Recycling acoustic products - improving circular economy in an industrial company

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MASTER THESIS

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- Improving circular economy in an industrial company

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Abstract

The construction and demolition sector stands for a large amount of the waste produced every year, roughly one third of all waste produced every year in Sweden, comes from this sector. The construction material manufacturer Ecophon is a world leading company in manufacturing of acoustic products made out of glass wool, which are used in all kind of buildings and the general geometry of an acoustic product can be described as a rectangular board.

Today, Ecophon use up to 70 % recycled glass in their acoustic products, but after the lifetime of their products, they usually goes to landfill. This answers to the definition of *Linear economy*, where the product is considered as waste when it reaches it end life. Therefore, actions have been taken to obtain a viable recycling process with the goal to improve circular economy, and hence increase their value proposition to the market. This is where this thesis comes in place.

The purpose of this thesis was to create concepts and carry out a pre-study to get insight of what areas that needs to be adapted, in order to reach a viable recycling process. The concept which the project aims to evaluate, is the possibility to recycle products out of bits and pieces from old and used acoustic products. There were several research areas of interest like manufacturing techniques, production, and product compositions. This resulted in three different acoustic product concepts, which are analyzed from a production and environmental perspective. The product concepts resulted in a 600x600x40 mm^3 volume tile, which uses rectangular rods or pieces as core material. The rectangular pieces are enclosed with surface layers and uses no glue between the pieces, this concepts is called *Glue surface*. The other two concepts could be seen an extension of the *Glue surface*, where additional thin virgin cheats of glass fibre wool are added to improve strength, these are called *Virgin board* and *Sandwich*. The concepts can be considered to have improved properties in comparison to corresponding products in different aspects, and could result in a good business case. The conclusion is that the generated product concepts are considered to provide a good starting point of which a recycle program can be build upon, and hence reach towards a *Circular economy*.

Sammanfattning

Byggnads- och rivningsektorn står för en stor mängd av det avfall som produceras varje år och ungefär en tredjedel av allt avfall som produceras i sverige kommer från just denna sektor. Byggmaterialstillverkaren Ecophon är ett världsledande företag inom tillverkning av akustiska produkter gjorda av glasull, som används i många typer av byggnader. Den generella geometrin som en akustisk produkt erhåller är i formen av en rektangulär platta.

Idag använder Ecophon upp till 70 % återvunnet glas i sina akustiska produkter, efter att deras produkter är förbrukade blir det vanligtvis avfall. Detta motsvarar definationen av en *linjär ekonomi*, där produkten anses vara ett avfallsmaterial efter dess livstid. Åtgärder har vidtagits för att uppnå en återvinningsprocess med målet att ingå i en cirkulär ekonomi och därigenom också öka värdet för produkten. Det är här denna avhandling kommer in i bilden.

Syftet med denna avhandling är att skapa koncept och genomföra en förundersökning, för att ge insikt i vilka områden som behöver anpassas för att nå en livskraftig återvinningsprocess. Konceptet som projektet kommer att utvärdera är möjligheten att återvinna produkter från bitar av förbrukade akustik produkter. Det fanns flera forskningsområden som är av intresse som exempelvis tillverkningstekniker, produktion och produktuppgyggnad. Det resulterade i tre olika akustiska produktkoncept, som analyseras ur ett produktions- och miljöperspektiv. Produktkoncepten resulterade i 600x600x40 mm^3 plattor, dessa använder rektangulära stavar eller bitar som kärnmaterial. De rektangulära bitarna är omslutna med ett ytskikt och använder inget lim mellan stavarna, detta koncept kallas för *Gluesurface*. De andra två koncepten kunde ses som en påbyggnad av Gluesurface, där ytterligare tunna glasfiberplattor adderas för att förbättra produktens mekaniska styrka. Dessa koncept kallas *Virgin board* och *Sandwich*. Koncepten kan anses ha erhållt förbättrade egenskaper i jämförelse med motsvarande produkter, utifrån olika aspekter och kan leda till ett bra business case. Som slutats kan det sägas att de generade produktkoncepten kan betraktas att ge en bra utgångspunkt för ett återvinningsprogram som kan utvecklas vidare ifrån, och därefter nå en ciruklär ekonomi.

Acknowledgments

We would like to start with thanking our supervisors Tommy Månsson at Ecophon and Jessica Wadin at Lund University. They have made this master thesis possible through valuable support and inspiration during the whole process.

Performing tests and evaluations to gather important data have been crucial during the project. To a big part this have been done through using prototypes, which were made possible thanks to Borut and Pia at the Design department at Ecophon. Thanks for always lending a hand and your expertise.

The team at Beyond have always shown a great interest in our work, and guided us with valuable information. Thanks to all patricians in interviews who provided us with important information throughout the thesis.

We want to express our gratitude to all companies that have let us take part and observe their processes, it provided us with valuable inspiration and insight of different areas.

Finally we want to thank Ecophon for letting us perform our master thesis and putting their trust in our effort. You have welcomed us warmly and made us feel like a part of the company.

Contents

List of acronyms

CE	Circular Economy
C&DWM	Construction and Demolition Waste Materials
D4S	Design for Sustainability
GB	Green Binder
PF	Phenolic binder

Terms and Definitions

Downcycling	A recycling process where the recovered item is broken down to retrieve usability.
Production waste	Waste material that is produced during the manufacturing process.
Recovered material	Products that have been in use and are returned back due to their end life.
Recycling	Any engagement where materials or products are recovered to prevent it of becoming waist. The recovered item are re-processed to fulfill a new purpose either through upcycling or downcycling. It could become a new product or material.
Remanufacturing	Recovering products in a component or subassembly level. The parts that are recovered that are reusable, is used to compile a new product. During this process improvements and quality assurance can be included.
Sub-concept	The product contains of three areas which are assembling, composition, and aesthetic appearance, also known as sub-concepts, together they form a final product concept.
Up-cycling	Process during recycling where increased value are maintained for higher quality before renewed usage.

1 Introduction

This chapter presents a brief introduction of the project and information about the company. A background of why this thesis is conducted is explained and a description of the objectives. At last assumptions and delimitation's are presented.

1.1 Background

Humans' consumption habits have a large burden on our planet resources and the construction and building industries are responsible for a big part of this (cf. (Naturvårdsverket, 2017a; European commission, 2009; BOSS, 2018)). About one third of all waste produced in Sweden every year comes from the construction and demolition sector and one fourth of all the waste that are considered as a hazard (Naturvårdsverket, 2017a). The *EU Framework Program Horizon 2020*, it is stated that by year 2020, 70 % of non-hazardous construction and demolition waste will be recycled (Pacheco-Torgal, 2014).

The life cycle of a building can be described as construction, occupancy, renovation, repurposing and demolition. During each phase of this life cycle, the buildings use energy, water and raw materials, which generate waste, and potentially harmful emissions. There are several countries that have construction and demolition guidelines and regulations which contractors must follow. In Sweden there are an organization called *Sveriges Byggindustrier* which repeatedly updates and summarizes these guidelines from e.g. authorities. According to *Sveriges Byggindustrier*, all parties which are involved in a construction project have a level of responsibility when it comes to C&DWM within their own framework of activities. The customer of a product also have a big role when it comes to the waste materials and should forestall negative impact on environment and peoples health (Svenska Byggindustrier, 2015).

Directives from EU and guidelines puts pressure and affects the material that should be used when constructing (cf.(Naturvårdsverket, 2017b;

J & C, 2009)). The private sector will have tougher environmental responsibilities in the future, and companies will more frequently have to prioritize construction plans that offer an environmental friendly solution (Sundbom, 2011). The environmental impact is one of the reasons why different building standards, certifications, and rating system have been established (Vierra, 2016). Certifications from third parties have been used for some time to indicate different qualities that a company has or follows (Green Building Alliance, 2016). Due to this, architects and developers tend to certificate their buildings (Byggtjänst, 2016) and frequently therefor chose environmental friendly products. This can put construction material suppliers in a position where they either adapt or consequently could lose contracts (Link Arkitektur, 2018).

Many companies are making efforts to adapt their impact on the environment through different measures. A solution that many suppliers take and tend to do, is to adapt into more sustainable oriented offers and develop environmental friendly alternatives e.g. use recycled materials for manufacturing. This change can contribute to many favorable business opportunities and decrease the environmental impact at the same time (Leising, Quist, & Bocken, 2017).

The acoustic product industry have been researched, by Jorge P. Arenas and Malcolm J. Crocker, in trends within sound-absorbing materials. They claim that the materials have evolved and become more "safer, lighter and technologically optimized". They also indicate to the market, sound absorbing products in the future in a sustainable, recycled, and environmental friendly fashion will be an important factor (Arenas & Crocker, 2010).

1.2 Ecophon

Ecohpon is a subsidiary to the global Saint-Gobain group. Saint-Gobain are a world leader in construction markets, design, manufactures and distributes buildings and high performance materials. They provide innovative solutions, energy efficiency and environmental protection (Saint-Gobain, 2018a). Saint-Gobain have many subsidiaries which can be seen in figure 1, which are divided in to four groups. Ecophon is a part of the 19 construction material companies (Saint-Gobain, 2018b).

Figure 1: Saint-Gobain's subsidiaries (Saint-Gobain, 2018b)

Ecophon has approximately 750 employees and business units in 14 countries and delegations in another 30 countries all over the world. The promise Ecophon gives is *"A sound effect on people"*. This promise is the core backbone of everything they do, which are development, manufacturing and markets of acoustic products and systems. Hence they can contribute to a good working environment and enhance peoples' performance and well being (Ecophon, 2017a).

1.2.1 History

Ecophon has a long history and the first acoustic products were manufactured by the then Gullfiber back in 1958, today known as Isover Saint-Gobain. Ten years later, special product group for acoustic products was formed. The Acoustic business area developed successfully during the

70's through sales organizations in Sweden, Denmark and Norway. In 1981 Gullfiber Akustik AB was formed and the manufacturing company Ecophon A/S in Denmark was acquired. Five years later all group of companies took the name Ecophon, and ever since, the Head Office and some of the production have been located at Hyllinge, Sweden (Ecophon, 2007).

1.2.2 Products and development

Ecophon have a large assortment of products within acoustic tiles, grids and related products e.g fasteners. The tiles are made out of porous glass fibre wool to obtain the acoustic absorption ability. The tiles can vary in size, shape, and thickness. Ecophon products are processed from a refined glass wool baseboard retrieved from Isover. The baseboard has a rectangular geometry and contains a binder to keep the glass wool fibers together. During the manufacturing of an acoustic tile, the baseboard is coated with a painted laminate for cosmetic purposes and cut up in desired size.

Ecophon's third generation acoustic tiles are today made up to 70 % recycled glass and uses a green binder (GB) consisting of biologic starch or phenolic based binder (PF). Usually the life expectancy of a tile in a building is about 15-20 years before it is being removed. Today Ecophon provides a service where they take care of the disposal of third generation acoustic tiles. These tiles are milled down and put in to a disposal program called *Ecodrain*. Ecodrain is a process where the waste tiles are used as a landfill material (Ecophon, 2017e).

Ecophon strives to have a lower environmental impact and work more with the principals of circular economy. Different actions have been taken to develop and enhance product lifespan and improve their recycling. A collaboration with *Lund Tekniska Högskola*, and a partnership with the Corporate Accelerator called BEYOND at Ideon, Lund. The purpose behind Beyond is for several companies to share information and knowledge with each other (Ecophon, 2017b).

The Ecophon team at Beyond have conducted a product planning phase where they have identified opportunities, evaluated & prioritized projects and allocated resources. As can be read in the background there is relevance for this project and certain parameters have already been identified. This project comes in at the pre-project planning phase and product development phase to research possibilities for recycling project.

1.3 Problem description

To stay strong and competitive on the construction market, a recycled product is of interest. Today there is no effective way of up-cycling or recycling acoustic products or materials. A team from Ecophon have provided the concept of recycling acoustic materials through assembling bits and pieces created from the recovered products. The question arises, if the used tiles are recovered, how should they be refined to form a new acoustic product in a sustainable way.

It will be necessary to generate a reasonable number of product concepts and define their possibilities. Analyze the production aspects based on one or more product concepts and provide recommendations for what the next phase in the project could be.

Research new ways of working with recycled materials. What phases can occur and how could they be handled. This could be both before and after the recycle material reached Ecophon.

1.3.1 Research question

A wide research question was established with employees at Ecophon, which was later divided into sub-questions.

- How can used acoustic tiles be recycled or up-cycled into a new product and become viable?
  - What are the properties that will contribute to an up-cycled

product and how will the customers respond to it?

– What manufacturing techniques and how can they be used in order to obtain a recycled acoustic product?

– How will a product based on recycled bits and pieces relate to circular economy?

– How will the recycled product concepts answer to the different product specifications?

1.4 Delimitation and assumptions

The time limit of this project is 20 weeks and the therefore this thesis will focus on the Swedish market and regulations even though Ecophon is a global company. The project will delimits on a recycled product based on acoustic tiles that have not been recycled before.

The project will not look closer into how the existing products should be manufactured to allow easier recycling for the future.

The new acoustic product does not necessarily have to contain of 100 % recycled materials. It should be used in an indoor environment and not be created for outside use. The surface layer of the tile will not be included in the recycling process.

This thesis will not look deeper into how the material will be recovered from the demolition or renovation projects. Instead it will recommend in what state and condition the recovered acoustic products should have to be able to produce a recycled acoustic product.

2 Methodology

This chapter will give an introduction to different methods that are being used for this thesis. Additionally, it will give deeper insight of the methods and how they could be accomplished.

2.1 Introduction methodology

According to Höst, Regenll and Runeson (2006), the methodology describes the basic workflow of a project and the principals for how it could be carried out. It does not describe in detail how and what is planned during the workflow. Instead the methodology is used as a tool to help to come from an overall goal and establish suitable steps in the right direction for an increased knowledge of the issues.

2.2 Methods and research design

The planning and the performance of the methods are explained here. This created a suitable work flow for the project, by adapting and choosing certain methods. Figure 2, explains the general pathway of the project. Through out the project inspiration from product development theories have also been used to focus on the right aspects.

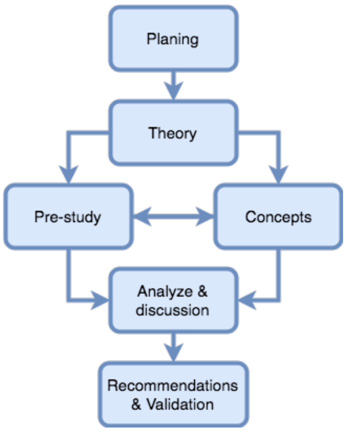

Figure 2: Workflow

In the beginning of the project a literature study was conducted. The literature provides usable theories about different areas of interest. Information is received through internet based sources, books and articles.

Simultaneously during the literature study, an internal and external study were performed through study visits, interviews and digital data, collected from the internet.

2.2.1 Literature Study

A literature study is important when areas in this project are investigated. A well performed literature study makes it easier to build on already known facts and also decreases the risk of ignoring knowledge that are already known (Höst & Runeson, 2006).

There are several approaches on how the literature study can be proceeded. This thesis have chosen a guideline established by Hart (1998), where the structure of the process is defined in a clear way. The first step is to frame a detailed planning of the literature study which will provide a performed study with right intentions (Hart, 1998). The guidelines for planning the literature study are listed below:

- *Define the topic.* Make general reading and get familiar about the topic . Encyclopedias shall be researched and prepare a list of terms for further research.

- *Think about the scope of the project.* What languages will be searched and what are the relevant subject areas. Prepare a 20 vocabulary list of terms and phrases that will be used for searching.

- *Think about outcomes.* What is the aim of the search and why should it be performed. What can be the possible outcome from it.

- *Think about the housekeeping.* It is important to keep record of what have been searched and how. This is in order to be able to go back to the same source and undertake further researches.

- *Plan the sources to be searched.* Investigate likely relevant sources of information that might be needed. Involve a subject librarian for guidance at this stage.

- *Search the sources listed.* Go through the list of sources that have been created. Start with the general and further the more abstract indexes. Take notes about leads and ideas that need to be further investigated.

This thesis have used literature studies focused on product development with an environmental perspective. It contains areas such as recycling, circular economics, and steps to take during a product development process. It was decided to use Ulirch Eppinger's product design process as a starting point, and then combine it with other theories as a compliment.

2.2.1.1 Ulrich and Eppinger

The project used Ulrich & Eppinger's product developing theory, this provided a system and a way organizing the product development process (Ulrich & Eppinger, 2014). Some of the steps and recommendations were excluded or altered to fit this project better. The focus were on development of concepts and evaluation how it answers to the defined specifications through a number of steps. In figure 3 the areas within the product development phase that have been circled, are the one being focused during this project.

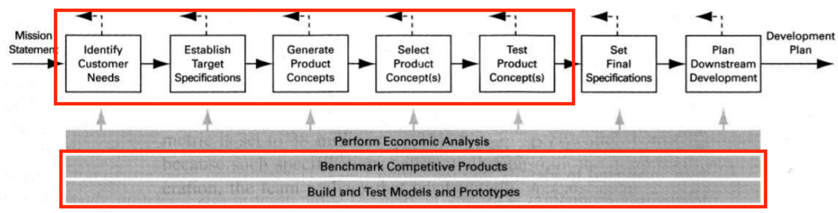

Figure 3: Chosen methods from Ulirch and Eppinger, Concept Development schedule (Ulrich & Eppinger, 2014)

2.2.2 Methods for gathering data

Several ways of gathering data have been chosen for this project. The reason for this, is that there are plenty of information sources that are of importance. The following methods are some of the one used during the thesis. This thesis both uses the method of quantitative- and qualitative-data. Quantitative-data is data that can e.g be presented with as numbers unlike qualitative which can be described through words and text (DeFranzo, 2011). Both these methods were used because the broad spectrum of the project. The qualitative data which are mainly presented during the pre-study is researched through e.g interviews, discussions and study visits. Meanwhile the quantitative data are collected through testing and measuring e.g prototype and material samples.

2.2.2.1 Interviews

Interviews were frequently used, throughout the hold project. Some had the purpose to scope certain areas that were related to the project. These interviews was more characterized as a discussion with the people that participated. Other interviews had the intention to give more detailed answers, which required a more strict agenda and well prepared question list. To read more about interviews and how they were performed look in

2.2.2.2 Study visits

During the project it was important to conduct study visits, both outside and inside of Ecophon. This provided a wider picture of the problems that are related to the project. Some of the study visits gave answer to specific questions while others served the purpose to give inspiration.

2.2.2.3 Case study

Case study is a method that was frequently used in different aspects. A case study aims to generate knowledge and data about area of interest. The outcome is usually unknown and some times a phenomenon that is hard to determine is the one being researched. It is frequently used during both the pre-study and the concept development when theories and ideas were developed. Small case studies were then established to research the areas of interest (Höst & Runeson, 2006).

There are several ways of gathering data when conducting a case study, some are described here in the method section, like observations and interviews.

2.2.2.4 Observation

A big part during the project have been to gain information through observations. This have been done internally as well as externally.

3 Literature study

This section of the thesis will give insight for some of the important litterateurs and theories that have a correlation to the project. The researched areas are theories within sustainability, product development, and acoustic.

3.1 Sustainability

Sustainability have a broad meaning and can be applied in many areas or aspects, according to Cambridge dictionary sustainability can be seen as the way of handling natural resources. This through forming or processing goods and services in a way that does not harm the environment or uses resources that can not be replaced (Cambridge University Press, 2018). Sustainability can also be described how biological affected systems stays productive and diverse, but the definition continuously evolves. New parts get included in the concept scope frequently, like developing sustainable models that meet today's needs and at the same time does not jeopardize future generations well-beeing or earths survival. More recent sustainability also includes more of a global society aspect where e.g.universal human rights and economic justice are included. Why the old models and definitions are changed throughout time is because to adapt to the growing human population, which affects the way of how each individual can or should think regarding resources (Sustainability Degrees, 2018).

3.1.1 Circular economy

There are plenty of descriptions and definitions of what Circular Economy (CE) is. It could be described as economic and environmental material worth are maintained for conceivably time by retaining them within the economic system. This could be through looping them back into the system. The material that enters the CE process then have to be accounted before, during and after the products lifetime (Hollander, Bakker, & Hultink, 2017). Another way of describing CE is to design products to be reusable and/or recyclable. This can be done trough different ways and the aim is to improve society-wide advantages. CE distinguishes between biological and technical cycles. Biological cycles are materials that can feed back in to the ecological system e.g. through anaerobic digestion and composting. Technological cycle depends on their design, and uses strategies to recover and recycle materials. Products can for example be produced so they can be easier to repair and take apart. These are the basic steps to move from linear economy, where products materials after its life are seen as waste. This circular way of thinking and acting is not only up to the suppliers but also the way individuals and companies uses the products and dispose them. The circular way of thinking compared to the linear, can be seen in figure 4.

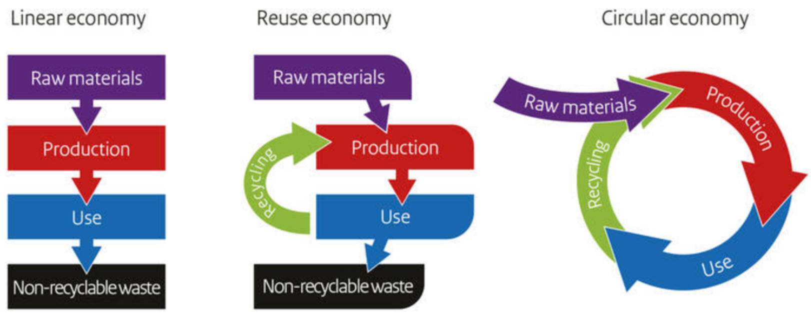

Figure 4: Circular economy (Government of Netherlands, 2017)

In the construction and building sector innovation moves relatively slowly compared to consumer driven sector and because of that the actual implementation of CE can take time (Leising et al., 2017). Focus have rather been on energy efficiency than on how the their materials will enter a circular flow. This can be a problem when politics and regulations prevents companies of handling and producing material in certain ways, especially when they are one of the main focus areas regarding CE. The construction sector stands for about 30% of the total waste produced and 40% of the total amount of material that goes in to the global economy (Leising et al., 2017). This contributes to the increased research and within the Construction and Demolition (C&D) sector regarding CE and sustainability, during the latest decades. Here the principals of CE are implemented to effect the construction and demolition waste materials (C&DWM), to implement a new way of thinking. Not seeing waste as a problem but as a potential resources and prevent the usual path. Were C&DWM are used as landfill in a linear economy (LE), which can be seen in the next figure (Ghisellini, Ripa, & Ulgiati, 2017).

