

# Research and design of a system/family of acoustic panels that follows the guidelines of the company Kinnarps.

Bachelor degree project in Design Engineering  
Level G2E 30 ECTS  
Spring term Year

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## Assurance of own work

This project report has on (2019/07/04) been submitted by Gabriel Juárez Mejía and Julián Soria de la Torre to University of Skövde as a part in obtaining credits on basic level G2E within Product Design Engineering.

We hereby confirm that for all the material included in this report which is not our own, we have reported a source and that we have not –for obtaining credits– included any material that we have earlier obtained credits within our academic studies.



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## Abstract

Development of a conceptual proposal of acoustic panels for the Swedish company Kinnarps. The project uses as main methodology Design Thinking with an user centred approach. Secondly is influenced by the product development process of Ulrich & Eppinger and some IDEO method cards. A literature review that mainly covers acoustics with an emphasis in absorption, a market research, and user studies were performed in order to have a based foundation to create feasible concepts. Along this report is possible to see how the development of the concepts has been done, how they were generated, evolved, and evaluated. As a final result it was proposed a family of 3 different types of structures with 4 variable absorbent panels that ease the way of mounting with a magnetic attachment, and gives several compositions to the customer. It is considered that the final concept fulfils all the demands, although there are some debatable requirements like the functionality, and sustainability that require further development. The methodology and the approach chosen were considered effective tools to work with product design projects that seek an innovative result because they give an appropriate mix of exploration and selection of ideas, and relevant input obtained by the involvement of the users.

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## 1 Introduction

The product development project presented here was conducted with the aim of developing a family of acoustic panels for the company Kinnarps AB, a Swedish company that provides interior workspace solutions for offices and public environments, distinguished by the quality and the low environmental impact of their products. Kinnarps is part of Kinnarps Group which consists of six brands (Kinnarps, Materia, Skandiform, NC Nordic Care, Drabert and MartinStoll) being one of Europe's leading suppliers of interior design solutions (Kinnarps Group, 2018). The company is highly interested in the acoustics of rooms, and in products for sound absorption, due to the recent growth of this market. They want to launch new families of acoustics panels, in specific sound absorbers, that are more accepted by their customers than the ones they currently sell. Therefore, the main goal of this project is to generate one or two feasible concepts, that reach an effective sound absorption, a proposal of feasible materials, manufacturing processes, a stable and easy way of mounting, and an attractive appearance for the target market.

To achieve this, “design thinking” was the main methodology chosen to be followed, with a user centred design approach. These concepts are described by different institutes and organizations as the *Institute of Design at Stanford*, and the American company *IDEO*. This method is distinguished by the use of divergent and convergent thinking by encouraging “creative learning while doing” with sketching and fast prototyping, by suggesting iterations between its different stages and by analysing and understanding the main problem while you search and try different possible solutions (IDEO, 2003).

Along this document is shown a description of the whole process of design and development of the product mentioned previously, following the principal steps suggested by the methodology chosen: Empathize, Define, Ideate, Prototype and Test. The results of each stage will be presented and discussed with a critical perspective.

Also a literature review is shown regarding sound absorption that gives a foundation on the topic and bases for proposing different concepts, followed by other tools that are part of the Product Design Engineering programme, such as Market Research, User Studies, Requirement List, Decomposition of problems, Brainstorming, etc, that can be applied for the design of almost any other product.

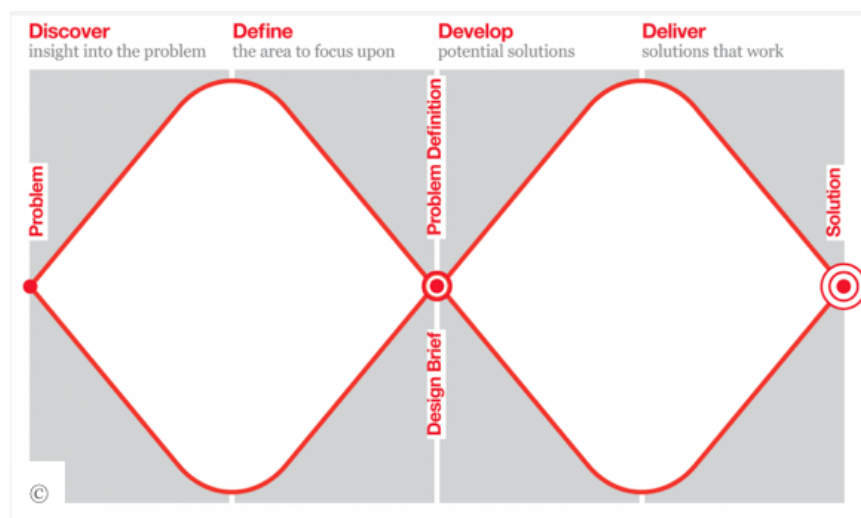
## 2 Methodology

The principal methodology followed in this project is Design Thinking with a human-centred design approach. It was chosen due to the structure it suggests, that is commonly used for projects that seek innovation, by involving creativity as a key strategy to solve complex and “ill-defined” problems (problems that do not have all the information available, that may not have a single perfect and correct solution) (Cross, 2006). An example of the use of this methodology with a human centred approach for trying to find innovative solutions is the American company IDEO (Zoltowski et al., 2012).

The human-centred design approach consists basically in having the human beings as the central element of the project, by studying the stakeholders since the beginning and involving them during all the stages (Zoltowski et al., 2012) This approach is based on finding innovation with a thorough understanding of the people, of their needs, and likes and dislikes regarding the existent products (Brown, 2008).

The project in development has a “Solution-focused strategy” that means the process should concentrate more in working with the solutions rather than with the analysis of the design problem itself. Design problems are not normally solved just by synthesizing the information collected. Instead, several directions followed while trying to solve them is what makes the problem clear and what influence and give input to find the most appropriate solution (Cross, 2006).

The method states to have a clear understanding of the two modes of thinking used during the development of the project, create and judge, converge and diverge. This separation of types of work will help to have a good flow in the search of innovation, by encouraging many ideas outside of the box in the divergent phase, and by having a critical judging in the selection of potential concepts, in the convergent one (Hartson & Pyla, 2012). *Figure 1* shows a graphic proposal of how the divergent and convergent phases are represented in a double diamond structure during the design process.



*Figure 1. Double Diamond of the Design Council UK*

The 5 main stages of Design Thinking that this project follows are: Empathize with the users, Define the problem, Ideate possible solutions, Prototype the potential solutions and Test them (Doorley et al., 2018).

1. Empathize with the users. Identify the users and try to understand their context, study their experience, their specific problems, their likes and needs, find design opportunities that help to create appropriate products for them. This stage is the most essential for a human centred design approach, even though the involvement of potential users and their insights should be considered through all the steps (Doorley et al., 2018).

Some research tools can be used to work with this kind of research, they are divided in 3 levels, low, medium and high, that state the level of user involvement, and depth of information. This tools go from questionnaires, web surveys, to workshops and evaluation meetings (Gheerawo et al., 2010). The information collected from the interviews can be synthesized and shown by making “Personas” which are concrete descriptions of typical users, and “scenarios” which are stories of the users that help the designers to make products that completely satisfy a small percentage of the total user population (Hartson & Pyla, 2012).

2. Define the problem. Use the information previously collected, analyse and synthesize it to reframe the problem and identify the key points that are going to be tackled in the next stages (Doorley et al., 2018).

3. Ideate possible solutions. Generate different concepts that solve the problem or parts of it, trying to think “outside of the box”, using different perspectives to approach it, encouraging innovative ideas. It is suggested to have a mixed verbal and visual brainstorming (sketching) of different solutions for the design problem (Hartson & Pyla, 2012). For this concept generation stage, analogical and lateral thinking were found as tools that can be used to get extra input, by looking to other things not related with the context you are working on, searching similarities of function or potential existing ideas that can “solve” your problem if they are modified, and also by focusing in the deficiencies of existing solutions (Rodgers & Milton, 2011).

4. Prototype the potential solutions. Choose the ideas that are considered to have more potential and make prototypes, these can be scaled versions of it, full size, or only parts of the complete concept, depending on the type of input that the design team wants to get. These input can be gaining a better understanding of the users relation with the product, explore several configurations, test, refine solutions or take decisions (Doorley et al., 2018). In this stage as in the whole creative process is common to use intuition as an important factor at the moment of taking decisions. Intuition can be seen as “abductive” reasoning, which is a type of thinking based in making suppositions (Cross, 2006).

5. Test the design. After prototyping the potential concepts, it is possible to make an evaluation of them in different areas like functionality, ergonomics or aesthetics. This stage may seem to be the last one but as it gives more input for the designer to redefine the concepts, or even the problem, the process does not stop here (Doorley et al., 2018).

An essential characteristic of this method is that it is considered a non-linear process or iterative, that means it gives freedom for the designers to go back to any stage, whenever is necessary, either to develop further potential solutions or to test new alternatives that may appear in the process, and so on (Interaction Design Foundation, n.d.). A graphic example of this is shown in *Figure 2*.

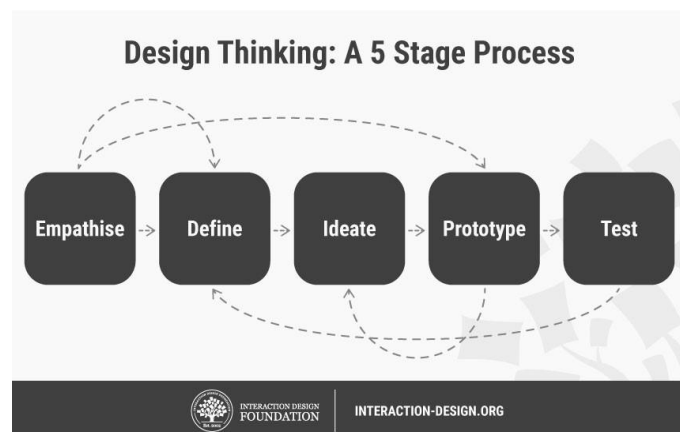


Figure 2. Design Thinking Diagram (Interaction Design Foundation, n.d.).



Some of the stages of the product development process established in the book *Product Design and Development* complemented and influenced the main methodology that guides the whole project. The stages are: planning, concept development, system-level design, detail design, testing and refinement and production ramp up. Highlighting the first five, that were considered more convenient for this project. The planning consists in stating the strategies, objectives and schedule to follow. The concept development is started by identifying the users and customer needs and wishes, then the product specifications are defined, and the concept generation is performed for later making a selection and testing the ideas created. By using a system level design is possible to decompose the problem into different subsystems, which is very helpful to perceive it in a simpler way and attack the problem separately. The main problem can be divided depending on the complexity of the product, by considering its functionality, the interaction with the user or the customer needs. This process makes also easier the ideation stage and encourages to have a considerable number of solutions for different parts of the product that can be further combined. The detail design mainly is the development of all the specifications of the product, considering all the parts that conform the product, and features such as size, materials, etc. The testing and refinement works with prototypes and their evaluations and finally in the production ramp-up the product is made as it is intended to be produced, seeking any remaining issues (Ulrich & Eppinger, 2008).

Extra tools for exploring different approaches that could be applied to several stages of the project were searched, and the following were found:

IDEO Method cards, tools that guide the design process with a human centred design approach, there are 51 cards that explains some methods that the American company IDEO has used to explore, gain new perspectives, and get inspired. This are examples and suggestions for finding new insights, not straight rules (IDEO, 2003). Although, after an analysis of them, only 5 cards were chosen to work with: shadowing (users observation), scenarios, competitive product survey, scale modelling, and experience prototype.

In general terms the methodology for the development of the concepts for the family of acoustic panels is based principally in the guide of five steps of the Design Thinking, and secondarily influenced by the product development process of Ulrich & Eppinger and the chosen IDEO cards.

### **3 Literature review**

Research in acoustics was necessary to generate a background of concepts and general knowledge in themes that could influence sound and the room acoustics, some phenomenon were studied such as reverberance, clarity, sound absorption, workspace. An emphasis in sound absorption is made to have a clear understanding of the functionality of the acoustic panels that are being developed and to find potential improvements for it. Some other factors that could influence the design direction were also investigated, such as workspace characteristics, materials, patents or user experience.

#### **3.1 Basic Acoustics**

To start with the literature review, an investigation of concepts about acoustics was made in order to have a foundation of this field, and be able to understand the complexity of the papers found about the next topics.

### 3.1.1 Sound

Ermann (2015, p.2) says:

“A sound is made when an oscillating membrane disturbs the molecules in an elastic medium-and that disturbance is heard.” Which means that the sound is produced by the motion of some objects, and it needs a medium to be transported to a listener, this is really easy to observe when someone plays musical instruments. Sound also depends directly on the changes of temperature and pressure (Ermann, 2015).

To understand the phenomenon of sound, it is useful to perceive that it behaves as waves in fluids, thus it is necessary to take into account other concepts as period, frequency, wavelength, and speed. The period refers to the time that takes the motion in being done (Long, 2005). The frequency expresses a way for differentiating the sound depending on the wave repetitions per second. Usually, sound frequencies are divided in octaves. This octaves are divided in different frequencies, which middle points are twice of the previous starting with 63 Hz (Ermann, 2015).

The speed gives the value of how fast the waves move, and the value in air at 20°C, according to Long (2005), is approximately around 344 m/s. The wavelength is the measurement of the distance between two peaks of the wave. This value helps to analyse how the different waves behave in the space, for example long wavelengths flow around objects when they have smaller measurements, and when small wavelengths meet bigger objects than themselves, they will be reflected (Long, 2005).

The wide range of sound intensities makes the need of using levels to express their values, this levels are perceived as fractions (10 times log of the ratio of two numbers). The units of these fractions are *bels*, and the multiplication by 10 has been established and agreed by the scientific community, in order to achieve numbers that have useful sizes. Thus the final units for levels are Decibels (dB). To express the strength that the sound has at its each cycle, exists a term called the sound power level (intensity), that is measured in watts, and is proportional to decibels (Long, 2005). A list of common sounds measured in Decibels is shown in *Table 1*.

Table 1. List of common sounds measured in dB (Hall, 1993).

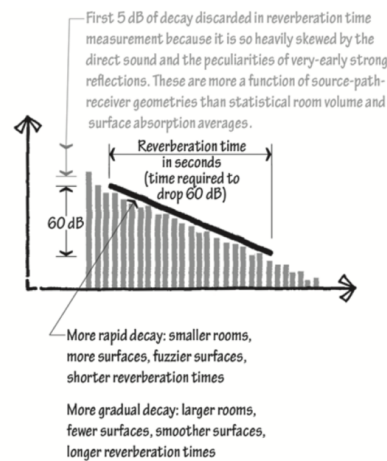
Sound source	(dB)	$I(W/m^2)$	$p(Pa)$
Jet engine at 30 m	140	$10^2$	200
Car stereo contest winner	130		
SST takeoff at 500 m	120	1	20
Amplified rock concert	110		
Heavy machine shop	100	$10^{-2}$	2
Subway train	90		
Factory	80	$10^{-4}$	0.2
City traffic	70		
Subdued conversation	60	$10^{-6}$	$2 \times 10^{-2}$
Quiet auto interior	50		
Library	40	$10^{-8}$	$2 \times 10^{-3}$
Empty auditorium	30		
Whisper at 1 m	20	$10^{-10}$	$2 \times 10^{-4}$
Falling pin	10		
	0	$10^{-12}$	$2 \times 10^{-5}$

\* While these are typical of levels that might be encountered in a variety of situations, individual examples could easily be 10 dB higher or lower.

### 3.1.2 Reverberance

Reverberance is one of the most common phenomena that affects work spaces, it is the process of reflection and attenuation of a sound. When a sound source for instance a speaker emits words and this message travels straight without obstacles to the listener, this type of sound is considered direct. Even though this rarely happens in rooms, what actually happens is that the sound emitted by the source is accompanied by later sounds that had being reflected in different surfaces like walls or furniture and did not follow a direct path to the listener, and that is what is called reverberance. This later sounds grow in quantity but decrease in their energy level (Hall, 1993).

The reverberation time expresses the length of time that this reflected sounds took to drop below the threshold of human hearing and be inaudible for humans. The shorter the reverberation time, the better is going to be the acoustics of a room in terms of speech intelligibility (Parkin, 2015). The standard reverberation time has been established from the start of the sound until it decays 60 dB, which is the range that human perception could be able to notice (Hall, 1993). This is shown graphically in *Figure 3*.



