Baumann & Tillman 2004).

We choose our case studies only focus on the use phase of the whole product life cycle. Other phase of the life cycle may contain raw material acquisition, manufacturing, maintenance, waste management and transportation between those phases. Our study aims to show a general understanding of the impacts when use different methods to recycle concrete with assumed amounts. The studies followed the manual of Eco-indicator 99. With this guideline and the data we found, our study can give a basic view of impacts in the use phase of recycle concrete. But it is just part study of eco-indicator 99. To do a compliment study, a whole life cycle process needs to be analysed by researchers.

Due to the limitation of the data, here we sum it to a list of assumptions, uncertainty over external influence and uncertainty over internal factors during our case studies

- **Assumptions**
  
  The assumption in our case studies is based on current understanding of construction site. We choose to study a concrete slab (10 x 10 x 0.8 m$^3$) which weight 224 tons. But in demolishing project, concrete in walls, floors of the building might not in the same shape and weight. We also assumed the distance of transportation (5 km from urban mining site to Demolition Company and 10 km from urban mining site to recycling company) and transportation speed (50 km/h for the transportation machine Volvo A30F). Those data will be changed if in a specific case studies. We also put some assumptions in the speciation of Volvo 310X in our case study 1. Since it is a future prototype real situation to use this kind of machine need to be further studied in the future.
• **Uncertainty Over External Influence**
  The uncertainties over external influence are mostly in energy price, and machine price. The diesel price we used is the current price, which is 14.22 SEK/L. The electricity price we used is current price, which is 1.82 SEK/kwh. Equipment like Volvo A30F, Volvo EC460CLD and Nordberg HP400 SX Crusher is from a discussion with expert in Volvo CE and researches from the Internet.

• **Uncertainty Over Internal Factors**
  We put assumptions in specification of Volvo 310X, diesel consumption in Volvo A30F, Volvo EC460CLD and Nordberg HP400 SX Crusher. For Volvo 310X, the specification is based on the Stanford engineers who design the prototype. Diesel consumption in Volvo A30F we used data from a heavy duty truck, Volvo EC460CLD we used data from Owning and Operating Cost Template of Volvo Construction Equipment document. The Nordberg Crusher we found data in previous report by Landfield and Karra.
In this chapter, according to results we got from previous needfinding, QFD and LCA study, an industrial product-service system (IPS²) design is presented below. The detail of urban demolition system activities in the urban mining market is described as well. After that, a current Volvo CE selling system and a new future PSS system is compared, one based on the current situation and closed as product-oriented, and the other is a conceptual use-oriented PSS solution that is proposed in order to adapt to a future urban mining system. We have conducted a qualitative assessment of the impacts for the whole demolition system.

6.1 Basis of PSS Design

We had held five meeting with Volvo CE. We both realized that today’s customer tends to purchase product and service in multiple values. According to a Volvo customer service department officer; now when customers choose equipment, either as large companies or as individuals, they are asking for much more than just the product itself. That means that customers not only want to buy machinery, but also that they want to find a professional solution to help them solve many more aspects of their problem.

Volvo CE themselves is aware of this situation and they start to analyse their service offering and plan to make drastic changes to it, which they call their ‘Vision 2020’. Vision 2020 is a concept that Volvo CE plan to reform their whole customer service system by exploring their all existing services. Since Volvo CE found their customer requirement trend to more complicated, they track and document them in to a diagram which includes their development plan and vision of the 2020. In our opinion, this would require Volvo CE have a precise analysis and understanding of the customer market, which also is our thesis output, a product-service system design.

In general, our industrial product-service system design purpose is to encourage service for better integrated into the product and pay more attention on sustainability world. We realized that it is important to have
close cooperation with customers. Thereby, operational structure of the value creation network as well as the customer interaction itself should be designed in order to continuous product and customer feedback. This feedback provides the basis for a continuous PSS-improvement process, and helps them to improve their service. In order to promote the implementation of PSS in practice, Volvo CE product focused on LCA and LCC can be taken as a methods and processes for extended value creation network having a common understanding of the necessary design, production and servicing processes.

As we focus on the demolition process system, how will we implement our product and service into this system? We divided our PSS design mainly into four phases – stakeholder, needfinding, QFD, LCA and LCC studies to prioritize activities in system design. Analysing Volvo CE’s stakeholders can help them clear their role between their customers and suppliers. The purpose for doing an LCA and LCC is to compare different machines in environmental and economic impacts that Volvo CE can use to help their customer to select the right one, as well as presents their machine in a comparable way to the customer and thus give well-founded suggestions. To be able to select the right machine that is suitable for urban mining. QFD also help Volvo CE to highlight the most important process need to pay attention to in their customer working environment. By using these approaches, we want to help Volvo CE to drive true customer intimacy: to include the customer in the business process to meet their needs.
6.2 QFD and LCA & LCC Result Application

In this section, we convert ideas into relevance of the proposed. These ideas are from relevant customer feedback, last group innovation and Volvo CE service engineer intentions. To make Volvo CE service able to manage increasingly complicated and demanding clientele, we choose to use LCA theory, LCC and QFD tools to establish better link between Volvo CE and their customer. Even as the arrival of more demanding clients, more complex projects and tighter deadlines underscores the advantages of exchanging ideas, information and best practices.