3.1.2 Reduce, Reuse & Recycle

There is a theory called *Reduce, Reuse & Recycle* (RRR) which is frequently mentioned by multiple sources and can be used for sustainable development (cf. (European Comission, 2008; Ahmadi, 2017; Rethink, 2015)). The theory is based on using different methods or measures to enhance sustainable development. Different activities is ranked according to their considered impact. The model which are frequently used can be seen in figure 5.

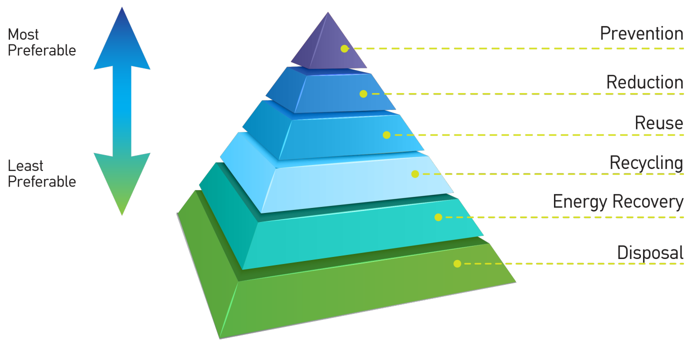

Figure 5: RRR-hierarchy (Rethink, 2015)

Prevention & Reduction is the highest ranked option of handling waste material. This correlates to improving manufacturing techniques and methods, reduce materials for packaging , optimizing usage of raw material and more. This can be achieved not only through implementing better and more sophisticated techniques but simply by making the right decisions by the management (Ahmadi, 2017). The consumers' demands have an impact and therefore they also have a big responsibility to consume more durable and waste smart(cf. (Ahmadi, 2017; Rethink, 2015).

Reuse is the next step in the hierarchy, which refers to reuse a product for a similar, the same or a completely new purpose than before. This without altering with the material or products shape in a large extent. This can either be done by consumer or a company, through repairing, selling or donating.

Recycle refers to waste material used in manufacturing of new products. This could be a process were both raw material and energy is saved compared with creating new products of the same kind (Rethink, 2015).

3.2 Product development

According to Bhamra & Lofthouse (2006), about 70% of a final product is direct influenced during the design stage of the product development process. This is where the most critical decisions with respect to: cost, appearance, material selection, innovation, performance, environmental impact and quality such as longevity, durability, reparability are made (Bhamra & Lofthouse, 2007).

3.2.1 Design for sustainability

Design for sustainability (D4S) is a useful instrument for enterprises and governments when working with product design which applies sustainability criteria (Crul & Diehl, 2005). D4S is focused on designing the product and make it become more sustainable, but in developed economies, D4S is more linked to wider concepts such as, sustainable product-service systems and innovation systems. As Ullman states, it is important to realize that design engineers have a big control over the product design and how it will affect the earth and environment its lifetime is over (Ullman, 2010). Environmental and social concerns are taken as key elements when industries work with the long-term product innovation strategy, from a D4S point of view. This means that companies embrace the social and environmental factors into product development throughout the life cycle of the product, supply chain, and their socio-economic surroundings, from local community for a small company to the global market for cross-border companies (Crul & Diehl, 2005).

3.2.2 Design for recycling

Design-for-recycling method is distinguished by incorporating recycling criteria into the design phase of products. The aim is to obtain recyclable and/or recycled products (Generalitat de Catalunya, 2016). In the *Journal of Cleaner Production*, there are different statements to follow when a product should be designed for recycling (Johansson & Luttropp, 2009):

- Minimize the number of parts.
- Standardize and use modular constructions.
- Place the components in logical groups according to their intended recycling strategy and the handling sequence in the disassembly process.
- Avoid integral constructions and unnecessary combinations of different materials.
- Reduce the number of non-recyclable materials and components.
- Ensure that the coatings, paints, etc. that are used do not present any problems.
- Make the joints, gripping points, breaking points, etc. easily accessible.
- Ensure that the disassembly can be made with conventional tools and equipment without special arrangements.
- Provide a technique to safely dispose of hazardous waste possibly found in the product.

The list consisting of nine set of statements above, are just one example a designer can take into action, when a product is under its development phase. In the journal *Production Economics 38*, a longer list of statements is presented. For instance, the design of the product should also inform the consumers how to recycle the materials, and encourage them to do so when the end life of the product has occurred (Kriwet, Zussman, & Seliger, 1995).

According to A. Kriwet et.al (1995), it is required to establish a long-standing business relationships with the manufactures, suppliers and the consumers, in order to address the environmental problems of the life cycle of the product. In the journal *Production Economics 38*, a model of a recycling network is proposed, with the purpose to provide necessary communication to support collaboration. The network should consists of a "server", where the designer and the clients are included, represented by the consumers, recyclers and the suppliers, see figure 6.

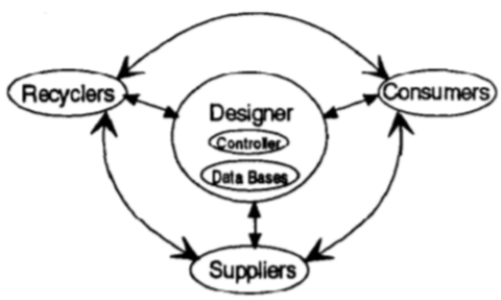

Figure 6: Recycling network (Kriwet et al., 1995)

3.2.3 Product development theories

There are many methods and strategies of how a new product can be created. According to *BusinessDictionary*, product development can be defined as making of products that provide benefits to customers though new or differently performed characteristics (Business Dictionary, 2018). Product development can also be seen as a multidisciplinary decision process with many constrains and obstacles along the way (Abele, Anderl, & Birkhofer, 2005). According to *Ulrich & Eppinger* it is necessary to use a well defined process to achieve a final product with quality assurance. Their theories can be found in *Ulirch and Eppinger Product Design and Development* which contains methods of how to perform a product design or development process (Ulrich & Eppinger, 2014). The activities during the concept phase can be seen in figure 7.

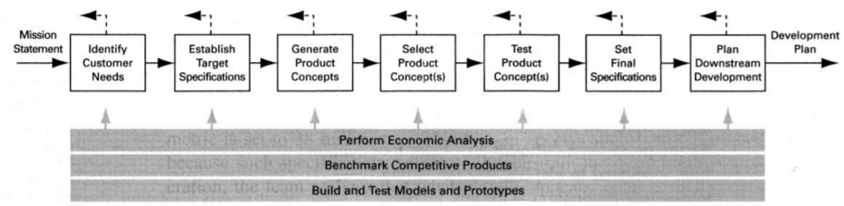

Figure 7: Ulirch and Eppinger (2014), Concept Development schedule

The book of *Environmentally-Friendly Product Development* contains methods and tools for product development (Abele et al., 2005). One of the models which creates methods for product development in the book is called *CRC 392* and approaches different aspects to take into account during developing environmentally products. This model is a result through a collaboration between a large number of researchers, professors and students. The point is to affect all life cycle phases which have an environmental impact and other constrains the product might have. The model for, which can be seen in figure 8, brings up areas that can be researched during a development process (Abele et al., 2005).

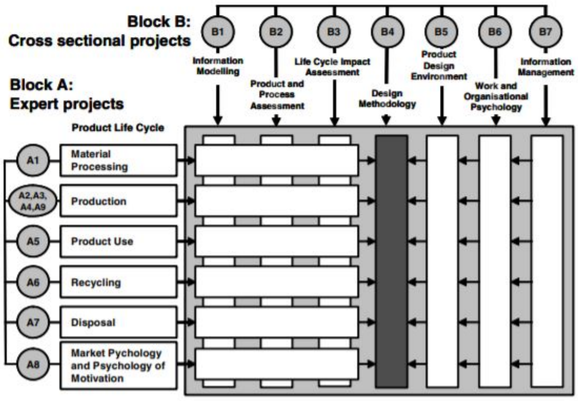

Figure 8: *CRC 392* model, (Abele et al., 2005)

Descriptions of how each cell within the block A and B can be obtained and used when developing a new or refined product.

Another person who have researched how to perform a development process is David G. Ullman. The book *The Mechanical Design Process* is based on some of his research, and correlates in many ways to theories in the book of *Environmentally-Friendly Product Development. The Mechanical Design Process* brings up lots of aspects and things to consider when developing something. Effectiveness of a design process can be measured in product quality, cost, and the time to market. It is stated that customers as well as management want changes so the products become cheaper, produces faster and have higher quality (Ullman, 2010). He implies the importance of communicating different areas within a development process. An overview over the design process,can be seen in figure 9, could according to Ullman look like the following.

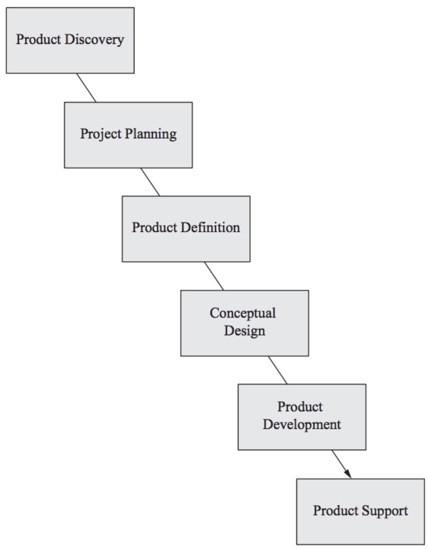

Figure 9: Overview over a design process(Ullman, 2010)

The individual boxes can then in turn be broken down in several sub-steps.

Either it can be communicated through describing texts, drawings, sketches, rules and conditions which applies to an object or physical models like prototypes. Before starting a project, needs should be established to verify a projects viability and guidelines. This is called *Product Planning* and *Product Definition* which is used to be able to create product concepts based on this information. When evaluating the different product concepts various methods can be used. One of these are SWOT-analysis which helps to define which concepts or project to continue with (Ullman, 2010).

3.2.4 Concept generation and evaluation

One phase during the product development process is the generation of concepts. The goal with this phase is to thoroughly explore the scope of products that may address the customer needs (Ulrich & Eppinger, 2012). The generation of concepts includes a mix of external search, problem solving within the team, and solution exploration of various concepts the team come up with. Each concept is represented by a sketch and a concise description.

3.2.4.1 XYZ-method

One internal search method that can be used during the concept generation phase is called the XYZ-method, which is described below (Olsson, 1985):

- Gather are group of X number of members. The group members will be instructed with the main guidelines.

- Each group member generates Y numbers of concepts, these will be illustrated and commented if necessary.

- After Z minutes all concepts will be rotated within the group and developed if possible. This process is repeated until all group members have developed all concepts.

3.2.4.2 Benchmarking

According to Ulrich and Eppinger (2012) it is critical to understand the competitive products in order to come up with successful positioning of a new product. Another benefit by using *benchmarking* is the providing of rich source of ideas for the product that is going to be developed, but also the production process design for it. It is usual to use *benchmarking* during other activities throughout the product development process.

3.3 Basic acoustics

Acoustics, the science of sound, are present in many places in our life and can affect us in different ways. Humans ears does not apprehend all frequencies and loudness of sound, which have resulted in a weighting standardization system (Marc, 2015), processed by International Electrotechnical Commission (IEC) (International Electrotechnical Commission, 2018). How sound is created and received various, countless variables also impact on how sound waves spread. The waves contain energy, which decreases every time the sound wave interferes or comes in contact with an object. This is why porous materials are suited for sound wave absorption (Arenas & Crocker, 2010).

As described by Ecophon, in sound absorption, the principal for the sound waves in correlation to a room can be seen in figure 10. Some of the sound that strikes a absorptive material bounces back in to the room and some are goes through. The sound to enter the material and are reflected several times inside of it, this decreases the energy of the sound wave and are converted in to heat energy (Ecophon, 2017c).

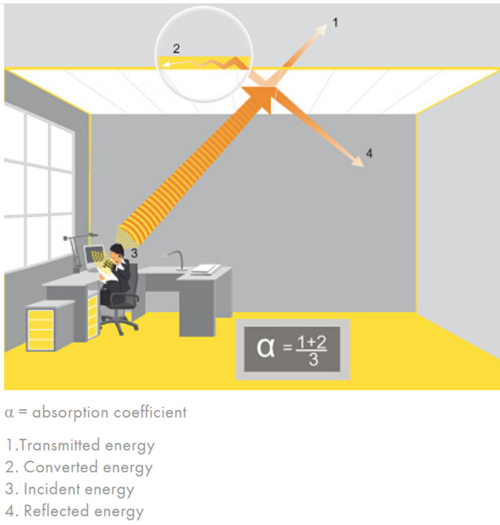

Figure 10: Sound absorption (Ecophon, 2017c)

Sound absorption ability depend on the properties of the material. The properties can be described with coefficient α, which is a function corresponding to the frequency. As can be seen in the figure 11, α reaches from 1.0, total absorption, to 0, total reflection (Ecophon, 2017c).

An absorptive material should at least have an absorption coefficient, α, of 0.5. This ratio of absorb-ability is defined as *"absorbed energy over incident energy"* (Marc, 2015). A way of control the absorption ability is by regulating the thickness of the materials. Thicker material gives better absorption performance in low-frequency area. Another way is by changing the density of the material which can affect the porosity. These factors affects the airflow receptivity, which can be measured by blowing through it. This indicates if the material is suitable for acoustic absorption (Marc, 2015). The classes which an acoustic product can obtain is graded from A to E, as seen in figure 11 (Ecophon, 2017d).

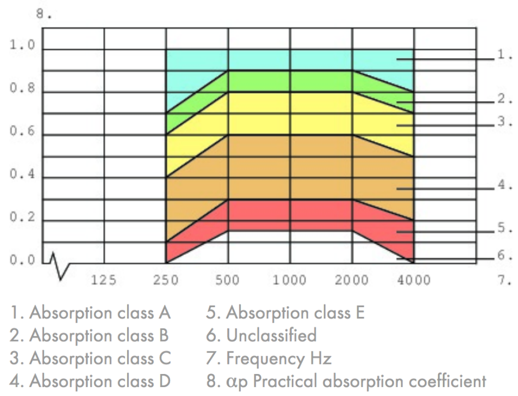

Figure 11: Sound absorption class(Ecophon, 2017d)

4 Pre-study

This chapter describes different problems and what demands there are for the project. The researched areas provide information which can be used in the analyze, it will also be used during the development process of acoustic product concepts.

4.1 Introduction pre-study

The development of acoustic products based on recycled glass wool tiles, covers different kind of areas that needs to be investigated. Some of these areas can be researched within Ecophon while others can only be found externally. This will clarify what resources that are available at Ecophon today and what resources that may need to be included in the future. In figure 12, a workflow can be obtained. The figure and way of working during the pre-study is inspired and uses Ullamn's and Ulrich & Eppinger's product development theories.

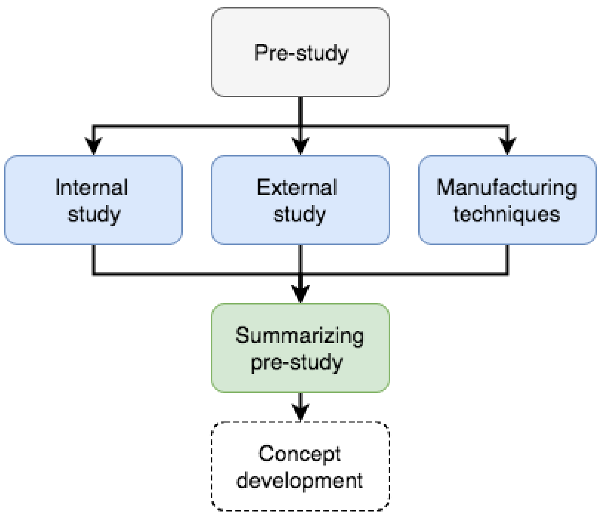

Figure 12: Pre-study

A mission statement was set up during and before the pre-study, which is seen in table 1. The purpose with a mission statement is to research and focus on the right areas. There is not time to research all areas of interest, and the ones performed during the *Pre-study* is the areas that are considered to provide usable data for developing and evaluating upcoming product concepts.

Table 1: Mission statement

Mission Statement: Recycled Acoustic Products	
Product Description	• Recycled acoustic products based on glass wool tiles • The recycled products should consist of recovered cut up bits and pieces
Benefit Propositions	• Increased acoustic properties • Customized design features • Mechanical properties
Key Business Goals	• Environmentally friendly • Support Ecophon's strategy for recycled products • Take advantage of recovered and/or production waste • Ensure that market demands and regulations are fulfilled
Primary Market	• Customers involved in Green building projects
Secondary Market	• Existing Ecophon market
Assumptions and Constrains	• Recycled glass wool tiles are recevied back to Ecophon
Stakeholders	• Saint-Gobain & Ecophon • Purchasers & users • Architects • Installer & service operations • Distributers & resellers • Subcontractors

4.2 Internal study

When investigating how the situation is for Ecophon today, there are different areas that need to be focused. The investigated areas within Ecophon are described with a short description below. All information have been collected through discussions, interviews with employees. Also through test and research performed at the facility in Hyllinge.

- *Product processing* - The processing of Ecophon's products and the different manufacturing steps they use today.

- *Production waste* - The situation of the waste material that is generated due to errors in production.

- *Raw material* - Describes the raw material that are used for the acoustic products and lab tests of it.

- *Assortment* - What kind of product groups are there and how does the requirements and regulations differ from each other.

The internal study also tries to define the possibilities of the project from Ecophon's point of view.

4.2.1 Ecophon's assortment

The product assortment are divided into different product areas, depending on how the product are formed and mounted. These are *Modular ceilings*, *Wall applications*, *Free hanging units and baffles*, *Lightning*, and *grids and accessories*, see figure 14 and 13 for example. In turn these groups contain different families of products. Furthermore, other companies buys Ecophon's products and integrate them in their own products to obtain acoustic properties.

Figure 13: Free hanging units (Ecophon 2018)

Figure 14: Modular ceilings (Ecophon 2018)

It is not decided what acoustic product areas this project will come up with concepts for. Depending on the area of usage the recycled product will have, different mechanical demands and fire regulations, which have an impact on how the product could be carried out.

It is understood during the internal study that lots of product features or properties not always are needed or intended. Some features like fire properties are usually relatively high in Ecophon products, but is not always needed or demanded by customer or regulations. Because the product obtain good fire properties it is used as an competitive leverage. The same applies for the mechanical properties which usually is much higher in some aspects than is actually needed or demanded.

4.2.2 Product processing

During the internal study it has been crucial to look deeper into Ecophon's way of working when they produce their products. The purpose is to get more insight of what techniques, resources and knowledge Ecophon have today. By investigating the manufacturing processes they use, creates a foundation of what they can and cannot produce today.

The material Ecophon processes when they manufactures an acoustic tile is called a *baseboard*, which consists of glass wool fibers and a binder substance. When the baseboard is delivered from the Saint-Gobain subsidiary Isover, it goes through different steps during the manufacturing of the acoustic tile, which is described in figure 15.

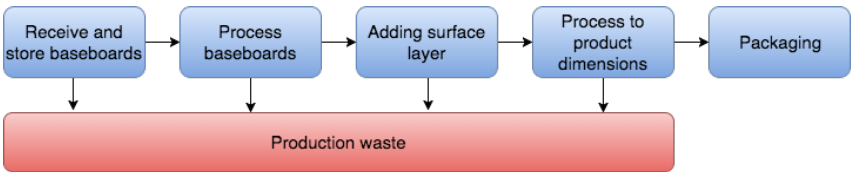

Figure 15: Process of acoustic tiles

The baseboard's surface is first grinded to make it more even, and depending on the product that is going to be produced, both surfaces are sometimes grinded. When it comes to Ecophon's production in Hyllinge, Sweden, only one surface is exposed to this process while the other surface sometimes has one layer of glass fiber sheet and is kept untouched.

When the first manufacturing phase is completed, the grinded surface of the baseboard is glued on with a pre painted glass fiber layer. This layer is representing the side of the acoustic product that will be seen by the customer when it is installed in a building.

The processed baseboard with added layer is cut into desirable sizes that answers to the final dimension of the acoustic product. Depending on the product, the sides around the tile are painted for different reasons, e.g cosmetic or mechanical purposes.

4.2.3 Production waste

During the production there are several steps that removes material to obtain a product. All theses steps contributes to discarded material being produced. Together with the other reasons that can be obtained in the paragraphs below the waste material produced sums up in a total of 15 % (Ecophon, 2017e). Even tough the percentage is low the millions of square meters being produced every year makes the disposed material sums up to a big number.

During the manufacturing process there are products being discarded, due to error in production. The definition of what makes a product not approved depends on the product and what level of faults that can be allowed. Errors can occur during many steps in the manufacturing process. It could be when the painted edge does not get an even paint result, or smudges and deformations created during transporting the product along the production line. In general it could be stated that faults located at the visual surface layer is not accepted. All the inspections of a product is done manually throughout the production, and a product which is noted to have an error, is removed manually as well. The majority of the products are light weight which makes this possible.

Material are being disposed before manufacturing of a product starts. The reason for this can e.g be transportation damaged pallets with baseboards. The baseboard can only be damaged along one edge but are declined being put through the refining process. It is difficult to keep track of individual baseboard along the production line, since this requires an observation from a production worker.

Ecophon have looked into the possibility about using vision systems that automatically can identify errors and remove the identified product. The problem when using vision systems is that they can be difficult to program in the right way. This can e.g be because there are many levels of faults that a human can perceive and estimations made of aesthetics, which can be complex to programs. If it is not programmed well it can result in disposal of products that are acceptable visually and mechanically. This can e.g mean unwanted negative environmental impact and economic losses.

4.2.4 Structure of a baseboard

As mentioned before, the raw material that Ecophon are using is called a *baseboard* which has a rectangular shape and can be seen in figure 16. The baseboard consists of glass wool fibers and a binder that keeps the fibers together and regulates the density of the baseboard. Today there are two different kinds of binders that are used by Ecophon. One is based on biological starch and referred as a *Green Binder* (GB), and the other one is petroleum based and referred as *Phenolic Binder* (PF).

