What's Next in Sustainable Acoustic Materials?

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BAUX
FUWL

What's Next in Sustainable Acoustic Materials?

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Abstract

As industries have begun to rethink the way they design, make and dispose of products for the purpose of sustainable development, manufacturers of acoustic products have been slow off the mark. The majority of acoustic products are still made of primarily virgin material made from petrochemical resources, which have a significant impact on the environment. This is problematic from an environmental standpoint, but also a commercial, as society is starting to favor materials fitting into a circular economy. Thus, consumers might break companies based on poor environmental strategy and branding.

As it is clear that well designed acoustic environments can lead to improved wellbeing, an area which has gained recognition in the later years, it is important that acoustic products keep up with the new green economy.

The purpose of this thesis was to answer the question, "*What's next in sustainable acoustic materials?"*, with the presumption that a truly sustainable material for an acoustic solution already exists but has not yet been applied in an acoustic product. In this thesis, already existing (or upcoming) materials were evaluated with regards to their environmental properties, their applicability in acoustic products and how the materials with the highest potential could be used in an acoustic solution.

Two distinct areas of interest characterize this thesis; firstly the material selection and its complexity regarding sustainability and secondly the development of an acoustic concept, *BAUX Flight Mode*, based on the aforementioned selection. The material search and selection process culminated in a list of 90 materials, which was filtered down to 12 materials with the help of a scoring system and later 3 through discussions and further analysis.

The final design proposal, *BAUX Flight Mode*, was based on one of these materials, *Circulose,* which are cellulosic pulp sheets made from textile waste. The concept makes use of these sheets by joining them together and extending them around a wooden billet fastened in a wooden base unit. An important aspect permeating the whole concept being that it is easily assembled and disassembled without the use of any additional parts, as well as being easily recyclable in an existing system.

The conclusion is that the generated design proposal is considered to provide a foundation onto which BAUX can develop a new, sustainable and unique product on the market, while at the same time offering the opportunity to redesign their business model.

Sammanfattning

Allteftersom företag har börjat att ompröva sättet de designar, tillverkar och avyttrar produkter inom ramarna för hållbar utveckling så har tillverkare av akustiska produkter varit långsamma ur startblocken. Majoriteten av akustiska produkter är fortfarande primärt sammansatta av nyråvara från petrokemiska resurser, vilka har en signifikant påverkan på miljön. Det är problematiskt ur både en miljömässig synvinkel, men även ur en affärsmässig, då samhället har börjat att föredra material som passar in i en cirkulär ekonomi. Således kan kunder komma att bryta ner företag baserat på dålig hållbarhetsstrategi och -marknadsföring.

Då det är tydligt att väldesignade akustiska miljöer kan leda till förbättrat välmående, vilket är ett område som har fått ökad uppmärksamhet under senare år, så är det viktigt att akustiska produkter hänger med den nya gröna ekonomin.

Syftet med detta examensarbete var att besvara frågan, ”*Vad är framtiden inom hållbara akustiska material?*”, med antagandet att ett verkligt hållbart material för en akustisk lösning redan finns, men ännu inte har använts i en akustisk produkt. Examensarbetet utvärderar befintliga (eller kommande) material med avseende på miljömässiga egenskaper samt användningspotential i akustiska produkter och hur de materialen med högst potential kunde användas i en akustisk lösning.

Två distinkta intresseområden karaktäriserar detta examensarbete; för det första materialurvalet och dess komplexitet gällande hållbarhet och för det andra utvecklingen av ett akustiskt koncept, *BAUX Flight mode*, baserat på det nyssnämnda urvalet. Materialsökningen och urvalsprocessen kulminerade i en lista bestående av 90 material, vilken filtrerades ner till 12 material med hjälp av ett poängsystem och senare 3 genom diskussioner och vidare analys.

Det slutgiltiga designförslaget, *BAUX Flight Mode*, baserades på ett av dessa material, *Circulose*, vilket är ark bestående av cellulosamassa utvunnen ur textilt avfall. Konceptet använder dessa ark genom att sammanfoga dem och utvidga dem runt en rundstav i trä som är fäst i en basenhet i trä. En viktig aspekt som genomsyrar hela konceptet är att det är enkelt att montera och demontera utan ytterligare delar, samt att det är enkelt att återvinna i ett redan befintligt system.

Slutsatsen är att det genererade designförslaget anses tillhandahålla en grund för BAUX att utgå ifrån i utvecklandet av en ny, hållbar och unik produkt på marknaden, samtidigt som den erbjuder en möjlighet att rita om deras affärsmodell.

Acknowledgments

Firstly, we want to express our gratitude to all the employees at BAUX and Form Us With Love for their engagement and feedback during this thesis. Especially our supervisors at BAUX and Form Us With Love respectively, Fredrik Franzon and Jonas Pettersson, for their assistance, inspiration and invaluable advice.

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Stockholm, May 2020

Anna Andersson and Klas Hellqvist

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Terms and Definitions

Acoustic

Frequency	The number of periods per second in a sound wave, determining the pitch of the sound. Measured in Hertz.
Reverberation	The persistence of sound after the sound is produced. Caused by numerous reflections of a sound wave.
Sound absorption coefficient	A representation of the amount of sound energy absorbed upon striking a particular surface, measured in theory on a scale between 0 and 1 but can in practice be higher.
Sound field	The dispersion of sound energy within given boundaries, e.g. the walls, ceiling and floor of a room.
Sound wave	A longitudinal wave consisting of areas of high and low air pressure.
Soundscape	The acoustic landscape within given boundaries.

Fire properties

Fire resistant	A material that is inherently resistant to catching fire, i.e. self-extinguishing, and does not melt or drip when exposed to extreme heat.
Fire retardant	A material that has been chemically treated to improve its properties regarding fire.

1 Introduction

1.1 Sustainability

In the recent decades, society has reached a widespread consensus about the challenges humanity faces regarding climate change. According to Lee, Markowitz, Howe, Ko & Leiserowitz (2015), a clear majority of people in the developed world are now aware of the change and considers it a serious threat to them and their relatives. This, in turn, is also noticeable in how businesses today operate. Industries have begun to rethink the way they design, make and dispose of products. However, for some lines of businesses this change has come quicker than for others.

In 2015, as a steppingstone towards a more sustainable industry, the United Nations (UN) adopted the *2030 Agenda for Sustainable Development*. It consists of 17 global goals for sustainability, where goal number 12: *Responsible consumption and production* aims to, among other things, promote resource and energy efficiency (United Nations n.d.).

The Sustainable Development Goals Report 2019 released by the UN explains the current progress in frank words; “Shrinking our material footprint is a global imperative” and that “the transition towards sustainable and resilient societies will ultimately depend on the responsible management of the planet’s finite natural resources” (United Nations 2019).

Acoustic products is one line of business where the change towards a more sustainable offer has been slow. Acoustic products are still primarily made out of materials such as mineral- or polymer fibers. The production of these fibers, often based on petrochemical resources, have a significant impact on the environment as they contribute to emissions of carbon dioxide, methane and nitrous oxide (Arenas & Crocker 2010).

Meanwhile, Arenas & Crocker (2010) also points out that as society is moving towards a “green” economy, the concept of environmentally friendly building materials is used in practice in an increasing number of European countries. This, combined with consumers favoring “green” materials (i.e. materials with low emissions, less contaminating processes and preferably made from recycled resources), makes for grim reading for producers of acoustic products.

It is therefore important both from an environmental standpoint, as well as a commercial, that makers of acoustic products focus on researching materials, suitable for acoustic purposes, based on renewable and/or recycled resources contributing to a circular economy. If not, consumers might break companies based on poor environmental strategy and branding.

1.2 The health impact of noise

While the awareness about climate issues is something that has increased in recent decades, the impact of noise on people is an issue that has long gone unnoticed. In the recent years however, this is an area that has got more recognition.

Noise is defined by Johansson (2002a) as sound that is unwanted by the listener. He furthermore describes how noise can damage hearing, be disturbing and tiring, mask conversations and other signals, cause various physiological reactions and cause sleep disturbances.

Lengthy exposure to noise associated with assignments that are affected by the noise has been connected with, among others, higher blood pressure and increased secretion of adrenaline and other stress hormones. Lengthy monotonous noise can also lead to the same effect on attention as fatigue. (Johansson 2002a)

This is the reason why well designed acoustic environments are important. While noisy environments can lead to health problems, quiet environments can lower stress- and blood pressure levels as well as decrease fatigue. Additionally, productivity improves among employees. Improvements of acoustic conditions in office environments have been proven to increase the ability to focus on tasks, decrease error-rates and decrease office-related stress symptoms. (BAUX 2020)

1.3 Purpose of thesis

This thesis is based on the above subchapters 1.1 *Sustainability* and 1.2 *The health effect of noise*. It is clear that well designed acoustic environments can lead to improved wellbeing. However, it is also clear that many current products fail to meet the demands of a sustainability driven society. Hence, for an acoustic product to be truly innovative and competitive in the future market, it has to be sustainable. This necessitates that the material/materials used in the product are sustainable, that the production methods used are sustainable, and so on.

The purpose of this thesis is to answer the question, "*What's next in sustainable acoustic materials?*", with the presumption that sustainable materials for this type of solution already exist but have yet not been applicated in an acoustic product. The thesis will evaluate already existing (or upcoming) materials environmental properties, their applicability in acoustic products and how they can be used in an acoustic solution.

1.4 Delimitations

This thesis is limited to finding already existing or upcoming materials. It does not include developing new materials.

As this thesis aims to primarily research interesting materials from a sustainability standpoint, only basic acoustic theory is used. No calculations to determine a materials acoustic quality were made except for external testing on a few selected materials.

1.5 Limitations

The timeframe for this thesis is 20 weeks which limits any extensive research into specific subareas in order to cover the full project brief.

Due to the pandemic COVID-19, some prerequisites changed during the thesis and therefore further limited the timeframe.

All information found during this thesis is limited to publicly published information or information provided through personal communication.

2 Background

2.1 BAUX & Form Us With Love

This thesis is made in collaboration with the companies BAUX and Form Us With Love (FUWL). The result of the thesis is meant to be usable in the future product development at BAUX but guidance and counseling during the process has been given from both BAUX and FUWL.

FUWL is a design studio based in Stockholm, Sweden. It was founded in 2005 on the belief that we all have the right to meaningful design. They work within the three areas: consultancy, ventures and civic.

BAUX is a company founded in 2013, also based in Stockholm, that develop and sell sound absorbing products worldwide to primarily offices, schools, retail and hotels. See figure 2.1 for examples of client cases. Their business is built around using environmentally friendly acoustic materials to offer a sustainable alternative within sound absorbing products.

Figure 2.1 From left: Stella McCartney store, Houston, USA; Aboriginal Community Centre, Victoria Australia; Opus Business Park, Helsinki, Finland (BAUX n.d.)

The founders of FUWL are also part of the founding members of BAUX, which clarifies the relationship between the two companies. FUWL have also historically been in charge for the product development at BAUX.

The first product launched by BAUX were the *BAUX Tiles*. The tiles consist of wood wool, i.e. long stripes of wood that are bonded together with cement, see figure 2.2. The second product put to market was *BAUX Acoustic Pulp*, that are panels made out of cellulose pulp, see figure 2.3. Both products are sound absorbing and are meant for room acoustics in indoor environments.

Figure 2.2 BAUX Tiles (BAUX n.d.)

Figure 2.3 BAUX Acoustic Pulp (BAUX n.d.)

Even though BAUX are working with sustainable materials today, they are still looking to expand their product line with exciting products, consisting of new and sustainable materials. This, in order to offer a broad variety of acoustic products and create, what they call, *House of Acoustics*.

3 Methodology

3.1 Double Diamond

The Double Diamond is a description of a design process based on divergent thinking and convergent thinking (Design Council 2015). The two diamonds seen to the left in figure 3.1 illustrates the divergent phases *discover* and *develop*, and the convergent phases *define* and *deliver*. The process is not linear since iteration within the stages occurs during the process.

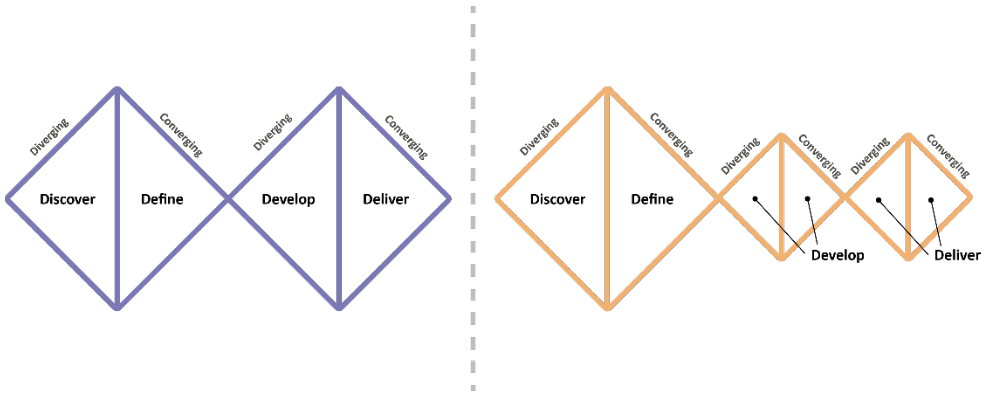

Figure 3.1 Left: the Double Diamond, right: the modified Double Diamond used in this thesis

For this thesis, a modified version of the Double Diamond was used. This, because the project brief includes two areas were, technically, each result within the areas could be presented on its own. The first area is finding sustainable acoustic materials and the second area is to implement the materials found. The two areas are based on each other but could be divided into two projects. Therefore, modifying the Double Diamond made it adapt to this thesis brief.

The modified Double Diamond can be seen to the right in figure 3.1. The area of finding sustainable acoustic materials is done during the first two phases *Discover* and *Define*, and implementing the materials is done during the phases *Develop* and *Deliver*. Because the later stage of implementing the materials follows a design process it was decided to make the *Develop*- and *Deliver*-phases both diverging and converging, thus more closely simulating a design process. More detailed descriptions of each phase are seen below.

3.1.1 **Discover**

Research about the problem is done during the stage *Discover*. In this stage the problem should be understood by doing observations, talking to concerned people and using other explorative methods. (Design Council 2015)

For this thesis, the *Discover*-phase was used for exploring the market of sustainable materials and discovering challenges within the area. It was done by gathering a large amount of information using several different methods.

3.1.2 **Define**

During the stage *Define*, the insight collected during the earlier stage should be defined to a main problem. This is done by sorting and prioritizing the information gathered during *Discover*. (Design Council 2015)

For this thesis, the *Define*-phase was used to create a scoring system from the information gathered during the *Discover*-phase. The scoring system filtered out the materials with the highest potential of being classified as sustainable acoustic materials.

3.1.3 **Develop**

Solutions to the problem are created during the stage *Develop*. This is done by using methods to visualize the users and the problem scenario and then brainstorming solutions as well as prototyping from that. (Design Council 2015)

For this thesis, the *Develop*-phase was both diverging and converging and was used to find solutions on how to implement the materials, filtered out during the *Define*-phase, into a product. The diverging was done by coming up with a large number of ideas and the converging was done by evaluating and defining the ideas.

3.1.4 **Deliver**

Testing and evaluating the solutions is done during the stage *Deliver*. The aim for this stage is to deliver a final product. (Design Council 2015)

For this thesis, the *Deliver*-phase was both diverging and converging to finally deliver a proposed design. The diverging was done by exploring and developing the selected concepts from the *Develop*-phase. The converging was done by finalizing one concept into a more refined design proposal.

4 Theory

4.1 Acoustics

Sound is created by sound waves that, in short, are particles put in motion. The sound waves can have different appearance which affects its characteristics. The appearance of the wave can be described by frequency. Frequency is the number of periods per second and is measured in Hertz [Hz] where a period is the time it takes for a particle to return to its rest position from the same direction, see figure 4.1. (Brandt 1958).

The relationship between frequency and wavelength can be described through Equation (4.1), where c is the wave propagation speed (347 m/s in air), f is the frequency and λ is the wavelength (LTH n.d.).

$$c = f\lambda \tag{4.1}$$

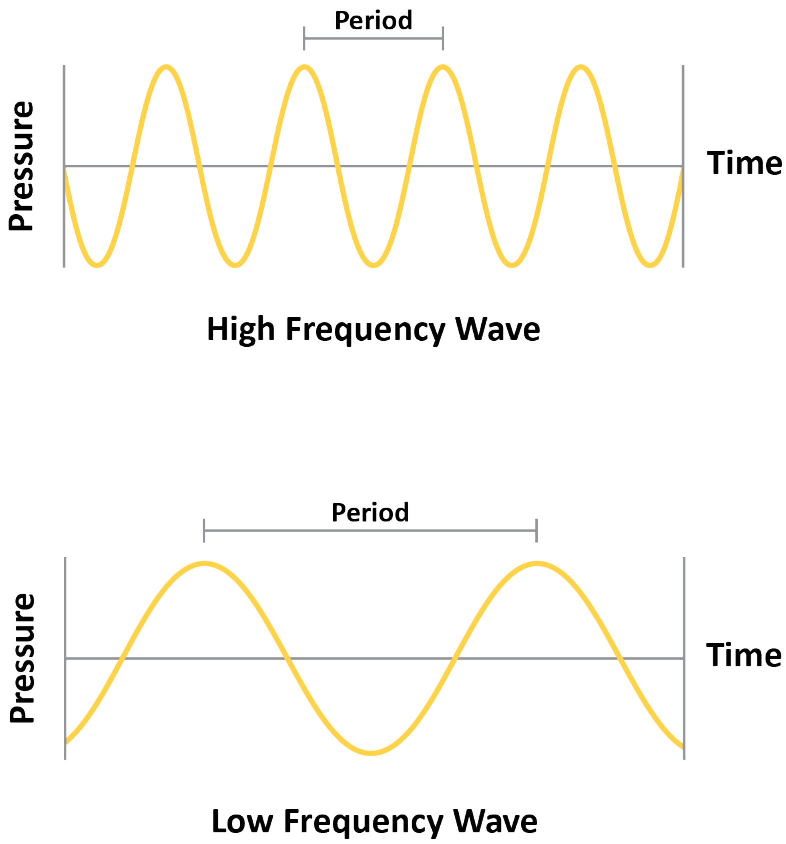

Figure 4.1 High and low frequency waves

Humans can hear frequencies between 20 to 20 000 Hz but the human ear is most sensitive of frequencies between 2,000 and 5,000 Hz (Bernström 1987). This range can be affected by hearing loss, which is a growing public health problem and affect about 15% of the Swedish population according to Hörsellinjen (n.d.). Hearing loss can be hereditary, but it can also occur from environmental factors, age and/or diseases (Hörsellinjen, n.d.). Human speech lays between the frequencies 250-8000 Hz, as seen in figure 4.2.

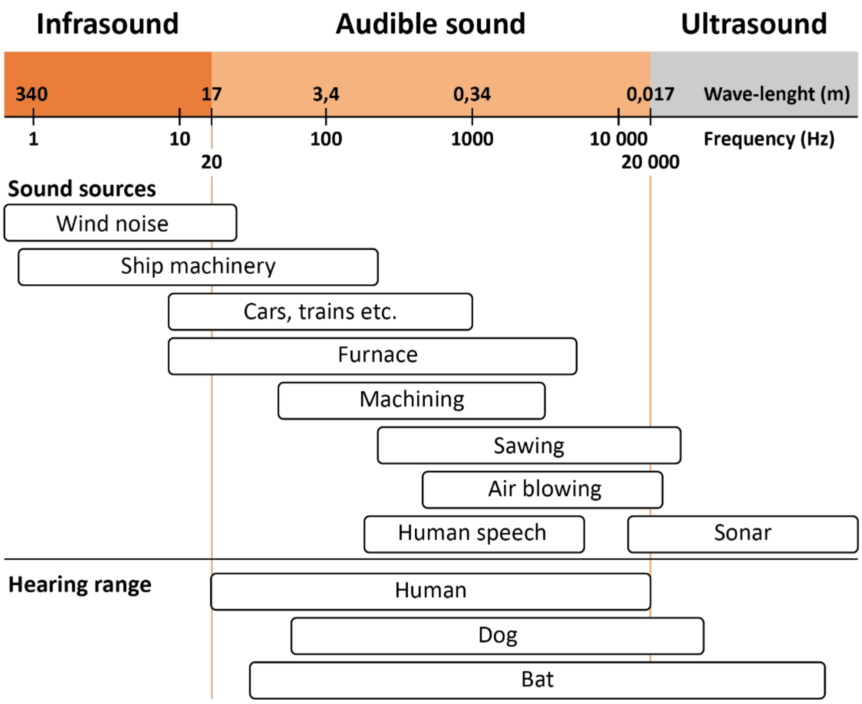

Figure 4.2 Frequencies of common sounds, and hearing intervals (Johansson 2002b, p.21)

Sound can be absorbed, reflected or transmitted when hitting a surface, see figure 4.3. During reflection the sound wave can either be completely reflected, when hitting a flat surface, or scattered when hitting an uneven surface. The uneven surface is called a diffusor. (Cox & D'Antonio 2005)

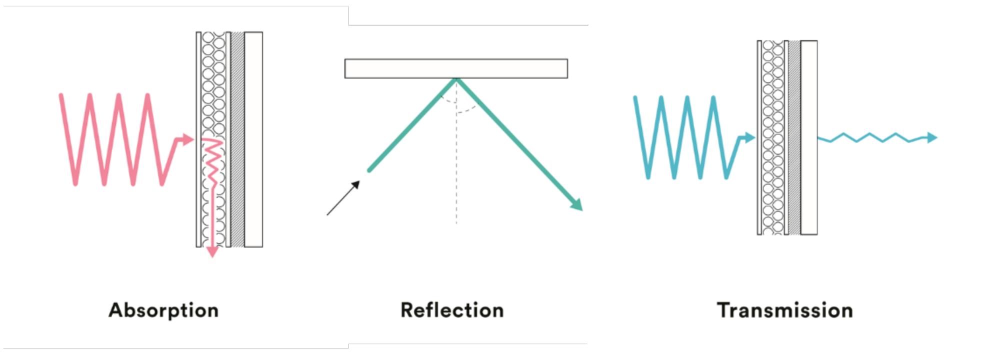

Figure 4.3 Sound absorption, sound reflection and sound transmission (BAUX 2020, p.17)

In this thesis, focus will be on absorbing and diffusing surfaces.

4.1.1 **Sound absorption**

Sound absorption occurs when a sound wave, hitting a surface, is absorbed rather than reflected. The amount of absorption (at a specific frequency) can be measured by the *sound* absorption coefficient, which is defined as "the ratio of the energy absorbed by a surface to the energy incident" (Cox & D'Antonio 2005, p. 9). The absorption coefficient lies between 0 and 1, representing completely non-absorbent and totally absorbing surfaces respectively. Values greater than 1 can be found in measurements but are theoretically impossible. (Cox & D'Antonio 2005)

The method of measuring the sound absorption coefficient of an object or product is described in SS-EN ISO 354, which further explains that measurements shall be made in one-third-octave bands between the frequencies 100 Hz to 5000 Hz (SIS 2003). These measurements can afterwards be used in the calculation of a product's sound absorption classification, which is further explained in the subchapter *4.1.4 Sound absorption classification*.

It is important to note that the efficiency of a sound absorbent does not only lie in the amount of absorption it provides, but also how large of an area that is covered by the sound absorbent(s). For example, a product's sound absorbing efficiency for speech sounds can be evaluated by the single number *N10*. This number is defined as "the number of objects required to obtain 10 square meters effective sound absorption area for speech" (Acoustic Facts 2017) and is calculated by dividing 10 by the sound absorption area at 500 Hz. The sound absorption area being "the area of a perfectly absorbing surface which would absorb the same amount of incident sound as the real object" (ISVR Consulting 2020). Hence, a totally absorbing surface at 500 Hz with an area of 1 m^2 would obtain N10 = 10, while the same surface with an area of 2 m^2 would obtain N10 = 5. This means that the lower N10 is for an object, the fewer objects are needed to achieve the preferred absorption, but it is still entirely achievable with additional objects of a higher N10. (Acoustic Facts 2017)

Depending on what range of frequency that is desired to absorb, there are two different types of sound absorbents; porous absorbers and resonant absorbers.