6.2.1 Application of LCA

The structure of our case studies consists of goal and scope definition, modelling, and exchanging. It mixed with indicators in environmental, economy and social aspects and combined LCA, and LCC. Nowadays, Volvo CE customers need more professional guidance to help them choose right product and service. As above theory mention, LCA plus LCC help manufacturers to consider more comprehensive factors around their products.

In our thesis we choose to compare Stanford’s prototype with current common solution and assume a simulation case to see how Volvo CE can use LCA and LCC to be a guideline and help their customer to choose a better solution. By following the guideline Volvo CE and the customer can identify their most suitable equipment and service combination to maximize their profits.
6.2.2 HoQ for Additional Service Options

Another output from chapter 5 is House of quality application. We hope to use HoQ as a screening method, to priority process in customer working system. As we cooperate with Stanford on the Volvo 310X concrete machine, here are our results for demolition process system.

Table 25. Indoor concrete demolition conditions HoQ highlight.

| Demolition market investigation shall be done before the purchase. |
| Human resource shall be matched with different conditions in service part. |
| The service system shall have selection between procurement or rent suitable demolition equipment |
| The service system shall have Urban mining site planning |
| Noise emission shall be reduced. |
| Indoor dust shall be reduced |
| Wireless internet System shall be contained in the machine together with the services. |
| Transportation service shall be developed with customer. |
| Demolishing management shall be developed with customer. |
| Recycling construction materials shall be contained in the machine and provide solution to customers. |
| Emergency plan and protective measures services shall be informed to customers. |

Above table shows the top list need to be highlighted in the demolition process, by analysing the difference of importance, we can find the impact from customer requirements to machine technologies and services we need to consider involving in this urban mining environment.

6.3 Demolition Machine PSS Details

So far as we completed a preliminary analysis of the demolition system and use LCA, LCC, QFD theory and methodology to find the answer of our research questions in product aspects and service aspects. Then it is time to design our new PSS solution for near future demolition system in urban mining.
Firstly we design a preliminary Product-Service System for concrete demolition machine development. It can be seen as a lifecycle plan from a machine design, selling phase, use phase to maintenance system and also include last recycle part.

In the beginning of design part, some kind of service already can be linked to customers. Consider special urban demolition environment, the designer ask customer size and functionally of machine customer wanted.

Then in the selling phase we use PSS theory provide three different types of product-service mode for customer. We design a use-oriented PSS mode for future small demolition customers and future individual customers. In future urban environment, Demolition Company may need more specialized tools and machines for their business. Then for saving their customer cost, Volvo CE can provide use-oriented model. Detail of use-oriented ideas is introduced at last part this chapter.

Use phase and maintenance phase are conventional part in the service system. Here we take Vision 2020, which is being planned by Volvo CE’s customer department. Vision 2020 is an actual daily production process which was described by customer and then thesis group analysed the actual “job” that customer wanted to accomplish in process. We listed some part below which includes collecting data automatically from the machines, analyse the data and offer maintenance solutions and to inform users if the machine need maintenance.

Recycling is a part most likely to be neglected. We also want improved service in recycling system by get the machine from customer or reused and recycled old products.
Figure 39 Preliminary Product-Service System flow chart

Figure 39 shows our preliminary Product-Service System. It is a long term in the machine development. As a company point of view, we need to think the whole system of such a machine and the services behind it, which may add value to the customer and meet the satisfaction of them.
6.3.1 Design

The design of the Volvo 310X is linked to the needs of customer and data, which collected from the using and maintenance part. We also named this service as “real time data tracking reporting system”. It is in a cyclic loop of data from customer needs and design stage.

**Design size of the machine according to the needs**

In our thinking, design is the most important phase for a product. The engineer should more contact with end user. Also in urban mining environment, many roads and doors will limit the big machine. This is also can be the basis of customers choose brand.

**Functionality of the machine**

Here we suggest technician and designer should have more communication with customer department, and get more information directly from the user of product. For implement this idea, Volvo CE long-term customer can choose to add this real time data tracking reporting system as a service, then some kind of useful data will send to designer and convenient to designer to update their products.

6.3.2 Selling

This part can clearly show the change of ownership as part of PSS thinking.

**Use Oriented:** the ownership is with Volvo CE. That means Volvo CE sells the usage functions to customers and the selling unit could be used in a period of time (e.g., use/hour or use/month). And customers will return the machine when they do not need it. Detail of this will be introduced at next section.

Usually there are two types of dealer in the Volvo CE’s selling system. Dealer who takes care of big contractor customer called key account, another types of dealer called sales channel often looks at the rest of customers like small demolition companies. Here we think in PSS design, the dealers can help customer to certain projects or activities to deliver better performance for customer and customers’ own ability to set up such projects.
6.3.3 Using

Supporting service during the whole using phase is one of the PSS advantages. Traditional service usually only focus on selling phase or the first few years after selling. In the use phase, a detecting system needs to be added to collect useful information about the parameter of the machine. A detailed using function need to be designed to suit the urban area.