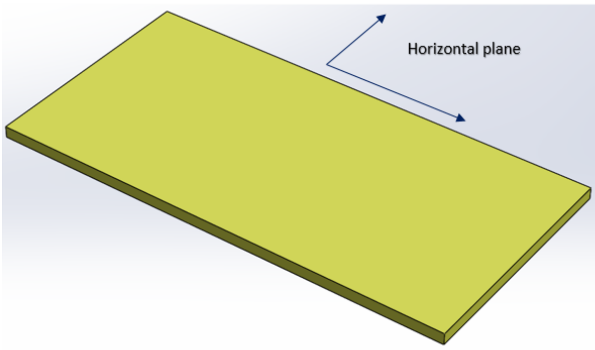

Figure 16: Baseboard

The horizontal plane of the baseboard is build up of thin laminate layers of glass wool fibers, which is described with a simple model in figure 17. The number of laminate layers varies, depending on the thickness and density of the baseboard.

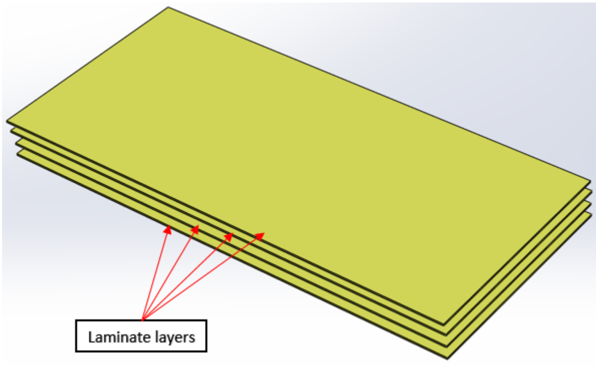

Figure 17: Structure of a baseboard

4.2.5 Recovered material

Acoustic products made out of glass wool are already being recovered and received by Ecophon today. The reason behind this is as described in section 1, which is the *Ecodrain* service, were milling down the recovered material is a part of the process. One industry that have experience of recovering their own building material, is the gypsum industry. Discussions with Ecophon employees, indicated that the gypsum industry have a capacity of recovering 100 % of the disposed gypsum, but only 15 % is recovered back today.

The demand on the customers when it comes to the quality of the returned glass wool material, is not high and it can e.g be damaged and have been stored outside before delivering, which can result in moister damaged products. In figure 18 and 19, an example from recovered material. However it is demanded from the customer that the material is well sorted, i.e no unwanted materials should be included in the shipping. The material is currently being received in large bags made out of woven plastic material.

Figure 18: Woven plastic bags

Figure 19: Recovered material

It is important to understand what problems can occur when dismantling a ceiling and how this could affect the recovered materials. Interviews and discussions with installers and employees were used to get information within this area. Even though it is not usual that an acoustic ceiling installer also dismantles ceilings, they are considered to have knowledge in the area. The things that were brought up during questioning were the following.

It is understood that dismantling a ceiling, for a person who have done it before, is not necessarily a difficult thing. Much depends on what product are being dismounted and the working environment. If it is a product that e.g is glued on to a ceiling, it is difficult to remove it without damaging the product.

It is likely that the products will receive some sort of damages during dismantling especially along the edges, which is an exposed area of products in general. It is also usual that a product which is being installed is cut e.g to fit along the walls in a room, or installations that need to penetrate the ceiling to fulfill its purpose, like sprinklers or ventilation systems. In figure 20 and 21, examples of tiles which are affected by such interferences is described.

Figure 20: Interference example

Figure 21: Interference example

4.2.6 Project possibilities

Ecophon is continuously working with sustainable development where the use of recycled glass in their products is one example (Ecophon, 2017e). Discussions and interviews with Ecophon employees provided insight of potential possibilities this project could contribute to, which can be seen in table 2.

Table 2: Project possibilities

Nr	Development possibilities
1	New manufacturing techniques are applicable with other potential or existing products
2	The products compliment the existing assortment
3	Contributes to Ecophon's future sustainable development
5	Enhance products' acoustic and mechanical features

When it comes to investments in the purpose of implementation of known or new techniques, many parameters have an affect on the final decision. One of the reasons for this is because Ecophon is a subsidiary to Saint-Gobain. Being a part of Saint-Gobain contributes to many levels when a decision is being made. Some of the factors that can have an impact if an investment should or should not be made, could be the ones listed below. These factors are only vague description but they implies and give an understanding in some of the values Ecophon and Saint-Gobain take into consideration.

- How high is the investment cost?
- How does the potential investment compile to regulations and work environment laws?
- Does the investment interfere with the interest of any other companies within the Saint-Gobain concern?

4.2.7 Lab tests on material

One of the features that were interesting to investigate during the project, were the laminar structure of the glass wool. Today, the baseboard and the acoustic products have their laminar structure horizontally orientated as laminate layers which is described in figure 17 in subsection 16. The direction of the laminar structure can be vertical orientated if the recycled product is built up with pieces from a recovered acoustic tile, see figure 22. Lab tests were conducted in order to see how the direction of the laminate layers could improve the mechanical and acoustical properties.

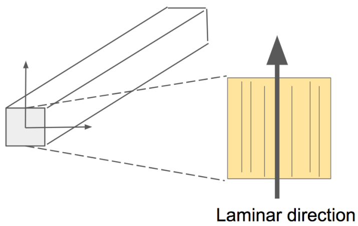

Figure 22: Test piece

It was also noticed that acoustic tiles with different thicknesses could be cut up into pieces and placed with a vertical laminar structure, and then be assembled together, and thereby achieve same thickness. This means that the thinnest tile that is cut up, must adapt it self to the thicker one, which is described in figure 23.

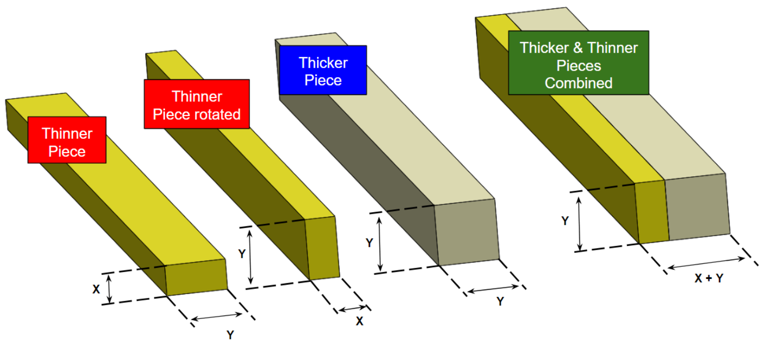

Figure 23: Test piece

4.2.7.1 Mechanical test

The mechanical test was conducted on glass wool rods with a cross section of 40x40 mm. It was decided to perform the test on pieces cut from grinded baseboards, one high density, and one low density. In figure 24 and 25, a visual description of how the tests was conducted can be seen. A more detailed description about how the test were conducted can be obtained in appendix E.1.

The test gave an indication of potential mechanical benefits of orienting the pieces in a vertical laminar direction of a product. The result are presented as a percentage in difference in how much better the vertical laminar piece withstands a force when applied there trough deflects it. Horizontal laminar structure is used as a reference see table 3.

Deflection test
The force it takes to deflect the material 7mm vertically when mounted as in figure 24.

Pressure test
The force it takes to deform the material 4mm vertically when mounted as in figure 25.

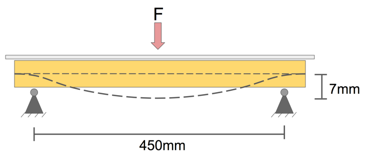

Figure 24: Deflection test

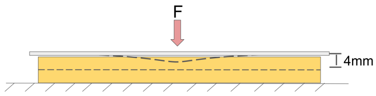

Figure 25: Pressure test

Table 3: Mechanical test results

Test	**Density**	**Horizontal laminar structure (Ref.) (%)**	**Vertical laminar structure (%)**
Pressure	Low	0	185
Pressure	High	0	253
Deflection	Low	0	26
Deflection	High	0	27

4.2.7.2 Acoustical test

Discussion with employees at Ecophon, gave insight into how different densities affect an acoustic product. The spectrum of densities also provides different sound absorption depending on the frequency a sound wave has. This rouse an interesting thought that a mixture of densities in the same product could have acoustical benefits.

At Ecophon, Næstved, Denmark, several prototypes were created by using rectangular shaped pieces with a vertical laminar structure. The purpose was to compare the resitivity between a vertical orientation of the laminates versus an original laminar structure. It was also decided to combine different densities of the pieces for some of the prototypes. In appendix E.2 the test is described more in detail.

The prototypes were compared against three different references with different densities, where all had original laminar structure. The result indicates that all prototypes had better resistivity value, regardless of reference which can be seen in table 4.

Table 4: Prototype acoustic test

Nr.	Density 1	Density 2	Cross section1 (mmxmm)	Cross section 2 (mmxmm)	Ref 1 (%)	Ref 2 (%)	Ref 3 (%)
1	Medium	Medium	40x40 V	40x40 O	11	29	38
2	High	-	40x40 V	-	4	23	33
3	Medium	High	20x40 V	20x40 V	22	28	46
4	Medium	High	40x40 V	20x40 V	31	45	52
5	Medium	-	20x40 V	-	35	48	50
6	Medium	High	20x40 V	20x40 V	25	40	48

Ref 1 = Low density , Ref 2 = Medium density, Ref 3 = High density

O = Original laminar structure, V = Vertical laminar structure

To complement the acoustic measurements some simple computer simulations were conducted at Ecophon in collaboration with acousticians. The simulations were done on the two least favorable compositions of the prototypes made from product concepts. The properties added in the simulation program are the same values used in the table 4. The simulation program simulates sound absorption in a 10 m^2 room with a ceiling covered with the chosen product, with certain properties. The results is absorption in correlation with different frequencies and a weighted α-value, which is explained in *Basic acoustics*, section 3.3. The results indicated a wheighted value between 0.9-1 α .

4.3 External study

Parallel throughout the whole project it has been necessary to conduct an external study. The external study have the purpose to generate knowledge and inspiration by studying other industries, research labs etc. All sources that have been studied do not necessarily have to be within the same applications as Ecophon. The external study was conducted through interviews, study visits and internet-based exploration.

4.3.1 Acoustic market

There are plenty of companies within the acoustic product industry that offers different acoustic solutions. They differ from each other through targeting different market segments or make acoustic products out of different materials. The purpose of researching companies within the same industry is to provide insight in different materials, methods, and ways of targeting customers.

Various porous materials comes with different advantages and disadvantages e.g acoustical, aesthetically, and mechanical properties. Some of the materials that occur in the market and for acoustic products can be seen in table 5 (Arenas & Crocker, 2010). The total amount of soft mineral fiber, including glass wool, produced each year reaches around 40 million square meters in Europe, according to several external sources.

Table 5: Acoustic materials

Material	**Description**
Mineral Wool	Rock- or slag fibre Wool
Glass Wool	Glass fibre wool
Wood	Wood based fiber materials
Hemp	Hemp based fibre materials
Polypropylene	Porous plastic material

Even though it have been mentioned before that porous material are preferable when it comes to acoustic absorption this is not the only way of coping with sound. Relatively solid materials like wood can be arranged in ways that allows sound absorption, e.g through *scattering* which reflects sound waves in different directions(Westervelt, 1957).

4.3.2 Certifications and regulations

There are different certification systems that take various areas into consideration. When meeting certain requirements, products can get labelled with *Green Product* certification that indicates that the product fulfills certain demands and environmental benefits. This can make the product influence and let it contribute to the environment larger extent.

The *Swedish Standard Institute* have a certification for requirements and test methods on suspended ceilings. This standard were issued by *Comity European Normalization* (CEN) in Europe 2013 and contains several aspects to take into account when putting a suspended ceiling on the market. Several countries including Sweden, have agreed to follow standards with regulations concerning European fire standards *EN 13501-1*, mechanical properties, installation, emissions etc (Swedish Standards Institute, 2014).

4.3.3 Study visits

During the project, different study visits were conducted to gain inspiration and data about different ways of processing materials. The study visits that were done and the purpose of them follows below. More detailed explanations can be read in appendix C.

- ***Kährs*** *in Nybro, Sweden* - An inspirational visit were techniques for sorting, cutting, and assembling were observed.

- ***Isover*** *in Lübz, Germany* - Horizontal band saw cutting are of interest for this project and were here reserched.

- ***Ecophon*** *in Næstved, Denmark* - Purpose of testing and making prototypes with known technologies and observe different tools.

- ***Swedish waterjet lab*** *in Ronneby, Sweden* - The purpose of the visit was observe, learn and test waterjet cutting on different glass fibre products.

4.3.4 Customer interviews

During the development of a recycled acoustic product, it was necessary to distinguish between different customer needs. It is important to have in mind that the individuals for each customer group may request different properties for the product. The group of customers are listed below:

- *Architects* - The customers who can design acoustic products into their projects.

- *Installers* - A customer who installs and handle acoustic products.

- *Suppliers* - Customers who buys and resell acoustic products. Could also be contractors who provides and decides building projects material choices.

- *Users* - The end user who is using and staying in an environment were acoustic products are used.

4.3.5 Customer needs

The first phase during the concept development process is *identifying customer needs*. This section concludes direct or indirect statements and results from both internal- and external studies which forms the customer needs. The different customer needs are presented in table 6 and which segments they correlate to. There are in total four segments of customers, Architects (A), Installers (I), Suppliers (S), and Users (U). The addressed customer needs are those considered to be the most important during the development of concepts. Some of the addressed customer needs is difficult to apply to the concept development process, since the usage area of the upcoming product concepts is unknown. In appendix B, a list of questions to the different segments of customer is shown.

Table 6: Customer Needs

Nr	**Customer**	**Customer Needs**
1	I	The product can be cut manually
2	I	The product is not to fragile to handle
3	A, I	Similar properties as existing products
4	A, I, S	The product is robust and durable
5	I, S	The product is easy to install
6	I, S	The product is easy to demount
7	A, I	The quality of the product is predictable
8	A, I	The product has low tolerances
9	I, S	The product is well packaged
10	A, I, S, U	The product has good acoustic properties
11	A, S	The product comes in several designs
12	A, S	The product is attractive to the market
13	A, S	The product is adapted to laws and regulations
14	A, I, U	The product can cover cables, pipes, etc
15	A, I	The product is adaptable for integrated installations
16	A, S, U	The product looks good in general environments
17	A, S, U	The product is functional with acoustic accessories
18	A, S, U	The product is recycled
19	A, S	The product have a motivated and reasonable price

A = Architect
I = Installer
S = Supplier
U = User

4.4 Manufacturing techniques

Insight of different manufacturing techniques for the project was obtained during the *Pre-study*, which were observed both internally and externally. The manufacturing process was divided into three different areas in order to produce a recycled acoustic product, these areas are described as following.

- *Sorting* - The recovered glass wool material can vary in quality, densities, thicknesses, and binder material, which will require a way of sorting.

- *Cutting* - In order to obtain glass wool pieces it is required to have a technique of cutting, which will depend on how the pieces will look like.

- *Assembling* - The cut up pieces based on the recovered material, will be assembled by using one or more techniques.

At this stage of the project, it is not decided how the recycled acoustic product should be designed. This made is difficult to determine the sorting and assembling techniques in a manufacturing process. However, the cutting techniques were an area that was considered to be possible to investigate more deeply. The reason behind this, is that the products will contain of bits and pieces, regardless of concept, while sorting and assembling depend on the final products. Therefor, a specific technique within sorting and assembling is not investigated, but instead the possibilities and delimitations of them are taken into account.

4.4.1 Sorting

There are a wide range of companies that specializes in sorting materials with the purpose to ease a recycling processes. This area have been researched because it is likely that products and materials that are being recovered will have to be sorted in some way before being processed into a recycled product. Therefor it is important to understand in what different techniques the market offers. As *Waste Management World* states, efficient sorting is the key to effective recycling (Waste Management World, 2008). There are plenty of techniques to choose from, which e.g specializes in sorting different kind of materials.

It is mentioned before that Ecophon today mainly use manual sorting during the production process. This technique works well according to themselves, especially because the complexity of the faults that can occur during processing and the downsides an automatic system could induce.

4.4.2 Cutting

Various manufacturing techniques have different characteristics and are capable to cut the tiles into smaller pieces. In appendix C, a list of ideas for cutting techniques can be obtained. After a rough sorting and prioritizing, four different cutting techniques were selected to be further researched, which can be seen in table 7 below. More information about the techniques can be obtained in appendix C.

Table 7: Cutting, manufacturing techniques

Technique
Waterjet cutting
Circular Saw
Band Saw
End Milling

There are several parameters that can be of interest when researching manufacturing techniques. This project finds itself still in an early and conceptual stage which limits the depth of the things that can be researched. After discussions and interviews of what parameters could be of interest to evaluate, some manufacturing features were set up as guidelines, see table 8.

Table 8: Features to evaluate

Features to evaluate	
Feature	**Description**
Non-linear cutting	If the technique allows non-linear cutting with good results
Waste and emissions	The amount of waste material and emissions produced, based on the cutting width
Processing speed	If it is possible to process glass fibre wool in a reasonable speed for mass production
Internal resource	Does the technique exists at Ecophon today
Quality	Result of cutting with this technique and how fuzzy the cutting surface is

Working with, testing, and researching the techniques provided a result table based on the features of interest, see table 9.

Table 9: Evaluation against features

Evaluation of cutting techniques					
Feature	**Unit**	**Waterjet cutting**	**Circular saw**	**Band saw**	**End milling**
Waste and emissions*	mm	<0.5 mm	>2 mm	<2 mm	>3 mm
Non-linear cutting	Yes/No	Yes	No	No	Yes
Processing speed*	Yes/No	Yes	Yes	Yes	No
Internal resource	Yes/No	No	Yes	Yes	Yes
Quality/fuzziness*	CC	4	2	3	1

TC = Technique Comparing, where 4 is the best result
*Depends on density

4.4.3 Assembling

There are different ways of assembling parts in order to create a final product. This can be complex depended on the product that will be produced and the parts it consists of. Some industries use more then one manufacturing technique when they assemble, where the order of the process can vary.

Today there is no assembling of parts within the manufacturing process at Ecophon, which made it difficult to investigate this area internally. Therefor, it was necessary to conduct inspirational study visits and benchmark different companies that are specialized in assembling techniques within a manufacturing process.

A study visit was conducted at the parquet floor manufacturing company Khärs, Nybro, Sweden. They process their products out of wood and have a long experience in assembling wooden pieces for mass production. Some of their products were assembled manually while others used automatically solutions, e.g industrial robots. The study visit was used as an inspiration to give a picture of how an industry of assembling smaller parts could look like.

4.5 Summarizing pre-study

Several areas were investigated during the *Pre-study* which gave important insights, see table 10 for summarizing.

Table 10: Investigated area during the pre-study

Insights internally	
Internal	**External**
Understanding for the production process and manufacturing techniques	Understanding the acoustic market
Products/assortment function and usage areas	Customer needs and demands
Internal needs, goals, possibilities and values	Ways of using and implementing techniques in production
Knowledge about glass fibre as material and its possibilities	Regulations and certifications of building materials

Following sections contains tools generated and knowledge's gained during the prestudy.

4.5.1 Evaluation areas for concepts

The obtained data and information during the pre-study provided an understanding about what areas that can be evaluated between the different concepts and prototypes that were developed. A target specification table is not possible to establish because the product is not decided. Instead an evaluation table were generated to help to evaluate future product concepts. Some of the specifications were undefined (U), since the usage area of the product concepts are not decided, see table 11.

Table 11: Evaluation table with specifications

Evaluation areas of product concepts			
Specification	**Unit**	**Interval**	**Ideal**
Product fire class	U	U	U
Estimated fire resistance *	Concept comparison	-	-
Product thickness	mm	U	-
Product life time	Years	15-20	20
Horizontal dimensions	mm^2	U	U
Tolerances *	mm	U	U
Recycled material	%	0-100	100
Ease of cutting manually *	Concept comparison	-	-
Able to cut manually *	Yes/No	No -Yes	Yes
Mixture of densities	kg/m^3	Low- High	U
Binder	GB or PF	U	U
Acoustic properties *	Concept comparison	-	-
Mechanical properties *	Concept comparison	-	-
Ease of manufacturing	Concept comparison	-	-

U = Undefined

*Depends on density mixture

4.5.2 Identified possibilities

New opportunities were noted during the *Pre-study* that could be used in subsequent steps for the recycled acoustic product, which are summarized below:

- *Vertical laminar structure of the pieces* - Increases the mechanical strength and improves the acoustical properties, compared to the structure of the laminates that is used today. It also makes it possible to combine different thicknesses of the recovered acoustic tiles, if they are cut up into pieces.

- *Mixture of densities and binder material* - The principal of using bits and pieces in order to create an acoustic product, makes it possible to combine different densities and binders.

- *Production waste* - The documented quality and volume of production waste at Ecophon can be used to create an acoustic product.

5 Concept development

The workflow during the concept development process of recycled acoustic glass wool products is presented in this section. It covers areas such as generating and selection of concepts, prototyping, and tests.

5.1 Introduction concept development

The pre-study provided information and usable data in order to generate concepts. The concept development is divided into two parts. One were *sub-concepts* which were generated and evaluated to later be combined in to *product concepts*. During the generation of concepts prototypes and testing were made. The workflow can be obtained in figure 26. Some of the tests done with prototypes are presented in the previous section *Pre-study*.

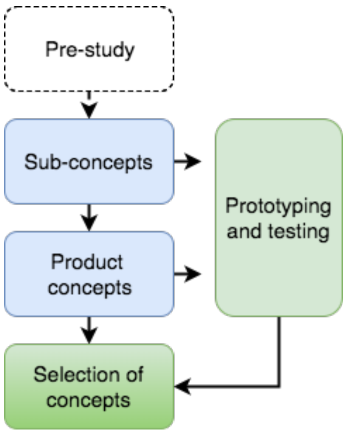

Figure 26: Product concept development

5.2 Sub-concepts

The concept of acoustic products based on recycled glass wool pieces can be carried out in many ways. To make it more easy to understand how the product may look like, it is chosen to divide the concepts into sub-concepts, which can be seen in figure 27. The figure shows how the structure of this sub-section is done but all the steps are iterative in the real process.