*Figure 3. Reverberation time (Ermann, 2015).*

Reverberation time tends to be longer in larger rooms with reflective walls due to the sound waves have a longer free route, without impacts in surfaces that produce loss of energy (Ermann, 2015). In architectural acoustics, reverberation is usually attenuated with sound absorbers in the ceilings, walls, carpets or other structures. Although some diffusers made with hard materials like wood are also used for the same purpose (Parkin, 2015). Their geometry can influence the room acoustics. Some shapes like convex curves, pyramids, angled surfaces, protruding pilasters, or craggy surfaces generate diffuse reflection because the waves impact on them and are reflected in an aleatory way. Diffusion is very helpful to reduce echo problems and improve the room acoustics increasing the understanding level of sounds because when a sound is reflected in different directions, the reverberation time becomes shorter. In concert halls, diffusing surfaces are used to create a homogenized atmosphere, trying to avoid hard specular reflections (Ermann, 2015). *Figure 4* shows an example of the difference between specular and diffuse reflection.

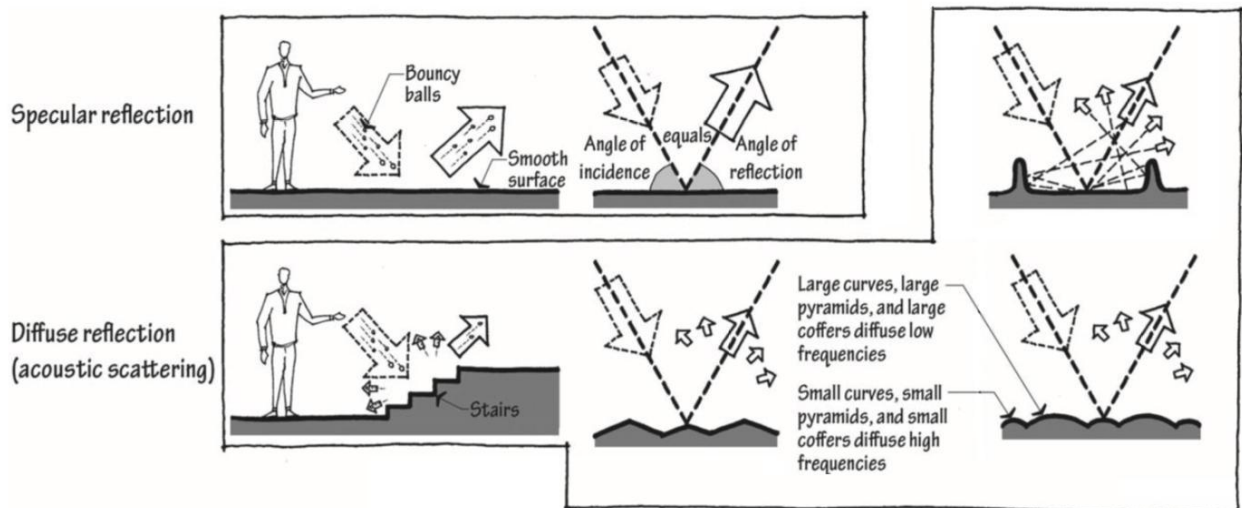


Figure 4. Specular and Diffuse reflection (Adapted from Ermann, 2015).

### 3.1.3 Clarity

People would like to hear words clearly without missing or confusing any of them. Clarity is based on having a firm direct sound with a proper strength. If the direct sound does not have to compete with a long and continued reverberation, this sound will be more easy to understand (Hall, 1993).

Human brains mix the main sound heard with early-arriving reflections. In this way, humans are able to distinguish between different notes or syllables. This combination is called “Haas effect” or “precedence effect”. The brain combines reflections that arrive up to 200 millisecond, measured since the sound reach the listener and depending on the balance, the type of sound and the configuration of the room (Ermann, 2015).

By measuring the sound energy that arrives later than 80 millisecond and comparing it with the total energy averaged for three octave bands, it is possible to obtain the clarity index. It is important to clarify that the clarity index only measures frequencies that are higher than 250 Hz because for humans auditory system is difficult to differentiate temporal effects in lower frequencies, commonly known as bass tones. This simply means that sound would be clearer when the clarity index is high (Ermann, 2015).

### 3.1.4 Noise

Noise is a common problem in working spaces, where concentration is crucial to do daily tasks, it is directly related with the dissatisfaction of workers with job, especially in open offices. There are studies that show that about 60% of the people who work in spaces with more than seven people in the same room, manifest inability to concentrate (Lucerne University of Applied Sciences and arts cited in Schittich, 2011).

Some people associate noise with dissatisfaction with the job environment. Noise is always an issue in working spaces that affects a large amount of workers, especially in open offices. This noise includes conversations and telephones’ ringing which create annoyance in these areas because of the intensity of the background sounds. It also decreases the efficiency of tasks that require concentration such as administrative tasks, highly demand motor tasks, vigilance or dual tasks (Sundstrom, 1986).

There are different types of sounds that contribute to the noise specifically in work spaces, but according to the limit to recognize a sound without perceiving it as separate thumps is 20 beats per second. The sounds with extremely low frequencies are perceived as noise for humans (Ermann, 2015). Some sounds distract people more than others depending if they perceived them as coherent or incoherent, so if someone is giving a speech, and you listen at the same time other coherent sounds, such as music, or people talking, it will catch your attention at disturb your concentration from the main activity you are developing (Copley, cited in Sundstrom, 1986). In working environments, noise can provoke loss of productivity and even physiological disorders in humans, such as headaches, or heart problems (Munjal, 2013).

There exists a measurement of the reduction of noise that is used to compare the absorption of some materials, it is called Noise Reduction Coefficient, and basically is obtained by the average of the absorption coefficient of the material for mid-frequency ranges, as it is shown in *Figure 5* (Ermann, 2015).

$$NRC_{noise\ reduction\ coefficient} = \frac{\alpha_{250\ Hz} + \alpha_{500\ Hz} + \alpha_{1000\ Hz} + \alpha_{2000\ Hz}}{4}$$

*Figure 5. Noise Reduction Coefficient (Ermann,2015).*

### 3.2 Human hearing

Humans perceive the sound through the eardrums that move when they catch the changes in pressure, transforming them into electrical stimulus for our brain (Long, 2005).

It is worth to mention that humans can not listen all type of sounds, humans can perceive only some sounds that have a specific range between 0 and 130 dB, considering zero as completely inaudible to most people, 20 dB as a whisper, and 130 dB as intolerably loud (Hall, 1993). The audible range for humans goes from 20 to 20 000 Hz, although the range between 500 Hz to 4000 Hz, known as “speech range” or middle frequency range, is the range that humans best hear (Parkin,2015) Humans are more sensitive to middle and high frequency (500Hz and above) than to those lower than 250 HZ because the sound wavelengths that these frequencies generate occupy a specific dimension that corresponds to the scale of the diameter of the human ear canal, unlike the ones generated by lower frequencies. For instance, to catch humans attention quickly , sirens, vehicle horns and alarms use generally high frequencies (Ermann, 2015).

### 3.3 Sound Absorption

The absorption of sound is the main function that the product in development needs to achieve. This is why a research has been done regarding how this effect works, how it could be measured and the different mechanisms to accomplish a high level of absorption.

The absorption actually occurs when sound waves interact with real objects by being reflected, transmitted and absorbed by the material, as it is shown in *Figure 6*, where also is possible to see how sound interacts with 3 different materials, having different percentages of absorption, reflection and transmission (Long, 2005).

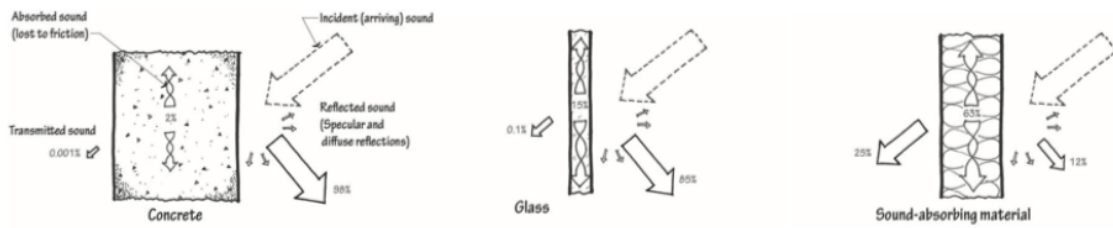


Figure 6. Sound absorption of 3 different materials (Ermann, 2015).

The absorption coefficient ( $\alpha$ ) is the most used value to express the material absorption. It is shown in different sources and material catalogues, this makes easy to identify and compare their functionality. Its value goes from zero to one, and determines the absorption level. It can be understood as the quantity of incident sound that is not reflected, and coming again in to the room. A higher value of sound absorption is proportionally correlated with the amount of sound energy absorbed or transmitted, what means a low level of reflection. Materials with more than 0.50 are considered absorbent materials and on the other hand, the ones with less than 0.20 are considered reflective (Ermann, 2015). The higher values are usually of materials that are more porous, lighter, thicker and less smooth. These high values are also often caused because of the fibres direction that forms interconnecting air spaces (Ermann, 2015).

Porous absorbers, work due to a mechanism called viscous drag that is the one that makes them to be good acoustic absorbers, and basically consists in sound waves provoking air motion in the spaces that exist between the fibres of the material. This movement of air goes in different directions and produces friction, losses of momentum, and heat, depending if they are high or low frequencies. There exists also a variant factor for thin porous absorbers, depending on the distance from them to the wall, the absorption coefficient would be influenced by the air space between them. If the porous absorber is positioned at a distance that corresponds to multiples of a quarter wavelength from the wall, an appropriate position for it will be achieved, because there is a point where the particle velocity is at a maximum point (Long, 2005).

This mentioned influence of the air backing of the porous absorber was confirmed in a positive way by the paper “Principles of Sound absorbers” (Qiu, 2016). The back air space increases the absorption at low frequencies because the velocity of particles next to rigid surfaces is generally zero, and with this space generated by having a layer of material further from the wall, a higher velocity of sound waves will be reached providing a better absorption. *Figure 7* shows a comparison between the absorption coefficients curves of the same material with different thicknesses and different distances from the wall. The red line represents a 5 cm thick absorptive material placed on a rigid wall. The dot line represents the same material placed 10 cm away from the wall. And the dash-dot line represents a 15 cm porous material placed directly on a rigid wall. It was concluded that placing the material separated from the wall increases the absorption levels at lower frequencies (Qiu, 2016).

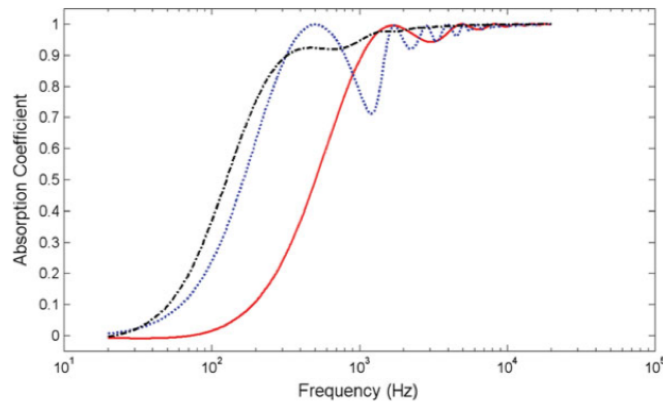


Figure 7. Chart of the influence that has thickness and air backing in the absorption coefficient of a material (Qiu, 2016).

The materials opposition against fluids passage through them, affects the absorption in absorptive materials. By perforating them, the mass would get lower and the air space that pores create would improve the absorption. Perforated panels with backing airspace act like a Helmholtz resonator, achieving a higher value of resonant frequency, affecting the sound waves. It is important to generate an enough open area for not blocking the flow of sound. These kind of panels are thought to absorb middle-frequency levels (Long, 2005).

The mentioned perforated panel act as the Helmholtz resonators-absorbers because the holes work as the neck of the resonator, the space between the panel and the wall act as the cavity, and finally the wall act as the surface of it, making a similar “mass-spring” system (Negro et al., 2015). Micro perforated panels are recently becoming more accepted as replacement of the porous absorbers (Wencheng & Hequn, 2015).

There are different materials that are used on architecture to improve the acoustics of the room, some are shown in Figure 8, it is interesting to observe the comparison between their absorption coefficients and it is worth highlighting the improvement that some materials have when they are perforated, like the plasterboards, metal faced plains or wood.

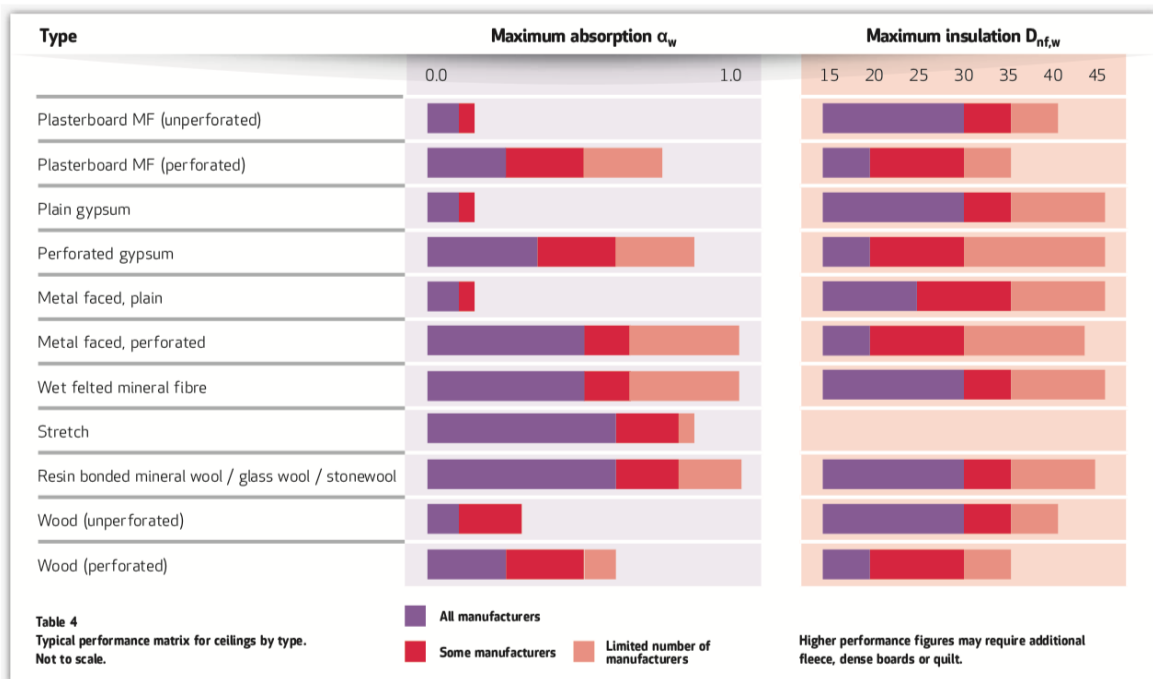


Figure 8. Typical materials used in ceilings of rooms (Parkin, 2015).

Absorptive materials could be overlaid without losing absorption properties. It is common to use wood or metal in order to cover these absorbers, and as can be seen in *Figure 9*, perforations in the facing are useful to maintain the absorption properties of the inner material. If the perforation percentage increases, the absorption is better, but from a 15-20% perforation percentage in the reflective surface, the inner material behaves as if it were unfaced (Long, 2005).

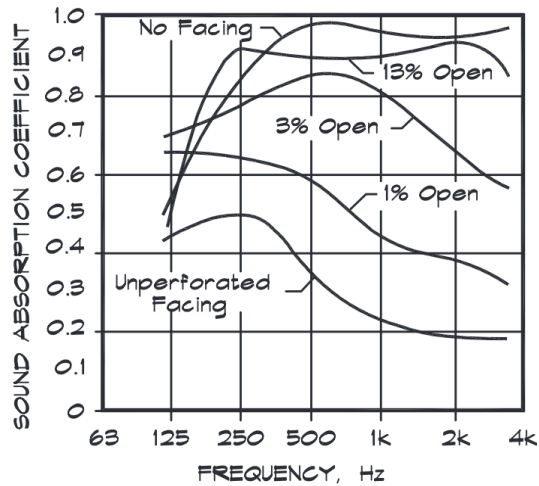


Figure 9. Comparison between perforated facings (Doelle, cited in Long, 2005).

Another system called mass-air-mass system is composed of at least two masses separated by an air space. It is lightweight thanks to the air space which acts as a spring which attenuates the sound. The two masses act as one at very low frequencies (less than 66 Hz) but in the case of higher ones, having these numerous air spaces can lead to a better absorption (Bradley, cited in Long, 2005).

### 3.3.1 Sound Absorption Testing

After visiting the company in charge of evaluating the current panels of Kinnarps, Akustikverkstan in Skultorp, some information about the absorption levels testing was obtained.

Kinnarps as a big amount of other Swedish companies, used the website [www.acousticsfacts.se](http://www.acousticsfacts.se) as a platform to show their acoustics results of a specific test based on three principal rules:

- ISO 11654:1997 – Acoustics - Sound absorbers for use in buildings - Rating of sound absorption
- ISO 354:2003 – Acoustics - Measurement of sound absorption in a reverberation room
- SS 25269:2013 – Acoustics – Screens or single objects – evaluation with regard to sound absorption and screen damping.