4.1.1.1 Porous absorbers

Porous absorbers are useful when the goal is to remove mid- and high frequency sounds. This type of absorber admits sound waves into a network of interconnected pores in such a way that viscous losses of energy occurs between the air particles and the material walls. (Cox & D'Antonio 2005)

A porous absorber needs to be placed at a distance from a room boundary where the particle velocity is at its peak, which is at the quarter wavelength position (a wavelength being the distance between two corresponding positions in the wave (NE n.d.)). This would for example be roughly 8,5 cm from the room boundary, such as corners or walls, for a 1000 Hz wave, based on Equation (4.1). This can be achieved by increasing the thickness of the absorber or by simply spacing the absorber away from the boundary with an air gap. The efficiency of a porous absorber is furthermore based on high tortuosity (i.e. high amount of twist within the internal pore structure), high porosity and the amount of flow resistivity (i.e. the resistance that the air flow meets when passing through the material). (Cox & D'Antonio 2005)

4.1.1.2 Resonant absorbers

Resonant absorbers are useful when the goal is to remove low frequency sounds. This type of absorber work through the principle of resonance and involves a mass vibrating on a spring consisting of an air cavity. The two most common types of resonant absorbers, seen in figure 4.4., are the Helmholtz absorber and the membrane absorber. In the case of a Helmholtz absorber, the mass consists of a plug of air in a perforated sheet while the mass in a membrane absorber consists of a sheet (membrane) of material. When the sound waves hit the mass, the mass starts to vibrate. The loss of energy is achieved through damping, e.g. by placing a porous absorbent where the particle velocity is high, i.e. in the neck of a Helmholtz resonator or behind the sheet in a membrane absorber (but not so close as to inhibit movement of the membrane). (Cox & D'Antonio 2005)

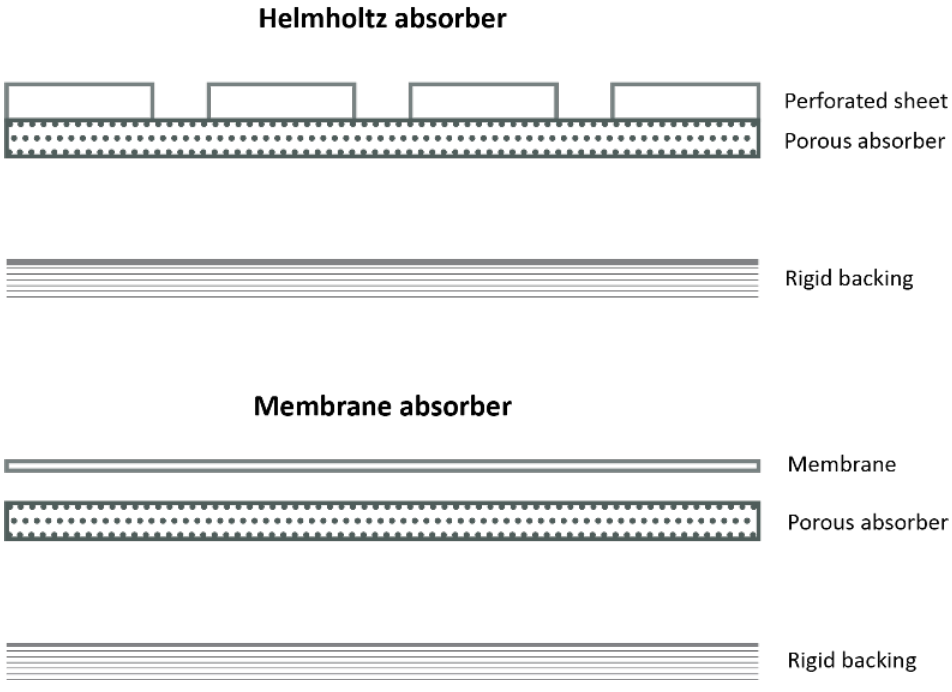

Figure 4.4 Helmholtz absorber and Membrane absorber

Most resonant absorbers are the most effective when placed close to a room boundary. In these areas there are high sound pressure fluctuations which causes the absorbers mass to vibrate, in turn converting the sound pressure fluctuations into air motion. As the mass vibrates, it pushes air through the porous absorber producing low frequency absorption. The most absorbed frequency by the resonant absorber will be the same as the resonant frequency of the device, which can be tuned by changing the mass or the stiffness of the air spring. However, this tuning can be challenging and while basic Helmholtz absorbers can be predicted with reasonable accuracy, other devices are still designed by trial and error. (Cox & D'Antonio 2005)

4.1.2 **Diffusion**

Diffusion is a term that describes the act of breaking up and/or spreading out sound waves in several different directions when reflecting on a surface. This method is preferred when the goal is to conserve the energy of the sound field, while still removing the problem of reverberation. (Cox & D'Antonio 2005).

4.1.3 **Material properties that affect acoustic properties**

Generally, soft and porous materials have good absorption qualities while hard and dense materials have good reflective properties. Heavy, dense materials are often used to block sound since they prevent transmission through the material. (BAUX 2020)

4.1.4 **Sound absorption classification (SS-EN ISO 11654)**

In order to properly classify and compare sound absorbents, a single number is used to convert the frequency dependent values (from measurements in accordance with SS-EN ISO 354) of the sound absorption coefficient. This number, in turn, can be used to obtain a specific sound absorption classification. (SIS 1997)

The single number is called the *weighted sound absorption coefficient* (α_w). This is defined as the "value of the shifted reference curve at 500 Hz" (SIS 1997, p. 4). An example of the calculation of α_w can be seen in figure 4.5. The full reference curve (line with square markings) is translated upwards from the bottom of the y-axis in increments of 0,05 towards the measured values (line with triangle markings) until the sum of negative deviations is less than or equal to 0,10. In this case, this occurs at 250 Hz, which translates to α_w = 0,6. (SIS 1997)

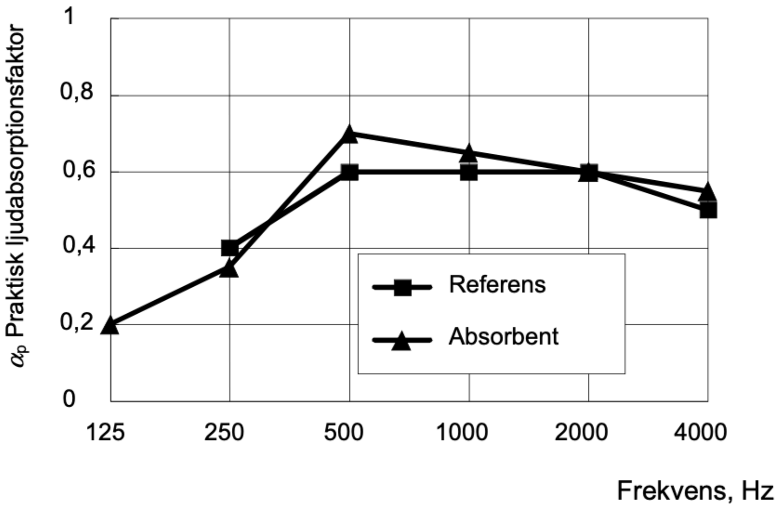

Figure 4.5. Example of calculation of α_w (SIS 1997, p. 7)

This value can in turn be used to calculate the sound absorption class of the absorbent, with the help of table 4.1.

Table 4.1. Sound absorption classes (SIS 1997, p. 8)

Sound absorption class	α_w
A	0,90; 0,95; 1,00
B	0,80; 0,85
C	0,60; 0,65; 0,70; 0,75
D	0,30; 0,35; 0,40; 0,45; 0,50; 0,55
E	0,15; 0,20; 0,25
Unclassified	0,00; 0,05; 0,10

Furthermore, if the measured values exceeds the values of the shifted reference curve by 0,25 or more, shape indicators is added to the α_w-value. The notation *L* is added if the excess absorption occurs at 250 Hz, *M* if the excess absorption occurs at 500 Hz or 1000 Hz, and *H* if the excess absorption occurs at 2000 Hz or 4000 Hz. (SIS 1997).

4.2 Circularity

Circularity is a term that refers to a material economy where resources are retained in a circular cycle, instead of being disposed (burned for energy purposes) after the first use. The Ellen MacArthur Foundation (n.d.) states that "A circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems".

4.2.1 **Recycling**

Recycling is one way to achieve circularity. The idea is to make sure valuable materials are recycled as many times as possible before being disposed of. For materials such as paper and plastic, the number of times the material can be recycled is finite; usually seven times before the molecular chains are too short to provide the desired mechanical properties (Elner Haglund & Nordisk Bioplastförening 2019). For other materials, such as steel, aluminum and glass, the number of times the material can be recycled is infinite (FTI n.d.).

There are two general types of recycling; internal and external. Internal recycling can be described as "the reuse in a manufacturing process of materials that are a waste product of that process" (Encyclopedia Britannica 2020). This process is for example common within the metal industry, where scrap parts and cut-offs are re-melted and recast.

External recycling is defined as "the reclaiming of materials from a product that has been worn out or rendered obsolete" (Encyclopedia Britannica 2020). This is the most recognizable to the general public, where everyday objects such as paper and plastic packaging, aluminum cans and glass bottles are externally recycled on a broad scale.

Regardless of the type of recycling used, the definition of a recycled material is a "material that has been reprocessed from recovered [reclaimed] material by means of a manufacturing process and made into a final product or into a component for incorporation into a product" (SIS 2017, p. 15).

4.2.1.1 Upcycling and Downcycling

The Ellen MacArthur Foundation (2013, p. 25) defines upcycling as "a process of converting materials into new materials of higher quality and increased functionality", as opposed to downcycling which is defined as "a process of converting materials into new materials of lesser quality and reduced functionality".

Downcycling is often used as an end-of-pipe solution, as some materials are not designed to be recycled (Ellen MacArthur Foundation 2013). An example of this is the grinding down of worn-out tires into rubber granules for use in artificial turfs.

The tire has been recycled, but into something of lesser value than the original product.

The goal of upcycling can be explained as “not to minimise the cradle-to-grave flow of materials, but to generate cyclical, cradle-to-cradle ‘metabolisms’ that enable materials to maintain their status as resources” (Ellen MacArthur Foundation 2013, p. 23).

An example of this is the reuse of waste streams in industries, e.g. making felt out of textile cut-offs.

4.2.2 **Biodegradation**

Biodegradation is another form of circularity, whereas an organic chemical compound (material) is aerobically broken down into new biomass, carbon dioxide, water and mineral salts. If anaerobically broken down, it results in new biomass, carbon dioxide, methane and mineral salts. (SIS 2000)

The purpose of biodegradation is that when the material developed from renewable resources is degraded, it releases nutrients that can be incorporated into the growth of new resources (Harris, Staffas, Rydberg & Eriksson 2018). Thus, contributing to a circular system. An accelerated process of biodegradation is composting (Elner Haglund, Nordisk Bioplastförening 2019).

4.2.2.1 Composting

A requirement for compostability is that “it shall have been demonstrated that a material can be biodegraded and disintegrated in a composting system […] and completes its biodegradation during the end-use of the compost” (SIS 2019a, p. 10). This can be achieved through a home-composting facility and/or an industrial composting facility.

The end product, compost, is defined as an “organic soil conditioner obtained by biodegradation of a mixture principally consisting of various vegetable residues, occasionally with other organic material, and having a limited mineral content” (SIS 2019a, p. 9). This includes quality criteria regarding low content of regulated metals, no ecotoxicity and no obviously distinguishable residues (SIS 2019a).

Biodegradable plastics are an example of this, where the plastic can be composted if subjected to a controlled environment regarding humidity and temperature, i.e. an industrial composting facility. (Elner Haglund, Nordisk Bioplastförening 2019)

In Sweden, as of today, industrial composting is not an occurrence. Organic waste is instead anaerobically decayed into methane gas, carbon dioxide and digestate. Other countries have however invested in plants dedicated to industrial composting, such as Italy (Elner Haglund, Nordisk Bioplastförening 2019). This means that for a material to be truly compostable in Sweden, it has to be possible for the composting to be achieved in a home composting facility.

4.3 Materials

4.3.1 **Renewable materials and non-renewable materials**

A renewable material is a "material that is composed of biomass from a living source and that can be continually replenished" (SIS 2017, p. 20). When a virgin material is claimed to be renewable, the source of the material should be replenished in an equal or faster rate than it is being depleted. (SIS 2017)

A non-renewable material is therefore a material that, in opposite to renewable material, is composed of mass from finite sources that cannot be replenished in an equal or faster rate than it is being depleted.

The benefits of using renewable materials compared to non-renewable materials is that renewable materials have absorbed carbon dioxide during growth and therefore acts as carbon trap during their life span. When the materials later are disposed, they do not contribute to net emissions of carbon dioxide like non-renewable materials do. This also means that the recycling of renewable materials will, in the long run, lead to less fossil carbon dioxide in the atmosphere since the recycled renewable materials will partly replace all types of virgin materials. (Harris et al. 2018)

4.3.1.1 Bio-based plastic

Plastic materials are today mainly produced of finite fossil-based resources, but the sector of plastics produced of renewable biomass is growing. A bio-based plastic can be completely or partly made from biomass and it can be biodegradable or unbiodegradable. Bio-based plastics that have the same chemical composition as a plastic made from fossil resources is called a *drop-in* plastic. (Cefur 2016)

Biodegradable plastics should not be recycled in Swedish recycling facilities today. If it is recycled together with other plastics it will degrade the quality of the recycled material. (Hållbara plastmaterial 2018)

Ensuring the quality of recycled plastics is a challenge, both for fossil-based and bio-based plastics. The goal is to get pure recycling streams of plastic with good quality without higher levels of impurities. Good quality refers to the plastic being recyclable without losing larger elements of its technical properties, unlike biodegradable plastics that are produced to degrade. The growing market of bio-based plastics leads to many new challenges in how to achieve these pure recycling streams and how to ensure the quality of the recycled plastic. (Cefur 2016)

4.3.2 **Composite materials**

Composite materials exist of fibers and a matrix material as a binder. The fibers can come from different sources depending on the desired material properties and often add strength to the material or reduce the weight. (Svensk Kompositförening n.d.)

Composite materials may need to be separated in order to be recycled. This cannot be done in regular recycling streams but must be done separately, which is an obstacle when recycling composite materials. (Hållbara plastmaterial 2018)

4.3.2.1 Bio composites

A bio composite is a composite material where at least one of the elements are bio based. (Bio Innovation n.d.)

4.4 Fire regulations

A requirement for materials mounted on walls and/or ceilings is that they must fulfill certain fire regulations since they are classified as construction products or building elements. These regulations are described in the paragraph below. If the material is used in interior, it is generally not regulated on the same level regarding fire safety. For mattresses and upholstery, there are a European standard regarding fire regulations but for most other interior products in Sweden, there are only recommendations regarding fire safety. (Sundström, Bengtson, Olander, Larsson & Apell 2009)

The European standard SS-EN 13501-1:2019 is used for classifying construction products and building elements regarding their fire properties. The classification ranges between the classes A1 to F and have two subcategories; smoke classification and drip classification. The classification is based on the products reaction to fire tests that are executed in accordance with the European standard SS-EN 13823:2010+A1:2014. See Appendix B for a description of each class.

Table 4.2 shows examples of various materials and their corresponding fire class. (Träguiden 2015)

Table 4.2 - Fire classification according to SS-EN 13501-1:2019

Fire class	*Smoke class*	*Drip class*	*Example of material*
A1	-	-	Stone, glass, steel
A2	s1, s2 or s3	d0, d1 or d2	Plasterboard (thin paper), mineral wool
B	s1, s2 or s3	d0, d1 or d2	Plasterboard (thick paper), fire proofed wood
C	s1, s2 or s3	d0, d1 or d2	Wallpaper on plasterboard, fire proofed wood
D	s1, s2 or s3	d0, d1 or d2	Wood and wood-based boards
E	-	- or d2	Some synthetic materials
F	-	-	No fire class determined

5 Discover

5.1 Methods

5.1.1 **Interviews**

Interviews were used in this thesis as an efficient way to gain deeper knowledge and understanding about specific topics relating to the thesis from experienced people in these fields.

Kahn and Canell (1957, see Preece, Sharp & Rogers 2015, p. 233) describes an interview as a "conversation with a purpose", which can be used to illustrate the way interviews were conducted throughout the thesis. All interviews during the *Discover*-phase were executed as *unstructured interviews*, i.e. exploratory interviews concerning a specific topic. Unstructured interviews provide rich data giving a deeper understanding of the topic, while also creating the opportunity for the interviewee to mention unconsidered issues (Preece, Sharp & Rogers 2015). For every interview, an agenda was written beforehand to ensure the main topics being covered.

5.1.2 **Literature studies**

Literature studies means browsing published information such as books, journals, and reports. It is a fertile source for gaining knowledge. (Ulrich & Eppinger 2012)

5.1.3 **Desktop research**

Desktop research means searching for electronic information found on the internet by using keywords. This includes searching on relevant databases. It is an efficient method to gather information, but it comes with some challenges. It can be hard to validate the quality of the information and it depends upon the use of good key words. It is also often required to make tradeoffs in order to limit the search. (Ulrich & Eppinger 2012)

5.1.4 **Benchmarking**

Benchmarking means to study existing products with similar properties and functions in order to find solutions to a problem or to look at strengths and weaknesses of those products. It can also be used to find gaps in the market where there are opportunities for new products to launch. (Ulrich & Eppinger 2012)

5.1.5 **Study visits**

Study visits means visiting places and corporations that are connected to the concerned area of interest. It can provide inspiration and a context that increases the understanding.

5.2 Internal Research and Results

5.2.1 **Interviews**

The internal interviews during this phase were conducted with key employees at FUWL and BAUX. Interviewees consisted of people presently and/or formerly involved in the product development of BAUX. The conversations were held with the purpose of painting a broader picture of BAUX vision and current offer, divided into a set of predetermined topics:

- Future product strategy
- Aesthetics
- Business model
- Design process
- Product requirements
- Material requirements
- Customer requirements
- Former ideas/concepts
- Scalability

Information from these conversations was used to create a greater understanding of the project brief and a foundation of knowledge needed for the thesis. Furthermore, wishes and demands from the different employees were compiled and used in the original design specification, found in the subchapter *5.5.2 Design specification*.

5.3 External Research and Results

5.3.1 **Literature studies**

Literature studies were conducted to absorb a basic knowledge about acoustics and in-depth knowledge about circularity and material definitions. The result from these literature studies has previously been accounted for in the chapter *4 Theory* in the report.

5.3.2 **Interviews**

5.3.2.1 RISE – Research Institutes of Sweden – Ann Marie Zachrisson

Early on during the thesis a meeting was scheduled with Ann-Marie Zachrisson, Project Leader at Research Institutes of Sweden (RISE), whose expertise lies in new bio-based materials. Also attending was Ann Lorentzon, Project Manager at RISE. The focus of the conversation was potential materials suitable for this thesis and to obtain valuable theoretical input about material properties and difficulties when developing new materials.

This interview led to a number of insights. Primarily the idea that an acoustic product is not demanding much from its material, except for the acoustic properties themselves, which Ann-Marie Zachrisson[1] means enables broader possibilities compared to applications that have higher functional- and strength requirements. Information acquired from this interview was also a number of websites, such as material databases as *Material District* which is a match-making platform in the field of innovative materials.

5.3.2.2 Materialbiblioteket – Björn Florman

Materialbiblioteket is a permanent showroom of materials open for creative professionals, such as designers and product developers. A meeting was held with Björn Florman, Creative Project Manager at Materialbiblioteket, to discuss materials that are interesting for our thesis as well as his take on sustainability and future material trends.

Florman[2] believes that producing products that can be recycled is the most sustainable choice based on how the Swedish society looks today. Sweden does not have any system to take care of biodegradable materials which leads to them being

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[1] Ann-Marie Zachrisson, Project Leader at RISE, interview the 31st of January 2020.

[2] Björn Florman, Creative Project Manager at Materialbiblioteket, interview the 12th of February 2020.

incinerated for energy purposes instead. Circularity should therefore be preferred because the materials can be recycled several times before being discarded and/or incinerated. It extends the life span of the material and minimizes the use of virgin materials. Florman did also point out that, in his opinion, bio composites should not be seen as a way of minimizing the use of plastics (by diluting it with an added bio based fiber) but instead a way of replacing the use of fibers from finite resources to strengthen a material.

A conclusion drawn from this interview, was that materials that;

- can be placed in a circular loop through recycling, and/or
- are made out of waste-/recycled materials,

are superior sustainability-wise compared with biodegradable materials due to the current waste management systems in Sweden.

5.3.3 **Study visits**

5.3.3.1 Prototypa – BMW Group – Renzo Vitale

On February 5th 2020, the design platform Prototypa organized a lecture where Renzo Vitale, Acoustic Engineer at BMW Group, presented his process when designing sound for electrical vehicles. This lecture was attended to obtain insights into a design method specific for acoustics and soundscapes. The result being inspiration from the different style of process and insight into how people experience sound and the playfulness connected to it.

5.3.3.2 Studio B3

A visit to *Studio B3* in Stockholm was made in order to gather insights, inspiration and tactile experience of materials. *Studio B3* is a showroom for both furniture and materials.

5.3.3.3 Materialbiblioteket

During the interview with Björn Florman, a tour of *Materialbiblioteket* was conducted, where close to 3000 material samples are available for exploration.

5.3.4 **Benchmarking**

5.3.4.1 Stockholm Furniture Fair 2020

Between February 4th and February 8th, Stockholm Furniture Fair was organized at Stockholmsmässan in Älvsjö. In preparation for the fair, a list of 72 interesting companies, such as competitors, material producers and -suppliers, was compiled and later visited. This in purpose to get inspiration and a better understanding of products already on the market.

A reoccurring similarity between competitive products at the fair was the combination of mineral wool, such as rock wool or glass wool, covered with textile made of polyethylene terephthalate (PET) or sheep wool.

It was noted that sustainability is an upcoming factor of interest for producers of acoustic products as many companies were marketing new products with elements of recycled or renewable materials.

5.3.4.2 Kinnarps

Kinnarps is one of Europe´s largest producers of furnishing solutions for offices, schools as well as health and social care. They have a clear focus on environmental and social responsibility, best illustrated by their sustainability index *The Better Effect Index*. Their index is constructed out of six areas of sustainability; *Raw Material and Resources*, *Climate*, *Pure Materials*, *Social Responsibility*, *Reuse* and *Ergonomics*. (Kinnarps n.d.)

Within the category *Reuse*, Kinnarps proceeds to grade the sub-areas *Possibility to recycle material* and *Made out of recycled material*. Their best scoring sound absorbent within this area is *Prim*, which is built with their own core material *Re:Fill*. *Re:Fill* is made from PET, where 50 % of the raw material used is recycled. The core is covered with a fabric made out of 75 % wool and 25 % polyamide. The materials in *Prim* are between 76-100 % recyclable. (Kinnarps n.d.)

Kinnarps does not disclose the absorption coefficient of their products, however they state that *Prim* has one of the market's best absorbance values according to tests conducted by Acoustic Facts (Kinnarps n.d.). When reviewing the results on Acoustic Facts website it can, with the help of Equation (5.1) where α_s is the sound absorption coefficient, m^2Sabin_{500Hz} is the equivalent sound absorption area of the test specimen at 500 Hz and A is the area of the test specimen (SIS 2003), be calculated that its absorption coefficient at 500 Hz equals 1,59 (Acoustic Facts 2014).

$$\alpha_s = m^2Sabin_{500Hz} / A \qquad (5.1)$$

5.3.4.3 Ecophon

Ecophon, a part of the Saint Gobain Group, is a producer of acoustic systems based in Hyllinge, Sweden with operations in 14 countries. (Ecophon n.d.)

Ecophon's products consists of a core material made out of glass wool, where at least 70 % of the glass used in every absorbent is recycled glass. This core material is covered with a surface consisting of paint, fabric or a film material. Over 20 % of the metal used also comes from recycled resources. Most of their products are marked as completely recyclable. (Ecophon n.d.)

Most of Ecophon's products reach a sound absorption class of A, indicating a weighted sound absorption coefficient of 0,9-1,0. (Ecophon n.d.)

5.3.4.4 Götessons

Götessons is a company that develops and manufactures products for offices, conference buildings and hotels. Their acoustic product range *Screen IT* is *Svanen*-certified, a Nordic ecolabel that puts high requirements regarding raw materials and chemicals used in furniture. (Götessons n.d.)

Götessons has their own core material called EcoSUND which is made from 50 % recycled PET and 50 % virgin PET. This core can, but does not have to be, covered with a fabric. (Götessons n.d.)

Honey EcoSUND is a wall absorbent from Götessons made with this core material which has a weighted sound absorption coefficient of 0,95. (Götessons n.d.)

5.3.4.5 Gustafs

Gustafs describes themselves as a leading manufacturer of sophisticated wooden interiors for public environments, where wood facing of walls and ceilings is their specialty. Their range of acoustic panels are of the resonance absorbent-type. (Gustafs n.d.)

Gustafs acoustic panels are made out of fiber reinforced gypsum totaling 94 % recycled gypsum of which 17 % is post-consumer recycled. These boards are covered with wooden veneer, while mineral wool and acoustic felt is inserted between the outside panel and the wall. (Gustafs n.d.)

The acoustic panels range between sound absorption classes of B-D, depending on the type of slots used in the veneer. Due to using the Helmholtz absorber type, the best performance occurs in the frequency range of 250-1000 Hz. (Gustafs n.d.)

5.4 Material search

5.4.1 **Desktop Research**

In order to gather a wide array of materials, a desktop research was conducted without any specific rules constraining the search. Different sources were used, such as books of materials, search engines and material specific websites. Materials that were considered to be of interest were those seeming to be somewhat sustainable and applicable for sound absorption based on the gained knowledge during the literature studies and research.

5.4.2 **Categorization**

The materials found during the search were recorded into an Excel-sheet. Basic information about each material was inserted in the sheet with the goal of constructing a searchable and filterable list of materials. The information inserted about each material was the following:

- Material name
- Type of material
- Supplier
- Acoustic application
- Virgin/Recycled content

See Appendix C for the full list.

The purpose of inserting type of material was to group similar materials and to give an overview of what kind of material it is. An example of the different material groups used here is plastics, bio-composite, wood, textile etc.

Under acoustic application, each material was categorized based on what kind of acoustic properties the material was estimated to have. For example, if it is a porous material it was estimated to be most suitable to use as a porous absorber. The estimations were based on the knowledge gained during the literature studies and research.

The content in each material was inserted into the sheet as accurately as possible with the information found. The content was divided into virgin content and recycled content since the research and earlier studies shows how it plays an important role in how sustainable a material is. Where information was not found, estimations were done based on the knowledge gained during the research. A category named unknown binder or unknown bio-binder were inserted as many of the materials lacked information about their binders. Through this way some indication of the complete content could be achieved.

The material list has been used in a dynamic way were new materials and information has been recorded or updated during the thesis. The last change occurred 2020-05-22.

5.5 Summary Discover

5.5.1 **Summary internal and external research**

The *Discover*-phase provided a great amount of information and new insights. The internal interviews established a clear picture of what the most important properties for a BAUX-branded material and product are. The external research provided basic knowledge in acoustics as well as a good understanding of circularity regarding materials. Circularity was also discussed during the external interviews which led to a deeper understanding of the complex process that is designing for sustainability.