Demolish concrete

Here we present our thinking about this machine. The main task for this machine is to break concrete then it can also store and suck debris from crushed materials. As mentioned from Stanford, they also think about mitigating dusts by watering and decreasing noise by using a skirt. If we suppose there is such a machine used to demolish the concrete, how can Volvo CE do to improve the machine? In many cases, we found customer do not really use the machine as expected from the designer. The feedback data will help engineer to give the machine user a warning before the machine need to be repaired. Such a way will increase the brand trust of the customer that the customer can prevent before the damage come.

6.3.4 Maintenance

Maintenance will directly affect the product life and safety. So we suggest that Volvo CE service engineer can design a real-time condition monitoring and fault diagnosis system, to eliminate hidden troubles.

Collect data from machine automatically

As mentioned before in the use phase, the engineers will collect real time data via sensors on the machine. Volvo CE could provide useful conclusion to customer and themselves, especially on maintenance aspect. It could be easier to find a problem to prevent it from becoming a major damage. The steps of this maintenance system will go through the steps from Data collection, Data analysis, Machine warning reminder and Maintenance the elements in the machine to achieve the service on tracking, monitoring and security etc.
Analysis data and offer solution

Traditional maintenance ways do not sufficiently provide information on the internal replacement or repair indications since that are not visible. However data tracking idea can be done to avoid making extra trips and try to offer better maintained solution.

Inform the user if the machines need to be maintained

Data collect tracking report’s proactive nature allows user to plan and schedule a repair and eliminate the cost of unexpected downtime. Significant cost can be saved if repairs are made before a failure took place.

6.3.5 Recycling

Based on our interview information, about 90% of old Volvo CE vehicle’s frame materials can be recycled. The reason is the strength of these materials from former equipment still good enough to be applied to a new one through professional reprocessing. Usually these devices are disposed because of engine aging. After disassemble the elements in the machine, engineers decide which part of the machine need to be recycling, reuse or even put them into a study phase.

6.3.6 PSS for Different Customers

From our global team brainstorming, we came up some inspiring ideas.

For the large machine customers, the machine could be embedded on the high reaching excavators. And the selling mostly focusing on selling both machines and tools.

Strategy: Selling products and provide services to customer and fulfil their needs (may contain different tool station and power station)

For the user may use it under an indoor situation, the machine can help the people remove a wall or other concrete materials. Projects like decoration and family use.

Strategy: instead of selling, providing a sharing and renting system between.
6.4 Current Product-Service System

Figure 40 Current business flow chart

Figure 40 shows the relationship between Volvo CE and current demolition business. From the picture is to find that Volvo CE current type looks like product oriented PSS. Volvo CE and its cooperation service company Swecon provide both tangible product (in our case the demolition excavator) and additional service, such as maintenance contracts, to the demolition company. And demolition company responsible for consumption, monitoring and disposal of the machine. In this case, the demolition equipment belongs to the Demolition Company and directly used in its demolition business. As traditional business process, current demolition companies buy the big machine from manufacturers like Volvo CE and get basic services Swecon; these basic services mostly chosen when buying such as additional accessory, also Swecon provide some kind of training education for driver. Then the rest of the services fall into maintenance and urgent maintenance. Demolition companies have the ownership of the product and find the demolition project as their independent business.

This model from PSS perspective is product-oriented PSS. This is quite popular in current manufacturing industry, when products are still sold, but with some additional services such as maintenance, upgrading, substitution. We discussed this business model with Volvo CE customer service department and draw this product-oriented flow chat based on the PSS design studies and the system analysis. By showing the information about stakeholder role in each process, the Volvo CE can understand the total role
of each stakeholder and dispatch the machines in order to meet the different production requirements on the working sites.

### 6.5 New Product-Service System Design

After discussing with Volvo CE staffs and construction front-line workers, we got some simply market forecast about features of future urban demolition market. On the basis of related information, this market is developing rapidly. Meanwhile we think that diversified products and more environmental policy will appear in this market. Therefore, we design a use-oriented flow chat for future urban demolition business.

![Designed Business Flow Chart](image)

*Figure 41 Designed Business Flow Chart*

As shown in figure 41, we designed a new business flow based on the theory of use oriented PSS. Although it is hard to judge whether this is suitable for Volvo CE now, all in all, a giant enterprise's business model is slowly evolving through half a century. However, when facing with the emerging market of urban mining, we still want to explore the possible opportunity what be brought by use oriented PSS innovation. This design also gets Volvo CE staff's affirmation and support. In fact, each arrow or stakeholder showed in figure 41 is obtained from communication with customer care specialist and interview and harvest of the previous big group.
If comparing with figure 40 "current business flow chart", you find that the most obvious change is Volvo CE product. And this is one of the most important needfinding results from our global group research. Through the survey of similar deconstruction industry, we found that demolition equipment tends to be smaller and intelligent (usually this is in order to enter the building and improve the efficiency and safety). Though Volvo CE is always focus on large construction machinery, small intelligent equipment still not out of their picture. This is why Volvo works with our global team, and agrees with Stanford's small concrete machine. In BTH perspective, we design this new business flow chart also for increase the value of Volvo310X.