(Akustikverkstan, n.d.).

Tests are placed in a reverberation room like the one shown in *Figure 10*. The test makes a comparison between the room's reverberation time without products and the reverberation time when the product is placed inside. It calculates the quantity of noise that is absorbed thanks to the absorption coefficient and the area of the product. After some sounds of different frequencies are played at a constant level the time is measured until the reverberation is reduced by 60 dB. Some surfaces were hanged in the reverberation room in order to diffuse the sound and generate different aleatory waves. For this test sound is considered in a temperature of 20°C and a range of humidity 50-70%, due to this are the values considered normal for interior rooms. (Acoustic Facts, 2017).





Figure 10. Reverberation room.

The range of frequencies that should be measured in these acoustic tests, following the Swedish standard SS 25269 is from 125 Hz to 4000 Hz. In the tests results is common to find a value called  $N_{10}$  that shows how many tested objects are required to have  $10 \text{ m}^2$  of effective sound absorption area. This value has been established in Sweden to evaluate the efficiency absorption in the human speech frequency average (500 Hz) and it is obtained by dividing the number ten by the sound absorption surface. (Kammarkollegiet, 2017).

The “sound absorption area” is measured in the unit Sabins, and it could be obtained from adding the multiplication of the absorption coefficients by the surface area of the products materials in a room. (Ermann, 2015). The lower the value of  $N_{10}$  , the better the sound absorption is.

### 3.4 Existing patents

Research in patents about acoustic absorbers was performed in order to find any existing design, configuration or mounting way which should be avoided during the design process. The results were some existing layer distribution for achieving greater levels of absorption and some mounting systems to avoid, but not any aesthetic design.

Here are the more relevant for the project regarding to the layer distribution inside the panels (Figure 11 and Figure 12) and some options for the mounting system (Figure 13 and Figure 14):

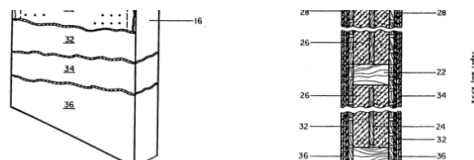


Figure 11. Acoustic panel (Kurrasch, 1991).

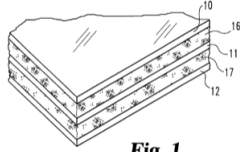


Fig. 1

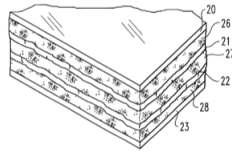


Fig. 2

Figure 12. Acoustic panels having plural damping layers (McNett and McNett, 2000).

Fig. 3

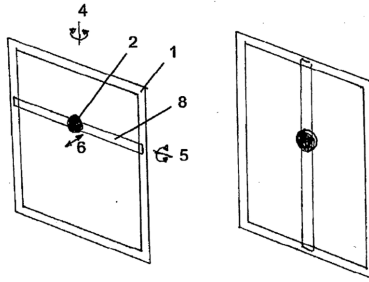


Figure 13. System for hanging different items on walls (Nicolaisen, 2009).

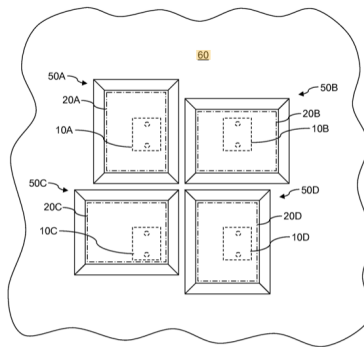


Figure 14. Magnet-based mounting systems for frames (Russo & Russo, 2011)

### 3.5 Absorbent materials

Kinnarps currently use “Re:fill” for the absorptive panels that they sell. It is a porous material made of 60% polyester fibres that come from their own textile waste and recycled PET. The absorption levels of this panels are published in [www.acousticsfacts.se](http://www.acousticsfacts.se). As an example (Figure 15), “Prim” standing panel with dimensions of 800mm x 1980mm and a thickness of 55mm reaches a  $N_{10}$  value of 4 ( $N_{10}$  is explained in Section 3.3.1).

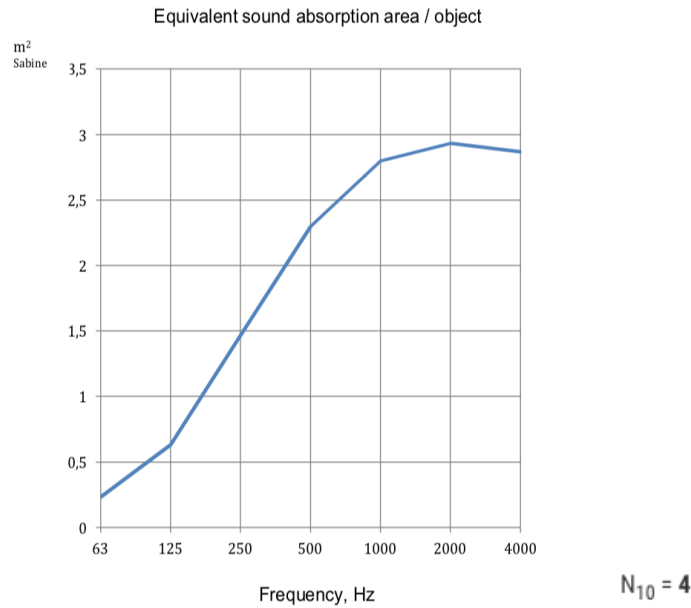


Figure 15. Prim acoustic test results (Acoustic Facts, 2017).

Many materials have absorbing properties and can be used for the acoustic panels, even though each material has a different sound absorption mechanism, and its performance is due to its interior crevice and pore (Bao-guo et al., 2002).

There are some other factors that influence the efficiency of absorptive materials, and that are necessary to analyse at the moment of choosing one for a product which functionality is based on this feature. It was found a list of this factors in a paper, although for the project, the following were considered as the most relevant: fibre size, airflow resistance, porosity, density and thickness. This paper also mentions important facts about how this factors increase the absorption of sound and that could be an appropriate guide for the selection of the material, like the following: Micro denier fibres have shown a high increase in acoustic performance. It exists a relation between high air flow resistance and high absorption in different materials but if the flow resistance exceeds 1000, the sound absorption would decrease due to the difficulty of movement within the material. For the fibres, if the surface area is bigger and the fibre size smaller, the absorption sound will also increase. An open structure of a material that has low density will perform better with low frequencies such as 500 Hz, while denser structures will absorb more high frequencies like above 2000 Hz. The air gap behind a layer of material will increase its absorption coefficient values. And for the thickness, it shows that for low frequencies, the best absorption will be achieved by having thicker layer of the materials (Seddeq, 2009).

In *Figure 8 (Section 3.3)*, some absorptions coefficients of different materials used for architecture are shown and it is possible to see that the higher ones are: mineral fibres and perforated gypsum. It was also found a paper about perforated okoumé plywood (4mm) that shows interesting high values for the absorption coefficient of frequencies around 500 Hz (Negro et al., 2015).

On the other hand, as one of the most important values of the company is the sustainability, some natural and biodegradable materials were sought, to analyse their absorption coefficients and study their feasibility for improving the absorption levels that the current acoustic panel of Kinnarps has. These are shown in *Table 2*.

Table 2. Sound absorption coefficient of natural materials (Berardi & Iannace, 2015).

Material	Thickness [m]	Frequency [Hz]					NRC	
		125	250	500	1000	2000		
Kenaf	(Light)	0.06	0.09	0.19	0.33	0.68	0.90	0.55
	(Dense)	0.04	0.08	0.18	0.32	0.70	0.94	0.55
	(Dense)	0.06	0.10	0.30	0.61	0.99	0.95	0.70
Wood	(Fibers)	0.06	0.20	0.40	0.50	0.65	0.91	0.60
	(Mineralized)	0.03	0.05	0.10	0.10	0.20	0.40	0.20
Hemp		0.03	0.01	0.15	0.25	0.51	0.70	0.40
Coconut		0.05	0.10	0.20	0.34	0.67	0.79	0.50
		0.10	0.25	0.42	0.83	0.81	0.94	0.75
Cork		0.03	0.01	0.02	0.10	0.30	0.86	0.30
Cane	(Mixed)	0.04	0.05	0.10	0.35	0.54	0.58	0.40
	(Mixed)	0.08	0.10	0.21	0.56	0.52	0.68	0.50
	(Only wooden)	0.04	0.01	0.06	0.12	0.47	0.43	0.25
	(Only wooden)	0.08	0.07	0.15	0.46	0.39	0.66	0.40
	(Only bark)	0.04	0.10	0.12	0.38	0.64	0.62	0.45
	(Only bark)	0.08	0.10	0.26	0.63	0.54	0.89	0.60
	(Only bark)	0.10	0.10	0.27	0.48	0.54	0.66	0.50
Cardboard		0.04	0.10	0.14	0.36	0.73	0.94	0.55
Sheep wool		0.06	0.15	0.28	0.66	0.95	0.94	0.70

The highest values for Noise Reduction Coefficient (NRC) in *Table 2* are of coconut fibres (10 cm) with 0.75, dense Kenaf (6 cm) and sheep wool with 0.70, and particularly for 500 Hz, which is the human speech frequency, the highest values are for the coconut (10cm) with 0.83, sheep wool (6cm) with 0.66, cane (8cm) with 0.63 and dense kenaf (6cm) with 0.61. It is important to note that the thickness of the sample affects these results. Even though in general terms the Kenaf and sheep wool seem to be better absorbing material (Berardi & Iannace, 2015).

### 3.6 User experience

User experience refers to how a product is able to cause effects in users thanks to their interaction with it. It is influenced by some factors such as usability, usefulness, functionality and emotional impact (Hartson & S. Pyla, 2012).

In the case of the acoustic panels it is possible to divide these factors into the different features that it has. Usability is focused on the mounters because they will be the ones that have a more direct interaction with the mounting system, and have to understand it properly in order to achieve a high quality result. On the other hand, usefulness, functionality and emotional impact are in this case more relevant for the main users of the product because they are the ones who will have the longer interaction, the ones who need proper acoustics in their spaces and that will perceive the benefit from its functionality. In the case of the emotional impact of the product, it may play a relevant role in offices environments because it affects the user feelings and mood, and these products could be used to achieve an improvement in the users attitude thanks to the workspace atmosphere accomplished.

#### 3.6.1 Mounters ergonomics

Regarding the ergonomics of the mounting process, it was found that there are work-related upper extremity musculoskeletal disorders such as DeQuervain's syndrome, the second most common disorder in the working population (Violante et al., 2000) ganglions, and tenosynovitis caused by actions like inserting screws in holes repeatedly, or epicondylitis ("tennis elbow") caused by actions like turning screws and assembling small pieces. As well it was found that having postures where the shoulder has more than 60° of abduction or flexion for more than 1 hour might cause acute shoulder and neck pain (Salvendy, 2012).

It is important to mention that these positions depend directly in the type of space where the panels are going to be and the number of panels mounted. The disorders mentioned previously depend on distinct factors like the posture, force applied, vibration or a combination of them. There is evidence for causal relationship between these factors shown in *Table 3*.

*Table 3. Evidence for Causal Relationship between Physical Work Factors and MSDs (Bernard cited in Salvendy, 2012).*

Body Part	Risk Factor	Strong Evidence	Evidence	Insufficient Evidence	Evidence of No Effect
Neck and neck/shoulder	Repetition		x		
	Force		x		
	Posture	x			
	Vibration			x	
Shoulder	Repetition		x		
	Force			x	
	Posture		x		
	Vibration			x	
Elbow	Repetition			x	
	Force		x		
	Posture			x	
	Combination	x			
Hand/wrist Carpal tunnel syndrome	Repetition		x		
	Force		x		
	Posture			x	
	Vibration		x		
Tendonitis	Combination	x			
	Repetition		x		
	Force		x		
	Posture		x		
Hand–arm vibration syndrome	Combination	x			
	Vibration	x			

Source: Bernard (1997).

### 3.6.2 Sensorial ergonomics

Good acoustics is considered very important for concentration according to office workers (Lesman cited in Tietema, 2017). It is usually given less attention than other aspects such as engineering issues in architectural design (Salter C., cited in Tietema, 2017) because of the lack of architectural acoustics guidelines and the failures at the moment of executing them (Tietema, 2017).

People commonly relate noise with dissatisfaction in workspaces. It is a significant problem that affects a big amount of employees. This problem increases in open spaces where conversations or the ringing of phones are really common (Parkin, 2015). The office environment is usually full of different types of sounds that distract people from the principal activities they are developing. Sound in workspaces could be controlled in two ways: absorption, which involves reverberation and makes it a better space to work, done through ceilings, rafts and wall panels; and insulation, that controls the sound transmission from one place to another, done through partitions and cavity barriers. There are some aspects that may improve the room acoustics. It should be considered solutions such as absorbent panels (around 1.7m height due to direct speech waves, not having a really high ceiling, because this is the most reflective surface of an open office), carpeted floor, determine acoustic requirements for each space, and taking into account the shapes, internal finishes of rooms and the objects inside of them. It is also important to take in account the room dimensions at the time of improving its acoustics (*Table 4*) because when the volume of the room increases, the reverberation times also do it (Parkin, 2015).

*Table 4. Reverberation time in different size rooms (Parkin, 2015).*

Room volume m <sup>3</sup>	Reverberation time RT	
	Speech	Music
50	0.4	1.0
100	0.5	1.1
200	0.6	1.2
500	0.7	1.3
1,000	0.9	1.5
2,000	1.0	1.6

To understand the efficiency of acoustic panels in workspaces, and their influence on the whole office environment, it was searched some evaluations of their functionality in rooms. A study shows how by replacing 100 square feet of gypsum board in an office with 100 square feet of a porous absorber, there was an increase in the total absorption of the room of more than fourfold the initial quantity, from 26 to 112 Sabins (Ermann, 2015).

Appropriate acoustics is an essential factor to consider in the design of a workspace. It is especially important in spaces that have big areas of concrete and glass (reflective materials). Acoustic design does not consist only in reducing noise, it pursues optimising the reverberance and the speech intelligibility by integrating different absorbing surfaces, acoustic furniture, carpets and dividers in the rooms (Schittich, 2011). Intelligibility is also another important factor that is sought for offices. This factor can be affected by masking effects caused by background sounds or reflections on the speech source. Intelligibility can be improved by several aspects like an adequate loudness, a uniform sound level, an appropriate reverberation, and low noise levels (Doelle, cited in Sundstrom, 1986).

### 3.7 Sustainability

Kinnarps Group has a deep awareness regarding sustainable issues. The company considers environmental risks and has developed sustainability strategies for all their brands. For instance, by trying to avoid leakage, waste or process errors, by managing chemicals and waste with special plans and by educating their employees on this. Some priority areas in which they work to continue achieving a low environmental impact are: use of raw materials and resources verifying them with traceable sources such as the FSC certified or recycled wood, energy efficiency and the use of renewable sources, use of pure materials by utilizing fewer chemicals and avoiding hazardous materials for the environment or health, use recycled materials and ensure a circular flow that increases the products and materials lives. Their waste is used for different applications such as heating manufacturing sites with the wood waste, or textile waste for creating new products. Some of their products can be easily upgraded, thinking on the reuse of parts. They offer a service in which the company take care of the customers used furniture (Kinnarps Group, 2018).

Looking through Kinnarps value chain (*Figure 16*) it is possible to observe some similarities with the cradle-to-cradle concept (*Figure 17*). Both follow a cycle where the materials of the final products can be recycled or reused, minimizing waste, pollution and natural resource depletion, and in this way reducing the environmental impact. The main goals are to have more than a single reuse of the final product and to reuse the waste of the manufacturing processes (Hagggar, 2007). Cradle-to-cradle imitates nature's system of regenerative productivity by changing the concept of waste for a new raw material. Design plays an important role here because it is necessary to think in materials that can be safely manufactured, used, recovered and reused, trying to ensure a sustainable product life cycle. These considerations can also benefit the industries economy by using their own waste and converting themselves into their own material suppliers (Hagggar, 2007).