The benchmark laid a foundation for the following work during the *Define*-phase. It provided inspiration and a good knowledge of the market of acoustic products. It is clear that the market is struggling with combining good acoustic results with sustainable materials. Many competitors use materials containing partly recycled content, but they often combine these with other materials, probably in order to achieve a better sound absorbent classification, for safety reasons or to increase the aesthetics. This can complicate the product's recyclability. Benchmarking reveals that BAUX is one of few companies using uncovered materials and that their product, *Acoustic Pulp*, is unique in using only a single sustainable material. It also confirms that this is the way to go for BAUX in order to retain a strong environmental profile.

5.5.1.1 Design specification

Information gathered during the *Discover*-phase was evaluated, discussed and compiled into an initial design specification, which is presented below in the table 5.1. It contains basic requirements of the desired material within four important categories.

Table 5.1 Design specification

		Class			Class
Technical requirements			***Sustainability***		
Be (at minimum)	Fire class EUR D	D	Allow	For certification	D
Withstand	Moisture	N	Be	Honest / Uncovered	N
Be	UV resistant	N	Encourage	Circularity	N
Be	Durable/Strong	N	Be	Locally produced	D
Have	Low weight	D	***Scalability***		
Have	Appropriate surface	D	Allow	Large production scale	N
Resist	Mold/bacteria	N	Exist	Production today	D
Be	Cleanable	D	***Acoustic requirements***		
Allow	Assembly	N	Be	Sound absorbing or diffusive	N
Simplify	Assembly	D	Be (at minimum)	D-absorbent	N
Resist	Corrosion	N	Offer	Variability	D
Have	Long life	D			
Withstand	Lighter impacts	N			
				N – needed	*D - desired*

5.5.2 **Summary material search**

The desktop research resulted in 90 (as of 2020-05-22) materials being listed. The amount of information available about each material varied significantly and sometimes complicated the task of recording the content of a material in the Excel-sheet mentioned in the subchapter *5.4.2 Categorization.* The sheet was still deemed a sufficient and effective tool to use throughout the thesis because of its ability to filter and provide a good overview of the materials.

6 Define

6.1 Methods

6.1.1 **Material Scoring system**

In order to differentiate between the listed materials from the material search, a rating system was implemented. This was loosely based on the method of *concept scoring* by Ulrich and Eppinger.

Because the rating system was to be applied on a list of materials, rather than different concepts, it had to be revised in a way so to best compare the material properties. Another significant change was that the step of combining and improving concepts was not applicable, as the materials were to be rated individually.

The method of *concept scoring* as developed by Ulrich and Eppinger (2012) is divided into six steps and, in short, is described in table 6.1. next to the final thesis specific scoring system.

Table 6.1. Side by side comparison of *Concept Scoring* (Ulrich & Eppinger 2012) and *Material Scoring*

Steps	*Concept Scoring (U & E)*	*Steps*	*Material Scoring (Thesis)*
1	Prepare the Selection Matrix • *Prepared with a reference concept used for comparison* • *Selection criteria chosen and added* • *Importance weights added*	*1*	Prepare the Selection Matrix • *Prepared with the design specification used as foundation* • *Selection criteria (sustainability and production) chosen from design specification and added* • *Grading system constructed, specifically designed to compile ratings for each of the selection criteria groups into one grade:*
2	Rate the Concepts • *Each criterion is rated on a suggested scale from 1-5 where:* *1. Much worse than reference* *3. Same as reference* *5. Much better than reference*	*2*	Complete Information on Materials • *Each criterion is filled in with information provided from material websites* • *Some text based, some score-based*
3	Rank the Concepts • *Scores calculated by multiplying raw scores by importance weights*	*3*	Material Grading • *Grades for each material calculated for the two criteria groups*
4	Combine and Improve the Concepts • *Changes and combinations of concepts in order to make improvements*		
5	Select One or More Concepts • *Initial evaluation explored by varying weights and ratings* • *Top concepts are chosen for further development*	*4*	Select One or More Materials • *Initial evaluation explored by varying grading systems, to determine effect on ranking* • *Passing materials selected for further discussion and development*
6	Reflect of the Results and the Process • *Making sure selected concept(s) have the greatest potential* • *Evaluating criteria, weighting and application*	*5*	Reflect on the Results and the Process • *Making sure selected material(s) have the greatest potential* • *Evaluating criteria, grading system formulas and applications*

Example snippets of the two different systems can be found in figure 6.1. and 6.2. The thesis specific scoring system (*Material Scoring*) is explained in more detail in the subchapter *6.3 Material Scoring*.

		Concept							
		A (Reference) Master Cylinder		DF Lever Stop		E Swash Ring		G+ Dial Screw+	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Ease of handling	5%	**3**	0.15	3	0.15	4	0.2	4	0.2
Ease of use	15%	**3**	0.45	4	0.6	4	0.6	3	0.45
Readability of settings	10%	2	0.2	**3**	0.3	5	0.5	5	0.5
Dose metering accuracy	25%	**3**	0.75	3	0.75	2	0.5	3	0.75
Durability	15%	2	0.3	5	0.75	4	0.6	**3**	0.45
Ease of manufacture	20%	**3**	0.6	3	0.6	2	0.4	2	0.4
Portability	10%	**3**	0.3	3	0.3	3	0.3	3	0.3
	Total Score	2.75		3.45		3.10		3.05	
	Rank	4		1		2		3	
	Continue?	No		Develop		No		No	

Figure 6.1. Concept Scoring matrix (Ulrich & Eppinger 2012, p. 154)

Name		Sustainability							Production Info			
Material Name	Type of Material	Pure material	Recycled	Finite resource (non-recycled, non-binder)	Renewable / Biobased	Recyclable (100 % today)	Origin	Sustainability Score	Scale (today)	Scaleability (future)	Price	Production Score
Moniflex	Plastic	Yes	0	No	2	Industrial compost	Nordic	OK	Off the shelf	Scaleable	3	EXCELLENT
Circulose	Textile	Yes	3	No	3	Internally	Nordic	GOOD	Off the shelf	Scaleable	3	EXCELLENT
Swedish Wool	Textile	Yes	0	No	3	Internally	Nordic	GOOD	Innovative	Scaleable	2	GOOD

Figure 6.2. Material Scoring matrix

6.1.2 **Interviews**

All interviews during the *Define*-phase were conducted as semi-structured interviews, i.e. interviews with both closed and open questions. Semi-structured interviews are supposed to be somewhat replicable in order to cover the same topics with several interviewees (Preece, Sharp & Rogers 2015). For every interview, an agenda was written beforehand to ensure the main questions being covered.

6.1.3 **Brainstorming**

Brainstorming is a method used to generate a large number of ideas in a short period of time. This is a specific method which aims to stimulate its participants creative potential by hearing and seeing others' ideas. Since the goal is to find something completely original among the developed ideas, there are certain specified ground rules to adhere to. These are as follows: Do not criticize any ideas, aim for crazy and wild ideas, combine and improve the ideas and aim for quantity before quality. Except for the above rules, the method of a brainstorming session can be infinitely adjusted. (Wikberg Nilsson, Ericson & Törlind 2015)

In the case of the *Define*-phase, brainstorming was used as a method during a workshop. A set of material-specific questions were constructed in order to stimulate the participants to come up with design ideas fitting the subject material.

6.2 Extended research and results

6.2.1 **Interviews**

The following interviews were conducted with material experts and/or company representatives in order to obtain knowledge about specific materials and their opportunities as well as difficulties.

6.2.1.1 Plastics – Katarina Elner Haglund

An interview was held with Katarina Elner Haglund, External Communicator at Nordisk Bioplastförening and Lecturer at Lund University, to discuss bio-based plastics.

From this interview it was deduced that the most sustainable plastic to use for this kind of product would be a 100 % bio based drop-in plastic and/or recycled plastic. This is because of the durability and the long lifespan of acoustic products. Elner Haglund[3] believes that biodegradable plastics should rather be used for products with a short life span, i.e. dirty packaging, that are hard to recycle. This is all based on the current possibilities for recycling in Sweden where biodegradable plastics are yet not recyclable. Therefore, using plastic that can be recycled and/or comes from recycled plastic is the most suitable for achieving circularity.

Elner Haglund suggested expanding plastic in some way to obtain a more porous, and possibly sound absorbent material.

6.2.1.2 Organoclick – Dan Blomstrand

Organoclick is a current supplier of material for and producer of BAUX Acoustic Pulp. A meeting was booked with Dan Blomstrand, VP Biocomposites. The purpose of this meeting was both to get a deeper understanding of the development process

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[3] Katarina Elner Haglund, External Communicator at Nordisk Bioplastförening and Lecturer at Lund University, interview the 11th of February 2020.

behind Acoustic Pulp, as well as gain insight into potential new materials developed by Organoclick.

Blomstrand[4] explained that an innovative material must fulfill three factors – price, function or sustainability – where the driver of the price is often cycle time to produce the product. The longer the material takes to manufacture, the more expensive the material becomes.

Regarding sustainability, he had a couple of key insights. Blomstrand explained that first and foremost the life span for a material is what matters the most when aiming for sustainability. Another insight was that a bio-based flame retardant is necessarily not equivalent to a sustainable flame retardant as some bio-based substances can still be harmful to the environment. He also mentioned that non-woven materials that utilizes fossil-based binders might not be the way to go as the European Union (EU) is considering putting limitations on products that cannot be recycled. As almost exclusively all non-woven materials contain a fossil-based binder, it is not biodegradable in a home compost, and hard to recycle as the binder needs to be separated during the recycling process.

While discussing the existing pulp material used in BAUX Acoustic Pulp, Blomstrand mentioned that a big problem with recyclability in a closed loop is the aesthetic in the "new" material. If Organoclick were to put old products back in the loop, they cannot guarantee the look and color of the new ones, which has been, thus far, a strong demand from customers. A key factor regarding Acoustic Pulp was also covered, that it contains a unique biobased binder which is cross-link cellulose in a matrix of covalent bonds, hence making the recycling process easier.

6.2.1.3 Reelab – Kristin Nilsson

A telephone interview was conducted with Kristin Nilsson, Co-owner of Reelab. Reelab is a recycled polymer-supplier. The aim of the interview was to gain a deeper understanding of opportunities and difficulties in using recycled plastic for new products.

Nilsson[5] mentioned that there are not really any limitations on processing recycled plastics. The limitation rather lies in the requirements of the product containing recycled plastic. It can also be tracked back to the people processing the plastic not being familiar with the use of recycled plastic as a raw material.

When discussing the origin of plastics and the limitations of the material, Nilsson mentioned that it is possible to trace the country origin of the material they provide and to make sure it does not contain anything harmful. What type of plastics that

[4] Dan Blomstrand, VP Biocomposites at Organoclick, interview the 20th of February 2020.

[5] Kristin Nilsson, Co-owner of Reelab, telephone interview the 24th of February 2020.

can be found differs depending on the country of origin. It might also be possible to trace the old plastic even further if desired by the customer. Regarding limitations, Nilsson[6] mentioned that only a few sorting facilities sort out plastic based on color because of the cost. Therefore, because several colors often are mixed in the recycling process, the cheapest and most common colors obtainable are black and dark grey.

6.2.1.4 Ragn-Sells – Lars Tolgén

A telephone interview was conducted with Lars Tolgén, R&D Project Leader at Ragn-Sells and Secretary at Ragnar Sellbergs Stiftelse. Ragn-Sells is a company within the environment and recycling industry. The aim of the conversation being to discuss waste streams and unexplored opportunities regarding recycled materials.

Tolgén[7] described that a big challenge of today is not if materials can be recycled, but rather if the materials are made from recycled material originally. He also mentioned that another big issue is not creating new ways of recycling, but rather to implement them and to change people's behavior, as this is expensive and takes a lot of time (about 17 years, maybe faster). In Tolgén's opinion it is too cheap to get rid of materials at the end of a life cycle and it should be made more expensive to buy virgin materials or to dispose of "trash material".

Regarding flame protection, it is according to Tolgén challenging to recycle materials treated with flame retardant, but not impossible. He suggested that companies making flame retardants should be interested in taking their product back at the end of the life cycle.

6.2.1.5 Rondo Plast – Fredrik Holst

A telephone meeting was conducted with Fredrik Holst, Product Manager at Rondo Plast AB. Also attending was Johan Svenmo, Technical Service at Polykemi AB. Rondo Plast/Polykemi are manufacturers of plastic compounds in the form of granulates. The purpose of this interview was to gain a deeper understanding of the production methods available when using recycled plastic and the optimal production methods for developing acoustic properties.

Holst and Svenmo[8] explained that Rondo Plast can offer recycled compounds where they mainly buy their recycled plastic from industries, e.g. faulty parts, cut-offs and other waste. For the recycled compounds, they offer only black or dark grey colors

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[6] Kristin Nilsson, Co-owner of Reelab, telephone interview the 24th of February 2020.

[7] Lars Tolgén, R&D Project Leader at Ragn-Sells and Secretary at Ragnar Sellbergs Stiftelse, telephone interview the 19th of February 2020.

[8] Fredrik Holst, Product Manager at Rondo Plast AB and Johan Svenmo, Technical Service at Polykemi AB, telephone interview the 28th of February 2020.

since the recycled plastic they use for the compounds often come in mixed colors. It makes it challenging to attain compounds with lighter colors, but this is something they say might change in the future.

The compounds they manufacture are most often used for injection molding. During injection molding, the plastic can be expanded through implementation of additives, however, Holst and Svenmo[9] explained that this will create a closed cell structure.

6.2.1.6 Mälarplast – Peter Wall

A telephone interview was conducted with Peter Wall, CEO at Mälarplast AB. Mälarplast is a supplier and manufacturer of thermo- and thermosetting plastics. This interview covered similar topics as the interview conducted with Rondo Plast.

Wall[10] had some new insight regarding the use of flame retardants. He mentioned that a difficulty is that, apart from making it harder to recycle the plastic again, the recycled material might contain substances that affect the flame retardant as it is not possible to be sure where it comes from.

Wall also explained that, because of traceability-issues, Mälarplast has started a leasing model where they lease dining plates. Because of this model they can recover the plates and replace them when they have worn out. This way they can recycle their own material and therefore has created a closed loop system.

His spontaneous idea for using recycled plastics in acoustics products is to use softer materials that are less dense. Or to shred old plastics and use a laminate to get a nicer surface.

6.2.1.7 Re:newcell – Jenny Fredricsdotter

A meeting was conducted with Jenny Fredricsdotter, Circular Business Manager at Re:newcell. Also attending was Harald Cavalli-Björkman, Chief Marketing Officer. The meeting was set up to discuss the properties of their recycled textile material Circulose.

Fredricsdotter and Cavalli-Björkman[11] described that Circulose contains 99,6% cellulose and is an alternative to cotton. The raw material used for Circulose is cutting waste and cotton textile waste from different sorting facilities. The raw material is transformed into pulp and processed into thin sheets. These pulp sheets are then sold to manufacturers of viscose that can use Circulose instead of virgin

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[9] Fredrik Holst, Product Manager at Rondo Plast AB and Johan Svenmo, Technical Service at Polykemi AB, telephone interview the 28th of February 2020.

[10] Peter Wall, CEO at Mälarplast AB, telephone interview the 3rd of March 2020.

[11] Jenny Fredricsdotter, Circular Business Manager at Re:newcell and Harald Cavalli-Björkman, Chief Marketing Officer at Re:newcell, interview the 11th of March 2020.

raw material to make viscose fibers. The end fiber has the same quality as when using virgin raw material.

For this thesis, the interest laid in using the pulp sheets without processing them into fibers.

Circulose is in production today, primarily for the fashion industry, with plans of expanding production within the next few years. Their material is low cost as it is a raw material intended for further processing into fibers. Fredricsdotter and Cavalli-Björkman[12] suggested using their cutting waste or secondary pulp sheets that do not meet the requirements for further processing for an acoustic product. This would essentially mean that the pulp sheets could be considered a recycled recycled material.

6.2.1.8 Fraunhofer Institute for Wood Research – Steffen Sydow

Mail correspondence was conducted with Steffen Sydow, Project Leader at Fraunhofer Institute for Wood Research to discuss the properties of their material Wood Foam. Wood Foam is a light wood-based material with an open-pore texture made up of finely ground wood (or non-wood lignocelluloses such as hemp or straw).

Sydow[13] described that Wood Foam is still under development, as they are looking for a company that can produce the material commercially. It is intended that the material should be low cost and possible to process like other wood based materials. Wood Foam comes in flats/boards and can be produced in different sizes and densities. The fibers can also be colored.

Initial testing, according to Sydow, indicates that Wood Foam is a sound absorbent material and would fulfill the requirements of fire class D. The fire retardance of Wood Foam, Sydow explained, can be increased through the use of biomasses with high silica content. However, this would increase the wear on the production equipment.

6.3 Material Scoring

A material scoring system (as described in 6.1.1 *Material Scoring system*) was used in order to narrow down the list of materials and only keep the ones with the highest

[12] Jenny Fredricsdotter, Circular Business Manager at Re:newcell and Harald Cavalli-Björkman, Chief Marketing Officer at Re:newcell, interview the 11th of March 2020.

[13] Steffen Sydow, Project Leader at Fraunhofer Institute for Wood Research, mail correspondence between the 26th of March and 20th of May.

potential of fulfilling the design specification. The system was built with two criteria groups, where each group filtered out materials that did not fulfill the requirements. The criteria groups were;

1. Sustainability - The materials qualification regarding sustainability.
2. Production info - The materials qualification regarding scalability and price.

The material scoring system also graded the remaining materials based on their score within the two criteria groups.

6.3.1 **Criteria group 1 – Sustainability**

The first criteria group regarding sustainability contained different criteria that played an important role in how well the material could be considered sustainable based on earlier research. The different criteria are described below.

6.3.1.1 Pure material

Binary score (Yes/No), based on if the material is a composite or not. As mentioned in subchapter *4.3.2 Composite materials*, composites are harder to recycle today which obstruct circularity.

6.3.1.2 Recycled

Based on the information gathered in the subchapter *5.3.4 Benchmarking*, a scale was constructed to indicate the percentage of recycled content in the material. The scope of each score was based on the general amount of recycled content in competitive products.

The score is based on the percentage of a material's content that comes from recycled resources:

0. 0 % of the material comes from recycled resources.
1. 1-50 % of the material comes from recycled resources.
2. 51-90 % of the material comes from recycled resources.
3. 91-100 % of the material comes from recycled resources.

Materials that scored 0-1 are materials that contain less or the same percentage of recycled resources as materials in most competitive products. A score of 2 indicating a material that contains a higher percentage of recycled resources than materials in most competitive products. The score of 3 indicating that the material contains an exceptionally higher percentage of recycled resources than materials in most competitive products.

6.3.1.3 Finite resource (non-recycled, non-binder)

Binary score (Yes/No), based on if the material contains any non-recycled finite resources.

Some materials require a binder, which in some cases is that of a finite resource. Since this has the potential to be switched out to a bio-based or recycled binder, materials containing a majority (> 80 %) of non-finite or recycled finite resources, combined with a binder from finite resources are considered to score a "No".

6.3.1.4 Renewable/bio-based

Based on the information gathered in the subchapter *5.3.4 Benchmarking*, as well as the criterion *6.3.1.2. Recycled*, a scale was constructed to indicate the percentage of bio-based content in the material.

The benchmarking showed that most competitive products contains little, if any, bio-based materials. Despite this, it was decided to use the same scope of scores from *6.3.1.2. Recycled*, as this would guarantee that the high ambitions of the design specification would be met.

The score is based on the percentage of a material's content that comes from renewable resources, either recycled or non-recycled:

0. 0 % of the material comes from renewable resources.
1. 1-50 % of the material comes from renewable resources.
2. 51-90 % of the material comes from renewable resources.
3. 91-100 % of the material comes from renewable resources.

Materials that scored a 0 are materials that contain less or the same percentage of renewable resources as materials in most competitive products. A score of 1 indicating a material that contain the same or a higher percentage of renewable resources as materials in most competitive products. The score of 2-3 indicating a considerably or exceptionally higher percentage of renewable resources than materials in most competitive products.

6.3.1.5 Recyclable (100% today)

Based on the information gathered in the subchapter *4.2 Circularity,* a criterion was constructed to indicate if the material can be recycled in Sweden today, and what the most suitable option for recycling would be in that case.

The rating is based on the type of recycling that could be considered the "correct" one for the specific material:

Yes:	The material can be recycled via external recycling
Internally:	The material can be recycled via internal recycling
Industrial compost:	The material can be composted in an industrial composting facility
Home-compostable:	The material can be composted in a home composting facility

Downcycle: The material cannot be recycled without being "destroyed", e.g. completely shredded

No: The material cannot be recycled at all, except through energy recovery

6.3.1.6 Origin

The score is based on where the suppliers are located; Nordic countries, European countries or other parts of the world.

6.3.1.7 Criteria group 1 - Sustainability score

The calculated sustainability score graded each material based on the above criteria:

GOOD: Scored a 3 on either *Recycled* or *Renewable/bio-based*
Originates from a Nordic or European country
Does not contain any finite resources
Scored Yes/Home-compostable/Internally on *Recyclable*

OK: Scored a 3 on either *Recycled* or *Renewable/bio-based*
Contains finite resources

or

Scored a 3 on either *Recycled* or *Renewable/bio-based*
Does not originate from a Nordic or European country

or

Scored a 2 on either *Recycled* or *Renewable/bio-based*

Does not qualify: Scored <2 on *Recycled* and *Renewable/bio-based*

6.3.2 **Criteria group 2 – Production**

The second criteria group regarding production contained criteria within price and scalability. The different criteria are described below.

6.3.2.1 Scale (today)

A rating based on the availability of the material on the market as of now:

Art project: The material currently only exists in the form of a student-, art- or design studio-project.

Future: The material is currently in an early research-state. Is not available on the market.

Innovative: The material is currently only produced in a small quantity, e.g. test samples, or is in the process of launching on a larger scale. Is commonly not available on the market.

Off the shelf:	The material is currently available on the market.

6.3.2.2 Scalability (future)

A rating based on the production-scale-potential of the material. The grade is based on raw material availability, production complexity and company-size (supplier):

Not scalable:	The material does not seem to have potential of being produced in larger quantities.
Moderate:	The material shows potential of being produced in larger quantities.
Scalable:	The material shows great potential of being produced in larger quantities or is already produced on a large scale.

6.3.2.3 Price

A rating based on the perceived cost structure of the material. It is based on the intended initial or current purpose of the material:

0:	The material seems to be intended for products of high cost, e.g. military- or space travel equipment
1:	The material seems to be intended for products of medium-high cost, e.g. luxury products, designer furniture and high end building materials
2:	The material seems to be intended for products of medium-low cost, e.g. more advanced building materials, packaging- and raw materials intended for medium cost products
3:	The material seems to be intended for products of low cost, e.g. standard building materials, packaging- and raw materials intended for low cost products.

6.3.2.4 Criteria group 2 - Production score

The calculated production score graded each material based on the above criteria:

EXCELLENT:	Material is available as *Off the shelf,* is *Scalable* and scored a 3 on *Price*.
GOOD:	Material is available as *Off the shelf,* is *Scalable* and scored a 2 on *Price*.
or	
	Material is available as *Innovative,* is *Scalable* and scored a 2 or more on *Price*.

OK:	Material is available *Off the shelf,* is *Moderate* with regards to scale and scored a 2 or more on *Price*.
or	
	Material is available as *Innovative,* is *Moderate* with regards to scale and scored a 2 or more on *Price*.
Does not qualify:	Material did not fulfill the requirements of any of the above categories.

6.3.3 **Result Material Scoring**

The Material Scoring system resulted in the materials being grouped based on their score. The materials that had a sustainability score of GOOD and a production score of GOOD or EXCELLENT were filtered out and placed in a list called *Materials of Interest* (MoI). It resulted in 12 materials ending up in the MoI-list, see table 6.1 and 6.2, that represented the materials that were considered to have the highest potential to fulfill the design specification.

6.3.3.1 Technical specifications

Technical specifications were recorded for each material in the MoI-list regarding acoustic properties, fire properties, processing methods and other technical data, see Appendix C for complete information.

Regarding fire properties, it was revealed during the interviews, see subchapter *6.2.1 Interviews*, that fire retardants often conflicts with sustainability and the material's recyclability. Therefore, the material's fire resistance is a challenging factor that often conflicts with sustainability. Most materials in the MoI- list are not fire resistant enough to fulfill fire class D, which is a demand in the design specification. They need the use of fire-retardant substances which in most cases are harmful to the environment. Because of this, a diagram was constructed and the materials in the MoI-list were placed inside based on their content and their need for fire retardant, see figure 6.1 The diagram provided a good overview of the materials and their fire properties, where the best achieving materials regarding both sustainability and fire resistance are found to the left in the diagram.