Then original link activities in figure 40 and figure 41 between demolition company (here is also considered as Volvo CE customer) and Volvo CE product reduced from three to one. We are reassigning the disposal duty and the Monitor duty to Volvo and its service company Swecon. The reason for doing this is because that the growing sophistication and complexity equipment increase general customers use-cost, Swecon as professional service firm can monitor Volvo CE product better. On the other hand Volvo CE can also help customer save the waste in disposal process such as recycling concrete, this is another way to increase value for demolition companies. The benefits of this change will be discussed in next sections. In addition to this, Volvo CE and its service companies will collect real time data on the machine through internet and responsible on monitor. Volvo CE can also help customer save the waste in demolition process such as recycling concrete. This is another way to increase value for demolition companies.

After that we can notice the cash flow arrow. The idea of use-oriented PSS model is that customer doesn’t need to buy the whole product. They only need to pay the consumption of using phase. The product will still be placed in demolition companies so they can use them anytime just like traditional way. So when housekeepers want someone recycle their house, they hire a demolition company, and Demolition Company can get money from owner as well as concrete. Base on the forecast of future technology, we have reason to assume that those recycled concrete or material will retain enough worth for selling to recycling company.
**Benefits for Volvo CE customer**

For the Volvo CE customer, the cost savings are enormous, and the time-to-market for new machine or functionality is greatly improved. The demolition companies do not need to pay for expensive machinery and still get satisfaction.

The relationship between Volvo CE and their customer does not end after the transaction, but continues in time. For example, in traditional way, Demolition Company buys construction equipment as firm infrastructure from Volvo CE, and then run their individual business. Demolition Company can order same equipment to start their business. When they have problem in demand in special machine can still receive help from Volvo CE. Causes in use-oriented, customer usually pay for function and satisfaction. At same time, with the help of more efficient tools, project period can be shortened and waste of value can be saved.

As result they can keep get good service and even reducing the energy consumption in use phase. Because when Volvo CE maintained their own product, they will be motivated in ensuring the good conditions of equipment and give better advice in use phase. Like introducing the most efficient engines, reducing machine instabilities and suggesting to construction site plan better.

Traditionally manufacturing companies have not considered the customer’s activities as a primary part of the value creation process, but merely as value extracting processes (Prahalad and Ramaswamy 2004). A key difference with the PSS approach to business creation, when compared to traditional product-oriented approaches, is that Volvo CE has the opportunity to play a greater role throughout their products life and not only in the production and sale of their products.

**Benefits for Volvo CE**

On the other side, use oriented can also help Volvo CE increase value. Although they looks like lose amount money from selling machine, this model will definitely increase in sales in the long run. For this model they can extend their product life and durability without hesitation as well as maximum utilize recycled product. Volvo CE will economically reduce the disposal costs and the costs for the manufacturing of new components. That is important for sustainability society.
Benefits for Urban mining market

In the future urban mining environment, more special products will be designed for complicated urban construction sites, but demolition companies may not have enough budgets to buy all of them. Our use-oriented business model is designed for dealing with this situation. This is a PSS where ownership of the tangible product is retained by the service provider, who sells the functions of the product, via modified distribution and payment systems, such as sharing, pooling, and leasing. So in this case Volvo CE and its cooperation service company Swecon need to responsible for both additional service and monitoring disposing. For Demolition Company, they are more similar to buy the function of the product rather than the product itself. There are several advantages to do this, one of them is Volvo CE can more professional monitoring and recycle of these machines. Some parts of the demolition equipment can be reused in production in a more valuable way. Relative to figure 27, the reason we added concrete and cash in the loop is because the purpose of our design is saving value of concrete in the process of recycling. So the concrete here has more value compared with the current way.
7 Result Discussion

In this section, we will talk about our three main results with the theory we used in context, and discuss these results we did in needfinding. Stanford render’s LCA and LCC data and relevant current other research. In addition, although our new use-oriented business model is designed for associating with Stanford’s Volvo 310X concrete breaker machine, we still keep looking on previous literatures about other companies’ new product and demolition system.

7.1 Lessons learned

Urban mining is a new concept. What should we consider when selecting the “most suitable” machine for urban mining? How should we do this selection? As a large construction equipment company, Volvo CE provides their customers so far twelve different types of machines and varied models. New machines will also be launched during the development process. We here want to present our thinking of how to hunt the right machine for Volvo CE customers. Customer usually focus on the price and profit in their businesses, thus, it can be a good way for Volvo to provide suggestions with a visible documents which including the information mostly concerned by the customers. Especially the specifications of the product, information like attachments, fuel consumption, life time, maintenance costs and efficiency are well concerned by customers.

So we use the machine selection guideline to collect different customer requirements, and consider three aspects in environmental, social and economy in a specific working condition where customer wanted. Then Volvo CE can use as part of selection services to help their customer select right machines for working and discuss with the customer to determine a final choice. This guideline is combined LCA and LCC result and to give customer suggestions with analysing the life cycle of the machines in three aspects which are environmental, economic and social aspects with the communication of Volvo CE customers. In the early time, the purpose of doing life cycle assessment is to select right materials for companies in production process of their product. For example, the first LCA study was in Coca-Cola Company who gets the hint to change the beverage cans materials from glass to plastic bottles (Baumann & Tillman 2004, 1). Since the development of LCA, the boundary of life cycle study is enlarged, it is
not only used in production process, but also in economic and social aspects, so we here use this in our guidelines to give Volvo CE customer a better choice when choosing machines. The guideline consists seven parts. A detail explanation is shown below with figure 42.