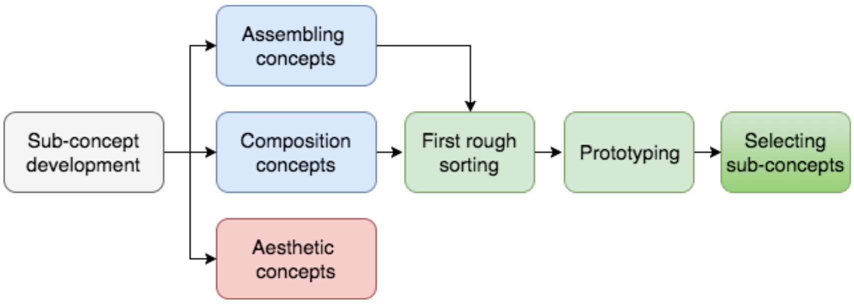

Figure 27: Sub-concept generation

The sub-concepts are explained briefly below and together they can form product concepts:

- *Assembling* - Concepts of how the recovered pieces can be attached together to form a new product.
- *Composition* - The shape, size, and the orientation of the recovered pieces.
- *Aesthetic Appearance* - The appearance of the product and how different customers experience it.

During the concept development process, several sub-concepts were generated. The creativity among the project members was enhanced by using different methods of generating ideas such as the *XYZ-method* and *Brainstorming*. All concepts were given an identification code and a name.

After generating a number of sub-concepts a first rough sorting was done. The purpose was to obtain a reasonable amount of concepts through ranking them with, *KEEP*, *LOOSE* or *HOLD*, see table 12. The excluded sub-concepts are explained more in detail and can be seen in appendix D.1. The rough sorting was based on discussion within the team and Ecophon.

Table 12: Ranking of sub-concepts after the rough sorting

Concept result	Definition
KEEP	Continue with concept
LOSE	Do not continue developing this concept
HOLD	Put concept on hold, which means it can be interesting to develop later on, but not for this project

The remaining sub-concepts (KEEP) after the first sorting were discussed more in detail and evaluated with pros and cons. This provided insights in some of the positive and negative aspects and made it easier to understand which concepts to continue with. The selection of sub-concepts is based on discussions and the results from the *pre-study*, and prototyping, which were done parallel through the concept development.

5.2.1 Assembling concepts

A short description and a decision whether a generated assembling concept should be developed further or excluded is presented in table 13.

Table 13: Description and decision for the assembling concepts

Code	Name	Description	KEEP/ LOSE
1A	Velcro	The Velcro technique is used to hold the pies together	LOSE
2A	Jigsaw	Pieces are cut in to jigsaw inspired shapes to connect to each other	KEEP
3A	Tonged	The tonged or grooved principal from the wood industry	LOSE
4A	Tape surface	Create a surface layer on a role that have integrated glue, like tape	KEEP
5A	Glue surface	Use same principal as today's glued on surfaces	KEEP
6A	Glue pieces	Use glue between pieces to hold them together	KEEP
7A	Needle stitch	Use needles to penetrate the pieces and drag some wool in to the next piece	LOSE
8A	Tailor board	Use some kind of thread to sew the pieces together	LOSE
9A	Spike surface	Create a surface layer with integrated spikes that connects to the pieces	LOSE
10A	Second board	Glue on one or two whole baseboards on to the pieces to hold them together	KEEP

After deciding which assembly sub-concepts to continue with, they were further developed and prototypes were made. To read more about the concepts go to Appendix D.1.

5.2.2 Composition concepts

The examples presented are coarse and mostly presented as geometries and patterns. All *Composition Concepts* can be combined with one or more *Assembling concepts*. The *Composition concepts* are divided into sub-groups, which can be seen in table 14. In appendix D.1.2, it is possible to see a more detailed explanation of the most interesting composition concepts.

Table 14: Composition concepts

Code name	Name	Description	KEEP/ LOSE
1C	**Rods and rectangles**	**Combination of rod and rectangles in different patterns**	
1C1	Brick formations	Rectangles are orientated like bricks on a wall, buckling lines across one side of the tile is avoided.	KEEP
1C2	Fish bone	Rectangles are angled and put together as a fish bone pattern	KEEP
1C3	Tilted rods	The rectangles'/rods' edges are angled like a parallelogram	KEEP
1C4	Spiral	Rectangles are placed out to form a spiral pattern, continuously buckling lines across the tile is avoided.	KEEP
1C5	Frame pieces	A frame where the core of the tile contains of pieces	KEEP
1C6	Parqutte	Air gap between lamella pieces in the core of the tile	LOSE
1C7	Two by two	Two rectangular pieces beside each, every other pair is turned 90 degrees. Together they create a unified board.	LOSE
2C	**Complex geometries**	**Pieces with shapes that are more complex, e.g v-shapes, arrows, irregular shapes etc.**	
2C1	Arrows	Arrow shaped pieces that allows them to fit together	LOSE
2C2	V's	"V" shaped pieces that fits together.	LOSE
2C3	S-hook	S shaped pieces	LOSE
2C4	Hourglass	Hourglass shaped pieces, reminds of the Diablo Spinning-toy.	KEEP
2C5	Patchwork	Irregular pieces of recovered tiles put together to a baseboard.	LOSE
2C6	Lightning	Cut in to zigzag pieces that fits together	LOSE
3C1	Planed pieces	Small pallet like pieces, not determined geometry.	LOSE
3C2	Pallet board	The pieces are planed and put as layers on top of each other	LOSE
3C3	Pyramids	The cross section of the piece are in the shape of a pyramid	LOSE
3C4	Diamonds	Diamond shapes that are creates a unified board	LOSE
3C5	Hexagons	Hexagons that together creates a unified board	LOSE
3C6	Crosses	Crosses that together creates a unified board	LOSE

The recovered pieces that will consist of recycled glass wool can vary in density, and in thickness. It is also possible to change the direction of the laminar structure by turning the obtained pieces, see table 15. However, it is considered to be difficult to change the laminar structure of the *Complex geometries*, and will make the surface uneven.

Table 15: Adjustable parameters for glass wool pieces

Parameter	**Unit**	**Alternatives**
Densities	kg/m^3	Low, Medium, High
Thickness	mm	20 - 60
Laminar structure	Degrees	0 - 90

5.2.3 Aesthetic appearance

Here the concepts can be seen as addition to the sub-concept and are meant to give insight in thoughts of how the product could look like to give different experiences for the customers. The appearance are usually done through changing the finishing surface layer or design of the product, see table 16.

Table 16: Description and decision for the aesthetic appearance concepts

Code	**Name**	**Description**	**KEEP/ LOSE**
1AA	Classic Appearance	Use the same appearance as Ecophon's products have today, which is a clean surface with different color options.	HOLD
2AA	True Appearance	Reveal the recycled material contained in the product, which can be made e.g using a transparent layer. Also gives the possibility to create a "two-sided" product where one side has a classic appearance.	HOLD
3AA	Patterned surface layer	Use customized pattern for the surface layer which are specific for this product.	HOLD
4AA	No surface layer	One or two sides are bare and do not have a surface layer, which would reveal the assembled pieces.	HOLD

5.2.3.1 Evaluation of aesthetic appearance

There are more ways of how a product could express itself to an architect or an end user. The aesthetic appearance section aims to explain ways of how a recycled product could be communicated to a customer without having a text in a specification list. As mentioned in the *Pre-study* it is not decided what type of product that will be made and how it should look like. A conclusion can therefor not be provided from these concepts before a decision is made. Even though this is the case, recommendations could be made based on interviews and research about customer needs in correspondence to aesthetic appearance.

5.2.4 Sub-concept prototype sessions

An iterative way of working took place during the concept generation phase, which required several prototype sessions. Each session had focus on different areas, such as mixture of densities, fibre orientation etc. Testing and notices were made on each prototype, in order to make the evaluation and selection of concepts easier. Below, the different prototype sessions are explained. More detailed information about the prototype sessions can be obtained in appendix E.

- ***Pieces and different geometries in a product***
  Seven prototypes were made with different pieces of different geometries in 20 mm thick 600x600 mm^2 products, which can be obtained in appendix E.1.3. All prototypes used horizontally laminar and fibre structure.

- ***Rods with different densities and thicknesses***
  Twelve prototypes were made at Ecophon in Næstved, Denmark, in the purpose of testing combinations of different densities in combinations with thicknesses, which can be obtained in appendix E.1.4. Another purpose is to research the acoustics of products with vertical laminar structure, which can be read about in the *Pre-study*. Also a different way of adding surface layers were tested. One prototype were earlier made at the design department at Ecophon, Hyllinge, more information can be obtained in appendix E.1.2.

- ***Geometries***
  Different geometries were cut up and tested during different prototype sessions. Some geometries were tested and generated during waterjet cutting study visit in Ronneby which can be obtained under appendix C 4.2. Were geometries were tested in correlation to a cutting technique. Some geometries were cut manually by hand, due to the complexity of the shapes, and can be obtained in appendix D.1.2.

- ***Adding second baseboards*** - Early in the development stage the second baseboard principal were tested at Ecophon in Hyllinge, which can be read more about in appendix E.1.2.

5.2.5 Selection of Sub-concepts

During the concept generating phase, it was determined to divide the layout of a recycled acoustic product into three sub- concepts, which were *assembling*, *composition*, and *aesthetic appearance*. Same approach was practised during the selection phase of these three concepts. This was necessary to do in order to decrease the number of final concepts and prototypes.

As mentioned before, a rough sorting of all the generated sub-concepts was conducted, which can be seen in appendix D. When a final number of sub-concepts were left after the first sorting, they were rated against different features, which were used as criteria. The features and the rating for each sub-concept were based on the *Pre-study*, prototypes, and discussions within the team and employees at Ecophon. A specific sub-concept could receive one up to five points for each criteria, where five points is the best possible value. After discussing the total points for each individual concept, a decision was made.

5.2.5.1 Selecting assembling concepts

It was decided to set up different features in order to decide a final number of *assembling concepts*, see table 17. The features are general and few since the final product concept is still unknown.

Table 17: General features of assembling concepts

Features	Description
Manufacturing	How easy a concept can be implemented into a manufacturing process
Mechanics	How much a concept considers to contribute to mechanical properties
Acoustics	How easy it is to introduce new acoustic possibilities features

The concepts for assembling were evaluated with respect to the features that were set up, and the ones that were evaluated can be seen in table 18 and 19.

Table 18: Assembling concepts that are evaluated

Code	Assembling concept
2A	Jigsaw
4A	Tape surface
5A	Glue surface
6A	Glue pieces
10A	Second board

Table 19: Ranking and decision of final assembling concepts

Assembling concepts					
Selection criteria (1-5)	2A	4A	5A	6A	10A
Manufacturing	2	4	5	3	4
Mechanics	1	4	4	3	5
Acoustics	3	5	5	5	4
Total points	6	13	14	11	13
Result	L	H	K	L	K

L = LOOSE, H = HOLD, K = KEEP

It was decided to put *Tape surface* (4A) on hold, since the technique was not possible to test. However, it is an interesting solution that could be investigated more in detail in the future.

Even though the *Glue pieces* (6A) scored relatively high, it was chosen to exclude it. The reason behind this, is due to the high amount of glue that will be accumulated between all pieces, which is not favorable from a fire safety perspective.

5.2.5.2 Selecting composition concepts

The same principal of using features as criteria was used when selecting the *composition concepts*, which can be seen in table 20.

Table 20: General features of composition concepts

Features	Description
Assembling	How easy the pieces can be assembled into a manufacturing process or combine with assembling concepts
Cutting	Rating in how easy a composition concept is to cut into usable pieces
Acoustics	How easy it is to introduce new acoustic possibilities with the pieces
Mechanics	How the pieces contribute to mechanical properties

As mentioned before, there are a vast number of geometries, sizes, orientations of the composition, and combinations between the pieces. The composition concepts that were evaluated are shown in table 21 and 22.

Table 21: Composition concepts that are evaluated

Code	Composition concept
1C1	Brick formation
1C2	Fish bone
1C3	Tilted rods
1C4	Sprial
1C5	Frame pieces
2C4	Hourglass

Table 22: Ranking and decision of final assembling concepts

Composition concepts						
Selection criteria (1-5)	1C1	1C2	1C3	1C4	1C5	2C4
Assembling	4	3	3	2	3	1
Cutting	5	5	2	5	5	3
Acoustics	5	5	5	5	4	1
Mechanics*	5	5	5	5	5	1
Total points	19	18	15	17	17	5
Result	K	L	L	L	L	L

* Depends on possibility of changing laminar structure
L = LOOSE, H = HOLD, K = KEEP

The only composition concept that was decided to be used for the product concept development phase, was the *Brick formation* (1C1). It was noticed during the prototype session that using different geometries and patterns did not have an impact on the mechanic strength. The parameter that contributed to a stronger piece, was to use vertical laminar structure, which was not possible with *Hourglass* (2C4), which, incidentally, got low points on the other criteria.

5.3 Product concepts

The decision on which sub-concepts that were considered as reasonable solutions, narrowed down the amount of combinations between *assembling-* and *composition* concepts, see table 23. This made it easier and faster when generating ideas for final product concepts, thus more focus could be put on testing and evaluation.

Table 23: Summarizing of selected assembling and composition concepts

Selected Sub-concepts	
Assembling	**Composition**
5A - Glue surface	1C1 - Brick formation
10A - Second baseboard	1C5 - Frame pieces

During the development of products based on the selected *sub-concepts*, different methods were used in order to obtain as good results as possible.

It was noticed that all sub-concepts could be combined with each other and also be built as prototypes at Ecophon, Hyllinge.

In figure 28 the workflow can be obtained, which describes the steps to able to evaluate the different product concepts.

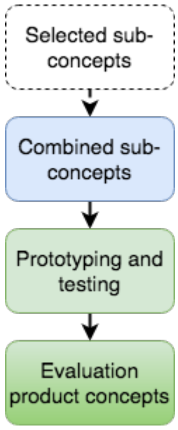

Figure 28: Combined concept workflow

5.3.1 Combined sub-concepts

5A+1C1 *- Glue surface*

Concept where rectangular pieces are connected through using a glued on surface layer on both sides. The rods or rectangular pieces vary in density and dimensions, figure 29.

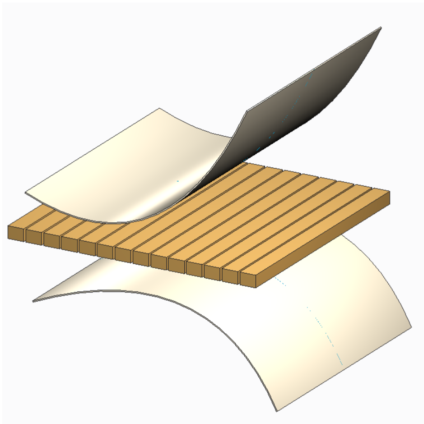

Figure 29: Glue surface layer

5A+10A+1C1 *- Virgin baseboard*

Concept were rectangular pieces are connected through using a glued on surface layer on both sides and a second baseboard on one side, figure 30.

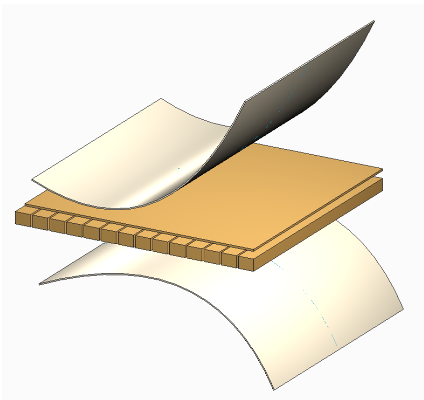

Figure 30: Virgin Baseboard

5A+10A+1C1 *- Sandwich*

Concept were rectangular pieces are connected through using two glued on virgin baseboard which stabilizes the tile, figure 31.

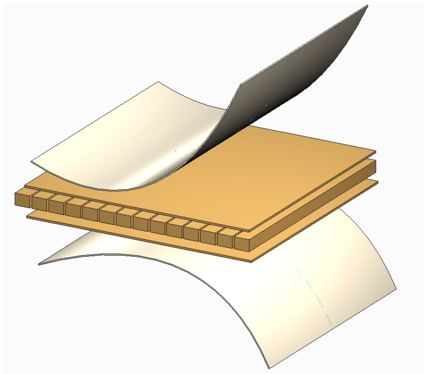

Figure 31: Sandwich

5.3.2 Final prototype Session

The first prototype gave insight in how and where prototypes could be produced. It was decided that the Design Departments at Ecophon, in Hyllinge, was the best place suited to perform the final prototype session. The combined concepts were processed with equal conditions, which was considered important for the evaluation . The prototypes were made with the same, glue, amount of glue, vacuum machine, cutting tools(Band Saw), wool binders(Green Binder), paint on edges, and surface layer(Akutex FT), when producing. The thought were to create a scenario were all tile-prototypes are the same beside the core compositions, see figure 32 and 33.

Figure 32: Final prototypes

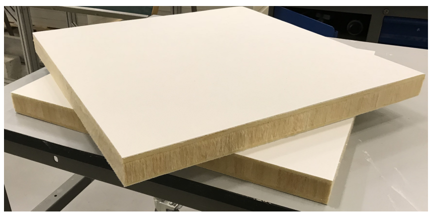

Figure 33: Prototype example

These prototypes were created with higher precision because they were going to be used in an evaluation test performed by Ecophon employees, students, and acoustic ceiling installer. More information about the tests and how they were performed can be obtained in appendix E.

Parameters can still variate within the concepts. To be able to create a reasonable amount of concepts, it is decided to set some parameters. The parameters can be observed in table 24.

Table 24: Fixed and adjustable parameters for prototypes

Parameter	**Unit**	**Value**
Densities rods	kg/m^3	Low, High
Density baseboards	kg/m^3	Low, Medium, High
Tile thickness	mm	40
Horizontal dimensions	mm^2	600x600

It was decided that at least one of each product concept were to be made. The concepts which contains more than one density, the rods with different densities are placed one after another. The concepts can be seen in table 25

Table 25: Prototypes built

Nr.	**Prototypes**	**Compositions**
1	Glue surface 1	Low density in all rods
2	Glue surface 2	Every other rod have low and high density
3	Glue surface 3	Same high density in all rods (shorter rods)
4	Virgin board	Low density baseboard and high density rods
5	Sandwich 1	Thin baseboards enclosing low and high density rods
6	Sandwich 2	Thin baseboards enclosing low density rods
7	Frame 1	High density frame and low density centre

5.3.3 Final product concepts

This project find itself in an early conceptual stage were several decision have to be made by Ecophon in order to select the final target specifications, which depends on product application areas. All the product concepts are considered to be reasonable and can have a broad application possibility. Therefor the concepts will be evaluated and analyzed in *Analysis and discussion* in the next section.

6 Analysis and discussion

In this section the product concepts and the project are analyzed and discussed from different aspects, e.g production and environmental perspective.

6.1 Evaluation of product concepts and prototypes

An evaluation table generated during the *Pre-study* was used to provide information and results of the concepts in correlation with the prototypes made. The evaluation table take various specifications into account, where some are not definable. The table contains a combined evaluation from students, Ecophon employees, and an acoustic ceiling installer. More information about the tests performed can be obtained in appendix E.

Below the evaluation table the different areas are further evaluated in words.

The *Concept Comparison* (CC) stated under the unit column in table 26, compares the three product concepts against each another. This comparison is an estimate, if the product concepts lives up to the specification in question, through scoring one (1), two (2), and three (3). If a CC sore is one (3) then it is estimated that this concepts is better at this specification compared to the others. If a score is used more then once on the same row, the concepts are considered to perform equally in the specification. The scoring are based on the *Pre-study*, *Prototype sessions* and the performed testings.

Table 26: Evaluation of prototypes

Evaluation of product concepts							
Nr.	**Specification**	**Unit**	**Interval**	**Ideal**	**Glue surface**	**Virgin board**	**Sandwich**
1	Product fire class	U	U	U	-	-	-
2	Estimated fire resistance *	CC	-	-	1	2	3
3	Product thickness	mm	U	-	40	40	40
4	Product life time	Years	15-20	20	U	U	U
5	Horizontal dimensions	mm^2	U	U	U	U	U
6	Tolerances *	mm	U	U	U	U	U
7	Recycled material	%	0-100	100	100	<80	<80
8	Ease of cutting manually *	CC	-	-	1	2	3
9	Able to cut manually *	Yes/No	No-Yes	Yes	Yes	Yes	Yes
10	Mixture of density	kg/m^3	L-H	U	L-M or M-H	L, M, H	L, M, H
11	Binders	GB/PF	U	U	-	-	-
12	Acoustic properties *	CC	-	-	3	2	2
13	Mechanical properties *	CC	-	-	1	2	3
14	Ease of manufacturing	CC	-	-	3	2	1

U = Undefined, L = low, M = medium, H = high

CC = Concept Comparison, Rated 1, 2 or 3

* Depends on density mixture

The previous table gives an indication of product specifications but not how the product concepts lives up to the customer needs. Through a discussion within the group, an evaluation is done if the different customer need can be achieved (A) with these kind of product concepts or if it is uncertain (U). The evaluation is based on the tests conducted throughout the project and can be seen in table 27. The reason for conducting a unified evaluation for the different product concepts in customer needs is because they are considered to fulfill the same needs, due to their similarities. Aspects concerning the customer needs are discussed and analyzed further on.

Table 27: The product concepts correlation to customer needs

Nr	Customer Needs	Achieved or unknown
1	The product can be cut manually	A
2	The product is not to fragile to handle	A
3	Similar properties as existing products	A
4	The product is robust and durable	A
5	The product is easy to install	A
6	The product is easy to demount	A
7	The quality of the product is predictable	U
8	The product has low tolerances	U
9	The product is well packaged	A
10	The product has good acoustic properties	A
11	The product comes in several designs	A
12	The product is attractive to the market	U
13	The product is adapted to laws and regulations	U
14	The product can cover cables, pipes, etc	A
15	The product is adaptable for integrated installations	A
16	The product looks good in general environments	A
17	The product is functional with acoustic accessories	U
18	The product is recycled	A
19	The product have a motivated and reasonable price	U

A = Achieved

U = Unknown

6.1.1 Fire properties

Specification table nr: 1 & 2

The fire class is undefined, because what exact product area the product concept will become are not defined. The reason for estimating that *Virgin board* and *Sandwich* have higher fire resistance, is because their second baseboards could act as a fire barrier.