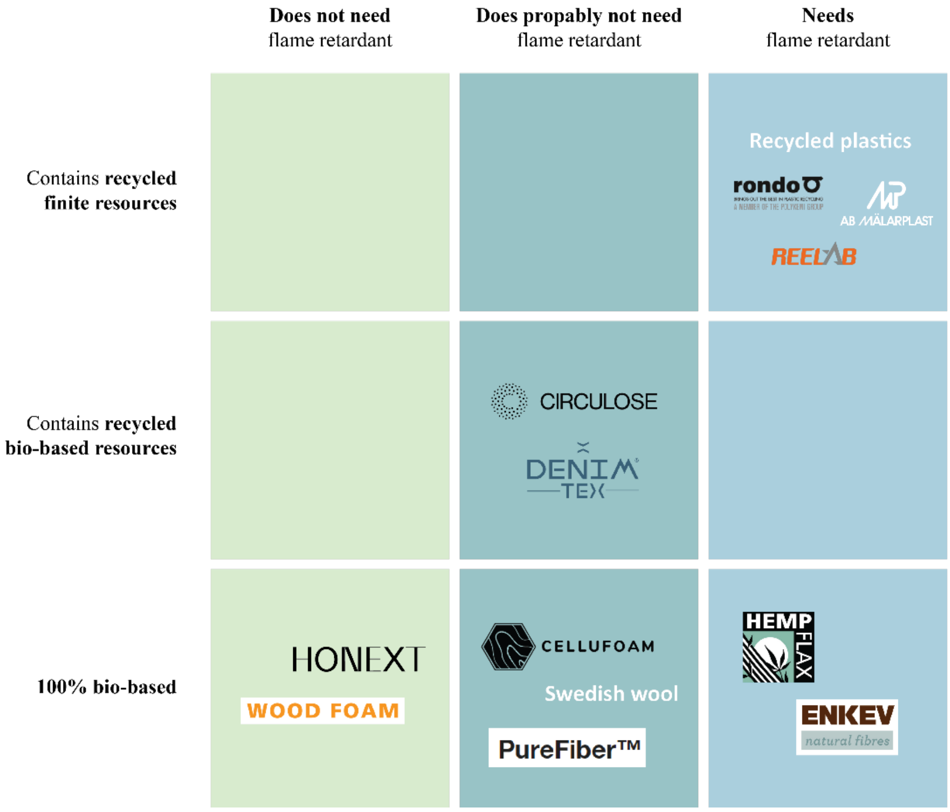

Figure 6.1 Diagram of materials based on fire resistance and content

6.4 Workshop

A workshop was conducted together with employees at Form Us With Love. The session was planned in the form of a brainstorming exercise. In preparation of this workshop, three distinct categories of material were selected, representing some of the materials in the MoI-list. The group participating in the workshop was however not informed about the specific materials that were being researched further, in order to not manipulate the result into favoring a specific material.

The aim of this workshop was to find solutions to areas of concern for each material group, helping with the selection of materials for concept development. The concepts created by the group were also earmarked for use during the *Develop*-phase of the thesis.

The group was introduced to one material group at a time, followed by a related question. The question was specific to a certain area of concern for that particular material group. The three material categories with questions can be found below:

Foam:	*How can this material be altered in another way than just cutting flat sheets for mounting on walls?*
Insulation:	*This material type was created to be hidden behind a wall. How can we bring it into a room and show it off, while making it beautiful?*
Loose material:	*How can we unite loose parts and make them into a united/singular object?*

Following each presentation and question, the group was given four minutes to discuss, sketch and visualize ideas and solutions. Each session was followed by a presentation and discussion about the concepts created.

6.4.1 **Result Workshop**

The workshop generated many ideas and concepts. Some general ideas that can be implemented for all kinds of acoustic products were:

- to make a changeable product considering both sound and light,
- to utilize something that is already in the room, e.g. dress a pillar with sound absorbing fabric,
- to make acoustic products into details in the room, e.g. lamps, pillows and cornices,
- to lease products in order to make it easy for the customer to change color/pattern.

6.4.1.1 Foam

The concepts and ideas developed for foam were the most implementable. This was probably due to that many are familiar with foam and using materials that are board-shaped. It also resulted in many ideas being similar to each other. The most common idea to the question was to use processing methods on the boards to create shape, patterns or a different surface structure.

6.4.1.2 Insulation

Many of the ideas and concepts developed for insulation were also implementable and somewhat similar to the ideas developed for foam. It occurred some ideas with intention to frame or parade the material, unlike most of the ideas that in some way still hid the material.

6.4.1.3 Loose material

Loose material could be seen being the most challenging to generate ideas around. It resulted in the most scattered and different ideas and concepts. The concepts often became naturally changeable due to the loose parts. They also often implemented additional functionality by combining the sound absorbers with another product, e.g. filling a cushion with the loose parts.

6.5 Material Selection

As mentioned in the subchapter *6.3.3 Result Material Scoring*, 12 materials were filtered out and placed in the list called *Materials of Interest* (MoI). These materials then laid the foundation for the workshop conducted with the purpose of finding solutions to challenges within some material groups. The workshop also helped indicate which types of materials that were seen as more interesting and generated creative ideas and concepts.

The gathered research from the interviews provided deeper knowledge and important factors to consider during the selection. Together with the result from the workshop, these were combined and analyzed in order to make a selection of materials from the MoI-list to bring into the next phase *Develop*. The selection can be seen in table 6.1 and 6.2.

No materials that solely can be used to diffuse or absorb sound as a resonant absorber have passed the selection based on the challenging task of designing such a device, as mentioned in subchapter *4.1.1.2 Resonant absorbers*. This is applicable to all dense materials with reflecting surfaces.

Table 6.1 Materials with a production score of EXCELLENT in the list *Materials of Interest* (MoI) and information about the selection.

Materials	*Description*	*Passed (y/n)*	*Comment*
Cellufoam	Boards of foamed cellulose fibers. Expected to have similar properties a s Wood Foam, see below. Is still in development and is yet not produced outside of lab environment.	No	Lack of information makes it difficult to develop further. Promising material but replaced by Wood Foam in this evaluation.
HONEXT	Pulp-/MDF-like material made from recycled paper and a bio-binder. The material fulfills fire class C. Expected to be processed similar to a chipboard. Suitable for use in a resonance absorber. Still under development.	No	Due to the decision to focus on materials suited for porous absorbers.
PureFiber	Thin sheets of pulp made from cellulose. Similar processing methods as plastics. Due to its likeness to other pulp materials it is expected to reach fire class D and be somewhat sound absorbent. Just hit the market. Expected be relatively cheap.	No	Promising material but replaced by Circulose in this evaluation.
Swedish Wool	Wool from Swedish sheep. Same properties as regular wool with okay fire resistance, expected to be sound absorbent and can be processed in different ways. Lack of larger supplier i.e. material must be bought from many sources today.	No	Lack of suppliers makes it difficult to develop further.
Wood Foam	Boards of foamed cellulose fibers. Can be processed like a chipboard. Lightweight and sound absorbent material. Can come in different sized boards and be colored. Boards with lower density (<120 kg/m^3) are brittle. Fulfills fire class D. Is not produced in a larger scale today. Low cost material.	Yes	Fulfills many demands in the design specification.

Table 6.2 Materials with a production score of GOOD in the list Materials of Interest (MoI) and information about the selection.

Materials	*Description*	*Passed (y/n)*	*Comment*
Circulose	Thin sheets of pulp made from recycled textiles. Due to its likeness to other pulp materials it is expected to reach fire class D and be somewhat sound absorbent. The materials properties allow multiple ways of processing. It is low cost and is produced today.	Yes	Fulfills many demands in the design specification.
Hempflax nonwoven	Non-woven fabrics made of needled hemp-/flax-fibers. The material has poor fire resistance. It is made as an alternative for synthetic reinforcing fibers and is produced today. Similar products are sound absorbent. The surface is frail, and fibers easily come loose.	No	Inappropriate because of its frail surface and poor fire resistance.
Jeans on the wall	A plaster made from recycled textiles and a bio-binder. It is normally applied onto walls. The material is sold as a sound absorber today. Price and fire resistance are unknown.	No	Lack of information makes it difficult to develop further.
Natural fibers	Soft boards and fabrics made from miscellaneous natural fibers. The fibers can be processed in many ways, most usually needled non-woven and sometimes strengthened with natural latex. Poor fire resistance and frail surfaces when not strengthened. Similar products are sound absorbent. Produced today, price unknown.	No	Lack of information makes it difficult to develop further.
Recycled plastics & Bonded Foam	Allows for numerous processing methods. Several suppliers available. Low cost material. Poor fire resistance. Depending on the type of processing, it can be made into a porous absorbent or a resonance absorbent.	Yes	Versatile material with a large established market and numerous suppliers.

6.5.1 **Result selection**

As seen in table 6.1 and 6.2, three materials passed the selection:

1. Circulose
2. Recycled plastic and Bonded Foam
3. Wood Foam

These materials were considered to possess the right properties in order to fulfill the majority of demands in the design specification, as well as offering a good foundation for developing qualified ideas and concepts. A more detailed description of each material can be found in the subchapter *6.5.1.1 Detailed information about the selected materials* below. Recycled plastics is not a specific material but a material group with many suppliers, where Bonded Foam is an important subcategory. The reason for it not being more specified is because of the broad and versatile market that more often customizes a plastic material to fit the demands than offering a finished batch.

The materials using natural fibers, like hemp and flax, are sustainable and show good potential in being sound absorbent. A problem is that they often have a frail surface and a bad fire resistance. There has been some information found indicating that it might be possible to increase natural fibers fire resistance without using harmful fire retardants. This information though, has not been sufficient enough and has not been given by the suppliers to the materials in the list. Therefore, the materials within this category does not pass the selection.

Other materials have also failed on either lack of information, where suppliers do not respond, or the lack of suppliers at all. This limits the possibilities to develop the materials further since there are too many uncertainties.

Some materials have been replaced by others since they have similar properties, but more information and/or more promising qualities have been found for the other materials.

6.5.1.1 Detailed information about the selected materials

Information about the selected materials Circulose, Bonded Foam and Wood Foam can be found below in table 6.3. Extended data for the materials can be found in Appendix C.

Table 6.3 Information about the selected materials

	Circulose	***Bonded Foam***	***Wood Foam***
Form	Cut sheets	Extruded boards	Extruded boards
Size	800x580 mm	Varying	Varying
Thickness	~1,5 mm	Varying	up to ~ 150-200 mm
Fire properties	Unknown, assumed to be somewhat equivalent to that of *BAUX Acoustic Pulp* (EUR D)*	Poor	Fire class EUR D **

* The fire properties of Circulose can potentially be improved by using an eco-friendly fire retardant currently under development to be used in the *BAUX Acoustic Pulp*-panels.
** Can potentially be improved by incorporating raw material with high silica content, such as rice straw

6.6 Summary Define

6.6.1 **Summary extended research**

The interviews conducted during the *Define*-phase gave a deeper knowledge of interesting materials and provided a clear view of different materials' possibilities and challenges. It became clear that fire retardance is the most challenging requirement to fulfill in the design specification.

Generally, valuable information gathered from the interviews were:

- to aim for a material with a longer life span that can be recycled,
- to try to reduce the number of processing steps of the material in order to lower cost and environmental impact,
- to avoid most fire-retardant substances,
- to look at possible ways of increasing the interest in recovering materials.

6.6.2 **Summary Material Selection**

The materials that were picked for further development in the *Develop*-phase are pictured below in figure 6.2. and were:

- Circulose
- Recycled plastic and Bonded Foam
- Wood Foam

According to the selection made in subchapter *6.5 Material Selection*.

Figure 6.2 The materials picked for further development. From left to right: Circulose, Bonded Foam (two colors represented in picture) and Wood Foam.

7 Develop

7.1 Methods

7.1.1 **Scenarios**

Scenarios are used in concept development to tell a story about the current or future user interaction in a specific situation where the idea is to understand the driving forces and behavior of the user. This allows for the development of criteria for the user's interaction with the intended solution. (Wikberg Nilsson, Ericson & Törlind 2015)

In this thesis, scenarios were used to explore the four public spaces that had been mentioned during the internal interviews in subchapter *5.2.1 Interviews* as the most interesting clients for BAUX. These spaces were hotels, retail, offices and schools.

The scenarios were illustrated with the help of computer sketches and then discussed regarding opportunities, challenges and common acoustic problem areas to establish a clear picture of the requisites for each space.

7.1.2 **Prototyping**

Prototyping is a method used to explore different design alternatives in order to better understand and develop early ideas. Several methods can be used in prototyping, ranging from simple sketches up to refined 3D-printed models. Regardless of the method used, the purpose is to better understand the design problem and to explore, evaluate and develop different solutions to it. (Wikberg Nilsson. Ericson & Törlind 2015)

In this phase low-fidelity prototypes were used to communicate different types of ideas, such as sketched prototypes and simple physical prototypes made from close-by materials.

7.1.3 **Brainstorming**

See subchapter *6.1.3 Workshop / Brainstorming* for the full description of this method.

In the case of the *Develop*-phase, a number of questions were constructed for specific areas of interest. These areas covered challenges with a particular material or public space, or general themes of interest such as customization. The questions could be answered in several ways, such as writing, prototyping, or collages.

7.1.3.1 Styling board

A styling board is a type of collage to create a visual representation of solutions that are similar to the one of interest in the idea development process, or of similar function, theme or technology. It can consist of pictures of competitive products, or of products, shapes, technologies, materials etc. of another origin that can spur the creative process. (Wikberg Nilsson, Ericson & Törlind 2015)

7.1.3.2 Scrum

A modified version of the framework Scrum was used as a method to enable an efficient way of brainstorming while working remotely from each other. This due to the ongoing pandemic Covid-19.

Scrum is a framework that is used to implement agile development. It is based on making a Backlog which is a list of tasks and requirements the final product needs. The Backlog is placed on a Scrum Board that is used to visualize and organize the tasks. Then you use Sprints, which are predetermined periods of time, to complete each task in the Backlog. During the Sprints, the Scrum Board is used to show the progress of each task. The teams have daily meetings and reviews each Sprint as they are completed. (Littlefield 2016)

The way Scrum was used in this thesis was by making Backlogs with different headlines where challenges/questions within the specific area were listed. Then each challenge/question were brainstormed around during a Sprint. The Sprints where short compared to regular Sprints and could be set between 30 minutes to a couple of hours. Each day, when Sprints had been conducted, a meeting to review and share the results were held.

7.1.4 **Idea Evaluation**

In order to evaluate a multitude of concept ideas quickly and with ease, a version of the method of idea evaluation was used. The core steps of this method is to present all ideas in a similar manner and afterwards letting all participants mark a set number of ideas which they consider have the highest potential while also commenting the advantages and weaknesses for each marked idea. (Wikberg Nilsson, Ericson & Törlind 2015)

The benefit of the method is that it allows for a fair assessment, compared to methods where ideas might be presented in differing ways, and that it provides a quick selection of ideas in the way that the participants only have a limited number of marks to allocate. (Wikberg Nilsson, Ericson & Törlind 2015)

In the case of this thesis, the idea evaluation was conducted by showing the sketches of ideas produced during 7.2. *Brainstorming*, providing a short explanation of each idea's advantages and weaknesses and letting each participant pick and comment the four ideas they considered had the most potential for further development. It was also used a second round on the concepts developed in a later stage.

7.1.5 **Sandbox Play**

Sandbox Play is a method used to consider solutions from three different viewpoints; the anthropologist, the business leader and the design engineer. The anthropologist's task is to look at the user's behavior and consider what drives that specific behavior and how it can be changed. The business leader is tasked with developing the business model, thereby reviewing how similar products are sold as of today and how that can be changed. Lastly, the design engineer looks at the properties of the solution and considers if something can be radically altered. The purpose of this exercise is to challenge the proposed solutions in three different dimensions, in order to explore if a new and radically different solution can be found. (Wikberg Nilsson, Ericson & Törlind 2015)

In this thesis, Sandbox Play was used as an inspiration to establish four different problem definitions. Through these definitions, separate ideas could be evaluated and grouped into combined concepts that each offered something different from each other.

7.2 Brainstorming

The purpose of the brainstorming was to produce a large number of ideas of product solutions or elements of solutions that could be combined and/or developed further during the next phase *Deliver*. The brainstorming was conducted using a method based on time-limited sprints as described in the subchapter *7.1.5.1 Scrum*. The sprints conducted and their duration can be seen in table 7.1. below.

Table 7.1 The sprints conducted during the brainstorm

	Sprints/Challenges	Duration
Materials		
Circulose	How can the sheets gain 3-dimensional shape?	1,5 h
	How can the sound absorption be improved?	2 h
	How can the sheets be processed?	30 min
	How can the sheets be connected?	30 min
	What other materials can Circulose be combined with?	1 h
	How can color be added?	30 min
Wood Foam	How can the boards be shaped?	2 h
	How can the boards be connected?	30 min
	What other materials can Wood Foam be combined with?	30 min
Recycled plastics	What types of recycled plastics can be used?	30 min
	How can smaller parts be connected without melting the plastic?	1 h
	How can sound absorption be achieved?	2 h
	How can a plastic product escape fire regulation without using fire retardant? (In an ethical way)	1 h
Public spaces		
Hotels	What types of acoustic products are needed in hotels?	1 h
Schools	What types of acoustic products are needed in schools?	1 h
Retail	What types of acoustic products are needed in retail stores?	1 h
Offices	What types of acoustic products are needed in offices?	1 h
General		
Dynamic product	How can an acoustic product be dynamic?	1,5 h
Inspiration	What inspired during the study visits and the Furniture Fair?	30 min

Before conducting the brainstorming, a list of advantages and disadvantages had been made for each material. These lists were then used to draft the challenges in the backlogs made for the materials. The scenarios created for each space were used during the sprints regarding the public spaces. They increased the understanding of the spaces regarding challenges, advantages, and common user behaviors. The aspects for each scenario were formulated in internal discussions.

For the duration of this thesis, pictures had been taken of interesting and/or inspiring ideas, solutions, and products. This was especially done during Stockholm Furniture Fair and the study visits. These pictures were used as inspiration to produce ideas in the sprint called *Inspiration*.

During all the sprints, the website Pinterest was used to create styling boards as a complementing tool to low-fidelity prototyping. Pinterest is a web-based service were users can upload and search for images and create personal collages. The styling boards were used as inspiration for ideas or to find solutions to elements of an idea.

7.2.1 **Result brainstorming**

The sprints conducted during the brainstorming led to a wide range of ideas of how to solve the listed challenges, an overview of all the ideas can be seen in figure 7.1. A subset of relevant ideas are described below.

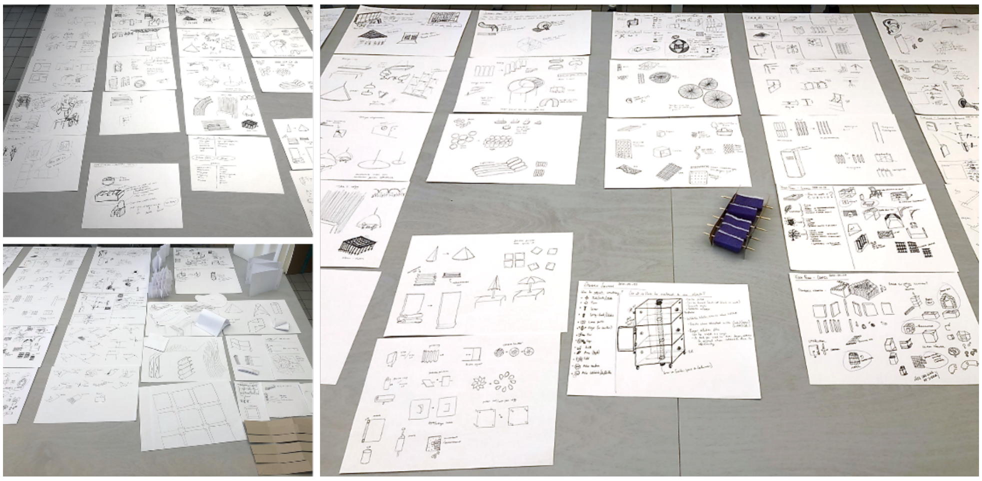

Figure 7.1 Overview of all ideas

7.2.1.1 Materials

Most time was spent on the sprints covering challenges regarding the materials. For Circulose, many ideas played on the concept of using textile methods in order to connect the material to its origin. Creating 3-dimensional shapes by bending or layering the Circulose-sheets was seen in many different ideas. One particular way of achieving shape was to use pleating. This allowed for dynamic product ideas when using the pleating to function as an accordion or hand fan.

For Wood Foam the ideas often had similarities to chipboard-based applications. One of the ideas was to use Wood Foam as building material by making blocks that can be built into a product, like with Lego-blocks. Combining Wood Foam with other types of woods reoccurred in several ideas. This could be seen in an idea based on placing shapes of Wood Foam around wooden billets, see figure 7.2. The wooden billets can be placed in rows as room dividers and be rotated. This rotation of the billets leads to rotation of the shapes which then changes the products visual expression and potentially its acoustic properties.

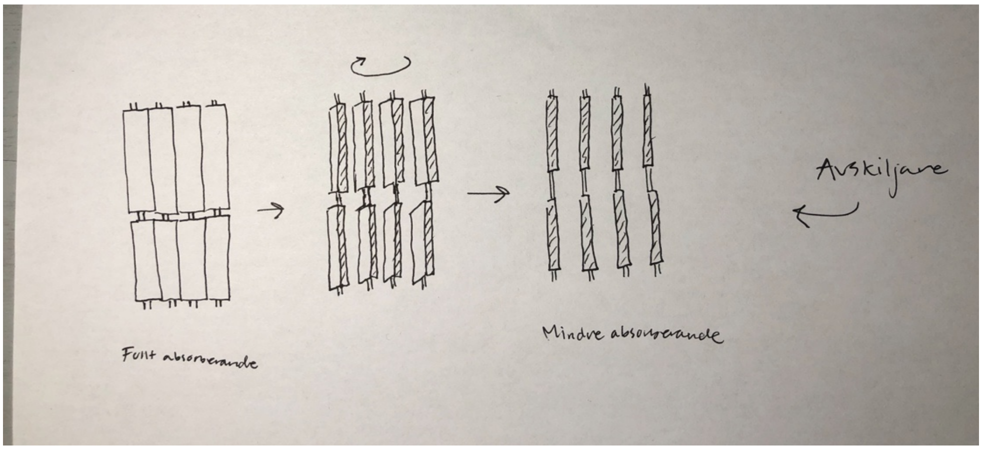

Figure 7.2 Shapes of Wood Foam around wooden billets

The ideas regarding the usage of recycled plastic ranged from creating shapes that trap sound if using non-porous injection molded plastic, to enclosing loose shredded plastic parts. It was the more challenging material to brainstorm around and resulted in many less developed ideas. Bonded foam was the easier form of recycled plastic to develop into product ideas.

7.2.1.2 Public Spaces

Brainstorming around the four different spaces led to ideas that did not consider using a certain kind of material but more that of a general product idea. This complemented the previous work with focus on materials and resulted in a broad set of ideas that could be combined with the more material-focused ones.

For hotels, many ideas took advantage of the often-common large surfaces on walls or in ceilings. This by covering the large surfaces with smaller sound absorbers placed next to each other. In some ideas, a framework acted as a suspension device where each frame holds a sound absorber, see figure 7.3. It was inspired by Shoji walls, which are rice paper sheets suspended on a framework that acts as a wall. If the mount between the frame and the sound absorber allows for disassembly, the sound absorbing material can be changed and/or rearranged.

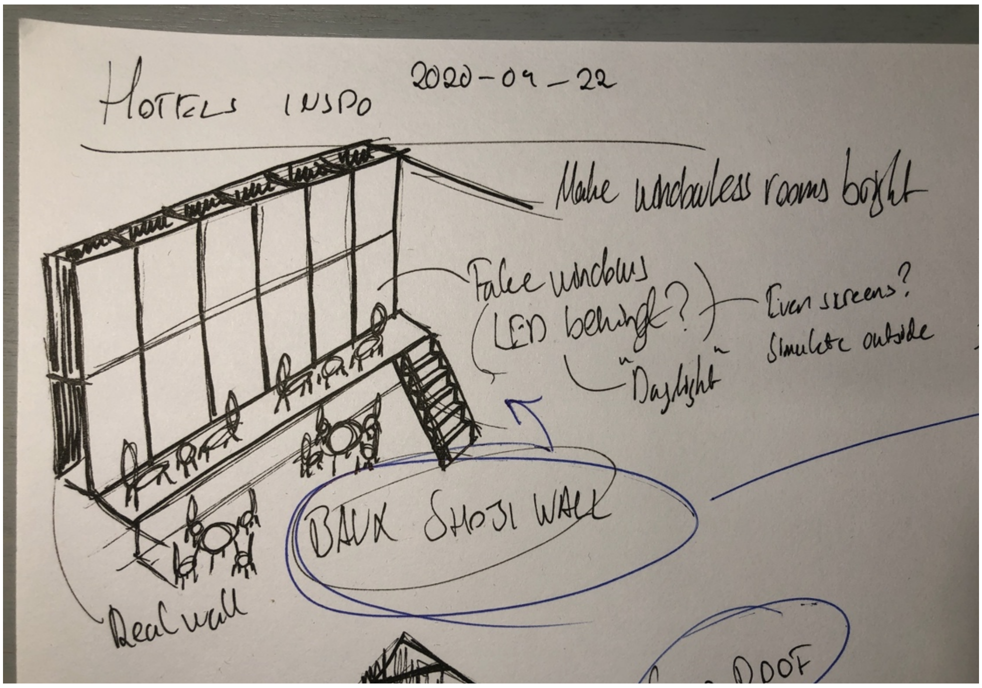

Figure 7.3 Framework holding sound absorbers inspired by Shoji Walls

Other ideas were to suspend a sound absorbent product from the ceiling to define an area, creating the feeling of a smaller room in a large space without using walls, see figure 7.4.

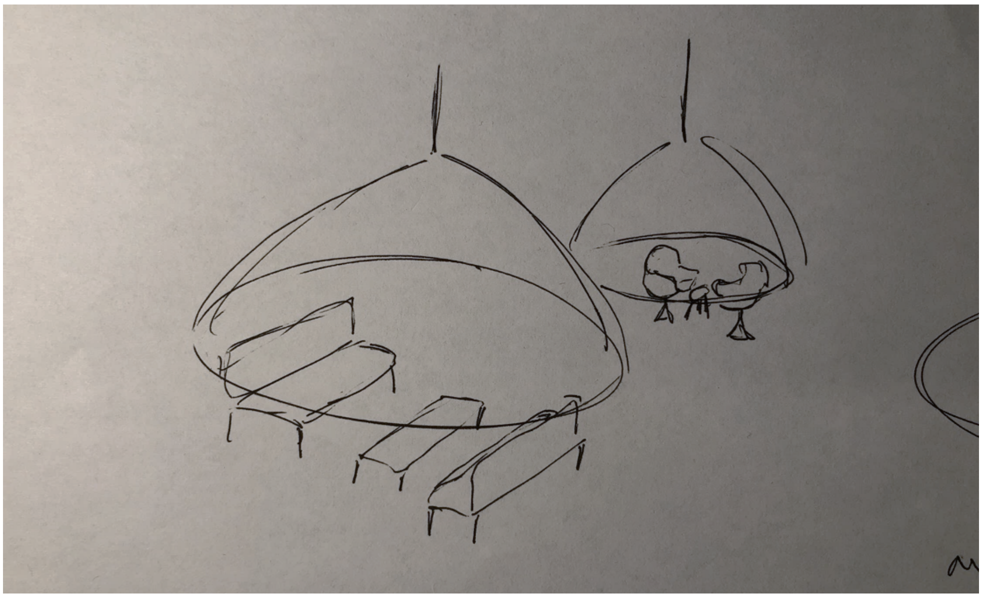

Figure 7.4 Suspended sound absorber from the ceiling

Since interaction is hard to avoid in spaces holding children or teenagers, a common characteristic for ideas meant to be placed in school environments was that the product should allow or even encourage interaction. Today, it is also common with smaller hideaways in school environments meant for play or studies. This inspired ideas of different open pod rooms that can be placed in a larger room where people can get away without being entirely enclosed.