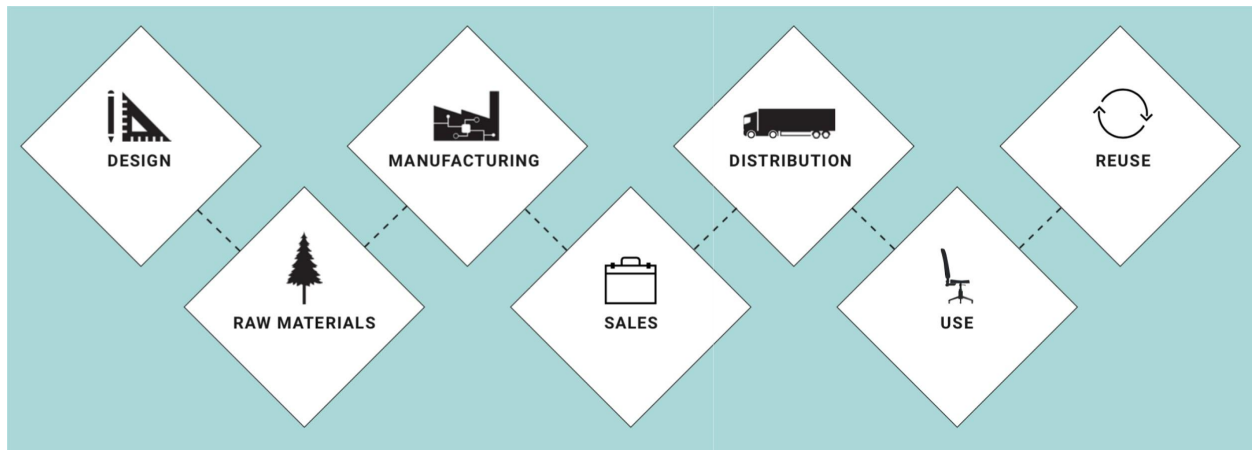


Figure 16. Kinnarps value chain (Kinnarps Group, 2018).

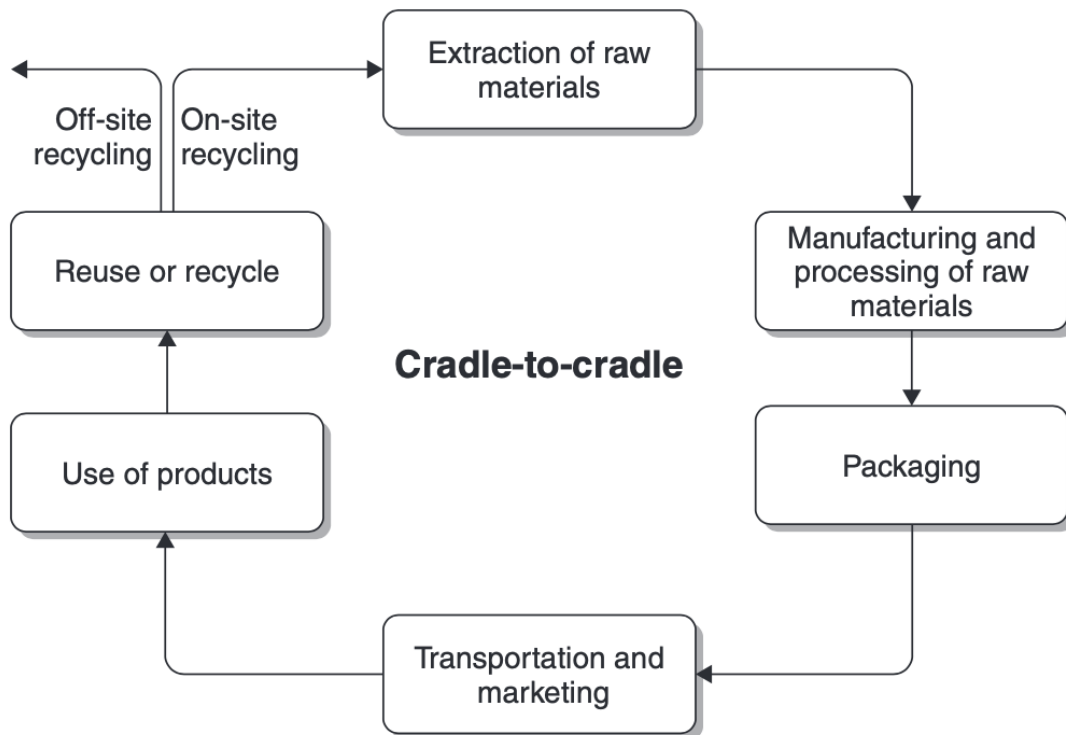


Figure 17. Life cycle analysis based on Cradle-to-cradle concept (Hagggar, 2007).

Kinnarps Group has developed their own sustainability measurement called “The Better Effect Index”. It consists in measuring each product in six different areas (some of them mentioned above): raw materials and resources, climate, pure materials, social responsibility, reuse and ergonomics. These are graded from 1 to 3 achieving a final result which is the average of them. The customers are also able to use a sustainability filter in which they can look for a product regarding these characteristics (Kinnarps, 2019). It is important to mention that there are other types of sustainability metrics, like the Life Cycle Analysis matrix, which is widely accepted for quantifying the environmental impact that a product generates in all the stages of its life. This method measures, among other things, the energy and resources needed, the distinct emissions, impacts in humans and environment, waste and the possibility of reuse (Mager & Sibilia, 2010). By comparing both methods is possible to see that Kinnarps index is covering a wider spectrum of sustainability, even though there are some factors that other methods like the Life Cycle Analysis cover more in depth.

One of the goals of the company is to have good working conditions throughout contributing to social development in the places they operate. An example of it is that they use some of their waste to provide artificial heat to their own factory and to the town where the company is located. The company follows the goals established in 2015 by the UN (United Nations). The ones where the company is having greatest direct or indirect impact are:

- Health and wellbeing: by creating working environments with good ergonomics and reducing unnecessary chemicals.
- Sustainable energy for everyone: efficient use of energy and increase of proportion of renewable energy.
- Decent working conditions and economic growth: good working conditions in their operations and supplier chain



- Sustainable industry, innovations and infrastructure: efficient industrial processes that make optimal use of materials.
- Less inequality: working on diversity and against discrimination and setting requirements for social responsibilities in their supplier chain.
- Sustainable consumption and production: reducing the environmental impact of the production and supplier chain, working with pure materials avoiding unnecessary chemicals and creating circular flows of materials and products.
- Combating climate change: reducing the climate impact of the production, premises and transportation.
- Ecosystems and biodiversity: using certified wood from responsible forestry.

(Kinnarps Group, 2018).

The materials on which the project will focus (the most used by the company) are: chipboards covered with veneer (instead of using solid wood); water-based lacquers treatments to increase the durability; textiles from which 69% are EU Ecolabel certified to follow a sustainable manufacturing process; and recycled metal. Some other chemicals are applied in lacquer glue or paint but as they are not eco-friendly enough, the company has stated the goal of developing surface treatments that can be utilized in different environments in order to fulfil sustainability requirements and continue achieving high quality results (Kinnarps Group, 2018).

## 4 Market Research

This search was done in order to have a general background of the aesthetic styles of this years, to know more about the products of the main competitors in this field and to avoid any kind of plagiarism. It was divided in three stages: a first web search on Swedish and international companies to have a first approach to them, and two visits to some of the most important furniture fairs on the world,; Stockholm Furniture Fair and “Salone del Mobile” during Milan Design Week. There was possible to learn about the new trends, get inspiration from them and to talk with different sellers about their products’ properties.

### 4.1 Moodboards of competitors’ products

Two type of mood boards were done, one taking into account Kinnarps local competition in Sweden, and the second international competition. The companies chosen stand out from others due to their attractive designs. Looking through the images of *Figure 18* and comparing them with the limited absorbers that Kinnarps produces, it is highly noticeable that the company needs some new ideas that could help them to be positioned in the acoustic absorption market as a powerful office furniture company that offers attractive solutions for acoustic absorption in workspace environments.

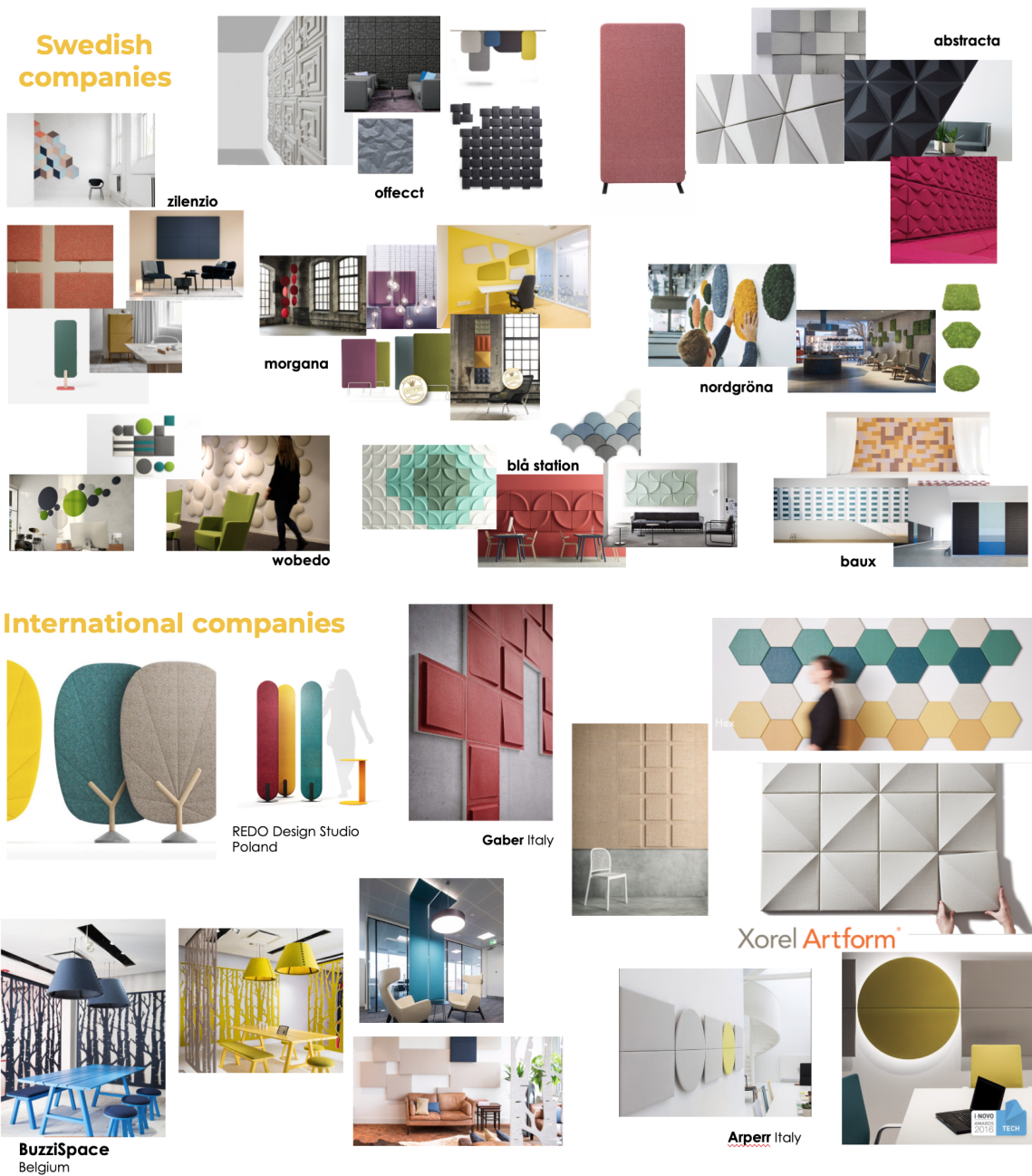


Figure 18. Competitors mood boards.

## 4.2 Stockholm Furniture Fair

During the visit to the Stockholm Furniture Fair, observations were carried out (Figure 19) in order to find the current Scandinavian trends in the field. Conversations with different sellers were helpful to learn how their companies are currently developing the interior of the acoustic absorbers, what types of materials are using and which system of mounting they prefer.

Interesting facts were founded there, such as the use of three different materials inside one single panel of the brand Decibel, the acoustic properties of Nordgröna's panels made of reindeer moss that use air humidity to survive without the need of watering it, the recycled cork used in acoustic absorbers by Abstracta, the Baux pulp and wood wool, absorptive carpets of the company Ogeborg and the new cylindrical shapes of the ceiling-hanged absorbers of the company Offect.

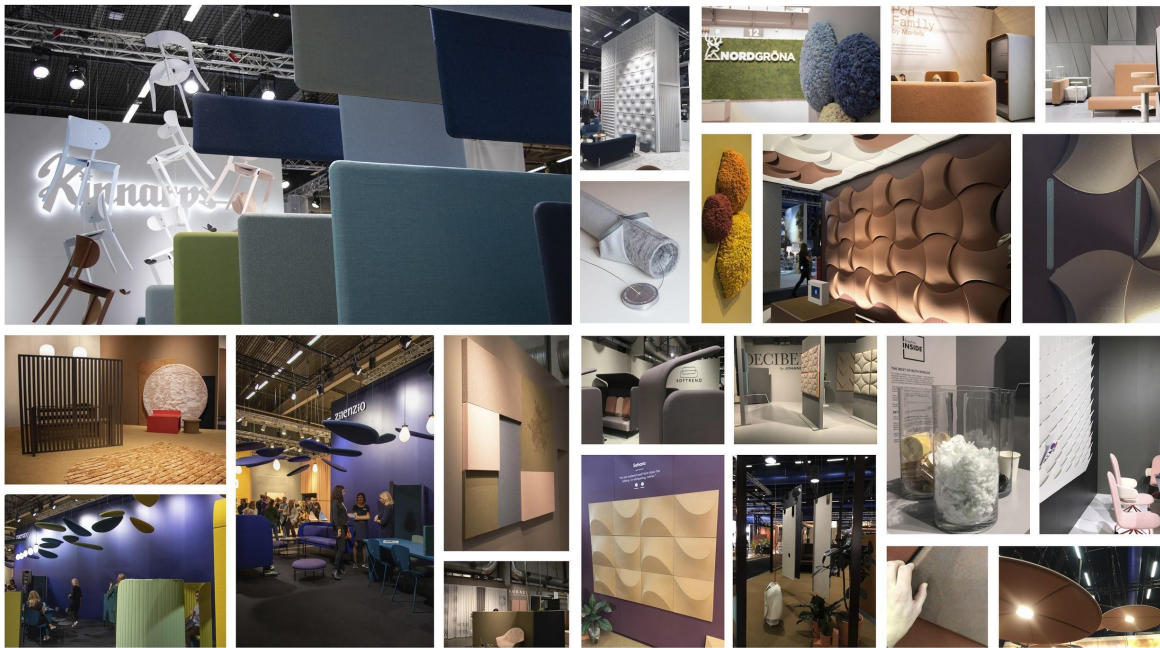


Figure 19. Stockholm Furniture Fair 2019 Market Research.

### 4.3 Milan Design Week

In the visit to the “Salone del Mobile” was possible to see a wide variety of international companies that offered several types of acoustic solutions. Here was also possible to talk with workers of some of the brands and to ask them about their products. Some highlighted products (*Figure 20*) were the absorbers of the company Sancal, that incorporated an absorptive material on a lamp, the use of cushions on the wall as acoustic absorbers by Santis, interesting textures on the fabrics made with seams by several companies, movable walls made of pressed felt, and wall panels with a mechanism that let the users choose the inclination.

Also an interesting material was found, a really thin absorptive material (textile felt of 10mm) shown in different colours, that was interwoven and created an attractive appearance. This panel is of the brand Wandschappen, although the textile felt was purchased from the Danish company Really.

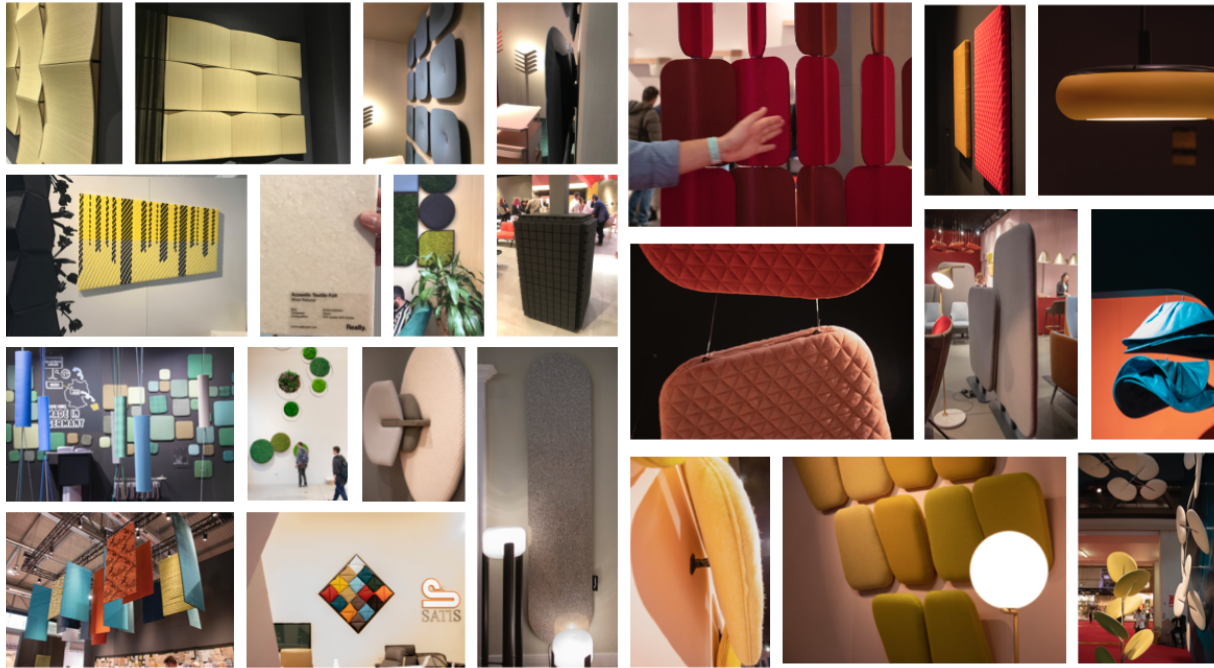


Figure 20. Milan Design Week 2019 Market Research.