A higher amount and type of glue would potentially be needed in the generated product concepts. Because glue have an impact on the fire properties of a product, this is an area that needs to be researched further.

6.1.2 Dimensions

Specification table nr: 3, 5 & 6

The prototypes that were built had same dimensions in order to obtain more reasonable results. However, the product application area are not decided which makes it impossible to determine the ideal dimensions for the product concepts.

All prototypes and concepts contains rectangular shaped pieces that have a vertical laminar structure. Turning the laminar structure vertically, instead of keeping the original horizontal direction, can have several benefits. One advantage is that the horizontal width of the cut pieces becomes the height of the product concepts, as noted during the *Pre-study*. In turn, the width of the pieces depends on what product concept it should be part of.

The optimal length of the pieces are not yet determined and the majority of the prototypes were containing rods with the same length as the tile itself. Different sizes of the pieces can have different benefits. Longer pieces creates fewer parts to handle during the manufacturing process. On the other hand, shorter and smaller pieces likely provides higher recycling grade from a recovered product. The *Glue surface 3* prototype contained shorter pieces with a length of 180 mm. It was reasoned that a recovered tile with the original dimension of $\leq 600x600\ mm^2$, probably needs to be trimmed along the edges, see figure 34. Trimming it would potentially remove damages or unwanted profiles and surface layer, which would result in a larger piece of pure glass wool and binder. To gain a reasonable amount of whole pieces from the trimmed recovered tile, three pieces of 180 mm were tested, which also resulted in an usable product concept.

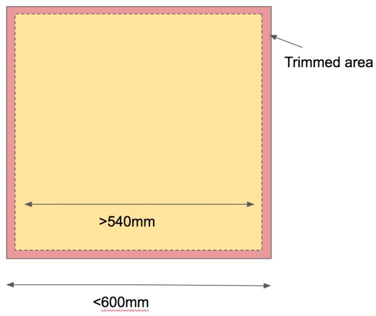

Figure 34: Recovered tile

A solution to be able to obtain as few pieces without only crating short pieces is to set a small number of standard lengths that can be used for different purposes. The different lengths could optimized over different recovered tile dimensions to get the most pieces out of it.

6.1.3 Recycled material in product concepts

Specification table nr: 7

The grade of recycled material might vary between the product concepts due to the second baseboard that is used for *Virgin board* and *Sandwich*. It might be possible to use recovered acoustic tiles as second baseboards but this will put demands in their quality, which may result in using non-recycled baseboards. The *Glue surface* is potentially capable of using 100 % recycled material, if the added surface layer is neglected.

6.1.4 Manual cutting

Specification table nr: 8 & 9

The product concepts turned out to be possible to cut manually, which is based on the installer test and evaluation, see appendix E. The installer indicated that the *Virgin board* and *Sandwich* prototypes were easier to cut thanks to the second baseboard(s). The second baseboards helped to steer the knife and made it easier to cut in a straight line.

6.1.5 Densities and binders

Specification table nr: 10 & 11

The prototypes were made with GB binder, which does not prevent the product concept from consisting of PF binder. What binders the product concepts consist of, is not decided and it could be decided that it is acceptable to mix densities. When testing combinations of different densities during the *Pre-study* and prototype sessions it was concluded that *Glue surface* product concept should preferably consist of densities that are in close range of each other, like *low* and *medium*, or *medium* and *high*. Otherwise weak areas can occur and harm the product in correlation with the differences in mass. This does not compile to *Virgin board* and *Sandwich* were it is considered possible to mix all densities thanks to the second baseboards. It should be noted that all product concepts which contains mixed densities always shuffle the densities equally throughout the product to obtain symmetry.

6.1.6 Acoustic properties

Specification table nr: 12

All of the generated product concepts have rectangular pieces with a vertical laminar structure which proved to be beneficial from an acoustic perspective. The *Glue surface* concept is almost the same as the original products where the only difference is the build up of pieces with a vertical laminar structure. The acoustical test that took place was performed on specimens of this concept, which showed to give low pressure resistance, which indicates that acoustic properties were improved, regardless mixture of density.

If the acoustic simulations done in the *Pre-study* are considered reliable they indicate that the product concepts can reach a classification A, based on the alpha (α). This can be concluded through using the figur X, classification table, presented in *Theory under Basic acoustics*.

6.1.7 Mechanical properties

Specification table nr: 13

The mechanical properties are considered to be difficult to improve since Ecophon's existing products usually have better mechanical strength then they need to have. However, the performed tests indicated that *Virgin board* and *Sandwich* have better mechanical properties then *Glue surface*. *Glue surface's* strength could be increased if a different surface layer is used, which will require further researches.

The parameters that was noticed and have an influence on the mechanical strength are the following:

- *Laminar structure of the pieces* - The mechanical strength is better if the laminar structure of the pieces is orientated vertically.

- *Glue* - The glue used when manufacturing a product, have a substantional effect on the mechanical properties.

- *Product concept* - The different concepts provides different mechanical properties.

- *Surface layer* - Stronger and thicker surface layer could provide better mechanical properties.

- *Densites* - Different densities affects the mechanical properties of the product concepts

Mechanical properties correlates to what densities the product contains, and the aim of the product concepts, is to provide the possibility to mix and use any densities. Tests and evaluations done, indicates that all densities can be included in all product concepts. The fact that the prototypes made at *Design*, Ecophon in Hyllinge, used a different type of glue and manufacturing process then the production lines at Ecophon, indicates that research and tests need to be done to ensure the test results. More information about densities can be obtained under section paragraph 4.2.1.5.

As described in the *Pre-study* an early idea were established that no glue would be needed between the pieces. Non of the concepts and the created prototypes are using glue between the pieces, only between the surface layers and the second baseboards, to create stability and durability in the product. The stability obtained is estimated to be efficient to provide an acceptable product.

6.1.8 Ease of manufacturing

Specification table nr: 14

During the *Pre-study* the project was focused on cutting techniques when investigating manufacturing in order to obtain usable glass wool pieces. This will not be different regardless of product concept. On the other hand, the assembling process will vary between the product concepts. The *Sandwich* concept is a build on of *Virgin board* which in turn is an extension of *Glue surface*. This might correspond to added manufacturing steps, depended on the product concept that is going to be assembled.

Read more about the potential implementation of a new manufacturing process in section 4.3.

6.1.9 Visuals and aesthetics

Specification table nr: -

One aspect the evaluation table do not take into consideration is the visual test results obtained during the tests and evaluations. The results were not included for various reasons, these were:

- The test were conducted to provide information if the prototypes were well performed

- The results can give false indications and effect the opinion of the product concept, which is stated in *Ulrich & Eppinger's* theories.

The results can be recovered from appendix E, and shows the employees evaluation corresponding to a *Master SQ* reference.

6.2 Production of recycled product concepts

Introducing acoustic products based on recycled glass wool tiles will require a new design of the manufacturing process. All of the combined product concepts that were generated, tested, and evaluated, contain elements which would put new demands on the manufacturing techniques. A detailed plan of how the manufacturing process will be designed is not possible to do, due to the scope and time limitation of the project, and the usage area for the recycled products is not yet decided. However, it is possible to do an analyze of the generated product concepts and what steps in a manufacturing process they require.

One of the researched areas was to observe the different steps that exist in the manufacturing process at Ecophon, Hyllinge. This gave insight on how the manufacturing works today while it creates a good starting point to build on. Some of the processes for a recycled product share the same manufacturing steps that are used for Ecophon's current products. These steps were defined in the *Internal study* and can be seen in figure 35. Although, these steps may require different techniques for manufacturing of recycled acoustic glass wool products.

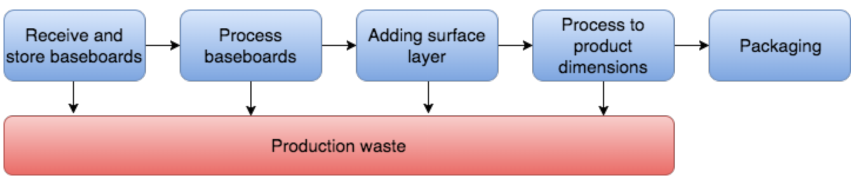

Figure 35: Current manufacturing steps

The new areas that emerged and have an influence on the production of recycled acoustic tiles, were researched and are described below and will later be analyzed:

- *Recovered material* - Receiving, handling, and sorting of the recovered waste material.

- *Sorting of material* - Sorting recovered material to create usable production batches.

- *Treatment of recovered material* - Treating the recovered materials or products to obtain "only" usable materials (could also be a part of the sorting process).

- *Process material into usable pieces* - Cut or disassemble the recovered material.

- *Potential storage of recovered materials* - Storing the recovered materials can be needed throughout different steps during the process of making a recycled product. This could either be e.g when receiving the material or processed pieces that are going to be used for production.

- *Use pieces in production* - Assembling processed pieces from recovered materials in the production.

An example of how a production workflow could look like, can be seen in figure 36.

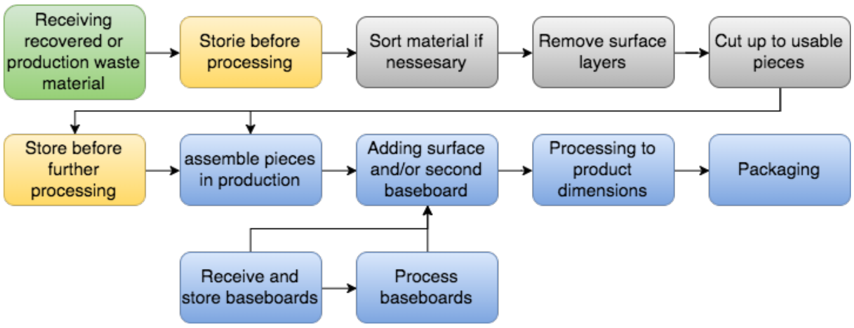

Figure 36: Potential production process

The whole project purpose is to research the viability of a recycled acoustic product to increase Ecophon's way of establishing a circular economy and become more sustainable. If a recycled product becomes viable depends on many variables. Different areas are analyzed with the purpose to find out what can increase the likability of a recycled product of becoming viable. How the different steps, within the boxes in the potential workflow, will be performed in detail is at this stage hard to answer.

6.2.1 Receiving recovered material

The quality of the acoustic tile that is recovered back to Ecophon must be specified, in order to produce a recycled acoustic product. The tiles' condition will vary in quality, and the decision of what condition the tiles must have, depends on the concept of the product and the processing of it. This means that a well considered manufacturing process can lower the requirements for the quality of the recovered material, which increases the ability to recycle acoustic tiles that have been in use before. Preparations of the material might be needed before it can be processed e.g the sorting of it which is one statement according to Ghisellini et al. (2017).

The areas that must be considered when investigating the recovered pieces are described as following:

- *Product concept* - What quality must the recovered tiles have in order to be a component for a new acoustic product.

- *Manufacturing* - What requirements does the manufacturing put on the recovered material.

- *Preparation of recovered material* - How should the recovered tiles be sorted, and do they need a treatment before it can be processed into to a new product.

The three mentioned areas above put requirements on the quality of the recovered material, but it might the opposite way. Which means that the tiles that are recovered controls the *Product concept*, *Manufacturing*, and *Preparation of the recovered material.* This approach may imply that the condition of the recovered material can have a lower quality, which is beneficial from a recycling perspective. However, this will put more pressure on the development of a product and the design of the manufacturing process.

It is important for Ecophon to know and make assure of the quality of the product produced from recovered material. This could also put higher demands on the customers way of handling that returns. By studying the concepts and prototypes generated, estimations can be made about what conditions and qualities the recovered material should have when recovered. It is likely that the received material must go through one or more sorting processes to be able to obtain batches of material with known properties. Otherwise there is a risk that the product qualities cannot be assured. There are multiple ways of conducting sorting processes and the options should be evaluated in detail.

When producing the prototypes of the concepts, new grinded baseboards were used to cut up pieces from. If similar quality wished to be obtained, the recovered waste material or production waste material should have an intact fibre structure/core material. This means that the material would not have been exposed to bending/buckling or been crushing force which destroys the glass fibres within the products. It is also preferable that the material do not contain or have absorbed to much moisture. Damages along the edges of the recovered material or holes in tile which can occur from e.g a ventilation system or a sprinkler, is acceptable. This is because it does not considered to be a damage that compromises the usage of the material in a manufacturing process of the recovered material. Such damages is considered to be possible to remove or fix during the manufacturing process.

6.2.2 Production waste

The discarded volume of material during the processing of Ecophon's products is today an extensive cost and environmental impact. The defects can occur in different manufacturing steps, which means that the appearance of the discarded material varies. In general, only a small area of a single tile that is considered as waste, have one or more defects. This means that the majority of a discarded tile have the potential to be recovered and used in a process, where the final products follow the same concept as a product based on recovered tiles that have been in use before.

A product based on production waste will not follow the same life cycle as a product that have been in use before. The *Reuse economy* way of thinking presented by *Ellen Macarthur foundation* does not not take production waste into consideration, which can be seen in figure 37. Therefore a gap analysis model is designed to give a picture on how the production waste can be reused in order to produce a new product, which can be seen in figure 38.

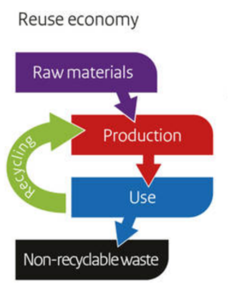

Figure 37: *Reuse economy* model

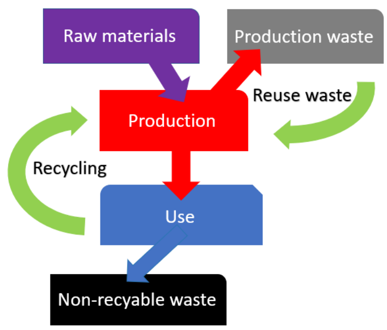

Figure 38: Modified *Reused economy*

Although the project's main focus is not on the use of production waste material, it is still an interesting area to investigate. One of the reasons is that the condition of the discarded material is predictable and known to Ecophon. The production waste might be the first step to put in trial in order to produce acoustic products, and thereafter evaluate the whole process.

6.2.3 Sorting material

The sorting process could appear during several step during the manufacturing. After researching this area in the *Pre-study* it was concluded that there are several techniques and companies that suited to solve the sorting of e.g recovered materials. It is to early to decide an optimal sorting technique for the different steps.

6.2.3.1 Sorting before material reaches Ecophon

Who makes the sorting and to what level is still to decide. It is reasonable that the demolition or ceiling installers dismounting the material and products, should do a coarse sorting at the construction site. Potentially new demands of what condition the material need to have when returning to Ecophon must be established. Based on interviews with installers some conclusions can be drawn. Installers do not consider it to be difficult to dismantle a ceiling without damaging the tiles substantially and to store them in piles. Therefor, recovering glass wool material in acceptable conditions seems possible.

The damaged materials could potentially be returned in the same large plastic bags that are used for returning waste material today. However, the undamaged and larger intact pieces could perhaps use a better way of being recovered, in order to preserve the quality. This could be done, by delivering the tiles on some sort of pallet or storage box that protects their mechanical properties and from moisture, see figure 39.

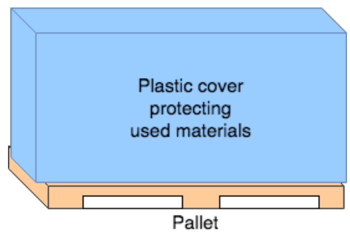

Figure 39: Covered pallet example

6.2.4 Removing surface layer

During the *Pre-study* one technique were tested for removing surface layers. The tests were conducted at Isover in Lübz, Germany and it can be concluded that horizontal band saw cutting is a functional technique for removing surface layers. Some of the cutting concepts which can be obtained in Appendix C.3, are also suitable for removing surface layers and are marked with H in column wide cut. It is not certain that band saw is the best technique suited for this task.

If another technique, could perform the same result as band saw but with decreased waste material. It could be seen as a better technique, given that the quality of the cut is well acceptable.

6.2.5 Processing to usable pieces

During the project, it was chosen to investigate the water jet cutting technique more in detail. The reason behind this, was the unknown design of the cut up pieces, where this technique have the potential to allow relative complex geometries. However, the design of all the final product concepts ended up of only using rectangular shaped pieces, which can be obtained of using more simple techniques, such as circular and band sawing. Today Ecophon are using circular and band sawing in their manufacturing process, and they also have long experience in these techniques. This can be beneficial if one of them or both, are going to be used in a future processing of recycled products.

The amount of waste during the cutting operation depends on the size of the cutting tool, and during the pre-study it was noted that water jet cutting showed the best results. This may not be of importance for the manufacturing of Ecophon's current production, where the number of cuts are few. However, the recycled products based on bits and pieces will result in a significant increase of cuts, which will lead to a higher amount of produced waste. In order to give a picture of how much waste that will be accumulated during the cutting operation, it chosen set up a scenario.

Scenario

An endless long baseboard are used with the width of 600 mm and a thickness of 40 mm, like in figure 40 below. What length of the baseboard is needed and how much potential recovered tiles have become waste material, if 10 000 recycled glue surface products with the dimensions 600x600x40 mm are going to be produced, can be seen in table 28.

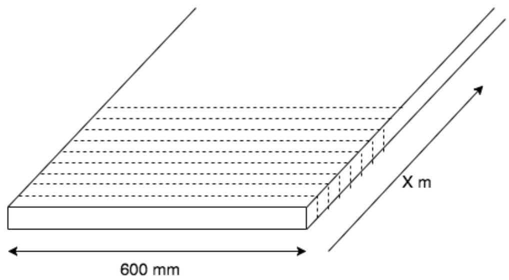

Figure 40: Manufacturing technique scenario

Table 28: Waste produced due to different cutting techniques

Produced waste expressed in baseboard length (Based on 10 000 tiles, 600x600x40 mm)				
Cutting tool technique	Water jet cut (ref)	Circular saw	Band saw	End mill
Cutting tool size (mm)	0.5	2	1.5	3
Total amount of waste/ Length of baseboard (m)	75 (125 tiles)	300 (500 tiles)	225 (375 tiles)	450 (750 tiles)
Length (x) needed for 1000 tiles (m)	6 075	6 300	6 225	6 450
Waste difference (%)	100	400	300	600

The scenario is used as an indication to show what impact the cutting technique will have on production waste. In the real case, the material that will be processed into pieces will consist of recovered tiles with various conditions and dimensions. Further researches must be done, in order to optimize the cutting, which depends on the recovered tiles and the design of the pieces.

As the scenario indicates, waterjet cutting technique could be preferable due to the potential low waste it produces. However it have to be considered that the pieces may need to be dried after cutting because of the water exposure.

6.2.6 Store pieces for manufacturing

Depending on how the production process is set up, it is possible that the pieces would need to be stored before, or between different production steps, see figure 41 for example of storage.

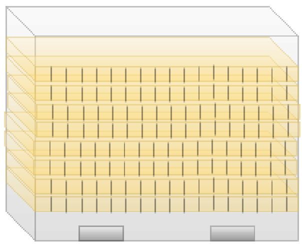

Figure 41: Storing pieces

There is one scenario were the recovered material could be sorted and refined into usable pieces directly when received. When the pieces are processed, it could be argued that they should be sorted and stored in order to create batches with usable pieces for production. This is however more of a logistic problem to be solved.

6.2.7 Use pieces in production

It is decided that *Glue surface*, *Virgin board*, and *Sandwich* are going to use rectangular pieces with a vertical laminar structure. This will put certain demands on the manufacturing process. During the project it has not been possible to investigate the techniques within this area more deeply. However, the conceptual performance of this manufacturing step can be analyzed.

From a mass production perspective, it is concluded that the best way of manufacturing the recycled acoustic products, is to create a continuously long baseboard made out of rectangular pieces, see figure 42. The continuous baseboard will later be assembled by using a surface layer on both sides, and thin second baseboards, depending on the product concept. When the baseboard made out of pieces is assembled, it will processed into demanded product dimensions.

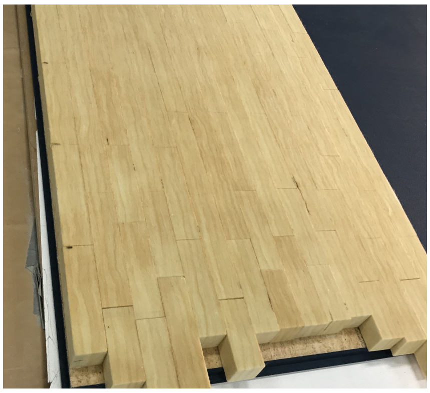

Figure 42: Pieces assembled to baseboard

One of the difficulties of using rectangular pieces with a vertical laminar structure, and combining various thicknesses of the recovered tiles, is to orient them in right way.

6.2.8 Last steps in production

The last steps in the new production process are summarized here. These steps are thought to be similar to the production process of an acoustic product today, which can be obtained in section 4.2.2. Depending on what product concept that is going to be manufactured, additional steps could be needed when adding second baseboards. If a product concept that uses thinner second baseboards, there are two options based on the *Pre-study*:

- ***Process received baseboards*** - Process thicker baseboards received from supplier to wanted thickness. The process could be, as researched during the *Pre-study* through, horizontal sawing method.

- ***Customized second baseboards*** - New dimensions of delivered baseboards are requested from supplier, which are optimized for product concept dimensions.

The adding of second baseboard for either the sandwich or second baseboard concepts could make the production process longer and perhaps more difficult.

6.2.9 Potential production process

To increase understanding of how the process could look, schematic figures have been drawn below and explanations follows. Note that this is only conceptual thoughts.

Sorting
In figure 43, the recovered products (1) need to be moved to a production line. In this case a robotic arm (2) that potentially could locate the tiles and lift them onto the line. This happens before it goes through a device (3) that identifies the products properties and dimensions. The e.g pneumatic arms (4) pushes the recovered recovered tiles into different lines or pallets (5) depending on decision for sorting. For example, the tiles can be sorted after densities, binders, thicknesses, whole, or damaged tiles.