The most essential factor in a retail store is that the majority of the products used in the space must have a purpose. The products are made to display the merchandise or in other ways make the customers want to shop. Therefore, the ideas regarding retail stores were all very functional. Just like for school environments, many of the product ideas were also made to interact with. Making building blocks appeared in ideas for retail too as it allows for changeable and buildable products. One specific idea was to create boxes in different sizes that could be used to display merchandise. A large box could even be used as a pod room, or specifically for retail, as a changing room.

For offices, the ideas were often dynamic and made to create smaller rooms in a large office space. Affordance played an important role for some ideas where a sound absorber was meant to be dragged or folded over a workspace in order to signal to the surrounding environment that the user does not want to be disturbed. Affordance is, according to Norman (2013), a term that describes the types of actions a product invites its user to perform, e.g. how a bench invites sitting.

7.2.1.3 General

Most of the ideas on how to make a dynamic product had been seen in the earlier sprints and have therefore already been described.

In the *Inspiration*-sprint, layered design was a reoccurring characteristic. One idea was to use a clamp to create and retain layers, inspired by the picture seen in figure 7.5. It is a simple way to make a changeable and rearrangeable product similar to if using a framework. This type of product would furthermore enable a new leasing-inspired business model, which in turn could allow for an internal loop regarding recycling.

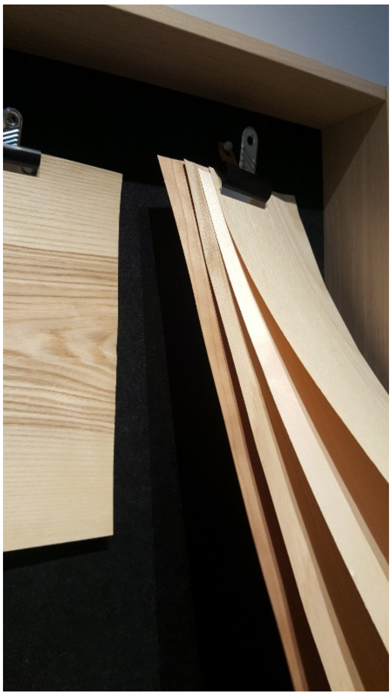

Figure 7.5 Veneer-sheets held together by a clamp

7.3 Idea Evaluation

The ideas from the brainstorming were discussed and evaluated together with relevant key personnel at BAUX and FUWL through the method described in 7.1.6. *Idea Evaluation*.

It is important to note that, during the evaluation, the participants reviewed each idea from a symbolic standpoint, meaning that each idea was considered to represent a theme of a solution rather than a specific design. As the evaluation proceeded, it was determined that clear problem definitions would help the selection of ideas.

7.3.1 **Sandbox Play**

In order to create the problem definitions, inspiration was drawn from the method of sandbox play, described in subchapter *7.1.5 Sandbox Play*.

A discussion was held covering the three different viewpoints regarding user behavior, business model and product properties. It was also decided that the idea of a general product was to be discussed, as this would be the 'safe' direction for a solution to take. The main and reoccurring topics of the discussion can be seen below:

User behavior:	How can we change the way users interact with acoustic products as of today?
Business model:	How can we alter the business model of today regarding acoustic products?
Product properties:	How can we change the way acoustic products are applied?
Commercial:	How can we reinvent something that is widely commercially applicable?

By asking these questions, four distinct problem definitions were developed.

7.3.1.1 *Problem Definitions*

In the below subchapters, the four problem definitions are presented.

7.3.1.1.1 User behavior

Acoustic products are generally static, mounted in one specific place and functioning in one specific way. If the user wants to adjust the soundscape, the whole room must be altered.

The solution could be to create a dynamic/adjustable product that entails the opportunity for visual as well as acoustic adjustments.

The inspiration for this solution being the internal interviews in the subchapter *5.2.1 Interviews*, as well as the design specification in subchapter *5.5.1.1 Design specification*.

7.3.1.1.2 Business model

The classic asset sales-business model used today when selling acoustic products prevents the manufacturer from taking a full responsibility for the product for the duration of its lifecycle. In order to make sure the product is truly sustainable, BAUX would need to keep control over their product's end-of-life.

The solution could be to design a modular solution, where interchangeable acoustic elements are mounted into a type of base module. This would enable the customer to adjust and change their acoustic product with ease, as well as allowing BAUX to recover the materials used in each product. A subscription- or leasing based business model would help this process, as BAUX would remain the owner of the product and therefore the responsible party.

The inspiration for this solution being the leasing business model of Mälarplast, mentioned in subchapter *6.2.1.6 Mälarplast – Peter Wall.*

7.3.1.1.3 Product properties

Acoustic products are often mounted on walls or ceilings in rooms where they function as interior details or accessories, albeit with a clear but limited functionality.

The solution could be to redefine BAUX as a building material. Meaning that the products are used to, in fact, build the rooms themselves or larger objects within the room. Instead of the solution being used to decorate the rooms with a functional object, it would be a functional room.

The inspiration for this solution being open office landscapes with rooms in rooms and Lego-bricks.

7.3.1.1.4 Commercial

A commercially widespread acoustic product is the one that offers the partitioning of an open interior landscape, as it is not preferable to do this by building traditional walls.

The solution could be based on the idea of affordance, where the product defines different areas in the room without the use of either traditional- or partitioning walls. A similar product exist in the form of suspended sound absorbers, but they are most commonly constructed the same way as most products in the subchapter *5.3.4 Benchmarking*, i.e. made from a core material covered with textile.

The inspiration could come from other interesting solutions to create a unique touch, e.g. pleating, dynamic suspension systems etc.

7.3.2 **Idea Evaluation 2**

After some discussion rooted in the comments provided for each marked idea, as well as their applicability to each separate problem definition, four different concepts were formed. These incorporated ideas from the brainstorming as possible solutions to said problem definitions, creating a theme. The four concepts were deemed explicit enough to perform a second round of idea evaluation, this time with each participant carrying two votes/marks.

The concepts are presented below in table 7.2., and are illustrated in figure 7.6.

Table 7.2 Concepts for further development

Concept Name and Description	*Advantages*	*Weaknesses*
Dynamic Billets Sound absorbers in irregular shapes mounted on billets made to rotate in order to create a dynamic room divider.	- High grade of innovation - Enables quick adjustments of the soundscape within a room - Provides a sense of joy when used	- Uncertainty if a single user will feel compelled to change the soundscape for the group
Building Blocks Interconnectable Lego-inspired sound absorbent building blocks.	- Playful - Enables “rebuilding” of a space with ease	- Difficult to design a sturdy interconnection - Can be considered too complicated to rebuild over and over. - Shipping might be inefficient with regards to sustainability
Clamp / Frame A type of mount that enables the use of interchangeable sound absorber elements.	- Enables a new and sustainable business model - Enables the product to be updated when needed/wanted	- Difficult to commercialize as a distinct product - Less developed as a concept - Might be more suited to work as a complement for the other concepts
Suspended Shapes Sound absorbing shapes suspended from the ceiling.	- High commercial applicability and demand - Allows for the reinvention of a common product	- Common product, must obtain a unique appearance

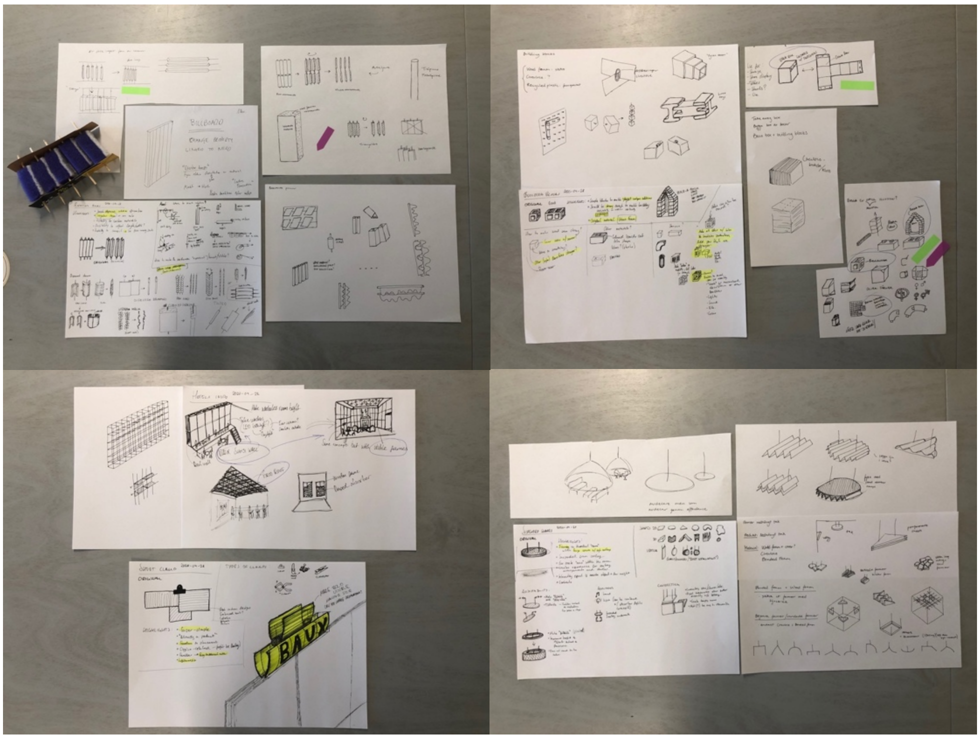

Figure 7.6 Concepts for further development. From top and left to right: *Dynamic Billets, Building Blocks, Clamp/Frame, Suspended Shapes*.

After the second round, it was clear that two of the concepts were considered the ones with the highest potential. These were *Dynamic Billets* and *Suspended Shapes*. The *Building Blocks* fell out of consideration due to the complexity of designing a product that can overcome the difficulties faced regarding the difficulty of – and time needed to – rebuilding the objects, as well as the inefficiency of shipping blocks of a large volume with regards to sustainability. The *Clamp / Frame* was deemed to be an interesting idea, but better suited to be further incorporated into the remaining two concepts. Hence, *Dynamic Billets* and *Suspended Shapes* were selected for further development in the *Deliver*-phase.

7.4 Summary Develop

The *Develop*-phase was centered around the goal of creating a significant amount of ideas that could be converted into concepts, describing how to make use of the materials selected in the *Define*-phase. A clear strategy and framework for brainstorming, described in subchapter *7.1.5 Brainstorming,* enabled this to be achieved quickly and efficiently despite the difficulties of working remotely at the time.

The use of idea evaluation, described in the subchapter *7.1.4 Idea Evaluation*, was efficient and essential in the selection of two concepts out of an initial some one hundred ideas. The concepts that passed selection represent two distinct design paths to follow, each considered to contribute something new, exciting and commercially appealing to BAUX assortment of products. With this foundation, it was possible to proceed into the *Deliver*-phase.

8 Deliver

8.1 Methods

8.1.1 **Prototyping**

In this phase, prototyping was used in a similar way as described in *7.1.2. Prototyping*. The difference being that high-fidelity prototypes, such as CAD-models and more complex physical prototypes, were used in order to communicate the concepts in a more refined state.

8.1.2 **Impedance Tube Measurement**

To measure the normal incidence absorption coefficient of the selected materials, samples of Circulose and Wood Foam (Bonded Foam was not included as measurements already were available, see Appendix D) were sent to an external source for use in an impedance tube measurement. The method allows for small samples to be measured under well-defined and controlled conditions, as opposed to using reverberation chamber tests which demands larger samples to be used (Cox & D'Antonio 2005).

The method makes use of a loudspeaker generating plane wave propagation in an impedance tube, see figure 8.1, whereas the plane wave propagates down the tube before reflecting from the sample, causing a standing wave to be set up. The reflected wave is altered by the impedance (i.e. the "resistance") of the sample and, by measuring the resulting standing wave, the normal incidence absorption coefficient and surface impedance of the sample can be calculated. (Cox & D'Antonio 2005)

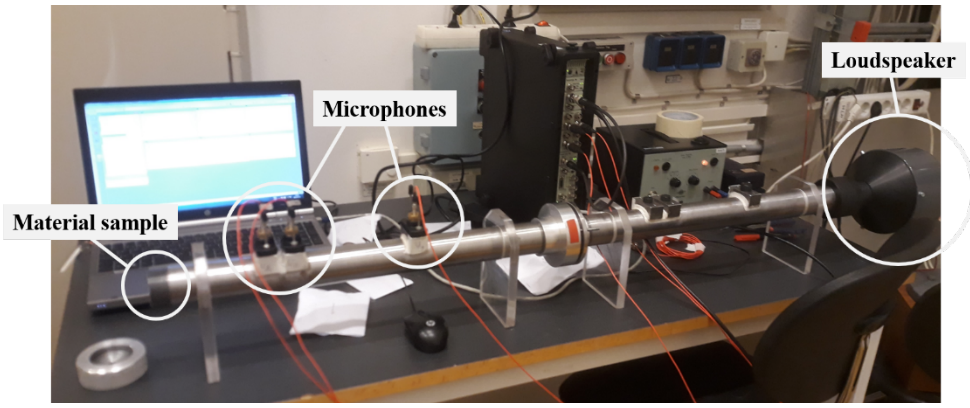

Figure 8.1 Impedance tube

This measurement was initially supposed to have been conducted during the *Define*-phase but had to be postponed due to the outbreak of Covid-19. Instead, they served as a validation during the *Deliver*-phase to make sure the initial assumptions made regarding the selected material's acoustic properties were correct. The full test report can be found in Appendix D.

8.2 Concept Development

During this stage, the two concepts that were selected for further development, *Dynamic Billets* and *Suspended Shapes,* were developed into more refined ideas with focus on the following parameters:

- How can the selected materials be implemented in the concepts?
- How can the materials be kept uncovered?
- How can the concept be combined with a sustainable business model?
- How can the product be made durable?
- How can the product be manufactured in a realistic and scalable way?
- How can the concept be as sustainable as possible and promote circularity?

The parameters were derived from the design specification and the work done during the previous phases. Within the category of recycled plastic, only Bonded Foam was determined to be suitable for the selected concepts.

8.2.1 **Dynamic Billets**

The concept *Dynamic Billets* is shortly described in table 7.2. It is based on ideas of irregular shapes that rotate next to each other. The shapes will create a more opened or more closed "wall" of sound absorbers depending on their orientation. It also includes ideas were the sides of each shape can be of different materials that absorb, reflect and/or transmit sound.

Further development of the concept *Dynamic Billets* was made by narrowing it down to its main function and from there develop more refined ideas of how to achieve that function. The main function was determined being a product that can be dynamically changed into being more opened or more closed, which both alters the soundscape and its visual appearance.

Different solutions were developed with the selected materials to achieve the main function. See figure 8.2 for a selection of the ideas.

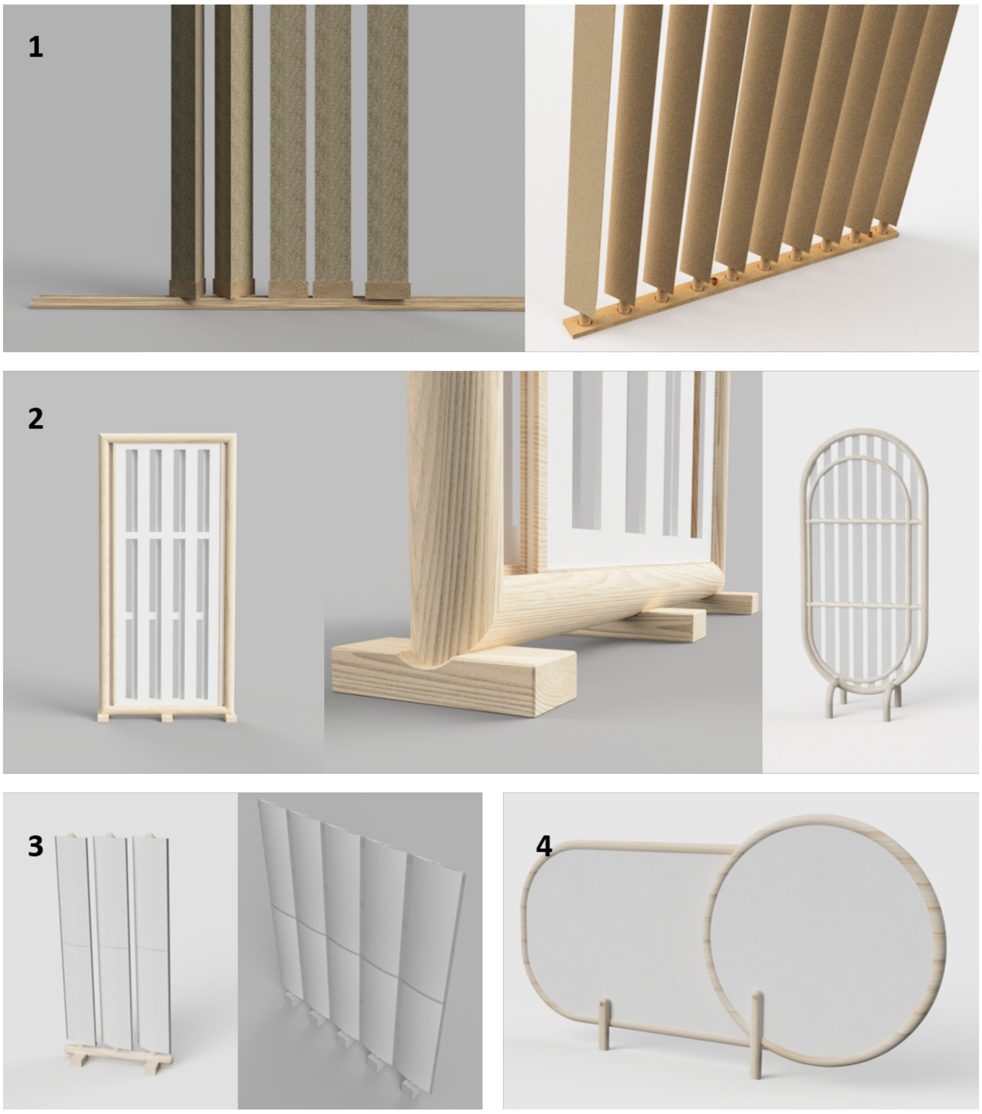

Figure 8.2 Selected ideas for the concept *Dynamic billets*

Short descriptions of each selected idea:

1. Billets in irregular shapes that can be rotated covered in or made from sound absorbing materials. Mainly applicable for Wood Foam or Bonded Foam.
2. Sound absorbing material placed in two facing frames. Sliding one frame to the side leads to an open or closed divider. Applicable for all materials.
3. Sheets joined on two opposite edges and mounted on a billet by flexing the sheets away from each other. The sheets can be rotated around the billet. Mainly applicable for Circulose.
4. Sound absorbing material placed in frames mounted next to each other. One frame (the circular) can be moved around its attachment to open or screen off as a desk divider. Applicable for all materials.

8.2.2 **Suspended Shapes**

The concept *Suspended Shapes* is shortly described in table 7.2. Due to its simplicity it started this phase as a more complete concept than that of the *Dynamic Billets*. During the idea evaluations, the design seen in figure 8.3 of having pleated suspended shapes was favored by a majority of the participants during the idea evaluations. Therefore, further development was focused on that design.

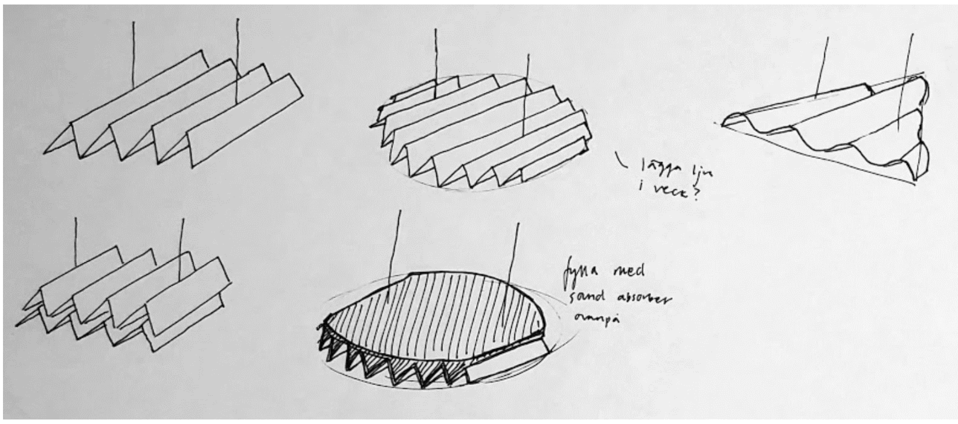

Figure 8.3 Pleated suspended shapes

The further development revolved around coming up with solutions of how to implement the selected materials. The idea was that the suspended shapes should be of different sizes where the largest was thought of as having a width of at least 2 meters. This, to create a grand effect.

If using Circulose, the large width would mean that several sheets need to be rigidly joined. If using Wood Foam or Bonded Foam, a solution of how to achieve the pleated look had to be found. These were critical aspects among the technical challenges regarding manufacturing, strength and suspension. A selection of solutions made for implementing Circulose can be seen in figure 8.4.

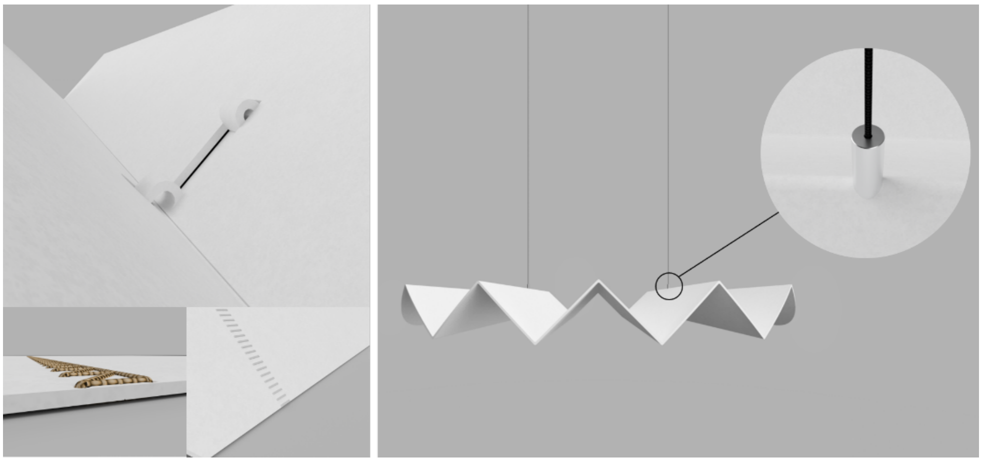

Figure 8.4 Solutions for joining Circulose-sheets and for suspension

8.2.3 **Final Concept Evaluation**

Together with the CEO of BAUX, the idea seen as number 3 in figure 8.1 within the concept *Dynamic Billets* was evaluated to have the most potential and therefore selected for final development. This decision was made based on the simplicity of the idea and its appealing aesthetic properties.

The rejected ideas all shared a complexity, a difficulty of manufacturing and/or issues regarding strength.

The ideas of framing materials within the concept *Dynamic Billets* were deemed to be unnecessarily complex by containing additional parts. Avoiding a frame also kept the material less covered, which was an important parameter. The idea of having rotating, irregularly shaped billets was hard to implement due to the properties of the selected materials. The height and the uncovered design force the use of a strong material with a non-fragile surface, which does not apply to the selected materials.

The concept *Suspended Shapes* was deemed to need more work on applicable solutions regarding manufacturing and strength. Furthermore, it was evaluated to not generally appeal as much as the selected idea within the concept *Dynamic Billets*.

8.3 The Design – BAUX Flight Mode

The selected design, henceforth titled *BAUX Flight Mode*, is shown in an exploded view below in figure 8.5.