## 5 User Studies

As it is mentioned in the methodology, the project has a user centred approach. Therefore, some studies were done to get useful information of the target group, to work with in the ideation process. Different tools with different levels of interaction were used like questionnaires, interviews, observation, etc.

### 5.1 Web questionnaire

To get a general background about the perception, preferences and particular characteristics of a larger number of people regarding acoustic panels, a 22 question survey was created. The questions provided information to know the users profiles, their work environment, their notion about acoustic panels and their insights about them. It was asked their preferences on the absorbers position, type, and aesthetics. In the questionnaire, it was included a Competitive Product Survey, making a comparison between different existing panels, including the Kinnarps solutions, in order to establish functional requirements, performance standards and other benchmarks based on the users preferences. As well their point of view about aspects such as customizability or sustainability was asked, requiring for an explanation in some cases (IDEO, 2003).

The questionnaire was done by 31 people, even though from those responses 30 have been taken into account because one of them did not pass the control question. It was only sent to specific people such as office workers, teachers, interior designers, architects, and design students. A balance between males and females was achieved with 53.3% of men and 46.7% of women, and also between students (53.3%) and employees (46.7%).

The main conclusions of this questionnaire were that 90% of the participants knew what an acoustic panel is, and 100% thought they affect in a positive way the work environments. Wall panels were preferred (76.7%) against suspended and standing panels. At the time of selecting between acoustic panels from different images (including Kinnarps products), there was a clear preference for the panels with a modern style of the companies Abstracta and Offect, something that encourage the initial task of introducing Kinnarps in the sound absorbers market. According to the responses of the users, the election between different panel was justified by mentioning aspects such as modularity, decorative appearance, organic or simple shapes, combination of colours, easiness to integrate with furniture. It is also important to mention that the 96.7% thought that is important the customization of the colours and position of the panels. All the questionnaire responses can be found in *Appendix 1*.

## 5.2 Interviews

Interviews offer more contact with the target group, it gives the opportunity to know more about them. The principal aspects that the interviews were focused on are: their personalities, likes, the principle features they consider when they choose acoustic panels, preferences of type of sound absorbers, how important is sound absorption for them in their work environments and to know if they were interested in customizable factors for the acoustic panels, that was the first idea that was wanted to be evaluated in this stage. The potential buyers chosen to be interviewed were architects, managers of schools/nurseries, and sales people who were in charge of choosing the acoustic panels for different projects. From these interviews, some conclusions were made such as:

- There is a tendency for choosing simple and discrete shapes for the panels, although other kinds of shapes are also suitable depending directly on the type of project they are working on.
- The price of the product influence their choice, should not be unreasonably high.
- An important factor is to give the customers the possibility to customize the composition, size and colours.
- Exists an interest in good acoustic properties.
- The type of absorbers that they mainly use are wall or standing panels, even though they also use furniture, and carpets.
- The appearance of the panels is a really important factor that was considered by the respondents.
- The interviewed people suggest creating innovative products that are not currently available in the market, develop a product with a “new thinking”.

The nurseries' managers show a lot of interest in sound absorbers, they state that by having a big amount of sound absorbing panels is easier to create a calmer atmosphere and encourage concentration. They also mentioned that they like that the children can interact with the panels, for example by putting their drawings on them. In this last case the papers might reduce the panels' absorption because they are covering the panel with a more reflective surface than the porous material they have under.

The complete interviews can be found in *Appendix 2*.

### 5.3 “Shadowing” Natural observation

In this stage, children, students, teachers, and office workers were observed in their schools and companies in order to understand their day-to-day routines and interaction with the absorbers. In this way it is possible to reveal design opportunities and show how the products affect their behaviour (IDEO, 2003).

In the nurseries it was possible to see how the children run next to the standing panels and how they touch them, while in schools for older students there was not a high interaction between the students and the acoustic panels besides that they put some papers on the panels with push pins. In the case of the companies, no interaction was observed. In these places, the most used absorbing panels were the ones that are mounted on the walls, and normally were located in places where a lot of people interact, like classrooms, halls, canteens and meeting/group rooms (*Figure 21*).



*Figure 21. Nurseries and companies visited.*

Other observations were carried out at the library study rooms of the University of Skövde, where there are five acoustic panels of 600 x 600 mm, with a thickness of 45mm in a 2x3x3 m space. In this room there are also 5 chairs with sound absorptive properties due to their filler covered by fabric. It was interesting to note how some people interacted with the acoustic panels in this room, they leaned on the panels as if they were “wall pillows” while they were studying due to the position in which the panels were mounted, at 95 cm from the floor (*Figure 22*). In other cases, some users seem to be curious and touch the fabric of the panel with their hands, but no other relevant interaction between them was found.



Figure 22. Study room at the University of Skövde library.

## 5.4 Keywords Survey

In order to have the general insight that people have of the brand Kinnarps, it was done a keywords survey (Figure 23) to 6 participants that know about the brand. This people was chosen because it was required a basic knowledge of the products of Kinnarps to be able to answer the survey and get relevant results. This information was collected to be used in the stage of concept generation, by taking into account people's view of the brand all the time and by trying to reflect it in the proposed concepts.

The most selected words that describe the company were “Scandinavian” and “offices”. Other repeated selections were “ergonomics”, “modern”, “comfortable”, “high quality” and “functional”. By considering these words as a design guideline, it is a way to ensure that the Kinnarps “style” is followed.

Choose the words that you consider describe best the company **Kinnarps**. (Max. 10 words)

**6 participants (Swedish furniture sellers, teachers, researchers and students)**

<b>Scandinavian (4)</b>	<b>Technological (1)</b>	<b>Innovation (2)</b>	<b>Traditional</b>
<b>Cozy</b>	<b>Offices (6)</b>	<b>Light</b>	<b>Functional (3)</b>
<b>Future (1)</b>	<b>Schools (2)</b>	<b>Strong</b>	<b>Honest</b>
<b>Heavy</b>	<b>Co-working spaces (1)</b>	<b>Authentic</b>	<b>Artificial</b>
<b>Ergonomics (3)</b>	<b>Hospitals</b>	<b>Original (1)</b>	<b>Natural</b>
<b>Acoustics</b>	<b>Home</b>	<b>Beautiful</b>	<b>Craftsmanship</b>
<b>Colorful (2)</b>	<b>Luxurious</b>	<b>Wide variety</b>	<b>Genuine (2)</b>
<b>Concentration</b>	<b>Comfortable (3)</b>	<b>Bright (1)</b>	<b>Exclusive</b>
<b>Modern (3)</b>	<b>Neutral</b>	<b>Darkness</b>	<b>Good finish</b>
<b>Sustainable</b>	<b>Fun</b>	<b>High quality (3)</b>	<b>Soft &amp; padded</b>
<b>Contemporary</b>	<b>Design (1)</b>		

Figure 23. Kinnarps keywords survey.

## 5.5 Personas

Inspired on the profiles of the interviewed people, three typical fictitious personas were created focusing principally on the ones in charge of choosing the acoustic panels. Two more personas were created inspired in the users that the company has as main target. The information is synthesized and visualized in a template that shows with concrete data their general information, goals, needs, personality and brand influencers. Doing these types of visualizations (Figure 24, Figure 25 and Figure 26) makes easier to keep in mind the key characteristics of the identified users you need to design for, during the whole process.

The target group was established thanks to this personas, focused on the people that are in charge of choosing the acoustic panels for different environments, such as architects, sales workers of showrooms, and managers of schools.

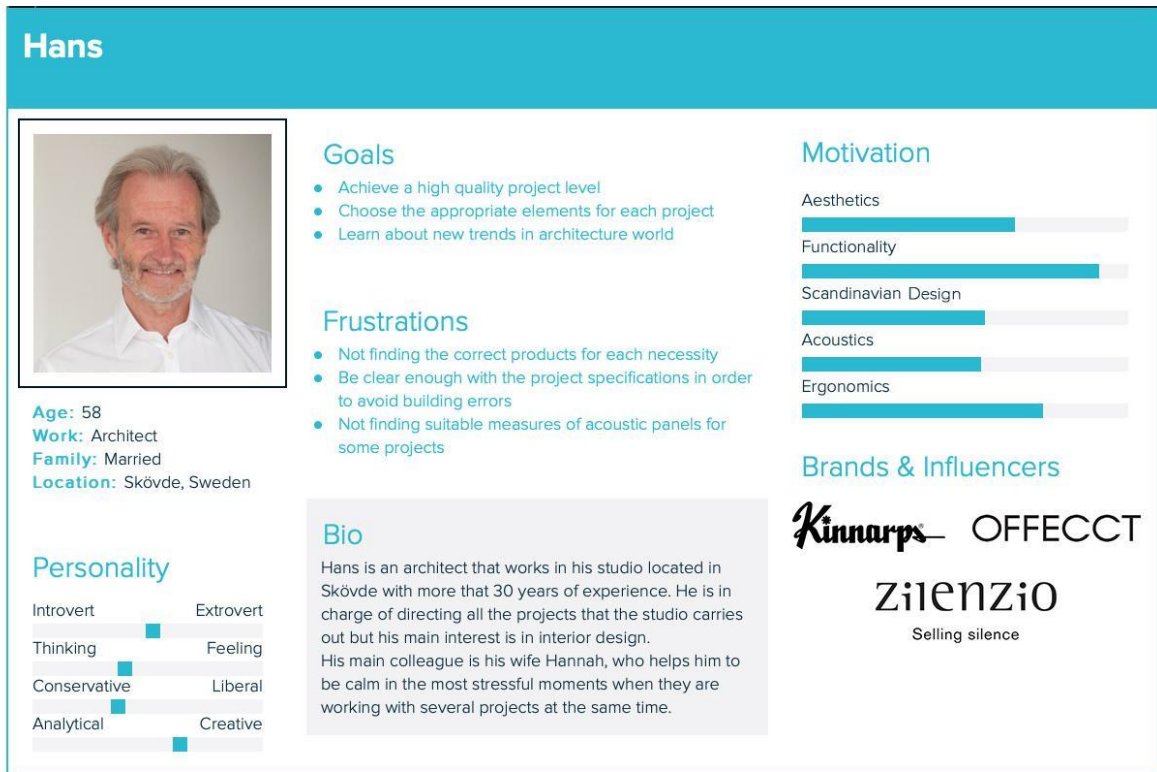


Figure 24. Persona 1 (Xtensio, n.d.)

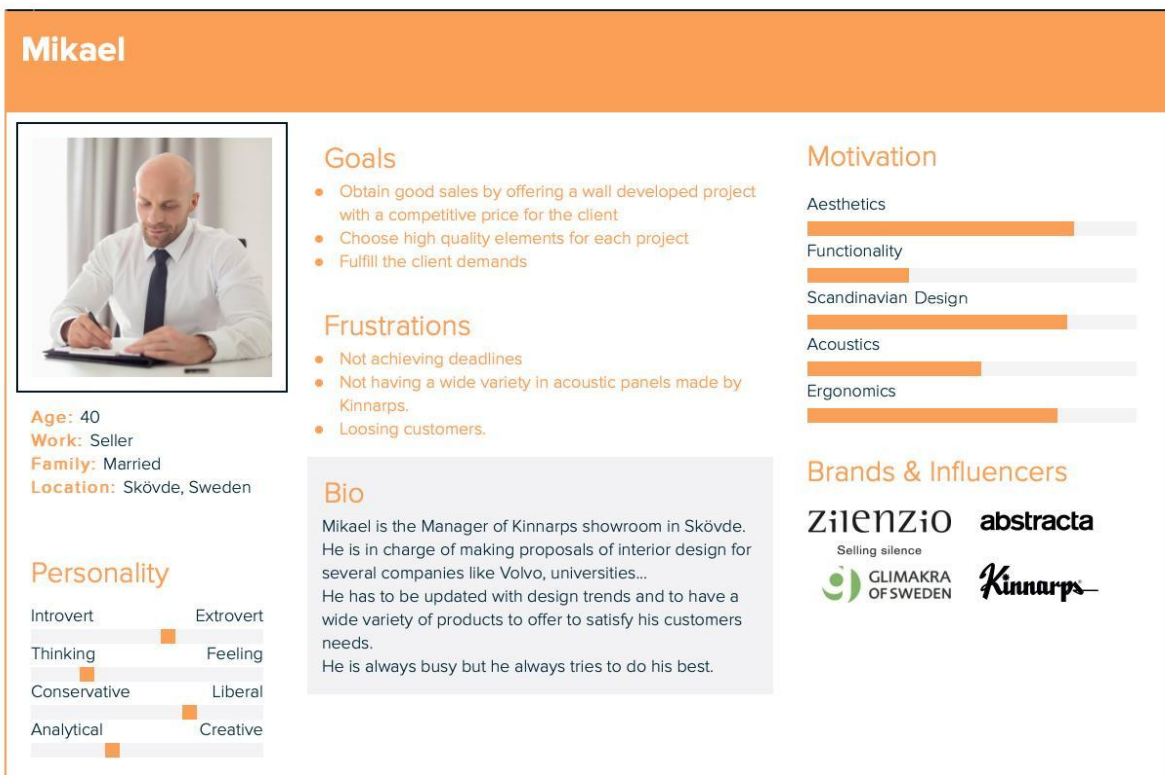


Figure 25. Persona 2 (Xtensio, n.d.)



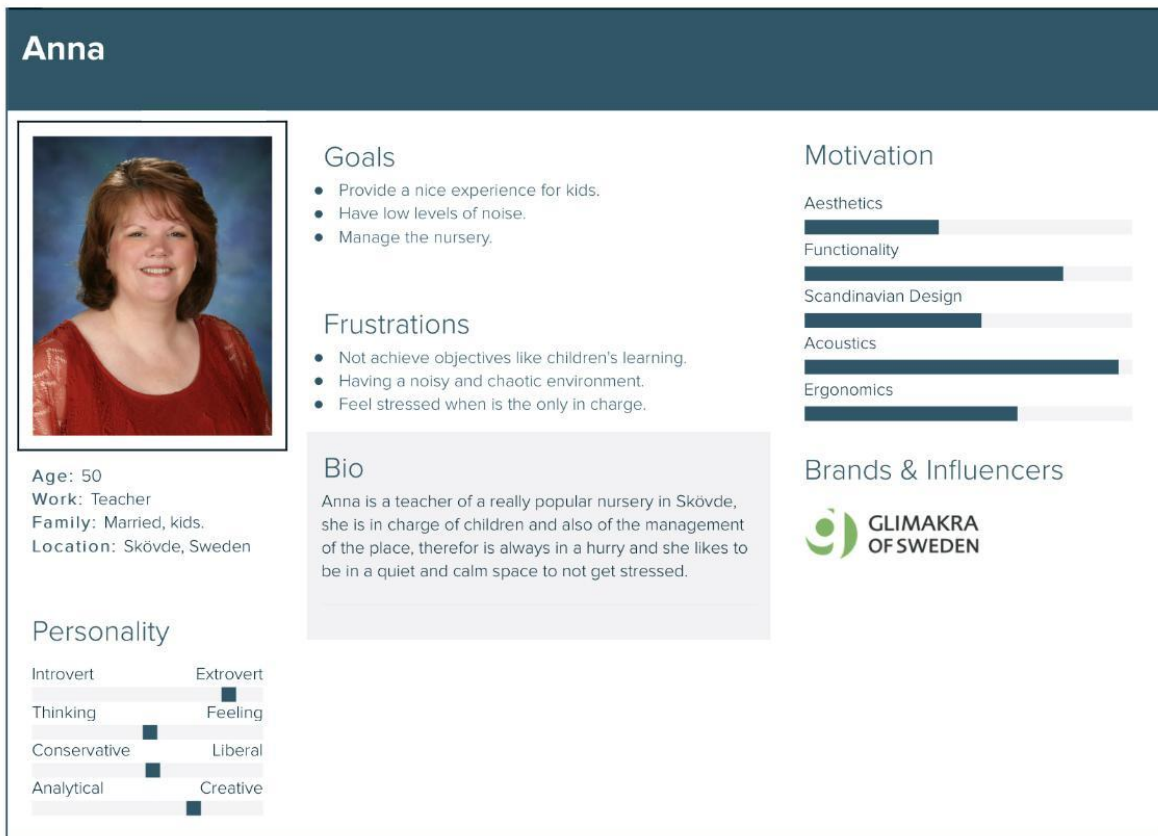


Figure 26. Persona 3 (Xtensio, n.d.).