1. **Identify Goal and scope together with customer**

Customers will not always express their needs well when telling the vendor what they want. To find the goal and limitation of the working environment together with customer can help increasing satisfaction of customers and understand what customer really want. Methods like interviews, discussions and field trips to sites can be considered in this part.
2. **Formulate customer requirements**

During the activities from guideline 2, different customer requirements will be collected. This activity is to translate customer requirements in a proper way and to list all the requirements of customers in a well-organized way.

3. **Choose target machines**

From the customer requirements, the customer will choose target machines they preferred.

4. **Understand the impact of whole working process with target machines (LCA and LCC study)**

To solve the selection problem above, a study with environmental (LCA), economic (LCC) and social perspectives in the specific working condition of the customer is considered in this section.

5. **Compare results in environmental, economy and social aspects of target machines.**

The LCA and LCC data of machines which customer prefer is compared in this section.

6. **Write blue print of solutions for each target machines**

This is a documentation section; all the results from customer, LCA, LCC and research will be documented and prepared for discussion with the customer to determine a final choice.

7. **Discuss with customer and select the agreeable machine solutions**

This is the part that Volvo CE will discuss with customer and together make a final choice.

Two case studies we did in Chapter 5.2 (Case Study 1 - Volvo 310X analysis) and Chapter 5.3 (Case Study 2 - Volvo CE Demolition Excavator Analysis) is to give examples in how to do the LCA and LCC study when compare two ways of recycling concrete in this guideline. This guideline is based on our master study that we want to put here to give a deeper thought on how to develop a PSS for real situation.
7.2 Contribution Discussion

Through it all, we want to design an open sharing and communications way that satisfied Volvo CE customer needs. Follow needfinding results, we involved House of Quality to better understanding customer needs and transforming the need into more specific technical and service targets. The reason we choose life cycle assessment to analyse the use phase of two different demolition solutions is because we want to calculate different impacts in the use phase of demolition excavator, crusher and transport. And we hope that this theory can give Volvo CE some inspiration about their product in sustainability future. We use guidelines to serve Volvo CE customer to make more accurate selection for their purchase by considering the environmental protection, economic terms and working efficiency. Also based on the consideration of future scarce resources, we design a use-oriented business mode, which support small and medium size demolition companies to reach product diversity and to enhance their competitiveness. The diversity of customer demand and uncertainty will also bring by rapid product replacement and have a tremendous impact on Original Equipment Manufacturing (OEM).

One of the important contributions in our thesis is the result of needfinding. As we mentioned above, we think there are five different stakeholders mainly involved in the urban mining, which are unions, industries, equipment manufacturer, government and workers. Comparing with traditional mining system, types of urban mining stakeholders will not change too much. But small equipment manufacturers with a series of powerful and innovative products will involve in urban mining business and make this market diversification. This is because of the complicated working conditions in city mining site. Maybe the jackhammer is favoured as well as excavator in urban mining site.

This also brings out another problem we found from needfinding, lack of communication. Though Volvo CE always focuses on meet customer requirement, those demolition companies still missed some of need. One reason is because the distance between the workers and designers. We were told from construction workers that they usually prefer to fix some problems with existing tools instead of right one because of human inertia. For instance they are used to choose one kind of hydraulic crimp to do the entire compaction work or use homemade simple flat car to replace the
forklift. These neglected details will hinder designer from product development.

From the LCA and LCC results we got, the future prototype Volvo 310X has better access in limited space location and it will be a beneficial for urban mining area if the urban area is crowded. Although the ability of demolish concrete in one Volvo 310X machine is much less than a standard demolition excavator, we can still find the advantages from different perspective. From economic aspect, the Volvo 310X can save a lot of labour cost for employer, in many developed countries, labour cost account for a large proportion in demolition companies. Beyond that, controlling the Volvo 310X remotely allows companies to avoid the risk from paying damage or death. From efficiency aspect, if we use more than one Volvo 310X at the same time can shorten the concrete demolition ability to excavator.

For the working condition, since the Volvo 310X can eliminate dusts in demolition process and in remote control, thus, it increase safety and provide workers a healthy working environment. For realizing this new urban mining future and add the value for Volvo CE customers, combined with LCA and LCC study, customer can select suitable demolition machinery and valuable services by House of Quality. The category like customer requirements, technical requirements and service requirements can be co-designed together with Volvo CE experts and customers. We think that talking with customers can increase customer satisfaction and add Volvo CE brand competitiveness in construction business.

Although our use-oriented model looks far from Volvo product-oriented model now, there are already many similar researches and discussions appeared now especially in e-business.

On the product aspect, we cooperated with Stanford engineer team and designed a concept model for robotic demolition system, the Volvo 310X concrete recycling robot. The Volvo 310X can automatically demolish buildings, as well as reclaim building material. In the future, though it appears to be designed for demolition concrete in building, there is no reason it could not assist in road demolition.
8 Urban Mining Market Conclusions and Future Work

In final section of this thesis, we present our result with popular mining researches presently and make our conclusion. A simple further work also is shown in the last.