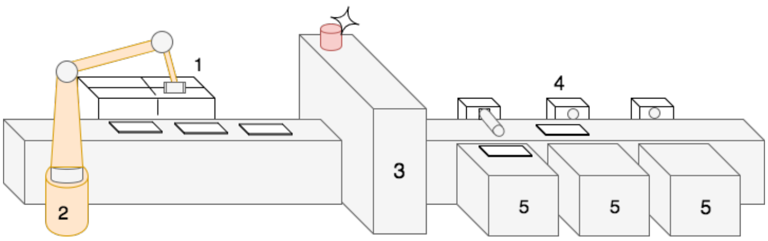

Figure 43: Sorting recovered material

Processing

The already sorted tiles are added to the line (6), in figure 44 below. After the surface layer is removed with a horizontal sawing technique (7). The tiles without surface layers enters a cutting process that trims the unwanted edges and create usable pieces (8). The waste material produce is also removed during the process. Somewhere during the manufacturing process, the pieces need to be oriented with a vertical laminate direction (9). Afterwards, the pieces are either stored like in figure 41 or goes on to the next step in production (11), figure 46.

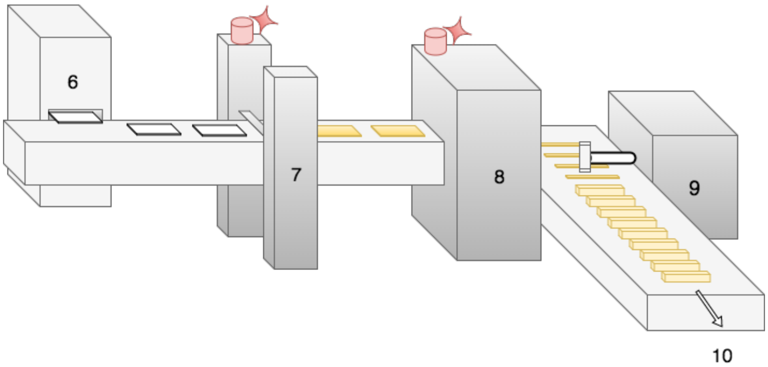

Figure 44: Process recovered material

After this the pieces could potentially be stored before being assembled together. The storing could be of rods/pieces with similar dimensions and densities (and perhaps binders), which is illustrated in figure 45.

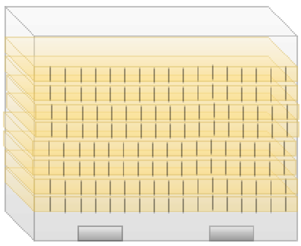

Figure 45: Storing pieces

Assembling
If the pieces is assembled together in the same sequence and not stored in between they could perhaps directly be stacked together in a continuously baseboard after cutting (11, 12&13), see figure 46. Otherwise the pieces could be be assembled from batches like the one in figure 45 above.

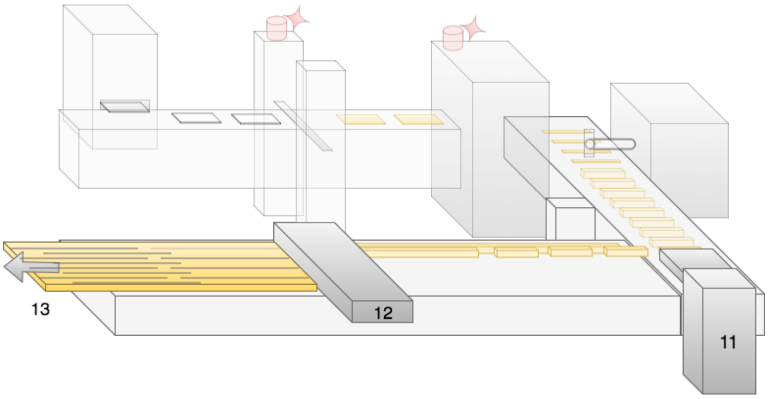

Figure 46: Pieces assembled to baseboard

If the product concept produced would be a virgin board concept, the final steps could look like the following in figure 47. After the pieces have been stacked they go on to potentially be coated with glued (14a) before a already processed second baseboard is added (15). It could e.g be done with a robotic arm. After the second baseboard is added a another glue coating could be added (14b) to be able to add the surface layer (16). The product then goes through a drying process in a heated area (17). Note that the surface facing down in the production line also would need some sort of surface layer after step 17.

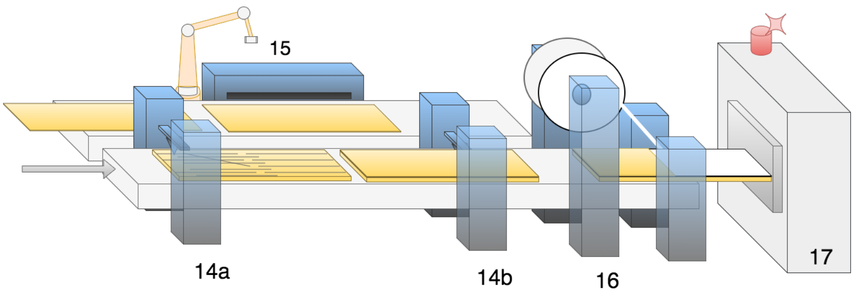

Figure 47: Pieces assembled to baseboard

6.3 Market acceptance

There is an unknowns factor in how the market and customers would accept a recycled product of this kind, mainly because there is no similar product on the market today. As described in the *Pre-study*, there are some features that is not needed for some of Ecophon's existing products. These features could be mechanical and fire properties with a higher class then is needed. This makes it hard to evaluate where a recycled product should place it self within Ecophon's assortment. If a recycled product have worse properties than the average Ecophon products, it could perhaps be considers as a lower quality product even though it still is within the frame of certifications and regulations.

The product concepts that were generated had pieces with a vertical laminar structure, which proved to increase the acoustical properties. This answers to the *Up-cycling* definition where the purpose is to add a value to the recycled product. From this points of view, the increased acoustical property might be a leverage which in turn encourage the market to buy a product of this kind.

Interviews with different architects, indicated that the price, is the most crucial feature of an acoustic product. If it turns out to be more expensive to buy a recycled acoustic product, it might result in an unattractive product to the market. However, in the *Background* to the project, it was mentioned that by year 2020 all non-hazardous construction and demolition waste will be recycled in EU. This is one of plenty examples that shows that the building market have to adapt them self in order to be more sustainable. These kind of directives from governments will most likely continue to increase, which might result that the building sector have to buy a recycled building material, whether it is more or less expensive.

The customer needs generated in the *Pre-study* can also be used, without implementing weighted value for the different needs, to indicate and evaluate market acceptance. It is difficult to give an exact appreciation if all the needs are obtained due to conceptual stage and that the final product are yet to be determined. If the conducted tests are to be used for evaluation ther

6.4 Circular economy

A way implement a CE is to, according to *Journal of Cleaner Production*, loop materials back in to a economic system, which have been one of the goals with this project. The combined concepts provides a solution which could lower material costs and prevent usable processed or used products or material to become landfill, which are considered to be the last stop in the reuse or linear economy. Even though landfill material can fulfill a purpose, it is reasoned that there the landfill material have become waste afterwords. This because it probably can not be looped back in to a economic system in a viable sustainable way. Production for new or recycled products will undoubtedly always result in some sort of waste material but could be reduced in a big way if some of the combined concepts were to be implemented. Given that a sustainable and functional system of collecting, receiving, distributing and manufacturing the products are generated.

According to Ghisellini et al. (2017), different statements were set up in order to design a product that can be recycled more easy. The statements that were most relevant to the generated product concepts are discussed and evaluated below. Even though the focus area of the project is on recycling acoustic products that have not been recycled before, it is still important to have these statements in mind in order to reach a circular economy.

Minimize the number of parts of a product will make it easier to recycle it. However, all of the generated product concepts are based on the idea of having recycled pieces from a glass wool tile that have been in use before. The number of parts will depend on the sizes of the obtained rectangular shaped pieces. The concept of a *Virgin baseboard* and a *Sandwich* can be seen as an extension of the *Glue surface*, where the glued on baseboard is an additional part. In this regard, it is not desirable to use a glued on baseboard, if this is a big problem, is today too early to say.

Avoiding unnecessary combinations of different materials is not considered to be an issue if speaking of the material it self, since it will only consist of glass wool and a binder. But the glass wool that can be found in a recycled acoustic tile will have various densities and binders. Early in the project, it was decided not combine the phenolic binder (PF) and the green binder (GB). This will put certain demands on the sorting of the recovered tiles, where the binder substance can vary. However, the combination of different densities is today an interesting thought, and if it turns out to be successfully, it will also require a system of sorting the material.

Ensuring that the disassembly can be made with conventional tools can encourage people to recycle a product in a more sustainable way. The generated product concepts are only assembled by using a surface layer or a baseboard, which keeps the glass wool pieces together. Today at Ecophon, there is no technique of removing the surface layer of the recovered glass wool tiles, which is desired in order to produce a recycled acoustic product.

6.4.1 Evaluation of environmental impact

In this section a coarse evaluation of what impact an implementation of the product concept could mean for Ecophon and the environment. A comparison between today's situation and after product concept implementation is done with a gap analysis. This will be done through using the hierarchy of Reduce, Reuse & Recycle theory mentioned in the *Theory* section. Note, that there are still a lot of parameters that are unknown and therefore this calculation is only for appreciation of what factors that can be affected.

There are already precautions being done to increase prevention and reduction of production waste as well as recycling. The comparison done here, is only for how one of the new production concepts can affect the current situation.

Because today's energy consumption is not researched or how new manufacturing techniques will affect it, this is not taken into consideration.

6.4.1.1 Today's situation

Ecophon have a production waste volume of 15 % when they produce their current products. Today 100 % of this volume of production waste goes to landfill. The idea of using production waste material in order to make acoustic products, prevents parts of the waste to become landfill material. The parameters that are considered are listed below:

$$\begin{cases} T_p = \text{Total Ecophon production today} \\ \sigma_p = \text{Fraction of the production waste today} = 0.15\ (15\%) \\ W_p = \text{Production waste today} \\ W_r = \text{Recovered waste today} \end{cases}$$

$$W_p = \sigma_p T_p = 0.15 T_p \tag{1}$$

Today there are both production and recovered waste material that goes to landfill, as can be seen in figure 48, and are both costly economically and for the environment

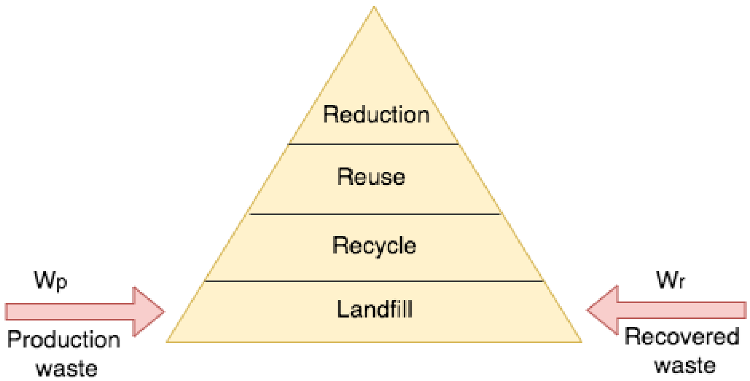

Figure 48: RRR today

6.4.1.2 After implementation of product concepts:

Production waste

It is not possible to determine the fraction of production waste that can be used for a new product. It is known that there is a large amount of usable waste material, but not the exact correlation to the 15 % production waste. Therefore it is decided to express the proportion of production waste that can be used in a new product as ε_P.

If a recycling process is implemented, there will be a certain amount of waste accumulated during the new manufacturing. The proportion of waste that will be produced in the new recycling process, cannot be determined, and is therefore expressed as λ. All parameters that are considered when analyzing the production waste are listed below:

$$\begin{cases} T_p = \text{Total Ecophon production today} \\ \sigma_p = \text{Waste in today's production} = 0.15 \ (15\%) \\ \varepsilon_p = \text{Fraction of usable waste (unknown), where, } 0 \leq \varepsilon_P \leq 1 \\ \lambda = \text{Waste in recycling production (unknown) where, } 0 \leq \lambda \leq 1 \\ U_p = \text{Usable waste on total production} \\ W_{pd} = \text{Production waste (decreased)} \end{cases}$$

The volume of production waste that can be prevented by implementing a recycling process can be seen in equation (2).

$$U_p = \sigma_p \varepsilon_p \lambda T_p = 0.15 \varepsilon_p \lambda T_p \tag{2}$$

When parts of the production waste is prevented and can be used for acoustic products, there will be a decrease of landfill material, which is obtained in equation (3), by combining equation (1) and (2).

$$W_{pd} = \sigma_p T_p - U_p = 0.15 T_p - 0.15 \varepsilon_P \lambda T_p = 0.15 T_p (1 - \varepsilon_p \lambda) \tag{3}$$

Recovered material from market

If the product concepts are implemented there are many parameters that can change. If a better way of returning the material would be established, more recovered waste could increase, how much is hard to say. When looking into the recovery of gypsum from C&DW, which is mentioned in the *Pre-study*, it is indicated that about 15% out of the total market waste can be recovered. It is estimated that at least the same amount of all acoustic product on the Swedish market could be returned, since they are easier to handle compared to gypsum.

How much of the recovered material that is usable to be recycled into a new product is unknown, and depends on the demands being put on the dismounting, and the returning and manufacturing process.

The parameters that are considered when analyzing the production of recovered material from the market, are listed below:

$$\begin{cases} V_r = \text{Recovered waste material today} \\ \varepsilon_r = \text{Fraction of } V_r \text{ usable for recycling, where, } 0 \leq \varepsilon_r \leq 1 \\ \lambda = \text{Waste in recycling production (unknown), where, } 0 \leq \lambda \leq 1 \\ U_r = \text{Usable waste on total volume of recovered material} \\ W_{rd} = \text{Waste, based on recovered material (Decreased)} \end{cases}$$

The proportion of recovered material that is used in a recycled product can be obtained in equation (4). This correlates to the recycling definition, where the waste material is used into a new product.

$$U_r = \varepsilon_r \lambda V_r \tag{4}$$

The amount of the recovered material that is left is put into landfill and can be seen in equation (5).

$$W_{rd} = V_r - U_r = V_r - \varepsilon_r \lambda V_r = V_r(1 - \varepsilon_r \lambda) \quad (5)$$

If the parameters are introduced in to the RRR-pyramid, it could look as in figure 49.

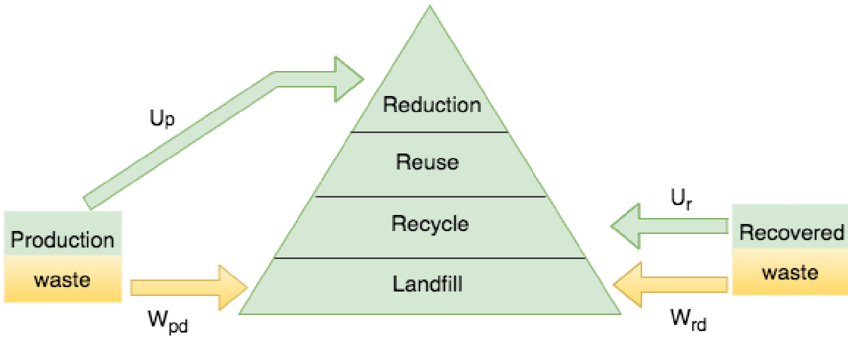

Figure 49: RRR After implementation of product concepts

Now, some of the recovered material can be considered to have become recycled material and a higher level of reduction and prevention of production waste have been obtained.

To be able to prevent or recycle as much waste material as possible, will require knowledge about what parameters that have an impact and how they can be improved.

The production waste generated in the recycling process (λ), depends on the design of the manufacturing and the products that will be produced. This is also the case for Ecophon's current production, with the exception that the design of their products are already made.

When looking into the recycling of the recovered material from the market, it is concluded that the quality of the material has the biggest impact on the capability of recycling it. If it turns out to be successful to recycle the material, this might increase the will for Ecophon to ensure its quality and to retrieve it back. This also means that the customers who have used Ecophon's products, need to have a purpose of returning it back into the recycling process.

6.5 Discussing thesis

Here a discussion of the project and process are made. The purpose is to explain different methods and phases during the project that have been used and how they were conducted. The point is to provide insight for the reader and ease an evaluation of the work that have been done.

There are several sources of information used during this project. Due to the amount of sources and information that have been processed, it possible that important facts and there through results have been lost in the process. Some of the theories have perhaps not been used as they are intended and own evaluation methods have evolved during the project. If these evaluations are trustworthy can therefore be questioned.

As can be seen in the literature study there are more then one method to utilize when it comes to product development. Some of the methods tend to explain more of a general guidelines for development processes, like *Ulrich & Eppinger* and others more to a specific areas like the *CRC 392* method. This thesis looked to guidance in known product development theories. Both *Ulrich & Eppinger* and *David G. Ullman* theories about the work-flow of a development project have been used as inspiration. *Environmentally-Friendly Product Development* were more used as an additional inspiration source. It is hard to say which of the methods are best suited for this project and therefore also their relevance. Overall it can be said that the different development theories have lots in common and therefor it can be reasoned that they work well in combination and as a compliment to each other. This is also a reason for this project to generate its own ways of interpreting and use these theories just as a tool, and not use every recommendation within.

During the project, there have been plenty of areas to investigate. There have been moments when researches have focused in areas that may not have been of the highest priority. It can be argued that the project should have delimits it self earlier, in order to receive more qualitative data. Since the project have looked into several areas, this report can be seen as a pre-study before making a decision.

It can be argued if the concept development and evaluation is done correctly. As mentioned, there are endless of geometrical combinations and opportunities to be generated, and the selection of concepts that are presented is relatively small. The reason behind this, is to make it more understandable for the reader and easier for researches to choose concepts. The concept development phase was an iterative process and lots of ideas were generated during discussions and conducted physical tests, and were not always properly noted. This might have resulted that concepts have been lost and forgotten in the process. This questions the relevance and liability in the product concepts chosen and generated.

Due to the stage which this project finds itself, there are little information and specifications that are certain or stated. The evaluation sections are therefor mostly done through discussions within the group and with specialists. The choices are some times hard to explain because they are made in correlation to observations and test done physically.

How the implementation of product concept will improve prevention or reduction, and recycling when it comes to production waste is unknown. Though, the evaluation of environmental impact indicates the potential of this project. To be sure, more exact numbers must be established and researched, which have been difficult due to the early stage this project find itself in.

Lots of time have been spent on making prototypes, conducting tests and performing study visits. Information were gathered during these sessions and the rapport were some times inadvertently under prioritized. This might have done that information that were received as feelings and intuitions some times can have been hard to recreate and note in the report.

More elaborate interviews with both Ecophon employees, architects, and installers and perhaps a broader and more correct evaluation could have been done. The time frame in which this thesis is done the amount of participants seemed reasonable.

7 Validation

Here a validation of the product concepts will be made in correlation to the research question and problem description, stated in the introduction.

Research question: - *How can used acoustic tiles be recycled or up-cycled into a new product and become viable?.*

From the *Analysis and discussion* it is understood that that implementation of one or more of the suggested product concepts, *Glue surface, Virgin board* or *Sandwich*, is preferable and achievable.

The product concepts can be considered to have been up-cycled in different aspects depending on product concepts. The acoustic tests indicates that the product concepts have the ability to obtain better properties than products with corresponding densities and original laminar structure. The mechanics can also be considered to be improved. However, both these features depend heavily on combination of densities and the different sizes of the pieces. It is evaluated that it can be easier to obtain good mechanical properties with *Sandwich Virgin board*, but consequently get worse acoustic properties, due to the added baseboards with original laminar structure.

It is also considered that a recycled product like the ones generated, can become viable, given that the unknown parameters also prove themselves to be achievable. If a product becomes viable or not, correlates to the customer needs and if they are achieved or not. Some of the customer needs that were evaluated in table 27 in subsection 6.1, were not possible to validate. Some of these needs are constraints, meaning that they must be fulfilled in order to be attractive to the customers.

The product concepts must be tested e.g for fire, in order to understand how well they meet laws and regulations. This will be of importance when deciding the usage area of the products, where the regulations varies.

The price of the recycled products is not possible to estimate today, but there is a risk that they might be more expensive then Ecophon's current products. This may results in an unattractive product. However, it is noticed that the building industry receives higher demands from the society when it comes to recycling their material. This might result that recycled building material must be prioritized, even if they become more expensive, which means that the generated product concepts are attractive from this point of view.

When it comes to improve Ecophon's working with circular economy, it is concluded that the product concepts follows this definition. This is a leverage and an advantage when stricter policies evolves, which is one of the most importance issues to adapt to, in the construction and demolition sector.

8 Recommendation & conclusion

Areas that are recommended to investigate further are explained in this section. This can e.g be the concepts and also what sort of products they should become.

This thesis should be used as a guideline and pre-study for further development of recycled acoustic products. As a conclusion of this project it can be said that implementation of one or more of the suggested product concepts, *Glue surface, Virgin board* or *Sandwich* potential viable products. *Glue surface* is considered to be able to contain different densities as long as it is not combined as low-medium and medium and high densities. The other two concepts are considered to be able to contain any combination of densities depending on what mechanical and acoustic properties that wants to be obtained. All concepts can be assembled without using glue between the pieces.

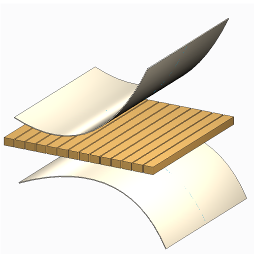

Figure 50: Glue surface

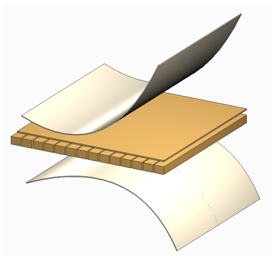

Figure 51: Virgin board

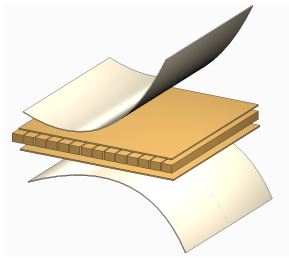

Figure 52: Sandwich

Production waste that is usable could be used as a material resource and a cornerstone in the beginning of the production. The production waste supplies high quality and known properties, for the product concepts. The recovered material can be used as a compliment in the beginning until a functional and reliable way of recovering materials have been established.