## 5.6 Scenarios

Once the personas were done, scenarios (Figure 27 and Figure 28) were developed for some of the profiles in order to illustrate the context of use of the product and to have an insight of possible situations in which the user and the product could be involved. This is helpful to understand the user experience and to know how could the users benefit from a product in a possible environment of use (IDEO, 2003).

Mikael is working in a coworking open-space trying to concentrate because he has an important project in development and his colleague Sarah had to discuss an important aspect of another project with someone close to Mikael, so he got completely distracted by their conversation and decided to move to another place that has a less noisy environment.



Figure 27. Scenario 1.

Today, as every Friday, the company's marketing team are having a meeting to show the progress with the currently project in the conference room. Mark is seated at the end of the table while Anna is speaking about the work done during the week. Mark feels a bit stressed because he listen a lot of reverberation in the room during Anna's speech and also he got distracted with noise made by his colleagues that are constantly moving their feet and themselves in their chairs. Mark asked Anna if she could speak louder, and when Anna started to speak louder she felt that the reverberation increases in the room causing an annoying situation for her.



Figure 28. Scenario 2.

## 6 Specifications

In this stage several requirements were defined for the final concept or concepts of acoustic panels. This requirements were agreed with the company and aim to guide and evaluate the possible solutions.

### 6.1 Requirements List

The requirement list was done following the guidelines given by Ulrich & Eppinger (2008). As it can be seen in *Table 5* the requirements are divided in different fields and marked as wishes or demands (W or D). Evaluation methods have been established for each requirement.

Some guidelines for this list came from the Keywords survey (*Section 5.4*). The most chosen words of the survey were taken into account in order to establish requirements and reflect these words in the resultant concept. Some examples are “Scandinavian”, “Modern” which are included in the requirement “Follow brand aesthetics”, “High quality” and “Functional” included in “Function” by achieving a N10 value lower or equal to 4 (Kinnarps value of current absorbers), “Offices” included in “Encourage concentration” and “Improve workspace atmosphere” and “Ergonomics” in “Kinematics”.

In addition, the University and the company supervisors gave some feedback by suggesting changes in order to improve it and make easier to check the fulfilment of all these specifications in the next stages.

Table 5. Requirement list.

Högskolan i Skövde - Kinnarps	Requirements List		Issued on 02/27/19
	Project: Family of acoustic panels		Responsibles: Julián Soria de la Torre Gabriel Juárez Mejía
Changes	D/W	Requirements	Evaluation method
02/13/19	D	Geometry: Thickness 35-80mm	Measurement
02/27/19	D	From wall to top of panel > 80mm	Measurement
	D	Kinematics: Easy to mount	Time and user test
	W	Fast to mount	Time
	W	Adjustable position	Yes/No
	W	Attachable modules	Yes/No
	D	Forces: Weight <1 kg + attachment parts	Measurement
	D	Function: $N_{10} \leq 6$ (6 wall panels or 1 standing (Sound abs) panel)	SS-EN ISO 354 and SS 25269
	W	Encourage concentration	Users test
	W	Improves workspace atmosphere	Users test
	D	Material: KCS Fabrics (If fabric is used)	Yes/No
	W	Recycled polyester filler	Yes/No
	W	Partly recycled	Yes/No
	D	Sustainable Value >2	"The Better Effect Index" by Kinnarps
	D	Safety: Operator safety	Swedish Work Environment Laws
	D	Mounter safety	Swedish Work Environment Laws
	D	User safety	Yes/No
	D	Manufacture: According to the industry standards	Yes/No
	W	Use existing facilities	Yes/No
	W	10.000-25.000 pieces per year	Yes/No
	D	Appearance: Brand colors	Yes/No
	D	Follow Brand aesthetics	Aesthetic analysis (Kinnarps keywords)
	W	Attractive to users and customers	Users/Customers questionnaire
	W	UX: Consider user studies conclusions	Yes/No
	D	Time: 5 months in development	Yes/No
	W	Price: 750 SEK	Yes/No
	W	Maintenance: Easy to clean	Users questionnaire

## 7 Concept generation

To generate different concepts for the family of acoustics panels it was used as input the information collected from the literature review mainly regarding the sound absorption, and the data collected from the preliminary studies, making emphasis in the user studies and in the keywords of the brand.

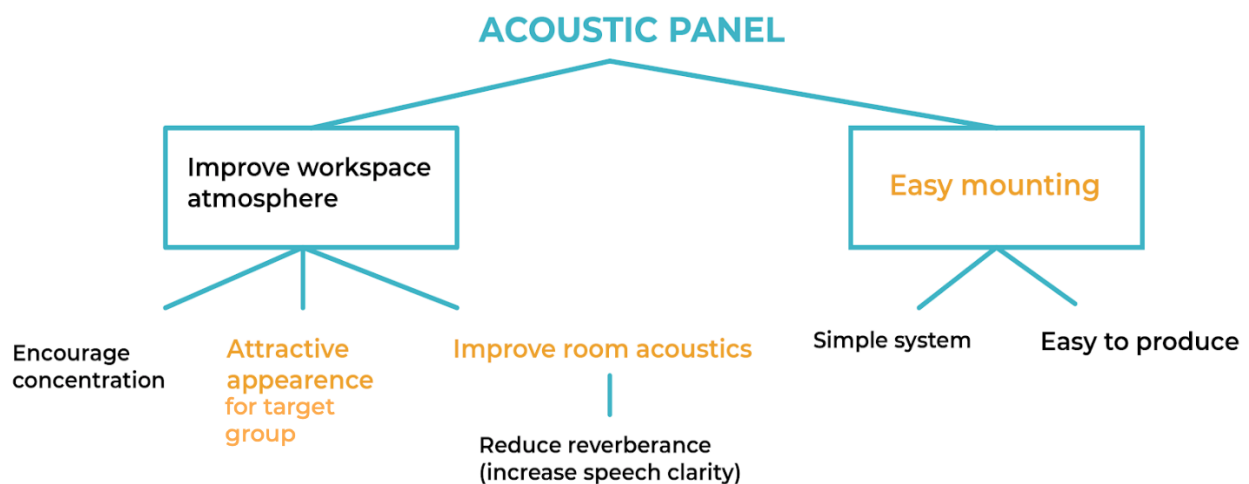
The process began with the method "system level design" that consisted in dividing the problem in categories or subsystems and approaching each separately, followed by a verbal brainstorming of possible solutions for this sub-systems, an exploration with sketching of different shapes and with rapid-prototyping (scale models).

## 7.1 System level design

The main problem of the design of this panels was decomposed in two main systems, improving the work space atmosphere and generate an easy way of mounting. These two were also divided into more sub categories, the first one in encouraging concentration, an attractive appearance for the target market, and improving the room acoustics by reducing the reverberance, while the second system was divided in a simple mechanical system and an easy production. This is shown in *Figure 29*.

Three main divisions were chosen to focused the concepts generation on, the attractive appearance for the target group, the easy mounting, and the improvement of acoustics which is highly related with the interior of the panel and the materials properties.

By dividing the complex problem in different categories, it was possible to work with more simple subproblems in an organized way, by looking for solutions for specific parts of the product separately.



*Figure 29. System Level design.*

## 7.2 Brainstorming

In this stage, two different types of brainstorming were developed. The first one sought different solutions for the main problem and the features it involves, shown in *Figure 30*. Divergent thinking and ideas outside of the box were encouraged. Some interesting data from the information collected regarding sound absorption and the users studies were considered.

Among the solutions explored in the brainstorming some can be highlighted like the use of magnets for mounting the panels, an increase in the thickness of the panels for better absorption, the use of perforated panels as an alternative for porous absorbers, different layers of materials for the interior of the panels, ones that have a better absorption for high frequencies and others that work better with lower, a simple and modern appearance, and customized panels.



Figure 30. Acoustic panels possible solutions brainstorming.

The main goal of the second brainstorming was to create a list of words that the company wants to reflect with their products in the present and in the near future. Feedback was given by the company regarding this brainstorming sessions. Minor corrections were done, including a change in one of the words, shown in *Figure 31*.

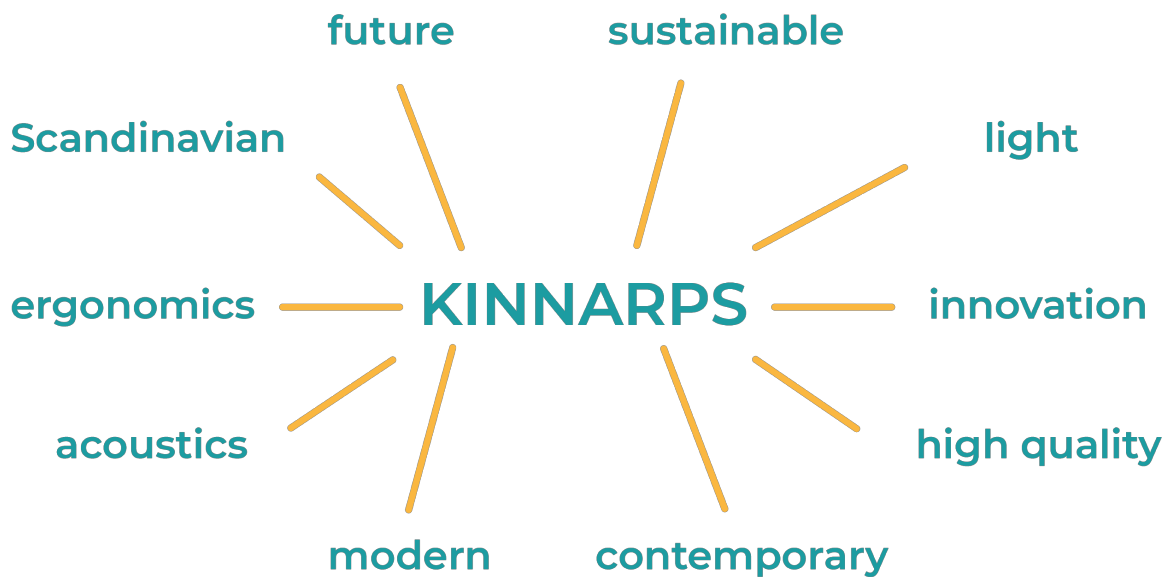


Figure 31. Kinnarps keywords.

### 7.3 Sketching and modelling

The sketching stage started at the same time as the literature review, market and users research in order to avoid losing ideas that were generated by reading or observing, although the major development of this stage was after finishing the initial research.

Some mood boards were developed as an inspirational tool in this stage, following the guidelines of “analogical thinking” (Rodgers & Milton 2011) that basically suggests to have an extra input and influence of products from another context (*Figure 32*). Other mood boards were made with interior designs made by Kinnarps to keep in mind the brand aesthetics all the time. (*Figure 33*)

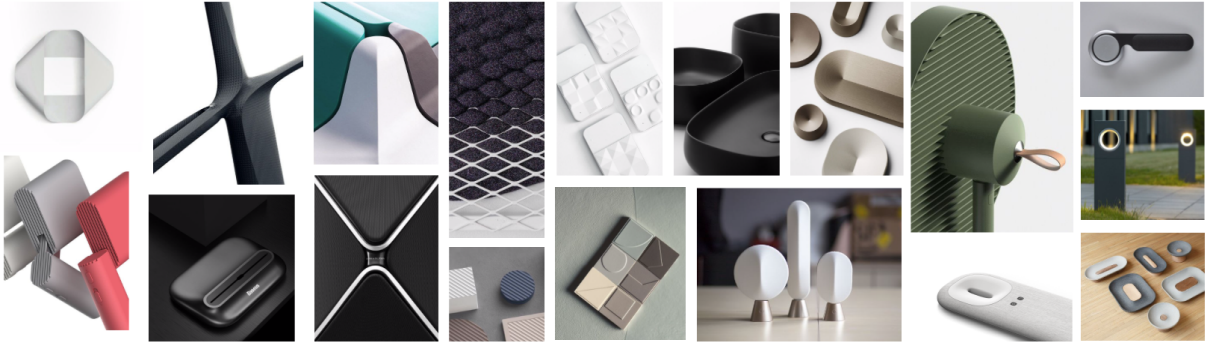


Figure 32. Analogical Thinking Moodboard.



Figure 33. Kinnarps aesthetics Moodboard.

The main goal of this divergent stage was to rapidly create different concepts, trying to generate as many ideas as possible, that could be combined and matured in next stages. During the process of sketching (*Figure 34* and *Figure 35*) was possible to create new input from every sketch by itself, which helped to continue exploring more shapes and have a clearer understanding of some aspects of the problem.

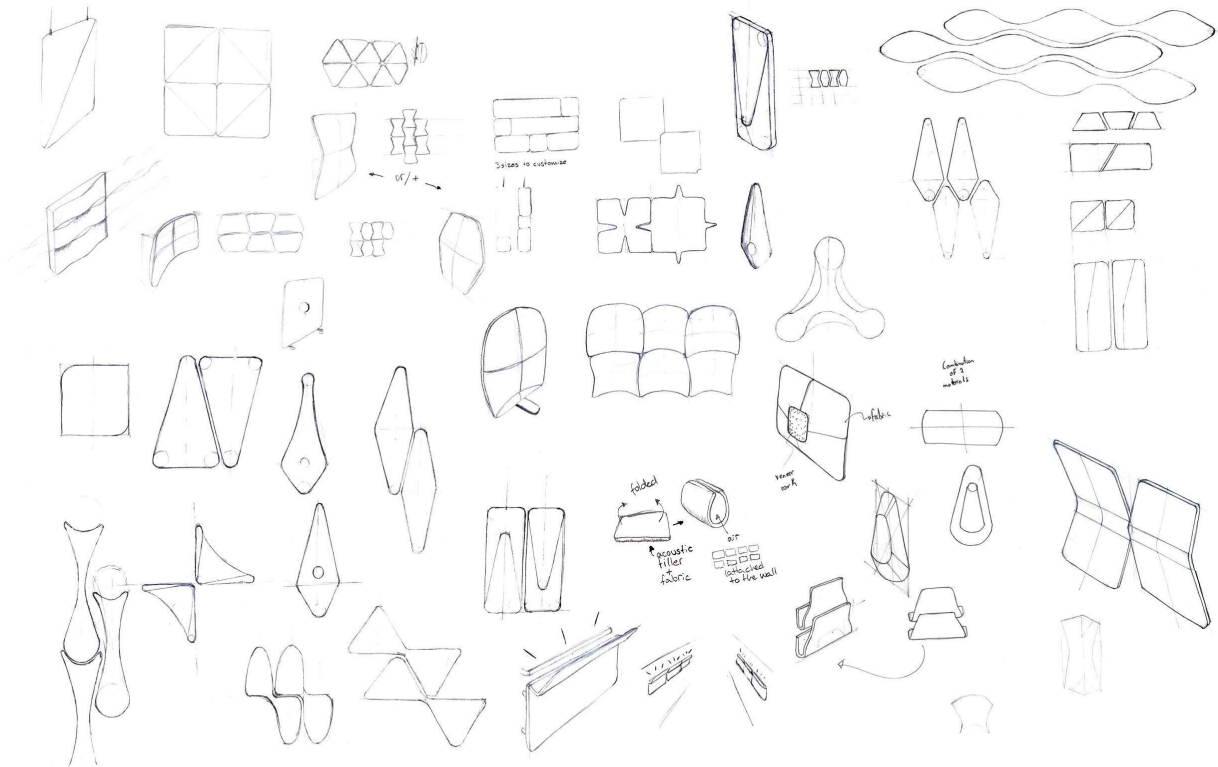


Figure 34. First idea sketching.