8.1 Conclusion

For enter the future urban mining market, Volvo CE has the challenges of understanding and defining what to develop in terms of products and services in order to remain profitable the competitiveness in construction market. This thesis has investigated status in current demolition system and how to satisfy customer needs in this field. A case study with the development of PSS solution by Volvo CE customer department in urban mining market was introduced. We provide a guideline in lessons learned for support professional solution to help current Volvo CE customer solve complicated challenge, and working with Stanford engineer to promote their specialized machinery for demolition concrete. To do the needfinding in different demolition system stakeholders, a questionnaire survey is been created. The QFD, LCA and LCC results show that highlight importance of process and selecting targeted tools can do more in saving costs and do good to environment. Likewise, we performed a potential PSS solution for future demolition system to solve the problem of equipment’s monitoring and recycling. The comparison shows that the new PSS solution brings sustainable advantages for urban mining customer.

Then after we finish our work, we need to look back and make sure if our results can solve the question we put at design research chapter.

1 Value aspects

What is the value in urban mining?

As we focus on demolition concrete, we think only recycled concrete part contains much potential value. But through our research, this value is easy to lose if companies do not pay enough attention to it. As research shows, two and a half tons per capita per year in concrete consumption and the amount of demolished concrete estimated will be increased to 7.5~12.5
billion tons. A huge energy and material saving we see if we can reuse and recycle the concrete debris. There is no doubt that by reclaiming compounds and elements from products; building and waste, people can save huge resource from urban mining.

How can Volvo CE make a contribution towards optimizing the value of urban mining?

Volvo CE as a construction manufacturer, they can optimize the value of urban mining by providing targeted mining products and service supported to their customer. New machines which designed based on urban environment can increase the satisfaction of the customer and more sustainable to the environment. A continually research on Urban Mining value and innovation in future machines under urban background will be a new strategy for Volvo CE to pursue. Volvo CE per se already make great efforts on emission control, service solutions for customers which could also combined in urban mining environment with a developed product and service system.

2 Product aspects

How can Volvo CE Satisfy their client with the most suitable solution?

In our thesis, we suggested that Volvo CE could use our structure of case studies to help their customer pick a right machine and use HoQ to highlight different process in the system for different customer. Together with service, equipment from Volvo CE can be more competitive. And in the future, when urban mining become more popular, Volvo CE can choose use-oriented mode to sell their product which means to develop product combined with services part to help customers achieve upmost goal in economy, social and environmental.

What will be the competitiveness if using the future prototype, Volvo 310X?

The Volvo 310X is a product that can remove concrete and thus a sub-system within the construction industry. We believe that this machine and overall system model can create a shift in the construction industry where smaller, semi-autonomous machines are used to address the monotonous and dangerous tasks on a job site. This will allow the construction workers, the valuable human resource on these sites, to use their skills and prowess in more effective decision-making roles on the job site.
3 Service aspects

What business model can provide a “win-win” situation for manufacturing and recycling companies and at the same time promote sustainability?

We designed a use-oriented business model associated with Stanford’s prototype. This new PSS design is different from Volvo CE current product-oriented model. We think the Volvo CE and its customer companies should work together with recycling companies to establish a multi-tier classification of existing product, separating urban demolition equipment from traditional construction equipment. In the future urban mining environment, more special product will be designed for complicated urban construction site, but demolition companies may not have enough budgets to buy all of them. Our use-oriented business model is designed for dealing with this situation.

8.2 Results Validity

The scope of this thesis was limited to exploring the field of future urban mining by designing PSS for Volvo CE; more specifically to the demolition process and recycled concrete. Our outcomes will help Volvo CE provide better service to their customer and cooperate with Stanford team to improve their product. The actual effects of our PSS design need to be validated by customer feedback. And the coming time of urban mining market also depends on resource consumption level in the global.

Another limitation is regarding the focus on Sweden. Although the whole Kiruna city moving project is a world-class urban mining site, comparing to those huge cities and the country with high population density, Sweden itself do not have a huge demand on demolition market. These opinions also come from our interviewer in Sweden. Because of the Swedish population density difference, most cities in Sweden do not have demolition requirements. Thus, it blocks us a little in comprehensive needfinding and stakeholder research.

However we are confident with the results obtained, the guideline we discussed in lessons learned we push forward aims to satisfy more customer needs. And the future use-oriented PSS design is also a part of global sustainability strategy. Future business models will pay more attention to reduce the consumption in extracting raw materials and to reuse existing
materials in proper way. Likewise, the Volvo CE can also be more globalization and sustainable when move to urban mining.

8.3 Further Work

In today's era of shortages of raw materials, urban mining shows more and more significant hidden value and economic benefits. So we suggest that Volvo CE as urban mining project sponsor should continually pay attention to this field.

As realized by us in the limitation on validation results with the method and theory we created in this thesis, we think the future work contains:

1. Take the Use-oriented PSS model as a foundation; make some preliminary attempt to the construction market. We suggest that further work can include machine tests and implementation of business model with customer or Volvo CE. According to the feedback from test and operation service, Volvo CE can continuously improve the quality of design, that performance of prototype will be more and more excellent. Meanwhile, Volvo CE can keep combination of production and study with BTH innovation project for improving current PSS model based on customer value.