At this moment it can be said that recycled products made out of bits and pieces, will require a significant increase of cuttings, which have an impact on production waste. Therefore choice of cutting and manufacturing techniques should be done with caution.

Next steps for this project could be recommended to decide what product application area a recycled product, like the ones suggested, could be suited for. When this is done, more specific target specifications and goals can be established. It is recommended to perform further testings of different prototypes in order to find the perfect combinations of densities, compositions, surface layers and glue. A businesses case can then be created depending on different production and product options.

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A Appendix Time plan and distribution of work

A.1 Original time schedule

In the beginning of the project a work schedule were performed to help with the project planning. The gantt schedule can be seen in figure 53. The plan was to follow the gantt schedule as closely as possible which turned out to be hard. The acctual process plan can be seen in the next section were also some of the reasons for the divergence.

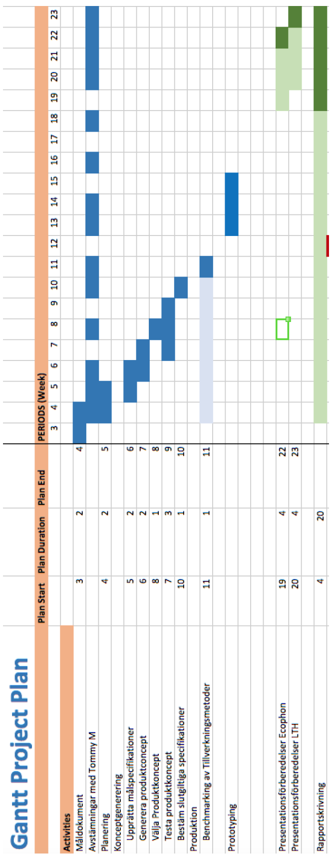

Figure 53: Original time schedule

A.2 Time schedule outcome

In the figure 54 the actual time schedule can be obtained. It turned out to be hard to stick to the original time plan for to several reasons. Most due to the study visits and prototyping sessions depended on booking times when others were available, which some times were difficult to predict. Prototyping revealed it self to be an important part of the project and more time were spent on making prototypes than first expected, this were also due to the poor insight in the creation of prototypes of this kind of products.

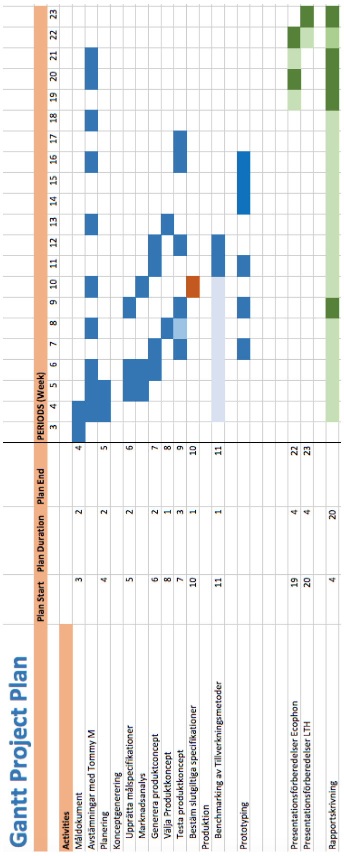

Figure 54: Outcome time schedule

B Appendix Interviews

B.1 Customer Needs

Here are the questions and the following customer statements presented. They were later used when target specifications were formed. The questions and the statements are described in separate categories, depending in what area the customer work with, such as architectures, installers, contractors, etc.

B.1.1 Internal interviews

Table 29: Internal interviews

Employee	**Occupation**
Erling Nilsson	Acoustics Specialist
Roger Lvdahl	Machine and Production Development
Rasmus Ekberg	Environmental Specialist
Pierre Chigot	Architect and Design developer
Tommy Månsson	Research Industrial Manager Baseboard
Thomas Nilsson	Senior Product Development Engineer
Thomas Asarsson	Machines and Production

B.1.2 External interviews

Job title - Occupation - Name:

Installer - X - Jörgen Mårtensson
Installer - X - Stefan Karlsson
Architect - Fojab - Magnus Nilsson
Architect - Fojab - Jonas Ruthblad
Architect - LTH -Thomas Tegil

General questions

- What is your profession?
- What is your title?
- How do you come in contact with acoustic products and tiles?
- What influence how you feel about a acoustic product?
- Do you feel there is a problem with current acoustic products on the market?
- Is there any features or aesthetics that you would like to see in acoustic products?
- How much influence do you have, regarding deciding the choice of building material?

Specific installer questions - What makes a product easy to handle when installing?
- What makes a product difficult to handle when installing?
- What improvements could be done for the current products?
- If you are informed that a specific product is more fragile then usually, would you approve to work with it?
- Are there other areas you like to add regarding installation of acoustic products?
- How often do you or a installer usually cut and/or change a existing acoustic tile?

Specific architect questions

- How do you choose materials for a project?
- What factors can effect your choice of features to for e.g a green building project?
- Do you or architects usually need to change material e.g because of economic reasons when it come to inner ceilings?
- How much say do the installers who will create and mount the product have a say in the choice?
- Are there other areas you like to add regarding choices of acoustic product range?
- Would you e able to choose a product that could be different aesthetically, if it is recycled? - Do you usually or want to use new (could be untested) materials or products?

Specific supplier questions

- Who are your customers?
- How do you choose materials/products to put in your assortment?
- Have you noticed any requests or costumer demands regarding different products than you provide?
- What makes you recommend or suggest a certain product?

B.1.3 External interviews conducted during study visits

Name - company:

Johan Karlsson - Kährs, Nybro
Anders Jönsson - Swedish Waterjet Lab, Ronneby

C Concepts for Manufacturing

C.1 Cutting Techniques

During the literature-, internal- and external study, ideas about which cutting techniques that could be used, evolved. Theses manufacturing techniques were listed and researched further to be able to finally evaluate the most relevant for this project. In table 31 below a list of the ideas which were generated. Some techniques is suited for cutting through longer and wider areas of a material at once, which could be useful for e.g removing surface layers through horizontal cutting. The techniques are marked with H if they are considered to be suitable for cutting wider sections at once.

Table 30: Different cutting techniques

Nr.	technique	Wide cut	Description
1	Circular saw		Rotating saw blade
2	Band saw	H	Sharp blade consisting of a continuous band of toothed metal blade
3	Wedging		Circular knife/blade which separates the material
4	Wire cutting	H	A wire removing separating and cutting trough moving at fast speed
5	Laser		High powered laser through optics
6	End mill		Drill bit that cutting through material in a axial direction through spinning in high velocity
7	Punching		Forming process that punch press to separate material via shearing
8	Compressed air		Highly pressurized air which is aimed through nozzle at processed material
9	Manual cutting		A person cutting through the material with a razor knife
10	Waterjet cutting		High pressurized water beam aimed at the processed material through a nozzle
11	Plane ”Hyvla”	H	Using plane technique to remove layers of the material
12	Grinding	H	Use a large sandpaper to grind of surface layers

H = Capable to cut horizontally

Four techniques, band saw, circular saw, end milling and waterjet cutting were selected to be investigated further. Below are descriptions of the techniques and how they were tested or observed. The result can be find in the *Pre-study*, *Cutting*.

C.1.1 Circular saw

The technique is based on a spinning circular metal disc with saw teeth located along the edge which can be seen in figure 55 (Publishers, 2018). The disc can have various diameters and thicknesses. Revolution speed depends on the material being processed and the saw being used. This technique was observed internally at Ecophon and externally at Kährs, a wooden floor manufacturer. It is a well proven technique that Ecophon is used to work with.

Figure 55: Circle saw (Amazon, 2018a)

Observing the technique within Ecophon shows proves the technique to be effective and the results are reliable. It is usually used during the early stages within the manufacturing process and the cut surfaces are relatively rough and fussy. There are few products that use this technique as the final step, and usually the edges created by the circular saw are further refined before the product is finished. The circular saws used in the production today is at least 2 mm in width. What the thinnest possible circular saw could be, is not defined. Therefore this measured width is used as a guideline.

C.1.2 Band saw

Band saw consists of a continuously looped serrated blade, which usually is driven by an electric motors. The blade can vary in shape and material depending on application area(Gregmatch, 2018). It was observed that the blades Ecophon are using, have a thickness less then 2 mm, which is a guideline when it is investigated . This technique have been tested and used both internally and externally. This made it possible to investigate the technique more in detail, and evaluate the results that were obtained.

Figure 56: Bandsaw (Homedepot, 2018)

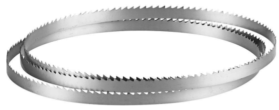

Figure 57: Bandsaw (Gregmatch, 2018)

Vertical band saw cutting
Internally at Ecophon, in Hyllinge, several test sessions using a manually operated vertical band saw were conducted. The band saw was frequently used for cutting products in e.g the Design department.

Horizontal band saw cutting
A study visit at Isover, Lübz, Germany was organized where the factory had a machine equipped with horizontal band Saws. The purpose was to evaluate how glass wool with various densities, thicknesses and binders would act upon different settings of the horizontal saw blades. When the test was performed, the material was cut into thinner pieces, where the removal of surface layers also was tested.

Figure 58: Horizontal sawing result

As can be seen in figure 63 above, thin pieces from recovered products can be obtained with precision.

C.1.3 End mill

End milling is a technique that uses a rotating so called flute, figure x, that through the rotating motion allows material to be removed from an object. One of the parameters that decides the amount of the removed material is the diameter of the flute (Harvey Performance Company, 2018). This technique is well known and used within Ecophon product processing. The manufacturing technique have several advantages, like multiple axis cutting. The downsides is that if less dust are to be generated, a smaller flute diameter can be used, but this also limits the processing speed. Discussion with external sources indicated that less then 3 mm in diameter of the flute is not an option.

Figure 59: End mill (Harvey Performance Company, 2018)

Instead of test end milling, researching were done through interviews and evaluation of cut up pieces of products were researched.

C.1.4 Waterjet cutting

Waterjet cutting is a technique which is made possible through highly pressurized water that is focused at the cutting objective with a nozzle, as seen in figure 60. There are two types of waterjet cutting, abrasive and non-abrasive, depending on what kind of materials are being handled (Fedtech, 2014). The technique have several advantages e.g. that parts and pieces can be cut with high accuracy and control. Depending on the width of the beam, little waste material can be prevented. Depending on usage of abrasive substances or not the method can cut through materials that are abut 80% the hardness of a diamond. It is a cold process that have no heat effect on the material being processed(Fedtech, 2014). Abrasives can be neglected, Non-abrasive waterjet cutting, when cutting certain materials like for porous, light and flimsy materials i.e. rubbers, silicone, thin plastics, food etc. If abrasive are added it allows cutting hard objectives e.g stone and metals.

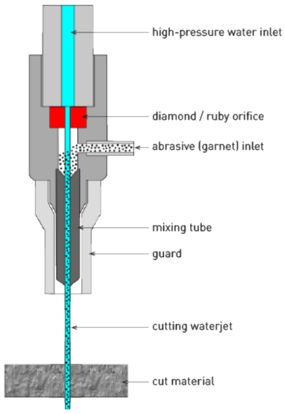

Figure 60: Water jet nozzle (alphalasercutting, 2018)

C.1.4.1 Evaluating waterjet cutting

Digital sources were used when researching waterjet cutting. There are a lot of information about water jet cutting in general and when processing various material, but enough when it came to waterjet cutting glass fibre wool. It was decided to test this technique though doing a study visit at *Swedish waterjet lab* in Ronneby Sweden. The aim were to conduct a test in order to research how different densities, binders, and thicknesses, of glass wool tiles works in correlation to waterjet cutting.

In preparation for the study visit, baseboards with the different densities etc. were grinded and cut in to tile like shapes of 600x600 mm. The point of this were to mimic a recovered glass wool tile were the surface layers had been removed(with arbitrary technique).

Swedish waterjet lab study visit
The test session were supervised by Dr. Anders Jönsson, who is an technician and researcher at water jet lab. The machine used at the lab, NC 3015 E, from Waterjet sweden that were used is not specifically intended for cutting glass wool, other materials that are not water sensitive are better suited for this machine, he explained. The material that are being cut/processed is placed on a grid above a water reservoir, which gathers the water, waste material and abrasive(if used). Even though the glass

wool may absorb and are being exposed to water the cutting surfaces results should give a good indication of how a optimized machine could perform, after the material have dried. A more optimized machine would e.g use vacuum suction underneath the processed and nozzle to minimize water exposure and absorption of material, Anders explained.

A selection of different geometries were drawn up, using a computer, to get a diverse and larger sample of cutting results. It was decided to test-cut all all densities of both green binder and Phenolic binder based products with no abrasive added.

during the test session a nozzle with 0.3 mm was used. It was indicated that a beam of this diameter is reasonable for this purpose.

C.2 Study visits

C.2.1 Isover, Lübz

A study visit at Isover, Lübz, Germany was organized where the factory had a machine equipped with horizontal saw blades. The purpose was to evaluate how glass wool with various densities, thicknesses and binders would act upon different settings of the horizontal saw blades. When the test was performed, the material was cut into thinner pieces.

C.2.2 Swedish Waterjet Lab, Ronneby

One technique that was investigated during the project was water cutting. The test was proceeded at Swedish Waterjet Lab in Ronneby where baseboards with different thicknesses, densities and binders was examined when they were cut into smaller pieces. Various geometries of the pieces that were cut was evaluated with focus on water absorption, processing speed and edge quality where the cuts were performed.

An issue that aroused during the test was the ability for the material to resist moisture, due to the water cutting. The material consisting of glass fiber wool and binders tend to swallow in volume if enough moisture is accumulated. After each cutting test, the pieces that were obtained were weighted instantly after the machine operation. When the pieces had dried they where weighted once more and compared to the first measure of weight, and hence it was possible to see the moisture uptake of the material. The pieces were also examined visually directly and after they were dry, in order to see if there were any signs of swallowing to the material. The cutting speed of the machine was adjusted to 10 m/s and the beam of the water cut was set to 3 mm.

According to Anders Jönsson at Swedish Waterjet Lab, it is possible to customize water cutters to reduce moisture uptake for the material by extracting the water by using vacuum. It is also possible to increase the operation speed of the machine by using several nozzles simultaneously.

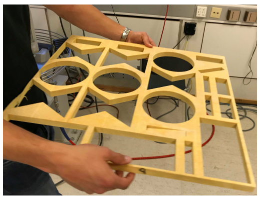

Figure 61: Cut out pieces

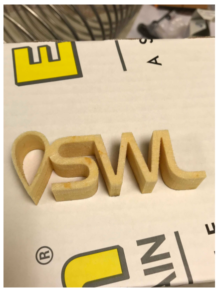

Figure 62: Water cut logo

Kährs, Nybro A study visit at Kä hrs were conducted in the early stage of the project to gain inspiration from another industry. Kä hrs is a wooden floor manufacturer based in Nybro, Sweden, and have a long history of creating e.g lamella-parquet floors. There for it could be interesting to get inspiration from an in industry that work with another product, which could be seen as the inverse of a ceiling, namely a floor.

D Concepts

All concepts that were generated are presented in this section, followed by the first selection which is described as the *rough sorting*.

D.1 Generating of Concepts

D.1.1 Assembling concepts

Concept 1A - Velcro

Cut/disassemble the recovered tiles with a manufacturing technique that creates fleeciness at the edges that are cut and allows these ends to connect like Velcro.

Figure 63: Velcro (berntilund, 2008)

2A - Jigsaw

Cut/dissemble the recovered tiles in to a geometry, in the horizontal plane, which allows the pieces to connect through ”locking” to each other in one to three dimensions. Does not necessarily need to have the specific jigsaw geometry but can be any arbitrary geometry.

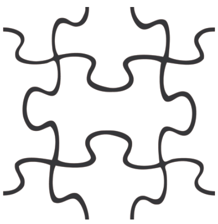

Figure 64: Velcro (plantillas powerpoint, 2018)

Concept 3A - Tongued

Cut or mill the pieces in the horizontal plane to create at tonged and grooved geometries that can connect to each other.

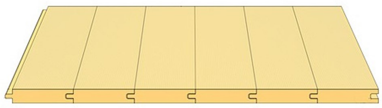

Figure 65: Wood Tongue (Bygghemma, 2018)

4A - Tape surface

Use tape to connect the pieces to each other. An idea could be to integrate a tape surface on today's finishing surface layer, which come rolled up in big roles. instead of adding glue separately on the baseboard the glue could already be integrated on the finishing surface layer. The thought originate from companies that specializes in tapes that can connect to various materials through customization.

Figure 66: Double sided tape (Amazon, 2018b)

5A - Glue surface

The same principle as today, where the painted surface is glued to the baseboard. The glued on surface layer holds the pieces together. If the existing glue does not fulfill the standards, another glue with optimized features could be developed.

6A - Glue between pieces

After the recovered products have been disassembled and should be reconnected to each other, glue between the pieces could be a solution. The same principle as the kitchen counter-top made out of wood pieces. An inspiration source were a manufacturing process observed at a study visit, at a wood industry. The glue could either be added manually, but preferable automatically.

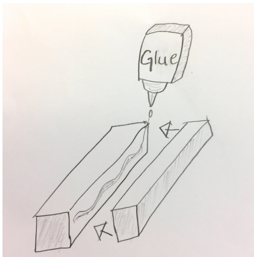

Figure 67: Glue between pieces

Concept 7A - Needle stitching

A concept were needles are used to penetrate the surfaces of the cut up pieces. Fibers from the different pieces should enter another piece and connect them.

Concept 8A - Tailor Board

The recycled pieces are attached together using a thread and needle. The pieces can either be sewed together above and below the board, or through the side planes.

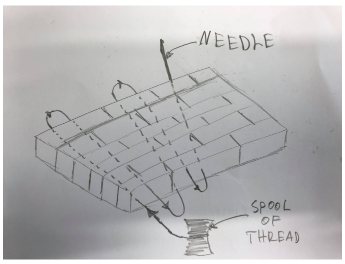

Figure 68: Sewing pieces horizontally

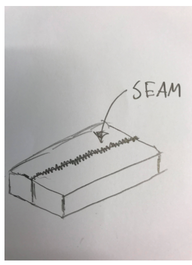

Figure 69: Seam pieces vertically

Concept 9A - Spike Surface

The surface have integrated spikes or stingers that penetrate the pieces in the horizontal plane and holds it together and at the same time creates the finished surface.

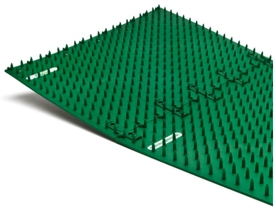

Figure 70: Spike Surface (Yogalife, 2018)

10A - Second Baseboards

Use a new or recycled intact covering thin glass fibre wool tile/baseboard as a support for the cut up pieces. It could either be on one side or both, and enclose the pieces like a sandwich. These covering second baseboards could be attached in different ways, most likely glue. Adding this could ensure at least one predictable surface finish.

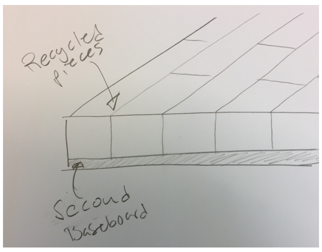

Figure 71: Second baseboard

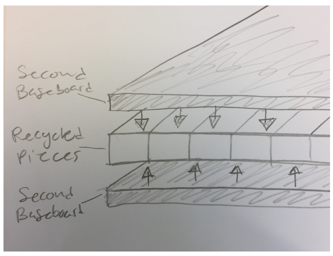

Figure 72: Sandwich

D.1.2 Composition concepts

Here the different compositions and combined geometries are presented. The figures are hand drawn to give a visual understanding of the concept in figure 73. Some of the composition concept are explained on next pages.

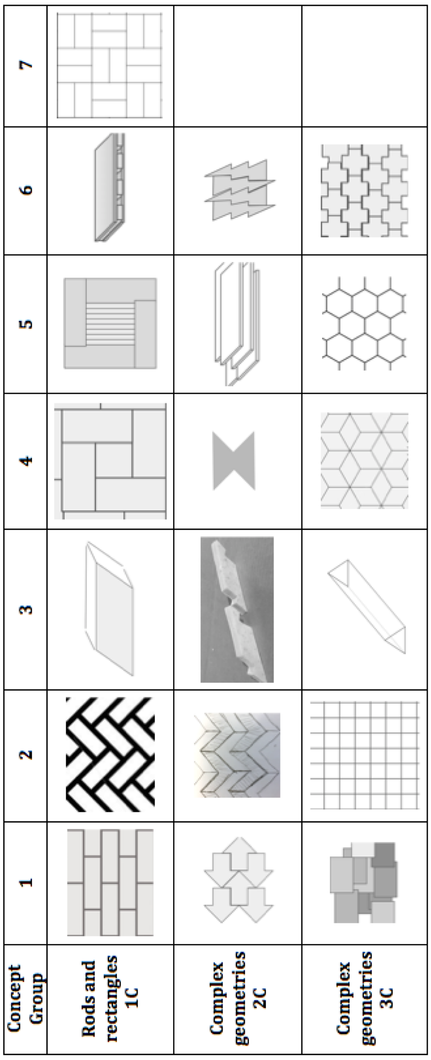

Figure 73: Composition concepts

1C - Rods or rectangles

The recovered tiles are cut in to rectangular rods or pieces to later be assembled back together, through placing the pieces in a certain patterns. If the laminar structure or fibre orientation e.g is vertical, the width of the cut up pieces should be the same as the wanted height as the recycled product, excluding the elements of the assembling concepts. The pieces length (z), width (x) and height (y) can there for vary.

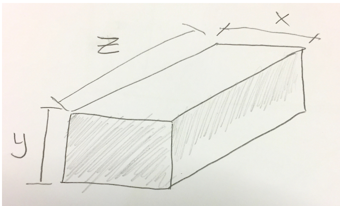

Figure 74: Rectangular piece

Table 31: 10A, pros and cons

Pros	Cons
+ Simple geometry	- Limits the possibilities
+ A number of ways to combine	- Bad result
+ Works with various manufacturing techniques	-

1C1 - Brick formation

Cut pieces in the same length and shapes to then be combined in linear patterns that creates baseboard/tile. The width, x, height, y, and length, z can variate. The pieces are placed so they create a brick like formation. This concept also contains the possibility to create more than one layer of rods in one direction. This creates a network which could potentially create a strong unit.