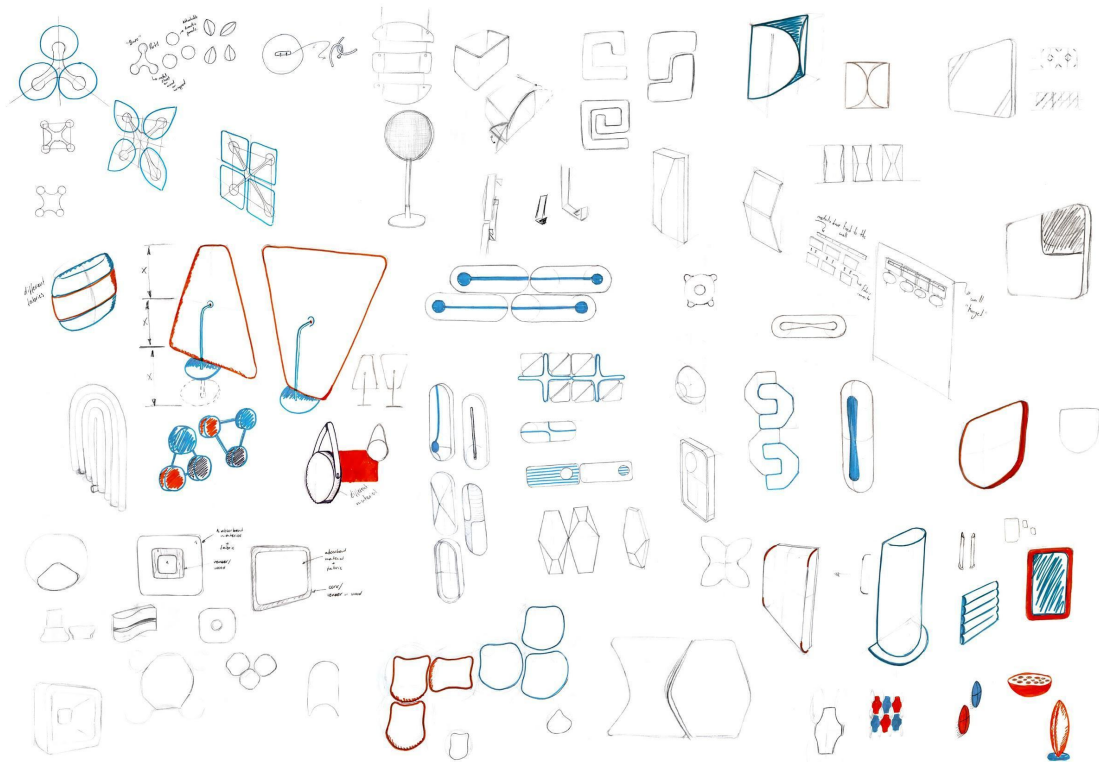


Figure 35. Second idea sketching.

Some of the concepts created in the sketching process were chosen to be developed in clay, cardboard and paper, following the guidelines of the IDEO Method Card (2003) “Scale modelling”. This method made easier the representation of the ideas in 3D, and gave more input to continue working further in the concept generation. It was also useful to create some variations of the chosen sketched concepts and to get a different and more realistic perception of the geometry than the one obtained through sketches. (Figure 36 and Figure 37).

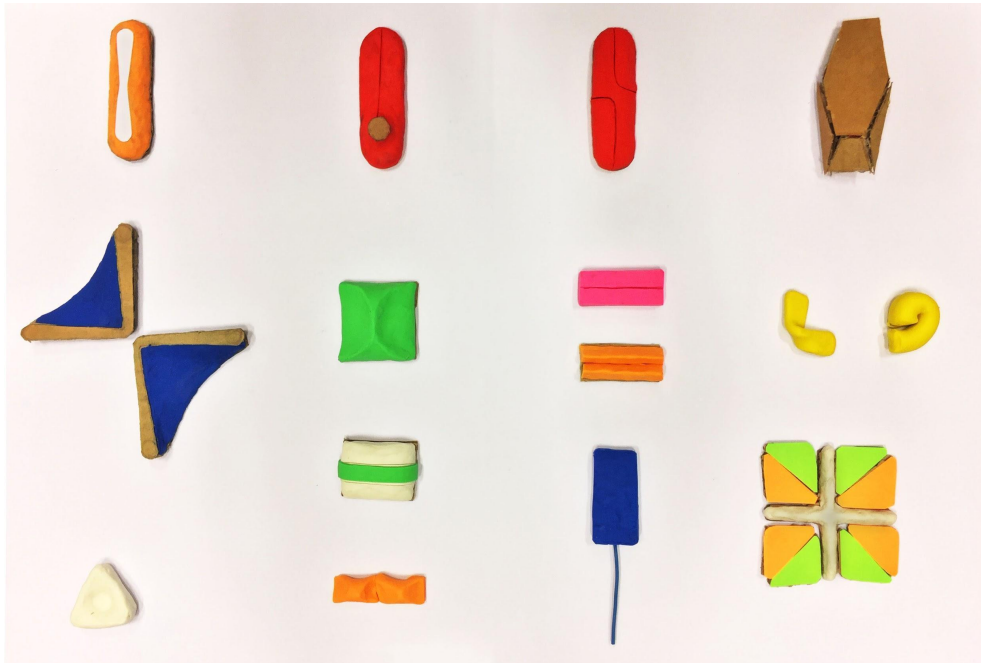


Figure 36. Rapid-prototyping (sketch model).

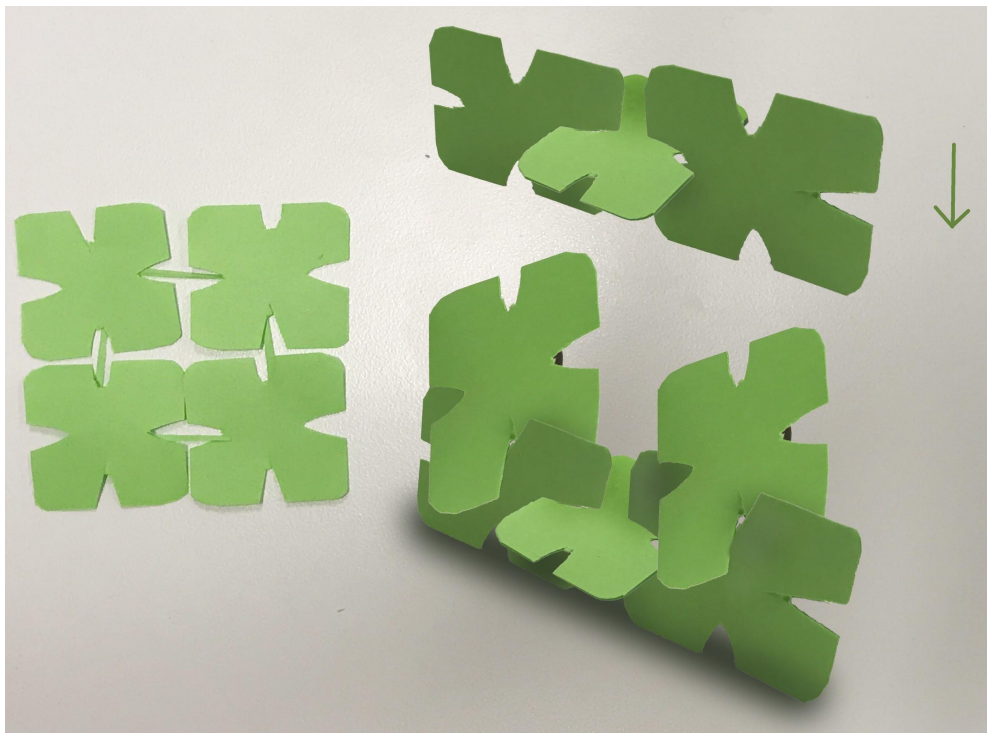


Figure 37. Rapid-prototyping (sketch model).



After having several ideas represented in sketches and models, a convergent thinking phase started. The company chose three potential ideas that set the routes to continue the concept generation (Figure 38).

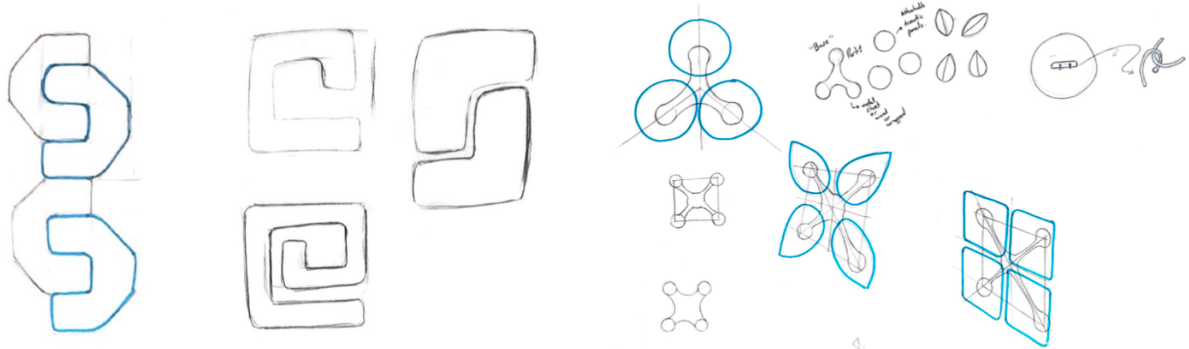


Figure 38. Kinnarps first selection of potential routes.

The concept generation continued further by following the selected routes. Study sketches (Evans et al., 2010) were developed for two purposes, define the geometry of the panels and generate more variants. (See Figure 39). This session of sketching was developed in the showroom of the brand in Skövde in order to be inside of the environments that their products create, and to be able to interact with the materials, colours and shapes of the brand.

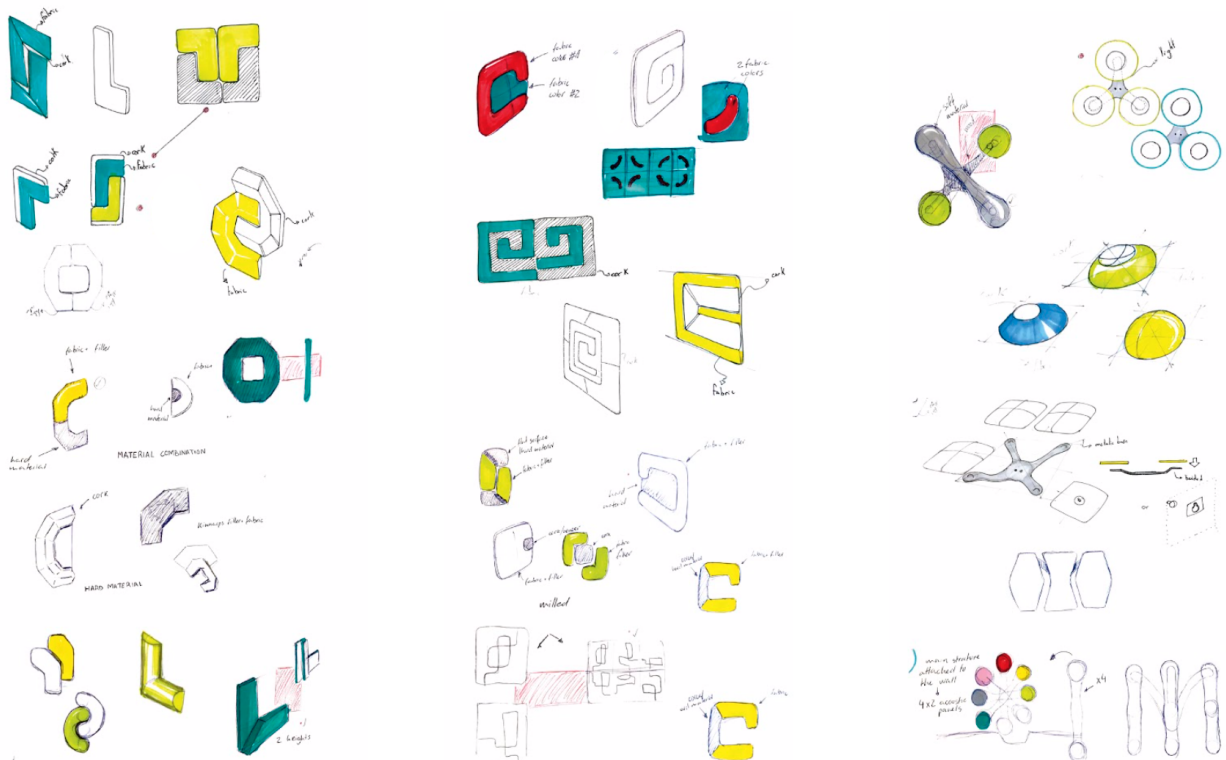


Figure 39. Study sketching.

The purpose of the next sketching sessions was to create new solutions for the mounting system. All of these solutions were based on reducing the number of attachments to the wall of each panel and in this way provide an easy installation system, as it is established in the requirements list. Some solutions identified are: Mount metallic sheets on the wall with screws and put magnets in the base of the acoustic panels, hung the panels with ropes from a metallic structure on the ceiling, wood bases mounted on the wall with 2 screws that can hold 4 panels. (Figure 40).

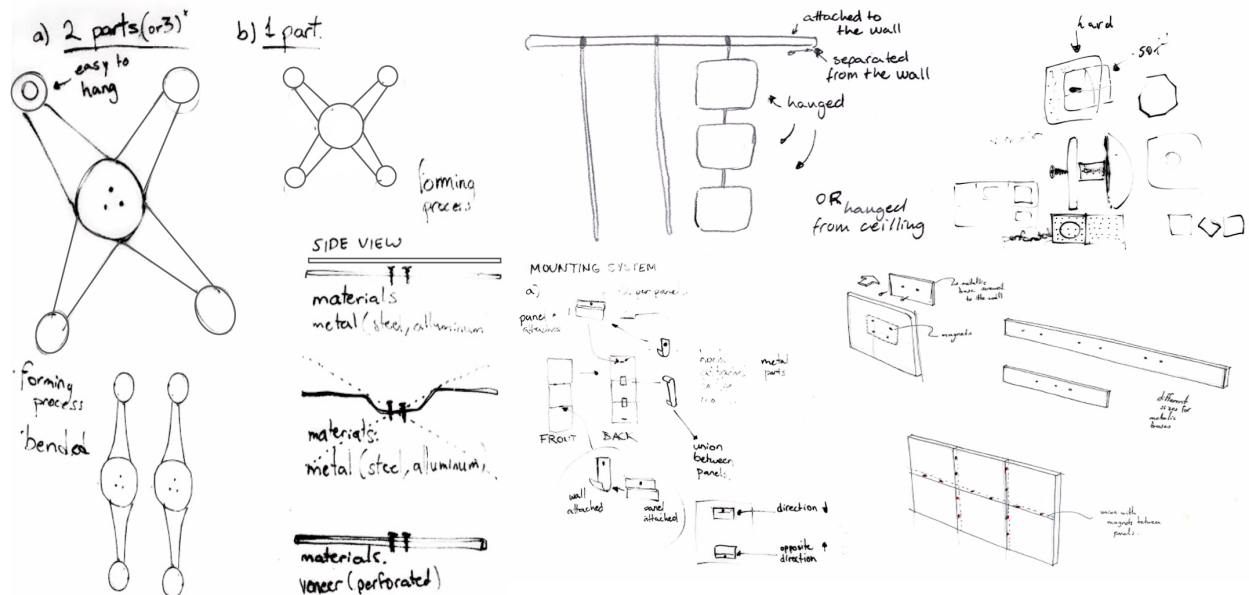


Figure 40. Mounting system ideas.

More detailed sketches in Appendix 3.

## 8 Concept selection

This stage aims to converge, to make a preliminary selection of potential solutions from the concept generation in order to develop them further and then a final selection of the most appropriate concept of the family of acoustic panels for the company.

In this part of the process is possible to see how the ideas were converged, evolved and evaluated. At the end, the final selection of the concept that better fulfils the requirements was made based in an appearance test with the target users, in the intuition of the designers and in the opinion of Kinnarps managers.

### 8.1 First selection

Basing on the intuition of the designers, there was a selection of the top ten concepts (Figure 41) that have an interesting appearance and have the potential to fulfil the initial requirements of the project. This first selection was made to frame the possible solutions and have less concepts to evaluate with a concept screening (Ulrich & Eppinger, 2008).

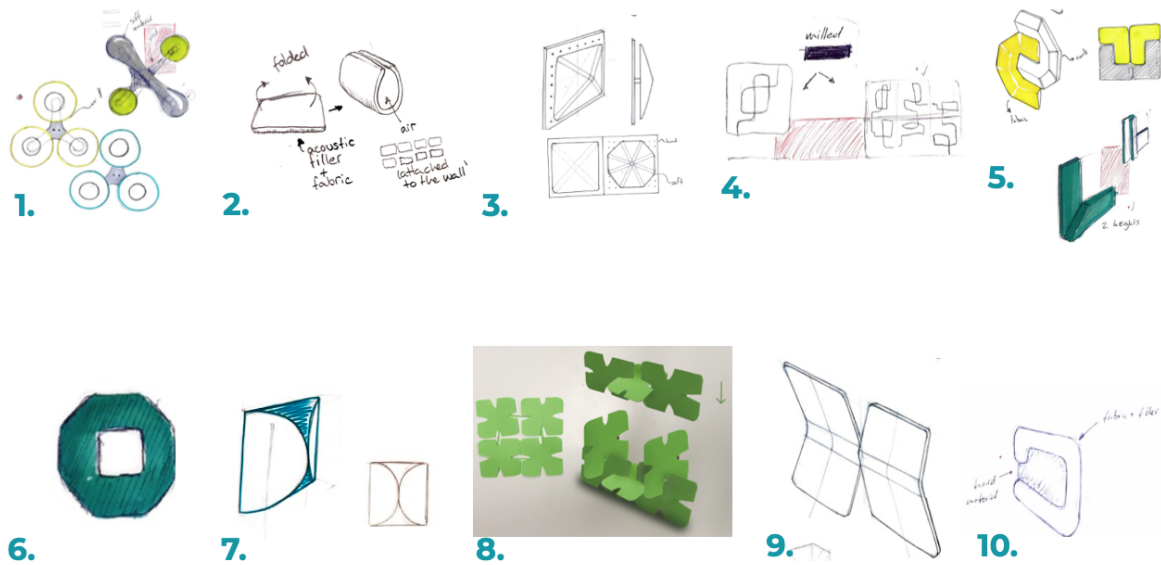


Figure 41. Selection for concept screening.