2. In our thesis, our needfinding results are from relevant customer feedback, last group innovation and Volvo CE service engineer intentions. We think Volvo CE should focus on customer segmentation, identify customer’s needs effectively and provide customers with difference services in the face of competition and future challenges. Needfinding can be expanded to include communication with current buyer. In the past, companies more easily to get advice from a complaining customer. In fact these people are only a small percentage. Volvo CE can get more good advice from those regular customers. More needfinding can help Volvo CE build a comprehensive, thoughtful business plan for construction worker.
References


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Appendices

Appendices 1:

Construction Machinery Investigation

Dear Sir/Madam:

Thanks you for your valuable time in completing this questionnaire. We are the BTH international students and not familiar with Swedish, so we in advance sorry to bring the trouble when you read English.

This survey contains 12 questionnaires about construction machinery, and contributed to our Master Thesis “Product-Service System Innovation in urban mining -A case study with Volvo CE”. The purpose of the study is to explore the value and need in the process of demolition city building, which may be provided better work environment and functionality for staff engaging in this field by improving existing Volvo CE mining machinery and service.

How to do this survey:

Please select the options on this document directly. Part 1 is background collection. Please choose the corresponding options of your positions and machines you worked before. Part 2 and 3 is the questionnaire; it contains options and essay questions. Please select the options according to your experience and write answers of the essay question in this document.

Examples:

Select the option by click the square frame ☒Selected ☐Unselected
Part 1 Basic Information

A. How many years have you working in construction area?
   - □ Less than 5 years  □ 5-10 years  □ 10-20 years  □ above 20 years

B. Which Company do you work for?

C. What kind of machine you have experienced before? (multiple chose, please select all machines you familiar with)
   - □ Wheel loaders (Hjullastare)  □ Backhoe loaders
   - □ Kompaktlastare
   - □ Excavators (grävmaskiner)
   - □ Articulated haulers (Ramstyrda dumprar)
   - □ Motor graders (Väghyvlar)
   - □ Demolition equipment (Rivningsutrustning)
   - □ Pipelayers (Rörläggare)  □ Pavers (Asfaltläggare)
   - □ Compactors (Vältar)

D. What’s your role in the company?
   - □ Administration  □ Project manager  □ Machine driver  □ Construction worker
   - □ Others

E. Have you heard the following words? (Multiple choice)
   - □ Urban Mining  □ Urban recycling  □ Sustainable  □ Eco-drive
   - □ Electrical Power
Part 2 Question Areas

Q1. What kind of machine in the company use mostly during the project? (Select top three)

☐ Wheel loaders (Hjullastare)  ☐ Backhoe loaders
☐ Kompaklastare  ☐ Excavators (grävmaskiner)
☐ Articulated haulers (Ramstyrda dumprar)
☐ Motor graders (Väghyvlar)
☐ Demolition equipment (Rivningsutrustning)
☐ Pipelayers (Rörläggare)  ☐ Pavers (Asfaltläggare)
☐ Compactors (Vältar)

Q2. How many hours you need to operate machinery to break concrete per week?

☐ Less than 10 hours  ☐ 10-20 hours  ☐ 20-30 hours  ☐ 30-40 hours
☐ above 40 hours

Q3. Please simply describe about how you deal with the dust.

Answer:

Q4: If your task is to demolishing buildings, what kind of function you want to have?

The building is made in concrete but without concrete reinforcing bars. (Multiple choice)

☐ Drill  ☐ Grab  ☐ Thump  ☐ Crash  ☐ Cut  ☐ Suck dusts  ☐ Watering

The building is made in concrete and concrete reinforcing bars. (Multiple choice)
Q5: If you are in a demolished concrete wall process, how you do that and which factors make you feel inconvenience?

Answer:

Q4: Choose the accidents you know below or adding accidents no listed. (Multiple choice)

☐ Collapse (buildings, tunnels and so on) ☐ Explosion

☐ Equipment falling  ☐ Electricity accidents

☐ Chemical or toxic accident  ☐ Fire  ☐ Others

How the accidents happened? How many people in the machine injured or killed?

Answer:

Q5: Which part of your body more easily feel tired when you just end the duration of work.

(Multiple choice)

☐ Eyes  ☐ Brain  ☐ Neck  ☐ Back  ☐ Waist  ☐ Leg  ☐ Foot  ☐ Arm  ☐ Hand  ☐ Finger

Q6: How you deal with your construction wastes or tearing down materials? (Multiple choice)

☐ Send to recycle companies  ☐ Send to construction companies

☐ Manage in the company you work with  ☐ Others ______

Q7: The situation about the fuel cost, do you think it is a worth considering in your company

How much percentage you think it is important to consider fuel cost in the company? (A higher percentage means more important)
Q8: Other suggestion of demolishing building future

Demolishing abandon building is one of the urban mining parts. It is for saving and recycling materials from cities. Please write your suggestions that you think it is important to the social ecological environment

Answer:

Part 3 New Concrete demolishing machine

We as a BTH thesis group also have a close relationship with a Stanford University mechanical group, which sponsors our hardware support. Currently they have a preliminary idea about concrete demolishing machine. It contains pneumatic chippers and functional air system. For practicability, 4 questionnaires below are raised based on their design.

Q9: If there is a function in the demolishing machine that can demolishing the concrete by remote control without dust and less noise, would you like to have it in your work?

Answer:

Q10: Please choose top 3 options you think is time consuming in the work.