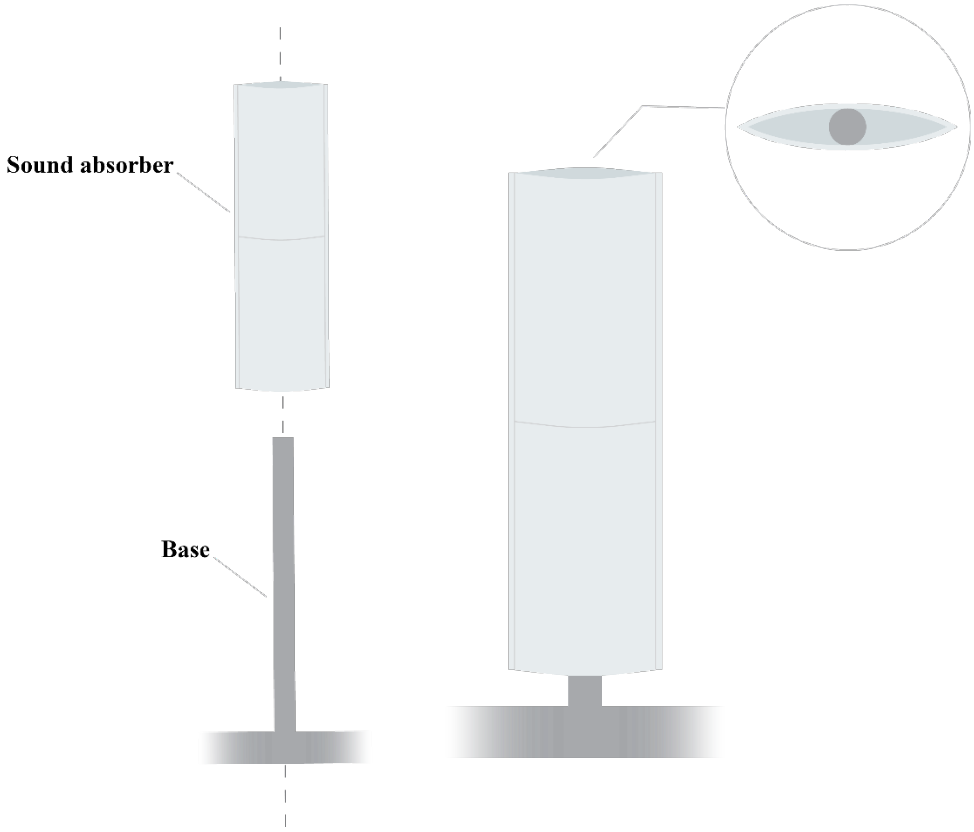

Figure 8.5 Exploded view of *BAUX Flight Mode*

The design consists of two elements; a sound absorber and a base. Each element possesses specific details which were explored and further developed in order to create the final design proposal for BAUX. A full-scale prototype, however only half the height due to material limitations, of the final design proposal can be seen in figure 8.6.

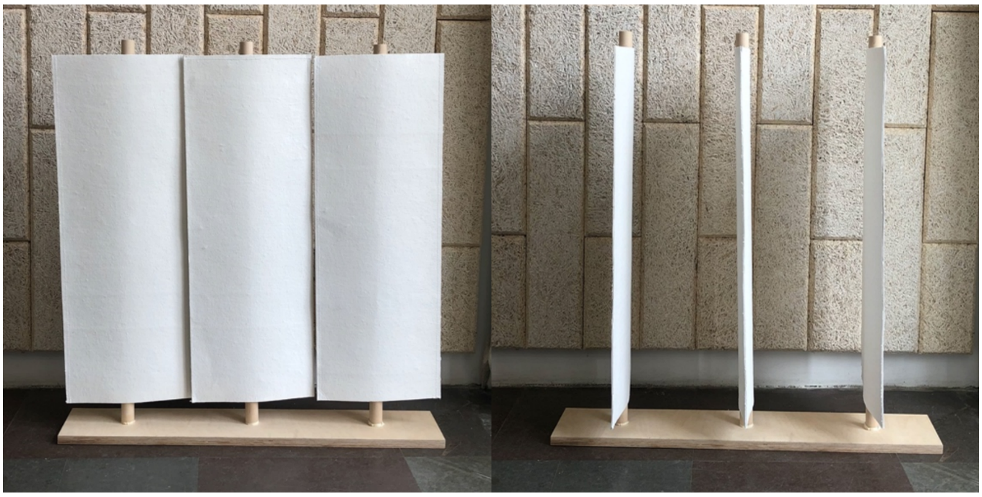

Figure 8.6 Full scale prototype of the final design proposal in closed and open state

Because of the unknown fire properties of Circulose, as for now, the material is best suited to be used in an interior product, due to the less restrictive fire regulations. As mentioned in the subchapter *6.5.1.1 Detailed information about the selected materials,* Circulose can potentially gain improved fire properties by being treated with an eco-friendly fire retardant. This would widen the opportunities of placing the product on walls or in ceilings.

8.3.1 **Sound absorber**

The sound absorber element consists of four or more lengthwise halved sheets of Circulose which are interlocked along the lengthwise edge in a manner that creates a single tall unit with two opposing sides that can be flexed away from each other, see the top right corner of figure 8.5 for a visual representation. When the unit is flat, it allows for optimized packaging and shipping. When the unit is dilated, it allows for assembly onto a billet which leads to the sides of the unit "hugging" it in place. Thus, creating an air gap between the two opposing sides which should, in theory, increase the unit's acoustic performance. Furthermore, it generates a look reminiscent of an airplane wing or windmill blade, which creates a lightweight and airy design.

8.3.1.1 Air Gap + Layers

The air gap created by the two dilated sides is the main detail of this unit, as it is what creates the design's distinct appearance while simultaneously affecting its acoustic properties. The width of the air gap is directly linked to the diameter of the billet holding it in place, which means these two parts are intertwined from a design perspective. It was concluded that a range of different diameters would need to be acoustically tested in a reverberation chamber to determine the optimal width of the air gap. However, in order to maintain a distinct wing-like appearance of the sound absorber, it was decided that the air gap has to be at least 30 mm wide.

The amount of halved Circulose-sheets needed to create the unit is a multiple of four, e.g. four, eight, twelve, and so on. The acoustic properties of the design will vary depending on how many sheets are used, wherefore the final amount used would be best determined by acoustic testing in a reverberation chamber.

8.3.1.2 Joining + Edge

Interlocking of the sheets along the lengthwise sides can be achieved through a number of different methods, e.g. sewing, pressing, framing, etc. The most important function of the joint is, naturally, keeping the sheets interlocked. However, it can also affect the unit's appearance. For example, if a frame is used as seen in figure 8.7, the frame will be an explicit visual element of the design while a pressed joint will be invisible. Another important aspect that was kept in mind was to have a joint that allows for easy recycling, e.g. a removable joint or a joint that could be recycled in the same loop as the sheets themselves.

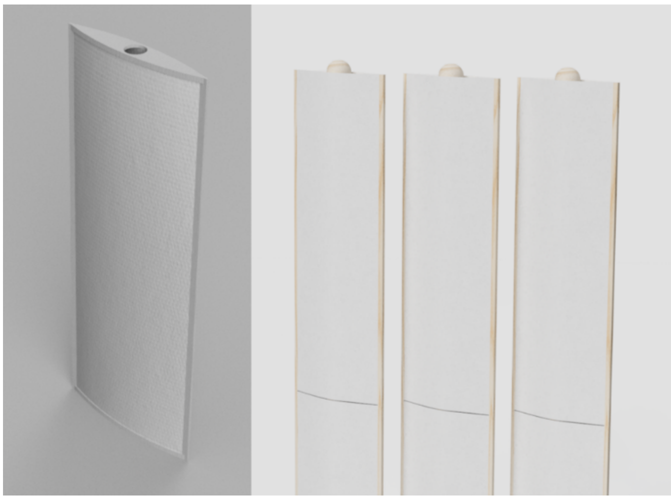

Figure 8.7 Framed sheets

Another discussion was to apply a reinforced edge, as seen in figure 8.8, or not. The Circulose-sheets might fray a bit on the edges, which is why it could be useful to add a separate edge. This would however raise the same question about the visual appearance as the usage of a frame.

Figure 8.8 Circulose with reinforced edge

Ultimately, while discussing the topic with employees at FUWL, it was determined that the clean look of the Circulose was preferable to that of the framed Circulose and that the issue of fraying should be solved without disturbing the clean appearance. For example, if the sheets are pressed together, the edge might also harden in a way that eliminates the issue for the lengthwise sides.

8.3.1.3 Centering Piece

While discussing the design with the CEO of BAUX, a question of visual consistency regarding the sound absorber was raised. When mounted, the prototype unit tilted slightly on the billet, which would disturb the holistic look when mounting several units next to each other. The solution to this would be to create a centering piece, a part connected to the unit which holds it in place while still allowing it to rotate. Several solutions, such as metal rings and an interior frame, were explored.

The final proposal to this issue incorporates a flap system, where a specifically cut flap is sewn on to each sheet along the short edges. Before mounting the unit onto a billet, the flaps can be extended and connected, forming a hole in the middle into which the billet can be inserted, see figure 8.9.

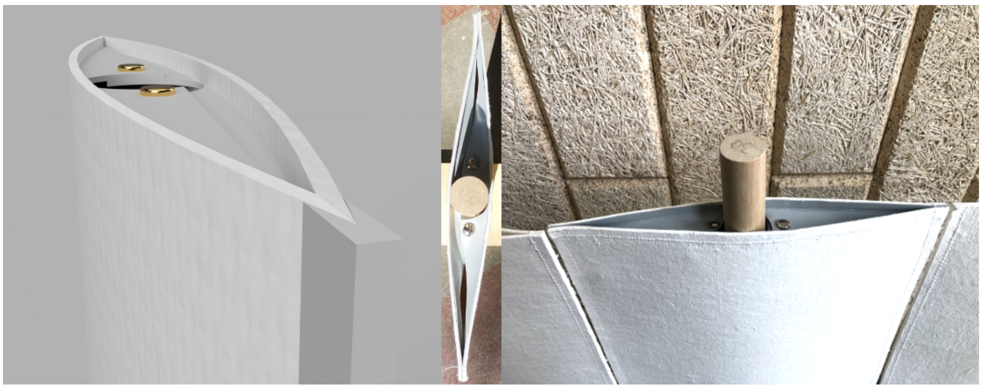

Figure 8.9 Connected flaps centering the unit when mounted on to the billet

Ideally, the centering piece should also prevent the sound absorbing units to move vertically on the billet. This can be achieved in several ways, e.g. using a groove or a bulge on the billet.

8.3.1.4 Interchangeability

A perk with the simplicity of the design is that it allows for interchangeability. As the unit is easily mounted and demounted, they can be switched out in intervals. If several different looking options of the unit are offered, it creates an opportunity for the customer to change the appearance of their product as they go, or to replace worn-out units. It also allows for a changed business model, subscription- or leasing-based, with the benefits of this mentioned in subchapter *7.3.1.1.2 Business Model*.

8.3.2 **Base**

The base consists of two elements; a ground unit and billets. The primary function of the base is to hold the sound absorbers in place while allowing rotation of the units. Depending on the design of the ground unit, feet might need to be added for stability. The base can however come in several forms, where some might be designed for placement on the wall or the ceiling. An important decision to be made was whether the base should hold one or several sound absorbers. After consideration, it was determined that a base holding several sound absorbers is the one most visually exciting of the two.

The base can be designed in several ways using different materials and manufacturing methods. Important factors to consider when choosing the material are that it should be durable since it is to be used in a product with a long lifespan, it should be able to be produced and processed in a sustainable way and it should be a pure material that can be recycled. Preferably, the ground unit and billets should be made of the same material and as few as possible – if any – fastener parts should be added to the design. Wood was considered early on as an interesting material as it is renewable and refers to the cellulosic content in the Circulose-sheets. It is therefore the material suggested for the base in the final design proposal.

8.3.2.1 Ground unit + Feet

When exploring the design of the ground unit, several options were considered, see figure 8.10. A cuboid wide enough to create stability, a cylinder resting on feet, bottom-split cylinders creating feet, etc. The two former options were selected as the most visually appealing, however as it was hard to determine which of these is preferable, it was decided to propose both as possible solutions for the final design.

Figure 8.10 Different designs of the ground unit

8.3.2.2 Billet + Joining

The billet is, as previously discussed in *8.3.1.1. Air Gap + Layers*, what determines the width of the air gap within the sound absorber and the general look of the product. While the diameter of the billet is preferably determined through acoustic testing, the length of the billet and how it connects to the ground unit were other aspects for consideration.

The length of the billet must be at least as long as two Circulose sheets (1600 mm). However, it can be longer to provide a space between the ground unit and the absorbers and/or to create a visual detail of overextending above the top line of the sound absorber unit.

Regarding the joint between the ground unit and the billet, a screw solution was considered the simplest. By threading the bottom of the billet and the holes in the ground unit, it is possible to join the two together simply by screwing, without the use of additional fastener parts.

8.3.2.3 Handling

An area that was explored was however it should be possible to move the product as a complete unit around after assembly. If it is to be possible, the base would also need to provide some sort of detail to ease the process. One suggestion was to incorporate handles in the shape of additional billets, see figure 8.11, allowing for lifting and moving of the complete unit.

Figure 8.11 Complete unit with handles

8.3.2.4 Modularity

While discussing the final design proposal with the CEO of FUWL, the topic of modularity arose. A trademark for BAUX products at the moment is that they are modular in the sense that you can build systems containing a multitude of products, which can be expanded with even more products if the need or desire arises.

In order to create a framework allowing *BAUX Flight Mode* to be modular, two different solutions were explored. Adding an optional chamfered edge on the short sides of the ground unit or by providing a curved (quarter circle) ground unit, see figure 8.12. This would allow for each complete unit to be figuratively or literally interconnectable into a system that would allow for the horizontal stacking of products along a line across a room.

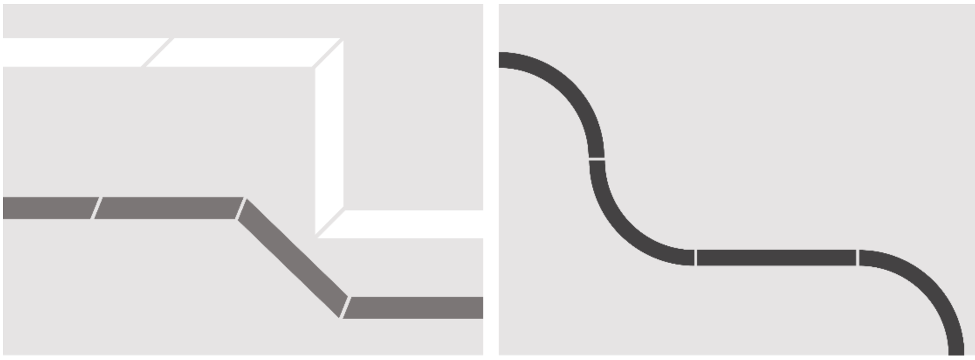

Figure 8.12 Left: Modularity by chamfered edge, right: Modularity by curved unit

8.3.3 **Final Design Proposal**

Renderings and illustrations of the final design proposal can be found below in figures 8.13 and 8.14 and 8.15. Additional images can be found in Appendix E.

Figure 8.13 Renderings of *BAUX Flight Mode*

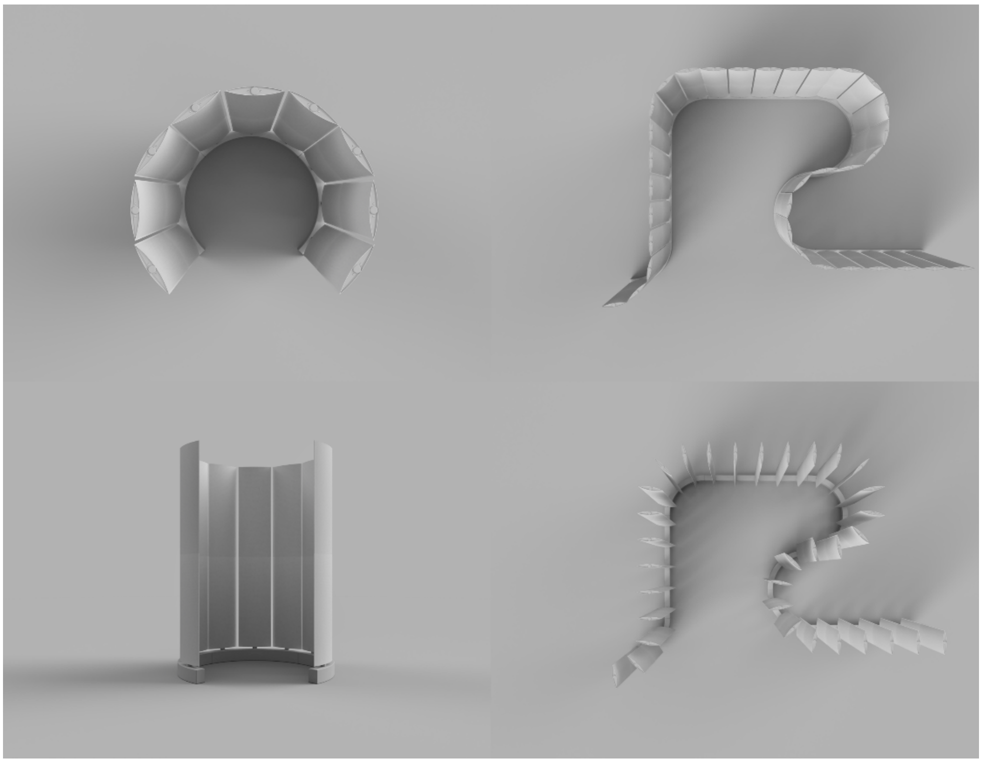

Figure 8.14 Renderings showing modularity of *BAUX Flight Mode*

Figure 8.15 Illustrations of *BAUX Flight Mode*

8.4 Impedance Tube Measurement

The acoustic measurements were made by comparing one sample of Wood Foam (s2) and two different samples of Circulose (s3 and s4) to a sample of the BAUX Wood Wool (s1), as seen in figure 8.16. For this thesis, only the samples s1 to s4 are relevant.

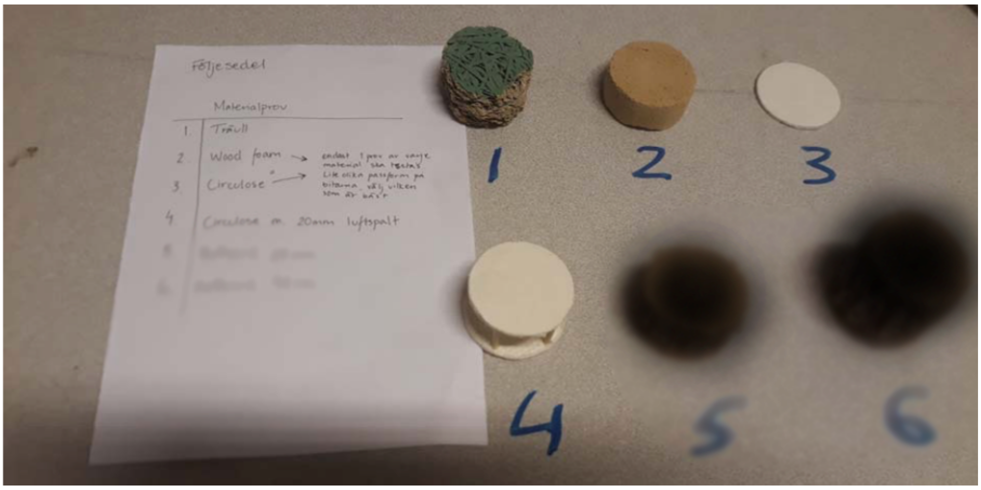

Figure 8.16 The samples sent for acoustic testing. From top left to bottom right: BAUX Wood Wool (20 mm) (s1), Wood Foam (20 mm) (s2), Circulose (1,5 mm) (s3), 2 plates of Circulose (1,5 mm) with 20 mm air gap (s4). Samples s5 and s6 are not relevant to this thesis.

The result from the acoustic test is found below in figure 8.17.

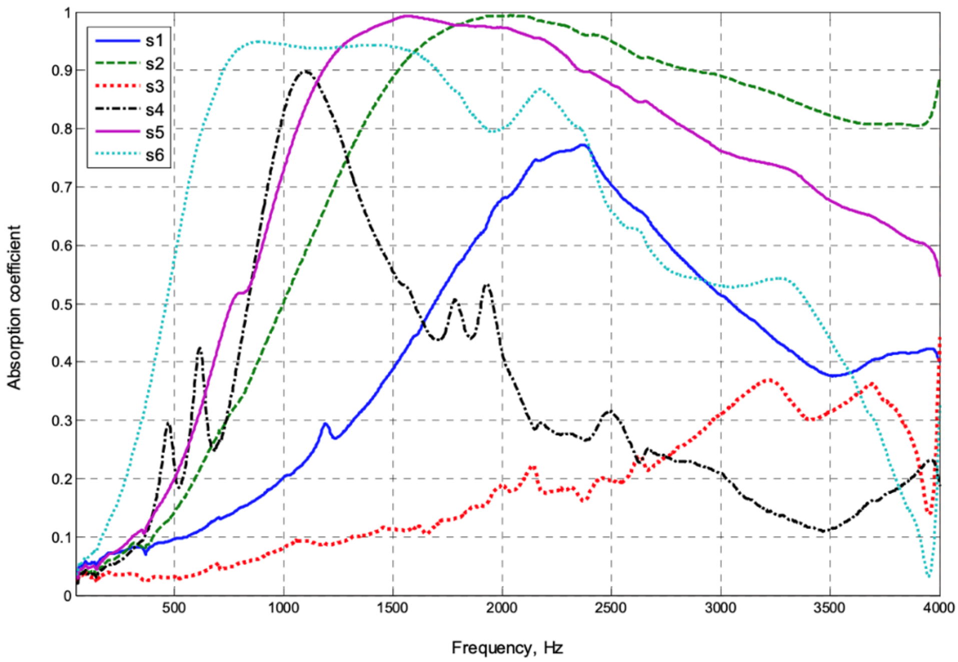

Figure 8.17 Results from Impedance Tube Measurements

The results from the acoustic measurements confirmed the assumptions made about the materials. Wood Foam (s2) performed well on higher frequencies and can be regarded as a highly interesting material for acoustic solutions.

Circulose (s3 and s4) can be seen as performing slightly worse on higher frequencies when compared to the other materials. However, the single sample s3 only had a thickness of 1,5 mm and layering several plates together might lead to better results. The sample incorporating an air gap (s4) had a large spike on lower frequencies which reveals that an air gap could dramatically improve the performance of the material regarding certain frequencies.

It can, when analyzing the chart along with information from subchapter *4.1.4 Sound absorption classification (SS-EN ISO 11654)*, be noted that the samples s2 and s4 would obtain a sound absorption class of E with an approximate weighted sound absorption coefficient of 0,2 and 0,25 respectively. However, it should be mentioned that all samples would most likely obtain improved values at lower frequencies with increased thickness, based on the theory regarding thickness and air gaps mentioned in subchapter *4.1.1.1 Porous Absorbers*. Hence, it should be possible to design a product with a sound absorption class of at least D with both Wood Foam and Circulose.

The proposed final solution in subchapter *8.3 The Design* incorporates an air gap with varying width and also allows for layering of multiple sheets. This makes it possible to optimize the design for higher acoustic properties by varying the diameter of the interior billet as well as by adjusting the number of layers.

8.5 Summary Deliver

The concept development resulted in more refined ideas within the two selected concepts *Dynamic Billets* and *Suspended Shapes*. The further development revealed challenges within each concept that played an essential role during the evaluation of deciding a final concept. It is important to note that some ideas that were rejected during the evaluation does still have potential but need more work that could not be delivered within the timeframe of this thesis. This also applies to the two other selected materials. Circulose was more fitted for the selected design proposal but none the less are Wood Foam and Bonded Foam potential materials that are recommended to be used in future designs.

The design that was selected as the final concept, *BAUX Flight Mode*, was broken down to its elements and developed further in more detail. The presented design is not final. It rather consists of proposed design elements that need to be further refined both aesthetically to reach a holistic design, but also in collaboration with manufacturers.

The benefits of *BAUX Flight Mode* is that it is designed to reduce complexity. During the thesis, it has become clear that a sustainable way of designing is to keep it simple in order to benefit circularity. Important principles that are implemented in *BAUX Flight* Mode are:

- Using as few types of materials and as few parts as possible
- Simplifying shipping and assembly/disassembly
- Choosing materials that are durable and can be produced and recycled in a sustainable way
- Taking responsibility for the product's full lifespan

These are all implemented in a scalable way, keeping a relatively low budget which will make the product last for the foreseeable future.

The acoustic measurements showed that Circulose have potential in being a good sound absorber. To reach higher values, the material needs to be optimized regarding thickness and the width of the air gap.

9 Discussion

9.1 The process

The process chosen for this thesis was a modified version of the Double Diamond. It allows for iterations as well as establishing a clear framework for when to diverge and converge. As this thesis was divided into two distinct and initially methodologically different sub-areas (Material Selection and Concept Development), it was a suitable model to build upon. The modification made to the *Develop*-phase offered a clearer end goal to the phase, as it was evident that some evaluation and selection had to be performed in order to advance into the *Deliver*-phase. In turn, the modification made to the *Deliver*-phase created a clearer path for the continued development of the selected concepts as it included a short diverging phase. This was made in order to ensure that several solutions for the same detail had been explored and evaluated.

However, with more time the most suitable method for this project might have been to divide the two sub-areas into two separate original Double Diamond-based projects. This would have ensured a more exhaustive result for both areas, as for example the Material Selection-phase would have had the opportunity to diverge and converge a second time, making sure that additional possibilities and issues had been explored.

9.2 Sustainability

Sustainability is a wide and complex area which has been in the epicenter of this thesis. As time was limited, several difficult choices had to be made with regards to what areas were deemed to make the most impact for an acoustic product.

In the end, it was determined that factors such as the materials and/or products lifecycle, material composition and origin were the most efficient to analyze with regards to their impact in relation to the time needed to uncover the information.

Other factors, such as pollution related to the manufacture and shipping of the materials and products, were still considered over the course of the thesis but had to be down-prioritized since it is both a time intensive and challenging task to estimate and/or calculate this for each individual material. This type of factors are still of great interest when estimating the impact of a material or product on the environment, and should be considered if the results of this thesis are used in further work.

As the thesis progressed, the mindset of what truly is sustainable, from a circular perspective, changed significantly. In the beginning, it was assumed that a biodegradable material would be the best to use as it would simplify the process of disposal at the end-of-life. However, as evident in the thesis, biodegradability is an area that is highly complex and its possibilities varies greatly between country borders. Therefore, this might still be the best solution if the product is to be used in a specific country, but not if it is to be used in for example Sweden.

This further illustrates how important it is to consider where the product is meant to be used when designing for sustainability.