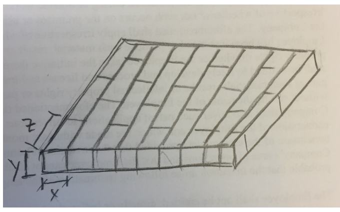

Figure 75: Brick sketch

Figure 76: Brick prototype

1C2 - Fish bone

Rectangular pieces placed in a fish bone pattern to create a baseboard unit.

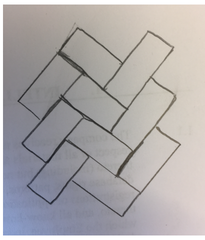

Figure 77: Fishbone

Figure 78: Fishbone 2

1C3 - Tilted rods

The pieces are cut so they support each other on tilting sides instead of straight vertical borders between pieces. The thought is to prevent direct vertical borders going straight through the recycled tile. The pieces could be be tilting in any direction and in the figure below, only the end are the one configured.

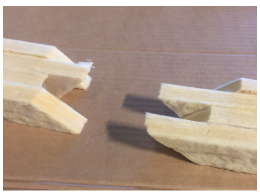

Figure 79: Tilted rectangles

Figure 80: Tilted rectangles

1C4 - Spiral

The rectangular pieces are put out so they crate a spiral shape in the horizontal plane, as seen in figure 81.

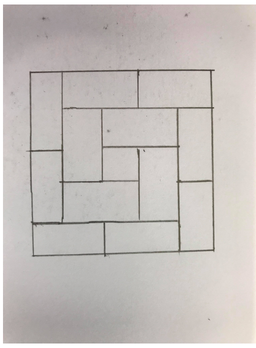

Figure 81: Spiral pieces

1C5 - Frame pieces

A method were a frame are used to contain and hold the cut up pieces together. The frame could be made from either glass fibre wool or alternative material like metal.

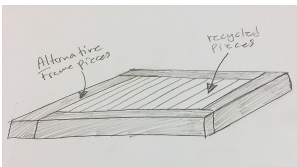

Figure 82: Sketch frame

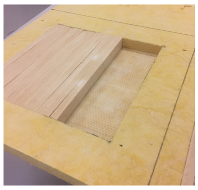

Figure 83: Physical test

2C - Complex geometries

Create more unique pieces that create more complicaded patterns to example prevent straight lines to run through the horizontal plane.

2C1 - Arrows

Inspired by Skånetrafikens logo were arrows creates a pattern. The figure 84 shows how the pattern could look like in the horizontal plane.

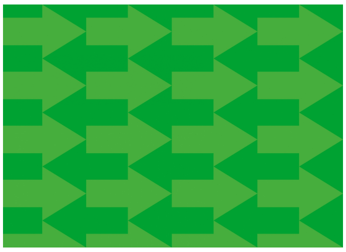

Figure 84

2C2 - V's

Geometries which have the shapes of a V. The pieces forms a united board through orienting the pieces together. Every other row is inverted. The composition prevents straight lines in the plane.

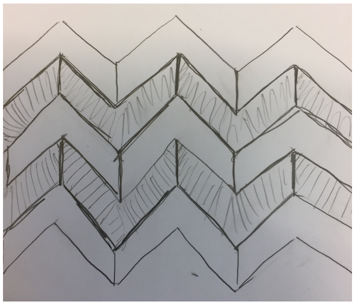

Figure 85: V sketch

Figure 86: V pieces

2C3 - S-hook

A concept were the pieces have got a shape that allows the pieces to hook on to each other.

Figure 87: S-hook

Figure 88: S-hook

2C4 - Hourglass

The pieces are cut in a hourglass shape and are placed next to each other and creates together a baseboard.

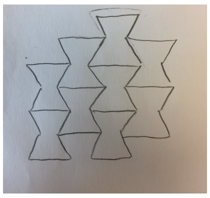

Figure 89: Hourglass

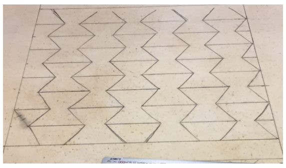

Figure 90: Hourglass

D.1.3 Aesthetic appearance

1AA - Classic Appearance
Use the same aesthetic appearance as Ecophon products have and uses today. Clean surface layer e.g like *Akutex FT* with mat finish and 16 different color options.

2AA - True Appearance
Take advantage of the recycled pattern within the new recycled product and let it be visible trough a transparent surface layer. This could give whole new aesthetic appearance and also gives the possibility to create a "two-sided" product. One side with classic appearance and one with true appearance.

3AA - Patterned surface layer
Create special or custom surface layer which are specific for this product. This surface layer could e.g have an integrated pattern. if its only applied on one side it could be used as a template for installers when altering with the product or applies other features like lamps etc.

4AA - No surface layer
One or two sides are bare and do not have a surface layer, which would show the connected pieces. This could be accomplished through using one of the assembling concepts were the pieces are connected so you do not need a surface layer on either side or on one side.

E Prototypes and Testing

This section goes through the different phases of prototyping and testing of the glass wool material, during the project.

E.1 Mechanical test

The mechanical test that were conducted on glass fibre rods with a cross section of 40x40mm. It was decided to perform the test on pieces cut from grinded baseboards, one high density, and one low density . A visual description of how the tests were conducted can be seen in figure 56. The tests were performed at Ecophon's laboratory with test equipment. To prevent the test equipment from penetrating the test pieces, a flexible thin plastic sheet were used to even out the pressure. The Pressure test controlled how much force it takes to deflect the material 4 mm, when an even support underneath the test pieces were obtained. During the deflection test the test piece were raised up on two supporting objects, and tested how much force it takes to deflect the test piece 7mm in the vertical direction. The result can be seen in figure 57 and 58 below. The impact from the plastic pieces that even out the force is not neglected. The reason for this is because a indication of the difference in mechanics are in focus.

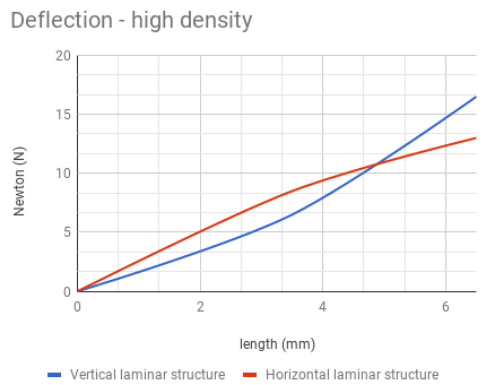

Figure 91: Deflection high density

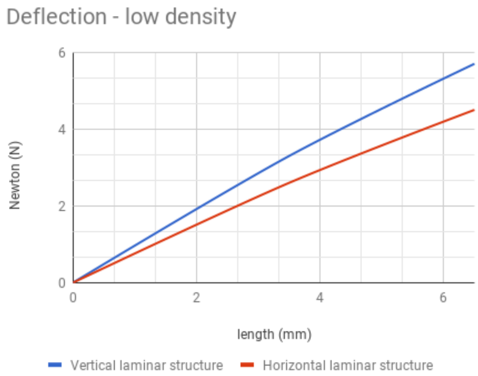

Figure 92: Deflection low density

E.2 Acoustical test

Twelve prototypes were built, using pieces with different densities where some were combined, table 32. The cross section dimensions of the pieces was either 40x40 mm or 40x20 mm. The baseboards were consisted of a green- or a phenolic binder, and these were never combined. The dimensions of the prototypes are 600x600mm in area, and 40mm in thickness, see table xx. One of the purposes with this prototype session were to find out if changing the laminar structure of the wool would decrease the resistance in the product. This were done through measuring the resitivity on six of the prototypes and comparing these to the resitivity of today's baseboards resitivity.

Figure 93: Acoustic samples

Three circular specimens from each prototype were extruded, which can be seen in figure x, and used with an instrument that measures the resitivity. The mean value from these pieces were compared to the mean resitivity of baseboards with original laminar structure and different densities.

The value that is obtained from the measurement instrument have the dimension $\frac{Pas}{m}$, where Pa is the pressure difference before and after the air passes through the specimen, s is the time the air is passing through, and m is the diameter of the specimen. When this value is measured, it is divided with the thickness of the specimen, which answers to the resistivity value ($\frac{Pas}{m^2}$). It is the resistivity value that is compared in order to give an indication how the acoustic properties get affected when changing the laminar structure of the specimen. This testing method is used at Ecophon frequently.

Table 32: Næstved prototypes

Prototype	**Density 1**	**Density 2**	**Binder (GB/Phenolic)**	**Cross section 1 (mm)**	**Cross section 2 (mm)**
1	High	-	Phenloic	40x40 V	-
2	Medium	-	Phenolic	40x40 V	-
3	Low	High	Phenloic	40x40 V	20x40 V
4	Medium	-	GB	40x40 V	40x40 O
5	High	-	GB	40x40 V	-
6	Medium	-	Phenolic	20x40 V	-
7	Low	High	GB	20x40 V	20x40 V
8	Medium	High	GB	40x40 P	20x40 V
9	Medium	-	GB	20x40 V	-
10	Medium	High	GB	20x40 V	20x40 V
11	Low	High	Phenolic	40x40 V	40x40 V
12	Low	Medium	Phenolic	20x40 V	20x40 V

O = Original laminar structure, V = Vertical laminar structure

E.3 Prototypes

E.3.1 First session

The first prototype session was made in Hyllinge Sweden, on line three in the factory. This was a early attempt to see if some of the chosen concepts were able to create with the machines Ecophon have access to today.

E.3.2 Second baseboards and rods

Early in the development process two prototypes were made at Ecophon in Hyllinge, at the design department. Both prototypes used manually cut rods from a band saw. The pieces had a cross section of 40x20 mm^2 and were 600 mm long. The resulting products were 600x600 mm^2. Both prototypes used one *Akutex FT* surface layer on one side and a thiner supportive surface layer on the other. A higher amount of and different glue were used than the usual produciton lines uses. This because the outcome of this type of product combination was unknown.

On one of the prototypes a 10 mm thick second baseboard were added for support and became in total 60 mm thick. The other only had the rods and became 40 mm thich as a result.

Both prototypes were durable and stable which indicated possibilities with this kind of concept cuild-up.

E.3.3 Composition build-up of pieces

Early in the project a number of prototypes were created with different *Composition Concepts* but all with the same *Assembling Concept*, which was to use a glued on surface layer (5A). Ecophon's most common surface layer *Akutex FT* was used and the amount of glue was the same for each prototype, in order to obtain equal terms and ease the comparing evaluation. All prototypes had a final dimension of 600x600 mm and a thickness of 20 mm. High density for each prototype was was used, and the glass wool used a green binder. It was decided to use the same original fiber direction of the pieces for all concepts. This means that the only parameter that varied between the prototypes was the design of the pieces and how they were placed. There were limitless number of concepts for how the composition might look like, therefore it was chosen to only test a few, which can be seen in table 33 .

Table 33: Tested composition concepts

Composition Concept	
1C1	Brick formation
1C2	Fish bone
1C3	Tilted rods
1C4	Spiral
1C5	Frame pieces
2C4	Hourglass

Figure 94: Prototype making

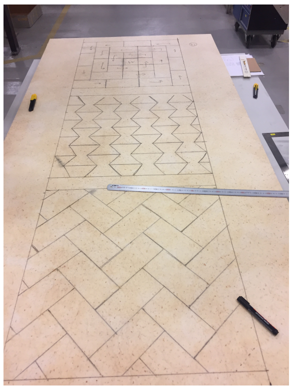

Figure 95: Prototype making

The purpose of the prototype session was to determine the following:

- Is it enough to use glued on surface layers to keep the pieces together?
- What impact does the geometry of the pieces have?
- How does the size of the pieces affect the result?

- What impact does the orientation of the pieces have?

When the prototypes were built, it was decided to use one of Ecophon's machine lines, which included the operation to glue on a surface layer on the loose pieces. The machine line that was used, is designed for mass production of Ecophon's current acoustic tiles. Afterwards, the assembled pieces with a glued on surface layer were cut up to obtain the final dimension of 600x600 mm.

Seven prototypes were built, using a glued on surface layer combined with different composition concepts. The prototypes provided the following impression:

- All prototypes seemed to have good mechanical properties.
- From some angles it was possible to see the pieces through the surface layer, regardless the design of the pieces.

E.3.4 Rods with different densities and thicknesses

In Næstved, Denmark, twelve prototypes were created with the purpose to combine different densities of the glass wool pieces. The cross section dimensions of the pieces was either 40x40 mm or 40x20 mm. The baseboards were consisted of a green- or a phenolic binder. The dimensions of the prototypes are 600x600mm in area, and 40mm in thickness.

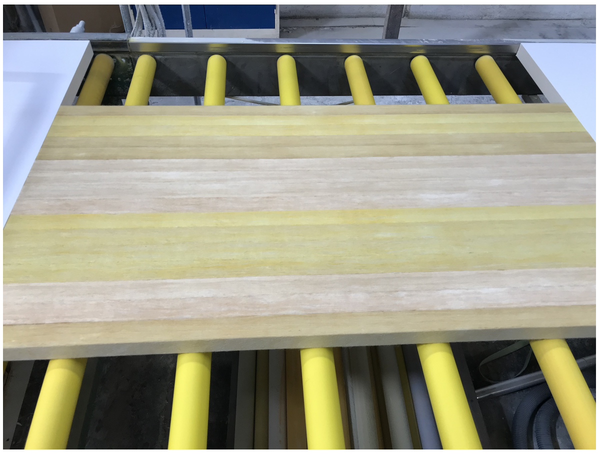

Figure 96: Mixed test prototype in Denmanrk

Table 34: Næstved prototypes

Prototype	Density 1	Density 2	Binder (GB/PF)	Cross section 1 (mm)	Cross section 2 (mm)
1	High	-	PF	40x40 V	-
2	Medium	-	PF	40x40 V	-
3	Low	High	PF	40x40 V	20x40 V
4	Medium	-	GB	40x40 V	40x40 O
5	High	-	GB	40x40 V	-
6	Medium	-	PF	20x40 V	-
7	Low	High	GB	20x40 V	20x40 V
8	Medium	High	GB	40x40 P	20x40 V
9	Medium	-	GB	20x40 V	-
10	Medium	High	GB	20x40 V	20x40 V
11	Low	High	PF	40x40 V	40x40 V
12	Low	Medium	PF	20x40 V	20x40 V

O = Original laminar structure, V = Vertical laminar structure

Evaluation Neæstved prototypes

All the prototypes were tested with four different evaluation methods. This to get a coarse indication of which prototypes were the best. All the different tests were evaluated according to a reference tile which was a 40mm thick 600x600 with the density of 80 kg/m^3. The prototypes were ranked and scored in compering to the reference, one by one.

Test 1:
The prototype is lifted with one hand and were evaluated after how it felt in comparison to the reference.

Test 2:
The prototype are cut through with a usually installer razor knife in multiple directions to get an indication how easy or not easy it is to alter the tile manually.

E.4 Testing combined product concepts

E.4.0.1 Employee evaluation

Testing and evaluation of the combined concepts were conducted when the final prototype session was completed. It was chosen to set up a focus group to be able to get valuable information and feedback on the prototypes made from the combined concepts. The focus group contained of ten Ecophon employees with different areas of expertise and one external installer, in order to receive more diverse opinions. Because the individuals had different backgrounds and areas of expertise it was decided to not make the same evaluation with all participants. The installer would e.g get the opportunity to cut in the product manually and answer questions more in relation to profession.

The purpose of testing and evaluating the different prototypes, was to provide better support when evaluating the concepts, and give insight for further development.

The areas that were focused on during the testing and evaluation session was *visual*-, and *mechanical* impressions. These were divided in to two stations isolated from each other. The reference product were a *Master SQ*(Ecophon, 2018) and were used as a reference both during the mechanical and visual evaluation. It can be considered a high quality product and other options for references were considered but decided against. When the individual test member had answered the questions, they were asked to answer a SWOT-analysis for each prototype. They also had the opportunity to discuss and make general comments on the concepts.

Figure 97: Test station one

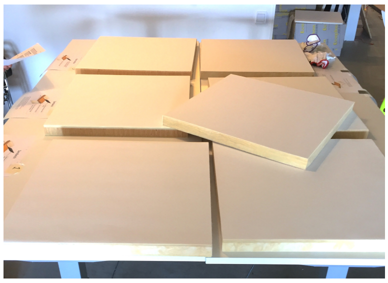

Figure 98: Test station two

Using a scale ranking system for mechanical and visual aspects gave numeric answers. As complement SWOT-analyze and discussing areas of interest were performed. As reference a similar product from Ecophon's assortment were used. Perhaps the test is not totally fair, one reason for is that the prototypes were hand made and not the reference. This have been taken in to consideration and also a reason why an open discussion during the test-session were chosen as a compliment. How the score correlates to the reference can be seen in table 35.

Table 35: Description of prototypes ranking

Scoring of Prototypes	
Score	**Description**
1	Not acceptable
2	Acceptable
3	Equivalent to reference
4	Better then reference

Interaction was made during the test to open up for discussion about the concepts. Some of the frequently asked questions were the following:

- Which of the concepts are your favorites and why?
- Which of these concepts would you think live up to the regulations depending on product application area?
- What are the positives and negatives with the concepts?

- Are there any concepts or feature you miss in the selection?
- What do you think is an important aspect to consider when developing these type of concepts or products?

Emplyee answers
From a mechanical point of view, the test members generally thought that the concepts were just as good or even some times better compared to the reference product. It was unexpected among the members that no glue were needed in order to obtain a "stable" product.

In table 36 below a combined result of the answers on the prototypes can be obtained. Some of the prototypes were dismissed because faults in test method or non efficient answers.

Table 36: Rating of final prototypes

Evaluation of Prototypes			
Nr	**Prototype**	**Visual**	**Mechanics**
1	Glue surface 1	1,3	2,8
2	Glue surface 2	1,0	2,6
3	Glue surface 3	1,0	3,0
4	Virgin board	2,9	2,9
5	Sandwich 1	2,3	3,2
6	Sandwich 2	3,0	3,3

The fact that none of the concepts use glue between the pieces (1C1 or 1C5), can be positive from a fire safety perspective. However, the *Virgin board* and the *Sandwich* concepts require a higher amount of glue, due to the baseboards applied. But these can also have an isolating ability against fire. None of the participants could give an answer regarding the fire safety to these two concepts, since it is required to perform a fire test. The conclusion from this is that a more detailed fire test and research should be done.

The visual evaluation scored lower on the prototypes, especially on the concepts only using surface layer and no additional baseboards. This were somewhat expected, and one reason for this could be because of the reference high quality. The pieces used for the prototypes were cut manually with a band saw which could resulted in some differences in width of the individual pieces. The width of the core pieces have a crucial impact on the end result of the product, which can appear visually through the surface layer. This could perhaps be rectified through grinding the pieces on the plane which is in contact with the surface layer or use a different surface layer.

Relevance of the reference can be discussed for different reasons, because the final product application is not yet decided and not necessarily need to be in the same category as the reference the weighted results perhaps can be miss leading. The recycled product could e.g be decided to be fitted into a lower quality group which could have given a more positive result if a corresponding reference had been used. The results of this test are because of that just used as guidelines.

E.4.0.2 Installer evaluation

A installer were invited to come to Ecophon and evaluate the prototypes. The installer had 25 years of experience of installing acoustic ceilings and is expected to have valuable input in some aspects. This test were performed differently that the one with Ecophon's employees. The session were divided in three parts were the following were discussed:

- Comment on the prototypes/product concepts when handling the product like a normal homogeneous acoustic product. Both before and after knowing the core structure.

- Cut along the tiles in two directions to provide information about how if the products were acceptable to cut through manually or not.

- Discussions about pro and cons between the different product concepts, also first intuitions to the concepts.

The general thought and indication from the installer were that all the prototypes and concepts have good enough mechanical stability. Handling one of these would not be a problem and some were surprisingly light, when in comparison with the stiffness of the surface.

When cutting through the tiles no complains were made. Some of the concepts were easier than the other. He thought that the second baseboards on the *Virgin* and *Sandwich* prototypes made the cutting easier, but cutting through *Glue surface* were no problem either.

When discussing areas that affects the product concept in other ways, dismantling of a ceiling were discussed. He states that dismantling a ceiling is not difficult at all, but of course it depends on the product. To dismantle usual tiles that are located in a grid system, are no problem. The tiles would also not receive any substantial damage, if this is wanted. It is not usual that installers dismount through e.g throwing the tiles on to the floor, because this could be dangerous. In stead the tiles are usually placed in piles and then removed.

A thing that can be considered to be difficult and some times a problem is is to demount a acoustic ceiling in the purpose of reusing it in the same area. This demands that the all tiles are handled in a flawless way.

Questioner employee evaluation test

Namn: ___________________________

Utvärdering av prototyper

I tabellen nedan besvaras utvärderingsfrågorna med poängsättning i förhållande till referensen. Referensen är en produkt Master SQ, 80kg/m^3, med samma utformning som prototyperna. Alla produkterna har ytskiktet Akutex FT.

<u>Prototyp poängsättning</u>
1 Poäng – Ej acceptabel
2 Poäng – Acceptabel
3 Poäng – likvärdig med referens
4 Poäng – Bättre

<u>Visuell 1:</u> Ser man ojämnheter på ytskiktet på avstånd (Läge 1)?
<u>Visuell 2:</u> Ser man ojämnheter på ytskiktet på nära håll(Läge 2)?
<u>Hantering 1:</u> Hur uppfattas produkten när man hanterar den? Bortse från massan.
<u>Favorit:</u> Kryssa de tre prototyperna som du anser har störst potential. (Görs efter Swot – svar.)

	Station 1		**Station 2**	
Prototyp	**Visuell 1**	**Visuell 2**	**Hantering 3**	**Favorit 4**
1				
2				
3				
4				
5				
6				
7				

OBS:
Nästkommande sidor innehåller möjligheten att utvärdera prototyperna med hjälp av en SWOT-analys.

Figure 99: First page from employee evaluation