☐ Pick out the wooden or steel frame of window and door
☐ Break the concrete
☐ Collect the crushed concrete
☐ Sort out the reinforcing bar and put to the certain ground
☐ Changing tools of the machine (For example, from drill to crab bucket)
☐ Move away the wastes from the demolished building
☐ Start the machine and drive to a suitable place before the demolishing work
Q11: How often you need to do machine maintenance?

☐ Once a year  ☐ Twice a year  ☐ Three times a year
☐ Four times a year  ☐ Five times a year
☐ Others _____

Which parts from the machine you call for maintenance mostly? (Engine, Boom, tire and so on)

Answer:

Q12: Depending on your experience, would your construction site use the material from demolition building or from recycling? What kind of trash still remains utilization value for construction site?

☐ Brick  ☐ Concrete  ☐ Glass  ☐ Rebar  ☐ Other _____

Thanks for your participation and your experience sharing!

Please save and send your results to my email: cychai2012@gmail.com

Thank You!

Tack så mycket!

Yi Chai & Zhenqing Gao

MSPI, School of Engineering

Blekinge Institute of Technology

March 2014
Appendices 2:

**Thesis research Plan and Time Line**

<table>
<thead>
<tr>
<th>Time</th>
<th>Working areas</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>W7</td>
<td>Basic Research</td>
<td>Formulate Group and Contact person</td>
</tr>
<tr>
<td>W9</td>
<td>Needfinding-Formulate interview companies and prepare for the interview</td>
<td>Interview survey, Research conclusion.</td>
</tr>
<tr>
<td>W10</td>
<td>Research related knowledge about urban mining and solutions about tearing down concrete (with Stanford).</td>
<td></td>
</tr>
<tr>
<td>W11</td>
<td>Interviews</td>
<td>Interview reports (Needfinding)</td>
</tr>
<tr>
<td>W12</td>
<td>1. Byggnads (union construction workers in Sweden)</td>
<td>Research Conclusions</td>
</tr>
<tr>
<td></td>
<td>2. Other companies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PSS research, Methodology research, Volvo CE existing Product and service research.</td>
<td></td>
</tr>
<tr>
<td>W13</td>
<td>1. Workshops and brainstorming with Stanford students during their visit in Sweden</td>
<td>Prepare questions, PSS thinking in Urban mining. Contact Volvo CE and Stanford.</td>
</tr>
<tr>
<td></td>
<td>2. Interview in Volvo CE at Eskilstuna (Together with Stanford)</td>
<td>Preliminary PSS, Reports</td>
</tr>
<tr>
<td>W14</td>
<td>Brainstorming of urban mining Solutions (May together with Stanford)</td>
<td>Brainstorming solutions</td>
</tr>
<tr>
<td>W15</td>
<td></td>
<td>Capture the knowledge of interviews.</td>
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<tr>
<td>Week</td>
<td>Activity 1</td>
<td>Activity 2</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>W16</td>
<td>Discuss with coaches and Volvo CE for further suggestions</td>
<td>Modify thesis reports with the opinion and suggestion of our coaches and collaboration companies.</td>
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<tr>
<td>W17</td>
<td>Video meeting with Volvo CE about customer service system</td>
<td>Arrange materials from the Volvo meeting.</td>
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<tr>
<td>W18</td>
<td>Research and writing Thesis documents</td>
<td>Working on thesis reports</td>
</tr>
<tr>
<td>W19</td>
<td>Following the collaboration process with Stanford’s students.</td>
<td>QFD</td>
</tr>
<tr>
<td>W20</td>
<td>Discuss with coaches</td>
<td>Modify documents</td>
</tr>
<tr>
<td>W21</td>
<td>Discuss with Volvo CE and coaches about the results.</td>
<td>Thesis reports and PPT documents</td>
</tr>
</tbody>
</table>

Interview in Byggnads, Karlskrona
Interview in concrete industry
Research methodology and theory at same time

Formulate our PSS and other concept design
## Cost of the Volvo 310X prototype

<table>
<thead>
<tr>
<th>Items</th>
<th>Costs</th>
<th>Items</th>
<th>Costs</th>
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<tbody>
<tr>
<td>Leeson 132044.00 Motor</td>
<td>$410.00</td>
<td>Batteries</td>
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<td>Milling Drum &amp; Hardware</td>
<td>$2,591.60</td>
<td>Mounting plate for tracks</td>
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<td>Steel housing for Part x</td>
<td>$382.25</td>
<td><strong>Steel tubing and assembly of frame</strong></td>
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<td></td>
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<td>water jet plates</td>
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<td></td>
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<td>steel tubing</td>
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<td></td>
<td>Water jet cams</td>
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<tr>
<td></td>
<td></td>
<td>Shaft + bearings</td>
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<td>Springs</td>
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<td>Foam and bondo</td>
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<td></td>
<td></td>
<td>paint</td>
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<td></td>
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<td>hood actuators (dampers)</td>
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<td>Belts</td>
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<td><strong>RC electronics</strong></td>
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<td></td>
<td></td>
<td>Radio Transceiver</td>
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<td>Servos + wiring</td>
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<td>Vacuum Cleaner and extensions</td>
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<td>Drive</td>
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Appendices 4:

*Table 26. Ecoindicator’99, based on Goedkoop and Spriensma (1999).*

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<th>Substance</th>
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<td>Particulates</td>
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<td>PM₁₀</td>
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