9.3 Material Selection

The development of a framework for the material selection was difficult, especially with regards to how the rating system was to be built. Several assumptions had to be made during the collection of data, but also when constructing the rating system. A slight change in the system could generate completely different results, which illustrates how critical it is that a system of this kind is grounded in correct and exhaustive data.

For example, the need or existence of a fire retardant within a material is something that could be argued to be an important factor in the selection of a sustainable material. However, this was not included in the scoring system as it was difficult to determine what type of fire retardant was used and therefore its environmental impact. Or, if one was used or required, many manufacturers of fire retardant are tremendously secretive about the chemical composition of their products and it proved too difficult to find enough information.

In relation to this, the decision to reject all materials derived from finite resources in the scoring system, could be questioned. Using a finite material, such as a material derived from stone, that is naturally fire resistant, could be more sustainable than using a renewable material in need of fire retardant. It can also be argued that stone is a more abundant finite resource than for example oil. Here, the discussion about composite materials also gets entangled. It was determined in the thesis that composites were to be avoided as they were not considered to be needed in an acoustic product since they complicate circularity. This could be challenged if the matrix material were to eliminate the need of a fire retardant, but further research is needed within these areas before a final conclusion can be made.

Related to the difficulties of finding information about fire retardants is the difficulties to find information about the composition of specific materials. Many materials included in the material selection are not a 100 % pure material, but rather consists of several different resources. In some cases, the different components could be found by further research or by inquiring the manufacturers of the material, however in some cases assumptions had to be made based on general information about the type of material.

Furthermore, another delimitation had to be made during the selection with regards to porous and non-porous materials. As non-porous materials generally would have to be implemented in a resonant absorber-solution, it was decided that these would not qualify for further development. This decision was based on the difficulties of designing such a solution and the more expansive acoustic tests that must be made in order to ensure their efficiency.

Hence, if the Material Selection-part of this thesis is to be used in the future, there can be work made in order to make it as fool-proof as possible. However, in this thesis and its delimitations, it worked well for its purpose of finding and highlighting materials with high potential with regards to sustainability and availability.

9.4 The Design

The final design proposal, *BAUX Flight Mode*, can overall be considered a concept of great potential for its purpose of being a sustainable and attractive acoustic solution complementing BAUX existing assortment of products. The main goal of designing a dynamic yet simple solution with an honest presentation was achieved, while the materials used ensures that it fits into a circular economy.

However, there are still aspects that can be explored and improved. The final design complements the Circulose with the use of wood in the billets and base unit, while wood is considered a sustainable material that is renewable, it might not be the absolute best material to use for this application. It can be argued that for example that aluminum might be a better material to use due to its ability to be recycled an infinite number of times (but this using a highly energy-consuming process). This can all depend on how long the product is used for, how the product is manufactured and how the material is taken care of after its end-of-life.

Circulose in itself is a material with high potential, but discussions with Re:newcell has to be conducted in order to ensure the best way to take care of the material after it has served its purpose. In this thesis, it is proposed that the best way to do this would be to let Re:newcell recycle the material into new Circulose. It might however be even better to recycle it in an already existing loop, such as paper. The best way to recycle Circulose would therefore be an interesting area to explore further.

While the proposed design technically is complete enough to be manufactured and sold, there are many aspects in need of further development in order to make it a commercial product with high-end design. The look created from the wing-like

Circulose-sheets is the essence of the concept where the design of the base unit can be altered in multiple ways, allowing for modularity and several different end-uses. All details, such as the joining of the sheets and the centering piece, need to be tested and developed in collaboration with manufacturers to make sure they work and can be made in a larger scale. When spending time developing these details further, other solutions would most likely occur that could be more well suited for production and the finalized design.

Generally, *BAUX Flight Mode* is to be considered an interesting proposal which BAUX can use as a foundation for a final product.

10 Conclusion

The foundation for this thesis was the question "*What's next in sustainable acoustic materials?*". As this is a question of an open character, it is quite hard to determine if it was in fact answered in this thesis, though it can be regarded as at least partly answered. This thesis should be used as a guideline and pre-study of how to design acoustic products for sustainability.

Several materials of high potential with regards to both sustainability and acoustic properties have been found and evaluated, and their applicability in a sound absorber has been tried by successfully designing a concept incorporating one of them.

The area of sustainability, as complex as it is, has been thoroughly investigated and some key insights have been presented. Designing for a circular economy can, for the moment, be equated as to design for recycling. While biodegradability is an interesting area that has great potential, the most established and functioning method is still recycling. If more countries invest in industrial compost facilities, this might however change. The best route to take at the moment though is to keep already extracted resources in the loop, by designing with recycled materials and making sure they can be easily recycled yet again after the products end-of-life.

The proposed new subscription- or leasing based business model can also be seen as a part answer to the question. Whatever material comes next, it has been established that it will not be truly sustainable until manufacturers take responsibility for it over its complete lifespan.

Circulose, Wood Foam and Bonded Foam might well be what's next in sustainable acoustic materials, just as a completely new material might be just as good or better. Meanwhile, they can be considered unique and somewhat groundbreaking materials in an otherwise conservative industry.

The next step could be to further improve the material selection framework and/or to further explore how Circulose, Wood Foam and Bonded Foam can be used in acoustic solutions. It is also recommended that the *BAUX Flight Mode*-concept is further tested to find the perfect combination of layers and implemented air gap to ensure that it becomes as optimal of a sustainable and dynamic sound absorber as it has the potential to become a unique product on the market.

11 Reflections

Overall, the thesis has progressed smoothly without any major obstacles. It has been a joy to dive into the subject matter with everything it has included. Our collaboration has worked well, both between us as thesis partners and between us and BAUX and FUWL. The good teamwork between us as thesis partners are perhaps somewhat founded in that we talked about our expectations before starting the thesis and could find a common ground. Our supervisors at BAUX and FUWL have trusted us to work independently which have led to us doing what we truly find exciting and with great energy.

Going into this thesis as engineers, we believed it would be unavoidable to include calculations of some kind. This has been proven wrong since we have almost not included any calculations throughout the thesis. From looking back at our work, this can be explained through that the areas of sustainability and materials are complex and ever changing. New solutions are constantly being found regarding sustainability and it is one of the most current topics addressed today, if not the most current. Therefore, there is no black on white of what the right answer is to "What's next in sustainable acoustic materials?", it all depends on the product, the prospectors view and where in the world you are. Instead of calculating how to make an optimal product from an acoustic standpoint, we have been forced to gather as many insights as possible to determine what we recommend is next in sustainable acoustic materials for BAUX.

This has required managing many parallel processes, unlike in school where the process often is linear and follows a clear path. It has made it feel more "real", where we have been implementing our knowledge gained during the five years of studies into understanding an entirety.

We truly hope that BAUX will have use of our work and that they will ingest our conclusions. This, by keeping up to date regarding sustainability and proceeding to look for new sustainable materials. Naturally, we also hope for further development of *BAUX Flight Mode* into a finalized product.

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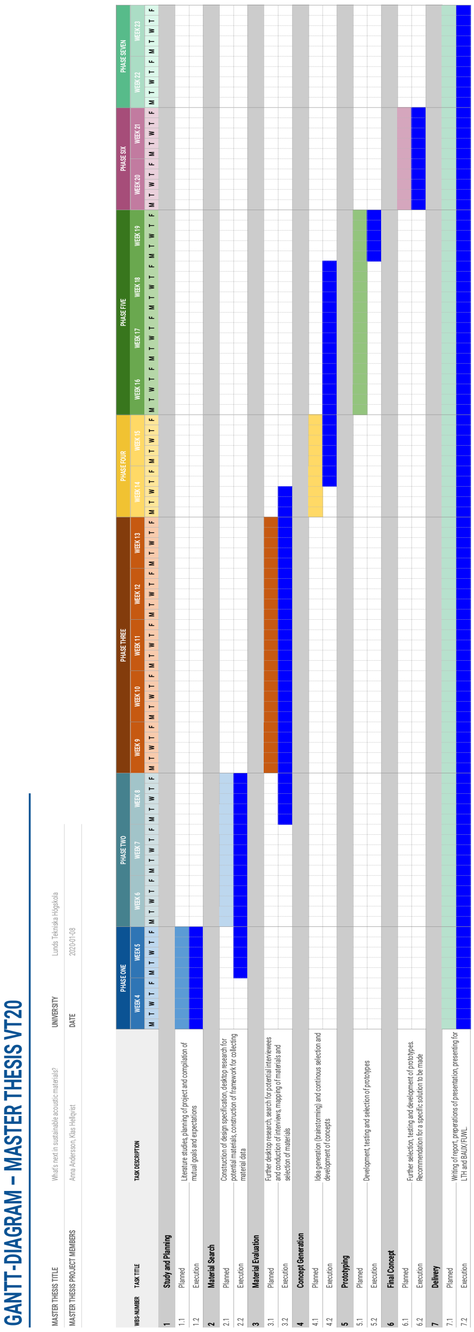
Appendix A Work distribution and time plan



Appendix B Excerpt from SS-EN 13501-1:2019 (Fire Classification)

The European standard SS-EN 13501-1:2019 provides a framework for fire classification of construction products and building elements, using data from reaction to fire tests (such as fire tests according to SS-EN 13823:2010+A1:2014). The following excerpt specifies the following ratings for all building products, excluding floorings: (SIS 2019b)

Fire

- **F**
  - Products not possible to be classified in accordance with below grades.
- **E**
  - Products that can withstand a small flame over a short period of time without considerable flame-spread.
- **D**
  - Products in appliance with criteria for class E that can withstand a small flame over a longer period of time without considerable flame spread. Furthermore, products classified as class D can withstand a thermal attack with a single flaming object with sufficient delayed and limited heat spread.
- **C**
  - Same as class D, but meets stricter requirements. Furthermore, products classified as class C have a limited horizontal flame spread during a thermal attack with a single flaming object.
- **B**
  - Same as class C, but meets stricter requirements.
- **A2**
  - Products that fulfills the same requirements as class B for SS-EN 13823. Furthermore, products classified as class A2 will not contribute considerably to the fire load and -development under the terms of a fully developed fire.
- **A1**

    - Products that will not contribute in any phase of the fire, including the fully developed fire. For this reason, they are assumed to automatically fulfill all requirements for lower classes.

Additional classifications for the production of smoke

- **s3**
    - No limitation is needed for the production of smoke.
- **s2**
    - The total production of smoke and the quota for increasement of smoke production is limited.
- **s1**
    - Meets stricter requirements than class s2.

Additional classifications for burning particles or drops

- **d2**
    - No limitations.
- **d1**
    - No burning particles or drops that remain for longer than a specific period of time have emerged.
- **d0**
    - No burning particles or drops have emerged.

Appendix C Material Selection

C.1 List of Materials

Name				Material Info			
Material Name	Type of Material	Comment	Suppliers	Acoustic application	Virgin content	Recycled content
Ioncell	Textile	Textile fibers made from recycled textile, paper or wood	Aalto University	Porous absorber	#N/A	Textile, Paper, Wood
Kaffeplast	Biocomposite	Biocomposite made from recycled coffe bean-shells and plastic	Huskee Cup (?)	Resonance absorber	Plastic (oil)	Bio-waste
Waste Based Bricks	Stone/Clay	Bricks made from recycled stone and glass	StoneCycling	Resonance absorber	Unknown Binder	Glass, Stone/Clay
Merdacotta	Stone/Clay	Bricks made from manure and clay	Museo della Merda (?)	Resonance absorber	Stone/Clay	Bio-waste
MycoComposite	Biocomposite	Boards made from mycelium grown on wood chips	Ecovative / Krown.bio	Porous absorber	Wood, Mycelium/Bacteria	Bio-waste
PureFiber	Paper	Pulp material	Stora Enso	Porous absorber	Wood, Unknown Bio-binder	#N/A
BioPeel	Biocomposite	Biocomposite made from disgarded orange peels and a binder	Denny Handley (student)	Porous absorber	Unknown Bio-binder	Bio-waste
Woolpower	Textile	Felt made of waste material from wool clothing production. Contains plastic for durability	Woolpower	Porous absorber	Plastic (oil)	Animalic
iCell	Paper	Insulation board made from recycled paper	iCell	Porous absorber	Plastic (oil), Flame Retardant	Paper
CelluPac	Paper	Research to develop cellulose based alternative for EPS	Linde Pac	Porous absorber	Paper, Unknown Binder, Unknown Bio-binder	#N/A
ecovio	Plastic	Biobased plastic based on "Ecoflex", PLA and additives	BASF	Porous absorber	Plastic (bio)	#N/A
Hampakalk	Biocomposite	Insulation board made from hemp fibers and lime stone	Ekolution	Porous absorber	Hemp, Stone/Clay	#N/A
Shou Sugi Ban	Wood	Burnt (fossilized) wood	TREE	Resonance absorber	Wood	#N/A
Chip[s] Board	Plastic	Biobased plastic (PLA) made from potato-waste, can be reinforced with fiber	Chipsboard	Resonance absorber	Unknown Bio-binder	Bio-waste
Bambu	Wood	Bamboo-boards	Holse & Wibroe	Resonance absorber	Bamboo, Unknown Binder	#N/A
SmartFoam	Paper	Research to develop foam material out of agriculture-waste	Chalmers	Porous absorber	#N/A	Paper, Bio-waste
Rattan	Plant fiber	Rattan		Porous absorber	Misc. plant fiber	#N/A
Reed	Plant fiber	Reeds, commonly grows in Sweden		Porous absorber	Grass	#N/A
AgraLoop	Textile	Fiber made from food-crop waste	Circular-systems	Porous absorber	Unknown Binder, Unknown Bio-binder	Bio-waste
Leca	Stone/Clay	Expanded clay		Porous absorber	Stone/Clay	#N/A
AeroGel (Quartzene)	Glass	Super-porous glass-material	Svenska Aerogel	Porous absorber	Glass	#N/A
Denim Batt	Textile	Insulation material made from recycled jeans	Inno-Therm	Porous absorber	Unknown Binder	Textile
Mossa	Plant fiber	Acoustic boards can for example be made from moss glued onto a backing material		Porous absorber	Misc. plant fiber	#N/A
Expanded Cork	Wood	Expanded cork is made from cork granulates (cork not possible to use in other applications) which is superheated through steam	Therma Cork	Porous absorber	Wood	#N/A
Wood Foam	Wood	Expanded cellulose. Hemp and straw can also be used as raw material, as well as sawmill by-products	Fraunhofer	Porous absorber	Wood	#N/A
Carbon Air	Other	Activated carbon, creates a "breathing" material that is super-porous	CarbonAir	Porous absorber	Wood, Misc. plant fiber	#N/A
Manureality	Stone/Clay	Board material made from manure, lime stone and dissolvable glue	Manureality	Porous absorber	Stone/Clay, Unknown Bio-binder	Bio-waste
Pine Needles	Plant fiber	Acoustic boards can be made from pine needles, e.g. with the help of pressing and/or binder		Porous absorber	#N/A	Bio-waste
Breathaboard	Biocomposite	Plasterboard made from clay and hemp (?)	Adaptavate	Porous absorber	Stone/Clay	Hemp
Hemp Fur	Textile	Fur-like material made from flax and/or hemp	DevoHome	Porous absorber	Flax, Hemp	#N/A
Hey Jute	Plant fiber	Needled felt made from jute	Alexander Marinus (student)	Porous absorber	Jute	#N/A
F-ABRIC	Textile	Textile made from flax, hemp and other natural fibers	Freitaq	Porous absorber	Flax, Hemp, Misc. plant fiber	#N/A
QMilk	Textile	Textile made from non-food milk	QMilk	Porous absorber	#N/A	Animalic
Flexzorb	Textile	Activated carbon-textile. "Breathing" material that is super-porous	Chemviron	Porous absorber	Wood	#N/A
Lisocore (Innermaterialet)	Wood	MDF-like board material that is pressed into a wave-shape	Lightweight Solutions	Resonance absorber	Wood, Unknown Binder	#N/A

Material Name	Sustainability							Production Info			
	Pure material	Recycled	Finite resource (non-recycled, non-binder)	Renewable / Biobased	Recyclable (100 % today)	Origin	Sustainability Score	Scale (today)	Scaleability (future)	Price	Production Score
Ioncell	Yes	3	No	3	Internally	Nordic	GOOD	Future	Scaleable	2	-
Kaffeplast	No	1	Yes	1	No	World	-				-
Waste Based Bricks	No	3	No	0	Internally	Europe	GOOD	Off the shelf	Moderate	2	OK
Merdacotta	No	2	Yes	2	No	Europe	OK	Art Project	Not scaleable	1	-
MycoComposite	No	1	No	3	Home-compostable	World	OK	Off the shelf	Moderate	2	OK
PureFiber	Yes	0	No	3	Yes	Nordic	GOOD	Innovative	Scaleable	3	GOOD
BioPeel	Yes	2	No	3	Home-compostable	Europe	GOOD	Art Project	Not scaleable	2	-
Woolpower	No	3	No	2	Downcycle	Nordic	OK	Off the shelf	Scaleable	2	GOOD
iCell	No	2	Yes	2	No	Nordic	OK	Off the shelf	Scaleable	3	EXCELLENT
CelluPac	Yes	0	No	3	Yes	Nordic	GOOD	Future	Scaleable	3	-
ecovio	Yes	0	No	2	Industrial compost	Europe	OK	Off the shelf	Scaleable	3	EXCELLENT
Hampakalk	No	0	Yes	2	No	Nordic	OK	Off the shelf	Scaleable	3	EXCELLENT
Shou Sugi Ban	Yes	0	No	3	Downcycle	Nordic	OK	Off the shelf	Scaleable	1	-
Chip[s] Board	Yes	3	No	3	Industrial compost	Europe	OK	Off the shelf	Scaleable	2	GOOD
Bambu	Yes	0	No	3	Downcycle	World	OK	Off the shelf	Scaleable	2	GOOD
SmartFoam	Yes	3	No	3	Yes	Nordic	GOOD	Future	Scaleable	3	-
Rattan	Yes	0	No	3	Home-compostable	World	OK	Off the shelf	Scaleable	2	GOOD
Reed	Yes	0	No	3	Home-compostable	Nordic	GOOD	Innovative	Moderate	2	OK
AgraLoop	Yes	3	No	3	Industrial compost	World	OK	Innovative	Scaleable	2	GOOD
Leca	Yes	0	Yes	0	No	Nordic	-				-
AeroGel (Quartzene)	Yes	0	Yes	0	No	Nordic	-				-
Denim Batt	No	2	No	2	Downcycle	Europe	OK	Off the shelf	Scaleable	2	GOOD
Mossa	Yes	0	No	3	Home-compostable	Nordic	GOOD	Innovative	Moderate	1	-
Expanded Cork	Yes	0	No	3	Industrial compost	Europe	OK	Off the shelf	Scaleable	2	GOOD
Wood Foam	Yes	0	No	3	Yes	Europe	GOOD	Innovative	Scaleable	2	GOOD
Carbon Air	Yes	0	No	3	No	Europe	OK	Innovative	Scaleable	0	-
Manureality	No	2	Yes	2	No	Europe	OK	Art Project	Not scaleable	1	-
Pine Needles	Yes	3	No	3	Home-compostable	Nordic	GOOD	Future	Scaleable	2	-
Breathaboard	No	2	Yes	2	Home-compostable	Europe	OK	Innovative	Scaleable	2	GOOD
Hemp Fur	Yes	0	No	3	Industrial compost	Europe	OK	Off the shelf	Scaleable	1	-
Hey Jute	Yes	0	No	3	Home-compostable	Europe	GOOD	Art Project	Moderate	1	-
F-ABRIC	Yes	0	No	3	Industrial compost	Europe	OK	Off the shelf	Moderate	1	-
QMilk	Yes	3	No	3	Industrial compost	Europe	OK	Off the shelf	Scaleable	2	GOOD
Flexzorb	Yes	0	No	3	Downcycle	Europe	OK	Off the shelf	Scaleable	0	-
Lisocore (Innermaterialet)	Yes	0	No	3	Downcycle	Europe	OK	Off the shelf	Scaleable	3	EXCELLENT

Material Name	Technical Specifications											
	Recommended acoustic product application	Recommended production methods	Acoustic comment	Absorption coeff.	Density (kg/m3)	Air resistance (kPa/(m/s2))	Fire class	Fire class drip	Fire class smoke	VOC	Cleanable	Surface type
Ioncell												
Kaffeplast												
Waste Based Bricks												
Merdacotta												
MycoComposite												
PureFiber												
BioPeel												
Woolpower												
iCell		Cutting		0,7-1,0	32	13-21	F				No	Rough
CelluPac												
ecovio												
Hampakalk												
Shou Sugi Ban												
Chip[s] Board												
Bambu												
SmartFoam												
Rattan												
Reed												
AgraLoop												
Leca												
AeroGel (Quartzene)												
Denim Batt												
Mossa												
Expanded Cork		Pressing					E			No	Yes	Mid
Wood Foam					40-280		D			No		
Carbon Air												
Manureality												
Pine Needles												
Breathaboard												
Hemp Fur												
Hey Jute												
F-ABRIC												
QMilk							B					
Flexzorb												
Lisocore (Innermaterialet)												

Name			Material Info			
Material Name	Type of Material	Comment	Suppliers	Acoustic application	Virgin content	Recycled content
Karuun Shine	Plant fiber	Rattan cut crosswise to show the capplilaries	Karuun	Porous absorber	Unknown Bio-binder, Misc. plant fiber	#N/A
DuraPulp	Biocomposite	Biocomposite made from PLA and paper/cellulose	Södra Cell	Porous absorber	Paper, Plastic (bio)	#N/A
HempFlax Nonwoven	Plant fiber	Felted flax and/or hemp fibers	HempFlax	Porous absorber	Flax, Hemp	#N/A
Trifilon Switch	Biocomposite	Biocomposite made from PLA reinforced with hemp	Trifilon	Resonance absorber	Plastic (bio), Hemp	#N/A
Nanai Salmon Leather	Textile	Leather made from salmon skins, waste from fish farms	Nanai	Porous absorber	#N/A	Animalic
Supernature	Textile	Needled felt made from wool	The Soft World	Porous absorber	Animalic	#N/A
Claytec	Stone/Clay	Unburnt clay, supposedly reshapable	Claytec	Resonance absorber	Stone/Clay	#N/A
Banana Fiber Paper	Paper	Paper made out of banana plantation waste	GreenBananaPaper	Porous absorber	#N/A	Bio-waste
Cocolok +more	Biocomposite	Coir (or other) -fibers glued together with natural latex	Enkev	Porous absorber	Misc. plant fiber, Latex	#N/A
Micromoulded biocomposites	Biocomposite	Biocomposites altered with a special heating machine to obtain soft, flexible areas in the material	Studio Bas Froon	Porous absorber	Textile, Plastic (bio), Misc. plant fiber	#N/A
Metal Waves	Metal	Paper- and metal-thread weaved together	Beck & Kinch	Porous absorber	Paper, Metal	#N/A
Valchromat MDF	Wood	MDF-board with pre-colored wood chips	Valchromat	Resonance absorber	Wood, Unknown Binder	#N/A
SCALITE	Other	Board material made out of 100 % fish scales, contains its own natural binder	SCALITE	Resonance absorber	#N/A	Animalic
Ocragela	Plant fiber	Student project material made out of ocre and binder	Soowon Chae (student)	Porous absorber	Animalic, Misc. plant fiber	#N/A
Phee Seagrass Board	Biocomposite	Board material made out of seagrass	Phee	Resonance absorber	Unknown Bio-binder	Grass
Feelingwood	Wood	Insulation material made out of cellulose	Thermocell	Porous absorber	Wood, Unknown Binder, Flame Retardant	#N/A
Kafee	Plant fiber	Veneer made from coffe beans and coffee bean-shells	Organoid Technologies	Resonance absorber	#N/A	Bio-waste
Spray-cork	Wood	Spray applied cork-insulation	Cork Sol	Porous absorber	Wood, Unknown Binder	#N/A
Sprayplan	Wood	Spray applied cellulose-insulation	AcoustIQ	Porous absorber	Wood, Unknown Binder	#N/A
Wooden Leather	Other	Paper with leather like touch made out of silk	Marlene Huissoud (designer?)	Porous absorber	Animalic	#N/A
Neptutherm	Plant fiber	Insulation material, 100 % seagrass collected from beaches, naturally fire resistant, 25-35 eur/m2	Neptutherm	Porous absorber	#N/A	Grass
Duralmond	Biocomposite	Board material made from almond shells and binder	Duralmond	Porous absorber	Unknown Binder, Unknown Bio-binder	Bio-waste
Circulation (HIVE)	Textile	3d-felted wool	Hive (out of business?)	Porous absorber	Animalic	#N/A
Masonitskiva	Wood	Board material made from 100 % wood, uses the lignin as binder	Misc.	Resonance absorber	Wood	#N/A
"Screen"	Paper	Board material made from unusable recycled paper waste	Tim Teven (student)	Porous absorber	Unknown Binder, Unknown Bio-binder	Paper
Summit Wall Tile	Stone/Clay	Acoustic elements made from beton with river sludge and clay replacing the cement	Beton-Lab	Porous absorber	Bio-waste, Stone/Clay	#N/A
Sea Stone	Biocomposite	Board material made from sea shells and binder	Newtab-22	Porous absorber	Unknown Bio-binder	Bio-waste
Brödfilt	Textile	Research into making fibers from mycelium and old bread	University of Borås (?)	Porous absorber	#N/A	Bio-waste, Mycelium/Bacteria
Glasskum	Glass	Foamed glass, highly porous and strong	Hasopor	Porous absorber	#N/A	Glass
Marinatex	Other	Algae- and fish waste-based alternative to plastic bags	Marinatex	Porous absorber	Algae	Animalic
Nuo	Wood	Laser engraved veneer mounted on cotton fabric. Expensive, ≈ €90/m2	Nuo	Resonance absorber	Wood, Cotton	#N/A
Bioflexi	Plant fiber	Research project developing a straw based fiberboard. If rice straws are used the material is naturally fire retardant	Stuttgart University (?)	Porous absorber	Plastic (oil), Plastic (bio)	Misc. plant fiber
Typha Insulation	Textile	Algae based textile	Studio Tjeerd Veenhoven	Porous absorber	Algae	#N/A
Rise by Bloom	Plastic	EPS mixed with algae	Bloom TreadWell	Porous absorber	Plastic (oil), Unknown Bio-binder, Algae	#N/A
Jeans on the Wall	Textile	Insulation material made from recycled jeans	Denimtex	Porous absorber	Unknown Bio-binder	Textile
Thin plywood	Wood	Very thin plywood that is transluscent	Misc.	Resonance absorber	Wood, Unknown Binder	#N/A

Name	Sustainability						
Material Name	Pure material	Recycled	Finite resource (non-recycled, non-binder)	Renewable / Biobased	Recyclable (100 % today)	Origin	Sustainability Score
Karuun Shine	Yes	0	No	3	Industrial compost	Europe	OK
DuraPulp	No	0	No	3	Industrial compost	Nordic	OK
HempFlax Nonwoven	Yes	0	No	3	Home-compostable	Europe	GOOD
Trifilon Switch	No	0	No	3	Industrial compost	Nordic	OK
Nanai Salmon Leather	Yes	3	No	3	No	Europe	OK
Supernature	Yes	0	No	3	Downcycle	Europe	OK
Claytec	Yes	0	Yes	0	Internally	Europe	-
Banana Fiber Paper	Yes	3	No	3	Yes	World	OK
Cocolok +more	No	0	No	3	Industrial compost	Europe	OK
Micromoulded biocomposites	No	0	No	3	Industrial compost	Europe	OK
Metal Waves	No	0	Yes	1	Yes	Nordic	-
Valchromat MDF	Yes	0	No	3	Downcycle	Europe	OK
SCALITE	Yes	3	No	3	Industrial compost	Europe	OK
Ocragela	No	0	No	3	Home-compostable	Europe	GOOD
Phee Seagrass Board	No	2	No	3	Industrial compost	Europe	OK
Feelingwood	No	0	No	2	No	Nordic	OK
Kafee	Yes	3	No	3	Industrial compost	Europe	OK
Spray-cork	No	0	No	2	No	Europe	OK
Sprayplan	No	0	No	2	No	Europe	OK
Wooden Leather	Yes	0	No	3	Industrial compost	Europe	OK
Neptutherm	Yes	3	No	3	Home-compostable	Europe	GOOD
Duralmond	No	2	Yes	1	No	Europe	OK
Circulation (HIVE)	Yes	0	No	3	Downcycle	Europe	OK
Masonitskiva	Yes	0	No	3	Downcycle	Europe	OK
"Screen"	No	3	No	3	No	Europe	OK
Summit Wall Tile	Yes	1	Yes	1	No	Europe	-
Sea Stone	No	3	No	3	Industrial compost	Europe	OK
Brödfilt	Yes	2	No	3	Home-compostable	Nordic	GOOD
Glasskum	Yes	3	No	0	Yes	Nordic	GOOD
Marinatex	Yes	3	No	3	Home-compostable	Europe	GOOD
Nuo	No	0	No	3	Industrial compost	Europe	OK
Bioflexi	No	2	No	3	Industrial compost	Europe	OK
Typha Insulation	Yes	0	No	3	Industrial compost	Europe	OK
Rise by Bloom	No	0	Yes	2	No	World	OK
Jeans on the Wall	Yes	2	No	3	Internally	Europe	GOOD
Thin plywood	Yes	0	No	3	Downcycle	Nordic	OK

Name	Production Info				Technical Specifications											
Material Name	Scale (today)	Scaleability (future)	Price	Production Score	Recommended acoustic product application	Recommended production methods	Acoustic comment	Absorption coeff.	Density (kg/m3)	Air resistance (kPa/(m/s2))	Fire class	Fire class drip	Fire class smoke	VOC	Cleanable	Surface type
Karuun Shine	Off the shelf	Scaleable	1	-												
DuraPulp	Innovative	Scaleable	2	GOOD												
HempFlax Nonwoven	Off the shelf	Scaleable	3	EXCELLENT		Cutting					E				No	Rough
Trifilon Switch	Innovative	Scaleable	2	GOOD												
Nanai Salmon Leather	Off the shelf	Scaleable	1	-												
Supernature	Art Project	Moderate	1	-												
Claytec	Off the shelf	Scaleable	2	GOOD					1600							
Banana Fiber Paper	Off the shelf	Scaleable	3	EXCELLENT												
Cocolok +more	Off the shelf	Scaleable	2	GOOD												
Micromoulded biocomposites	Art Project	Moderate	1	-												
Metal Waves	Art Project	Moderate	0	-												
Valchromat MDF	Off the shelf	Scaleable	3	EXCELLENT												
SCALITE	Innovative	Scaleable	2	GOOD												
Ocragela	Art Project	Not scaleable	0	-												
Phee Seagrass Board	Off the shelf	Scaleable	2	GOOD												
Feelingwood	Off the shelf	Scaleable	3	EXCELLENT							E					
Kafee	Off the shelf	Scaleable	2	GOOD												
Spray-cork	Off the shelf	Scaleable	2	GOOD			Maybe create a mould or similar for applicaiton as a collaboration-product?		500-700		B	d1	s3			
Sprayplan	Off the shelf	Scaleable	3	EXCELLENT			Maybe create a mould or similar for applicaiton as a collaboration-product?				B	d0	s2			
Wooden Leather	Future	Moderate	1	-												
Neptutherm	Off the shelf	Scaleable	1	-												
Duralmond	Innovative	Moderate	1	-							C	d0	s2			
Circulation (HIVE)	Innovative	Moderate	1	-												
Masonitskiva	Off the shelf	Scaleable	3	EXCELLENT							D				Yes	Mid
"Screen"	Art Project	Moderate	2	-												
Summit Wall Tile				-												
Sea Stone	Future	Moderate	2	-												
Brödfilt	Future	Moderate	2	-												
Glasskum	Off the shelf	Scaleable	1	-												
Marinatex	Innovative	Moderate	3	OK												
Nuo	Innovative	Scaleable	0	-												
Bioflexi	Future	Scaleable	1	-							C	d1	s2			
Typha Insulation	Art Project	Moderate	1	-												
Rise by Bloom	Innovative	Moderate	1	-												
Jeans on the Wall	Off the shelf	Scaleable	3	EXCELLENT	Porous absorber	Pressing										Rough
Thin plywood	Off the shelf	Scaleable	3	EXCELLENT		Cutting			1012		E				Yes	Smooth

Name			Material Info			
Material Name	Type of Material	Comment	Suppliers	Acoustic application	Virgin content	Recycled content
BioFoam Pearls	Plastic	PLA alternative to EPS	TermoKomfort	Porous absorber	Plastic (bio)	#N/A
MYX	Biocomposite	Student project material made from mycelium growing on plant fibers	Jonas Edward (student)	Porous absorber	Mycelium/Bacteria, Misc. plant fiber	#N/A
Ullisolering 'Lana'	Textile	Wool insulation consisting of virgin wool (cirka 88%), binder of polyester (12%), syntethic pyretrum (against moths) (<0,1%)	Alchimea	Porous absorber	Plastic (oil), Animalic	#N/A
Moniflex	Plastic	Cellophane based insulation material commonly used in trains	Isoflex	Porous absorber	Wood, Unknown Binder, Flame Retardant	#N/A
Circulose	Textile	Pulp sheets made from recycled textile (sold to fiber manufacturers to make viscose). Sheets are paper/carton-like	re:newcell	Porous absorber	#N/A	Textile
Swedish Wool	Textile	Swedish sheep-farmers burns around 7000 tons of wool every year	Misc.	Porous absorber	Animalic	#N/A
Luffa Sponge	Plant fiber	A type of porous cucumber that when dried could be used as a porous absorber	N/A	Porous absorber	Misc. plant fiber	#N/A
Arboform	Plastic	"Liquid wood", made from ligning mixed with hemp or flax fibers and a binder	Tecnaro Gmbh	Porous absorber	Wood, Flax, Hemp, Unknown Bio-binder	#N/A
Recycled plastic	Plastic	Recycled plastic, for example PE, PP or PS. Can be foamed.	Reelab, Rondo Plast, AB Mälarplast	Porous absorber	#N/A	Plastic (oil), Plastic (bio)
Cellufoam	Wood	Foamed cellulose	Cellutech (Stora Enso)	Porous absorber	Wood, Unknown Binder, Unknown Bio-binder	#N/A
Grape waste board	Biocomposite	Board material made from waste grape stems and binder	Matter eco	Porous absorber	Unknown Bio-binder	Bio-waste
Bonded Foam	Plastic	Recyled foamed plastic bonded together	Special plast	Porous absorber	Unknown Binder	Plastic (oil)
Loop Factory (filt)	Textile	Felt made from traceable textile	Loop Factory	Porous absorber	Unknown Binder	Textile
Natural fibers	Textile	Needled felt made from misc. fibers	Enkev	Porous absorber	Animalic, Misc. plant fiber	#N/A
Natural fibers (w Latex)	Textile	Nonwoven material made from natural fiber, might be needled	Enkev	Porous absorber	Flax, Hemp, Animalic, Latex	#N/A
HONEXT	Paper	Pulp-/MDF-like material made from recycled paper, enzymes and "additives"	Honext	Resonance absorber	Unknown Bio-binder	Paper
Acoustic Textile Felt	Textile	Compressed recycled textiles (cotton or wool 70 %) blended with PP and PE (30 %) into a board with density of 100 kg/m3	Really.	Porous absorber	Plastic (oil)	Textile
Solid Textile Board	Textile	Compressed recycled textiles (cotton 70 %) blended with PP and PE (30 %) into a board with density of 1200 kg/m3	Really.	Resonance absorber	Plastic (oil)	Textile
CALOSTAT	Glass	Made from synthetically amorphous silica (> 60 M.- %), silicon carbide (9 - 29 M.-%) and textile staple fibers based on silicon dioxide (1 - 10 M.-%).	Evonik	Porous absorber	Glass	#N/A
Claytec LEMIX	Stone/Clay	Boards made from clay, earth, wood fibre, starch and jute mesh	Claytec	Porous absorber	Wood, Jute, Stone/Clay	#N/A

Material Name	Sustainability							Production Info			
	Pure material	Recycled	Finite resource (non-recycled, non-binder)	Renewable / Biobased	Recyclable (100 % today)	Origin	Sustainability Score	Scale (today)	Scaleability (future)	Price	Production Score
BioFoam Pearls	Yes	0	No	3	Industrial compost	Europe	OK	Off the shelf	Scaleable	2	GOOD
MYX	No	1	No	3	Home-compostable	Nordic	GOOD	Art Project	Moderate	1	-
Ullisolering 'Lana'	No	0	No	2	Internally	Europe	OK	Off the shelf	Scaleable	2	GOOD
Moniflex	Yes	0	No	2	Industrial compost	Nordic	OK	Off the shelf	Scaleable	3	EXCELLENT
Circulose	Yes	3	No	3	Internally	Nordic	GOOD	Off the shelf	Scaleable	3	EXCELLENT
Swedish Wool	Yes	0	No	3	Internally	Nordic	GOOD	Innovative	Scaleable	2	GOOD
Luffa Sponge	Yes	0	No	3	Home-compostable	World	OK	Innovative	Moderate	2	OK
Arboform	No	0	No	3	Industrial compost	Europe	OK	Off the shelf	Scaleable	2	GOOD
Recycled plastic	Yes	3	No	0	Yes	Nordic	GOOD	Off the shelf	Scaleable	3	EXCELLENT
Cellufoam	Yes	0	No	3	Yes	Nordic	GOOD	Innovative	Scaleable	2	GOOD
Grape waste board	No	3	No	3	Industrial compost	Europe	OK	Innovative	Moderate	2	OK
Bonded Foam	Yes	3	No	0	Internally	Nordic	GOOD	Off the shelf	Scaleable	3	EXCELLENT
Loop Factory (filt)	No	3	No	3	Downcycle	Nordic	OK	Innovative	Scaleable	2	GOOD
Natural fibers	Yes	0	No	3	Home-compostable	Europe	GOOD	Off the shelf	Scaleable	3	EXCELLENT
Natural fibers (w Latex)	Yes	0	No	3	Home-compostable	Europe	GOOD	Off the shelf	Scaleable	3	EXCELLENT
HONEXT	Yes	3	No	3	Yes	Europe	GOOD	Innovative	Scaleable	2	GOOD
Acoustic Textile Felt	No	2	Yes	2	Internally	Nordic	OK	Off the shelf	Moderate	1	-
Solid Textile Board	No	2	Yes	2	Internally	Nordic	OK	Off the shelf	Moderate	1	-
CALOSTAT	Yes	0	Yes	0	Internally	Europe	-	Off the shelf	Scaleable	1	-
Claytec LEMIX	No	0	Yes	1	No	Europe	-	Off the shelf	Scaleable	2	GOOD

Material Name	Technical Specifications											
	Recommended acoustic product application	Recommended production methods	Acoustic comment	Absorption coeff.	Density (kg/m3)	Air resistance (kPa/(m/s2))	Fire class	Fire class drip	Fire class smoke	VOC	Cleanable	Surface type
BioFoam Pearls												
MYX												
Ullisolering 'Lana'		Cutting									No	Mid
Moniflex		Cutting		0,4	13		B				Yes	Smooth
Circulose		Cutting	Thin sheets of material, might reach good values if "draped"		460		D				No	Mid
Swedish Wool							E					
Luffa Sponge												
Arboform												
Recycled plastic							E					
Cellufoam					40-280		B			No		
Grape waste board												
Bonded Foam		Cutting		0,8	80-240		F				No	Mid
Loop Factory (filt)												
Natural fibers		Cutting									No	Rough
Natural fibers (w Latex)												
HONEXT		Cutting			400-700		C				Yes	Smooth
Acoustic Textile Felt		Pressing		0,95	100		E	d2	s2		No	Mid
Solid Textile Board		Cutting			1200		D	d0	s1	No	Yes	Smooth
CALOSTAT							A2	d0	s1			
Claytec LEMIX					1400							

C.2 Materials of Interest (MoI)

Full Material list FILTER imported from Master List w/ Sust score GOOD and Prod score EXCELLENT or GOOD. In order of EXCELLENT->GOOD and ALPHABETICALLY

Name			Material Info				Sustainability				Production Info		Technical Specifications											
Material Name	Type of Material	Comment	Suppliers	Acoustic application	Virgin content	Recycled content	Pure material	Recyclable (100 % today)	Origin	Sustainability Score	Scale (today)	Production Score	Recommended acoustic product application	Recommended production methods	Acoustic comment	Absorption coeff.	Density (kg/m3)	Air resistance (kPa/(m/s2)	Fire class	Fire class drip	Fire class smoke	VOC	Cleanable	Surface type
Bonded Foam	Plastic	Recyled foamed plastic bonded together	Special plast	Porous absorber	Unknown Binder	Plastic (oil)	Yes	Internally	Nordic	GOOD	Off the shelf	EXCELLENT		Cutting		0,8	80-240		F				No	Mid
Circulose	Textile	Pulp sheets made from recycled textile (sold to fiber manufacturers to make viscose). Sheets are paper/carton-like	re:newcell	Porous absorber	#N/A	Textile	Yes	Internally	Nordic	GOOD	Off the shelf	EXCELLENT		Cutting	Thin sheets of material, might reach good values if "draped"		460		D				No	Mid
HempFlax Nonwoven	Plant fiber	Felted flax and/or hemp fibers	HempFlax	Porous absorber	Flax, Hemp	#N/A	Yes	Home-compostable	Europe	GOOD	Off the shelf	EXCELLENT		Cutting					E				No	Rough
Jeans on the Wall	Textile	Insulation material made from recycled jeans	Denimtex	Porous absorber	Unknown Bio-binder	Textile	Yes	Internally	Europe	GOOD	Off the shelf	EXCELLENT	Porous absorber	Pressing										Rough
Natural fibers	Textile	Needled felt made from misc. fibers	Enkev	Porous absorber	Animalic, Misc. plant fiber	#N/A	Yes	Home-compostable	Europe	GOOD	Off the shelf	EXCELLENT		Cutting									No	Rough
Natural fibers (w. Latex)	Textile	Nonwoven material made from natural fiber, might be needled	Enkev	Porous absorber	Flax, Hemp, Animalic, Latex	#N/A	Yes	Home-compostable	Europe	GOOD	Off the shelf	EXCELLENT												
Recycled plastic	Plastic	Recycled plastic, for example PE, PP or PS. Can be foamed.	Reelab, Rondo Plast, AB Mälarplast	Porous absorber	#N/A	Plastic (oil), Plastic (bio)	Yes	Yes	Nordic	GOOD	Off the shelf	EXCELLENT							E					
Cellufoam	Wood	Foamed cellulose	Cellutech (Stora Enso)	Porous absorber	Wood, Unknown Binder, Unknown Bio-binder	#N/A	Yes	Yes	Nordic	GOOD	Innovative	GOOD					40-280		B			No		
HONEXT	Paper	Pulp-/MDF-like material made from recycled paper, enzymes and "additives"	Honext	Resonance absorber	Unknown Bio-binder	Paper	Yes	Yes	Europe	GOOD	Innovative	GOOD		Cutting			400-700		C				Yes	Smooth
PureFiber	Paper	Pulp material	Stora Enso	Porous absorber	Wood, Unknown Bio-binder	#N/A	Yes	Yes	Nordic	GOOD	Innovative	GOOD												
Swedish Wool	Textile	Swedish sheep-farmers burns around 7000 tons of wool every year	Misc.	Porous absorber	Animalic	#N/A	Yes	Internally	Nordic	GOOD	Innovative	GOOD							E					
Wood Foam	Wood	Expanded cellulose. Hemp and straw can also be used as raw material, as well as sawmill by-products	Fraunhofer	Porous absorber	Wood	#N/A	Yes	Yes	Europe	GOOD	Innovative	GOOD					40-280		D			No		

Appendix D Acoustic Measurements

D.1 Impedance Tube Measurements

KTH Engineering Sciences

MEASUREMENTS OF NORMAL INCIDENCE SOUND ABSORPTION COEFFICIENT BY USING IMPEDANCE TUBE METHOD

Technical Note no.:	2002
Client:	Anna Andersson Klas Hellqvist LTH/Baux
Carried out by:	Leping Feng
Signature:	
Report complied by:	Leping Feng
Signature:	
Measurements carried out:	2020-05-15
Report compiled:	2020-05-15

1. Measurement method

The measurements are performed in accordance with standard SS-ISO 10534-2:1998 Acoustics – Determination of sound absorption coefficient and impedance in impedance tube – Part 2: Transfer function method. The useful frequency range, determined by the impedance tube (φ44) and microphone calibrator (φ50) used, is 50 Hz – 4000 Hz.

2. Instrumentation

B&K Pulse Frontend type 2807-002, series number 2348588
B&K Power Amplifier type 2706, series number 660122
Personal Computer with B&K Pulse software
MWL impedance tube (φ44)
¼" Microphone set G.R.A.S. 40BD-S3/26CB, MWL 05, 06 and 07
MWL 8-channel microphone calibrator (φ50)

3. Environment condition

Temperature: 21°C Relative humidity: 41% Ambient pressure: 1004 hPa

4. Test samples

Six samples, named s1 … s6, are tested. Photos of the samples are shown below.

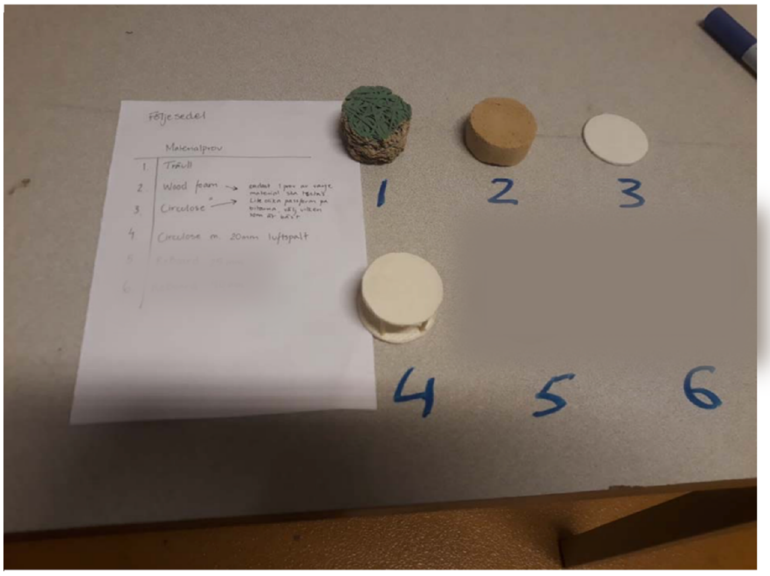


Photo of the test samples and the description

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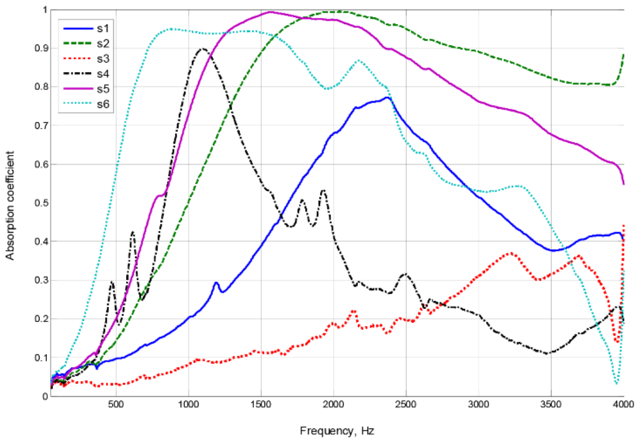
5. Results

Results are summarised in the figure below. All data in Matlab format are supplied. The jump of the curves close to 4 kHz is due to the microphone calibrator (cut on frequency ~ 4000 Hz).



Sound absorption coefficients

Appended files:

Data files: s1, s2, s3, s4, s5 and s6 in Matlab format
Figure: absorption coefficient
More photos

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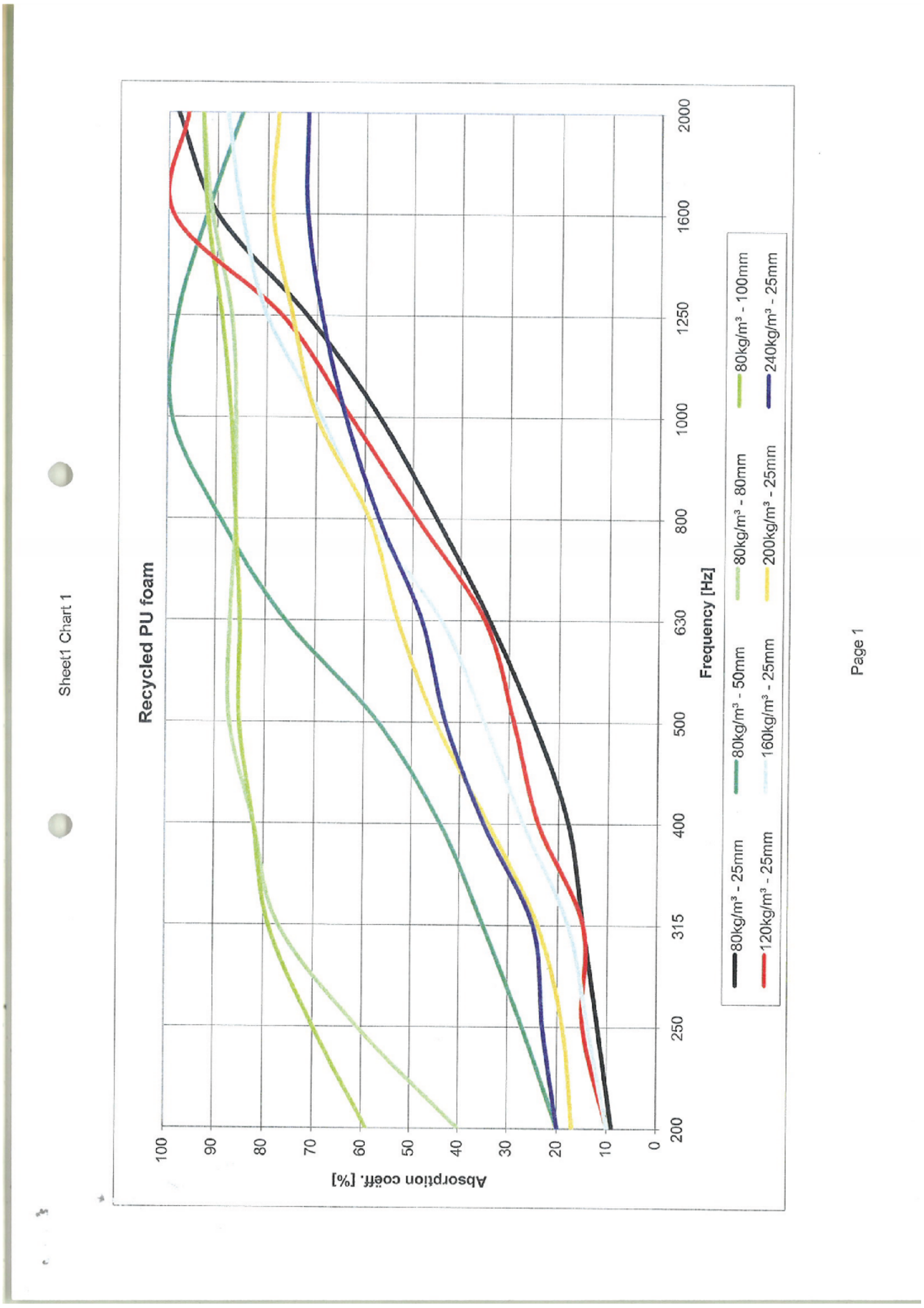
D.2 Bonded Foam – acoustic measurements



Appendix E Final Design Proposal