## 8.2 Concept screening

With the 10 selected ideas of *Figure 41*, a concept screening (Ulrich & Eppinger, 2008) was carried out in order to find the potential concepts that were going to be developed more in detail. The baseline chosen to compare the concepts was “Triline” a panel from the company Abstracta (*Figure 42*) which was the most popular choice of wall panels in the web questionnaire performed as a preliminary study.

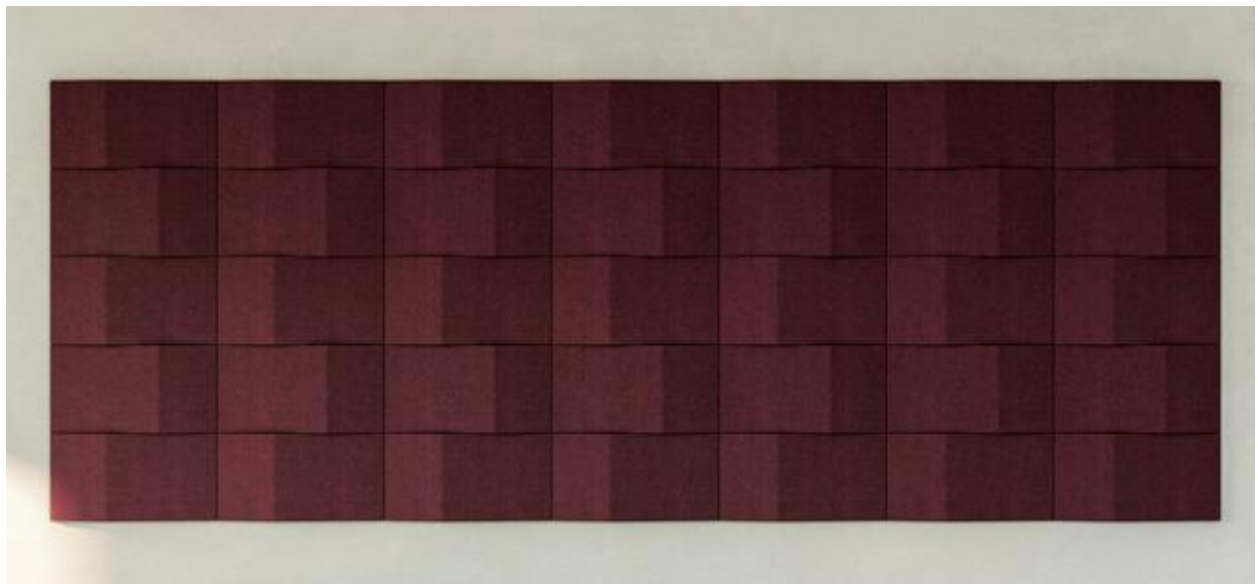


Figure 42. Baseline (Abstracta AB, n.d.).

As it is shown in *Figure 43* five main criteria from the requirement list were used for the concept screening: geometry, aesthetics, maintenance, manufacture and sustainability. If the evaluated concept was considered better than the baseline it received a positive point, if it was considered equal it received no points, and if it was considered worse it received a negative point. The points were summed and the results showed that the concepts that should be developed further were concepts 1, 2, 3, 5 and 8.

Concept screening

Selection criteria	Concept										N (BASELINE)	
	1	2	3	4	5	6	7	8	9	10		
<b>GEOMETRY</b>												
Thickness	1	0	1	1	1	1	0	1	1	1	0	
<b>AESTHETICS</b>												
Encourage concentration	1	0	1	-1	0	0	1	-1	0	-1	0	
Improves workspace atmosphere	1	0	0	0	1	0	1	1	0	-1	0	
Attractive appearance	0	1	0	0	0	-1	1	1	1	1	0	
Material choices	1	0	1	-1	1	1	0	0	0	0	0	
Color choices	1	0	0	-1	0	0	0	0	0	0	0	
Shape variety	1	0	1	1	1	0	0	0	0	0	0	
<b>MAINTENANCE</b>												
Easy to clean	-1	1	-1	1	-1	0	-1	0	1	0	0	
<b>Manufacture</b>												
Easy to manufacture	-1	0	-1	0	-1	-1	-1	0	-1	-1	0	
<b>Sustainability</b>												
Materials with low environmental impact	0	1	1	1	1	1	1	1	0	1	0	
<b>Final score</b>	4	3	3	4	3	3	2	3	2	0	0	
<b>Ranking</b>	1	2	2	4	2	3	3	2	3	5		
Continue?	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No		

Figure 43. Concept screening.

### 8.3 Kinnarps selection

The five concepts chosen were developed further with some referential sketches and 3D printings, each concept was explained more in detail, by considering their mounting system and functionality. These concepts were presented to the company and according to their preferences, three were selected as the concepts that would be developed with prototypes and posteriorly evaluate.

#### 8.3.1 Referential sketches, concept development

Concept one (*Figure 44*) provides different types of MDF structures that work as a base, where 2, 3 or 4 acoustic panels can be easily attached with hooks, magnets or ironworks. This concept seeks to reduce the number of holes on the wall per panel in comparison to the one that the company currently has (4 per panel). The structure has 2 parts that together create 26 mm of thickness, generating an air back space between the panels and the wall. The air backing space as it is shown in the literature review (*Section 3.3*) of this document increases the absorption of sound by catching the sound at a higher speed. This concept also gives the customer the possibility to choose and combine different types of panels in different positions.

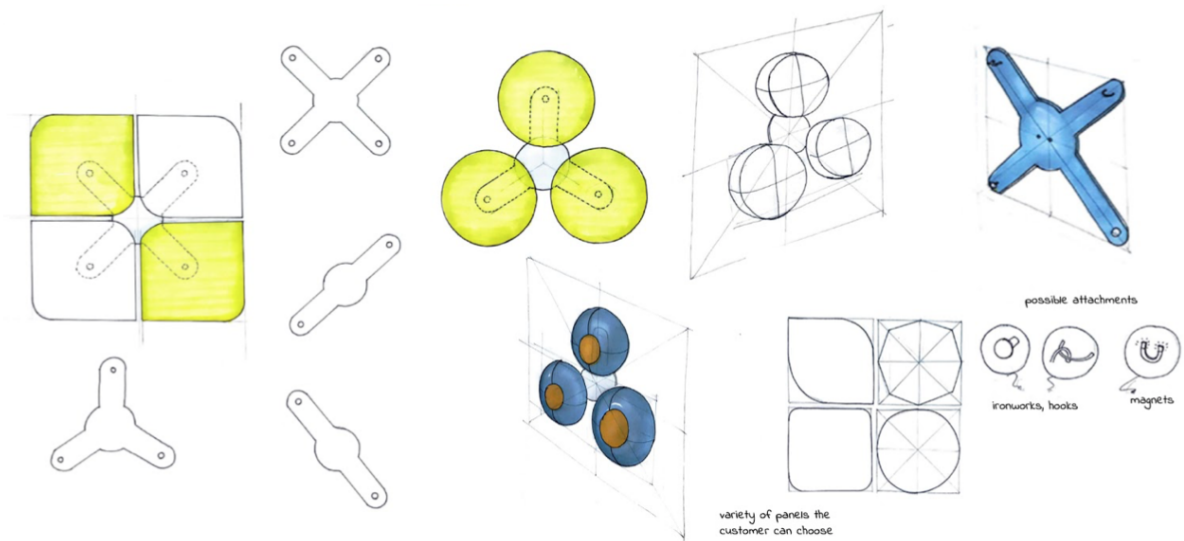


Figure 44. Concept 1.

Concept two (Figure 45) consists of three different folded panels that allow several compositions on the walls. The absorptive material would be moulded on this shape and covered with the fabrics used by Kinnarps. The appearance of this acoustic panel tries to differentiate from what was found in the market research (Section 4.1). This folding shape provides an air space (Section 3.3) between the surfaces where the sound goes through and this is expected to increase the level of absorption.

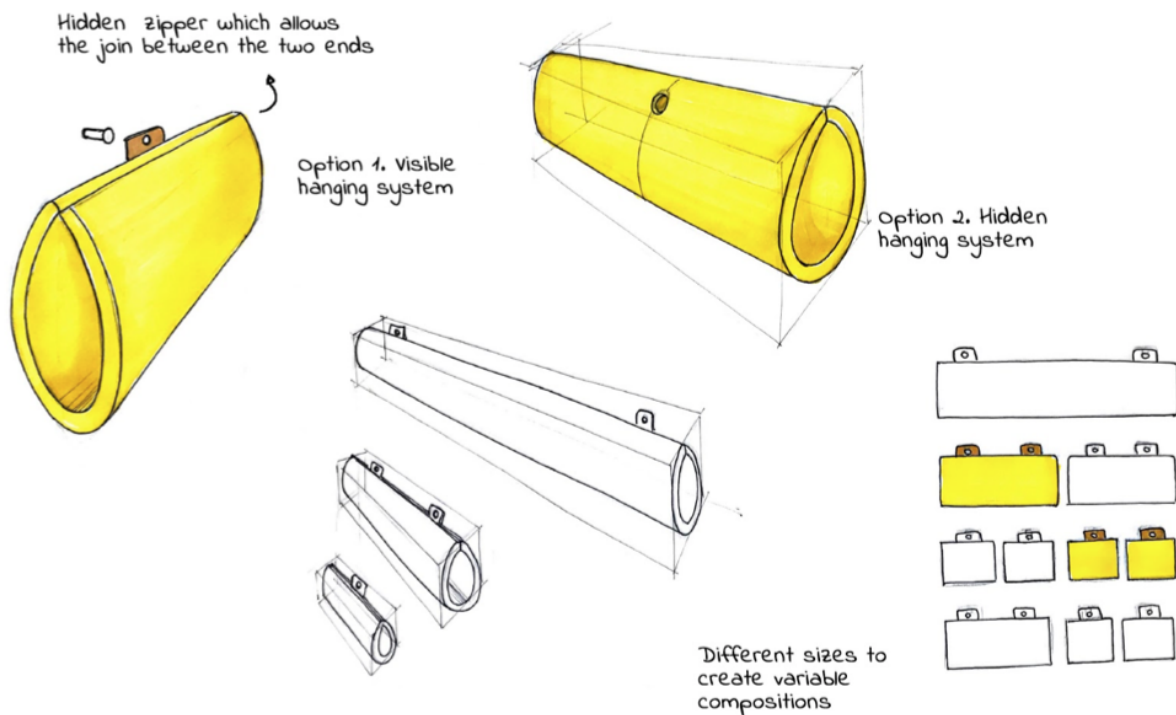


Figure 45. Concept 2.

Concept three (*Figure 46*) combines a perforated wood panel that has good absorption properties according to the literature review (*Section 3.3*) with an upholstered panel. The pyramidal geometry of these panels helps to create the diffusion of sound (as is shown in *Section 3.1.2*).

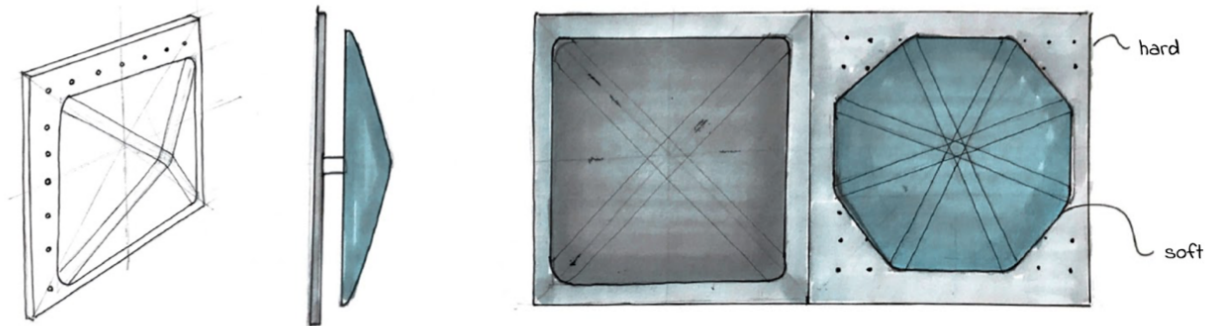


Figure 46. Concept 3.

The main purpose of concept four (*Figure 47*) is to combine different types of acoustic panels in a modular way. The customer would be able to combine different materials, colours and finishes of the same panel for various compositions.

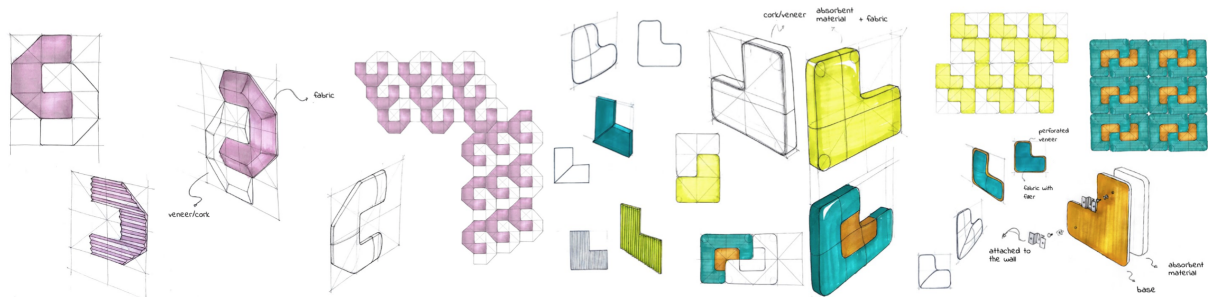


Figure 47. Concept 4.

Concept five (*Figure 48*) was developed to provide an interactive acoustic panel. It is a combination of a structure, an acoustic absorbent filler and fabric that gives the customer the possibility of joining different panels and generate a standing panel due to its shape. At the same time it gives the possibility of customizing the compositions due to the 2 different shapes it has available. This concept also can be combined with another version of it that is made of wood with grooves and a sound absorbent material inside.

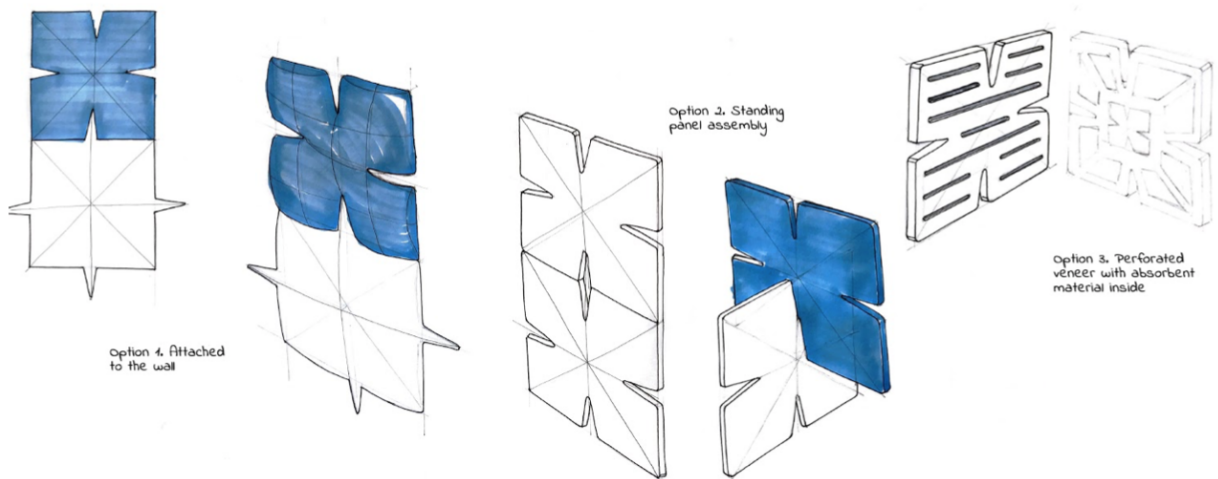


Figure 48. Concept 5

### 8.3.2 3D prints

3D prints of the five concepts were performed because they give a more realistic perception of the geometry that the designers want to communicate and allow to configure different compositions in scale (Figure 49).

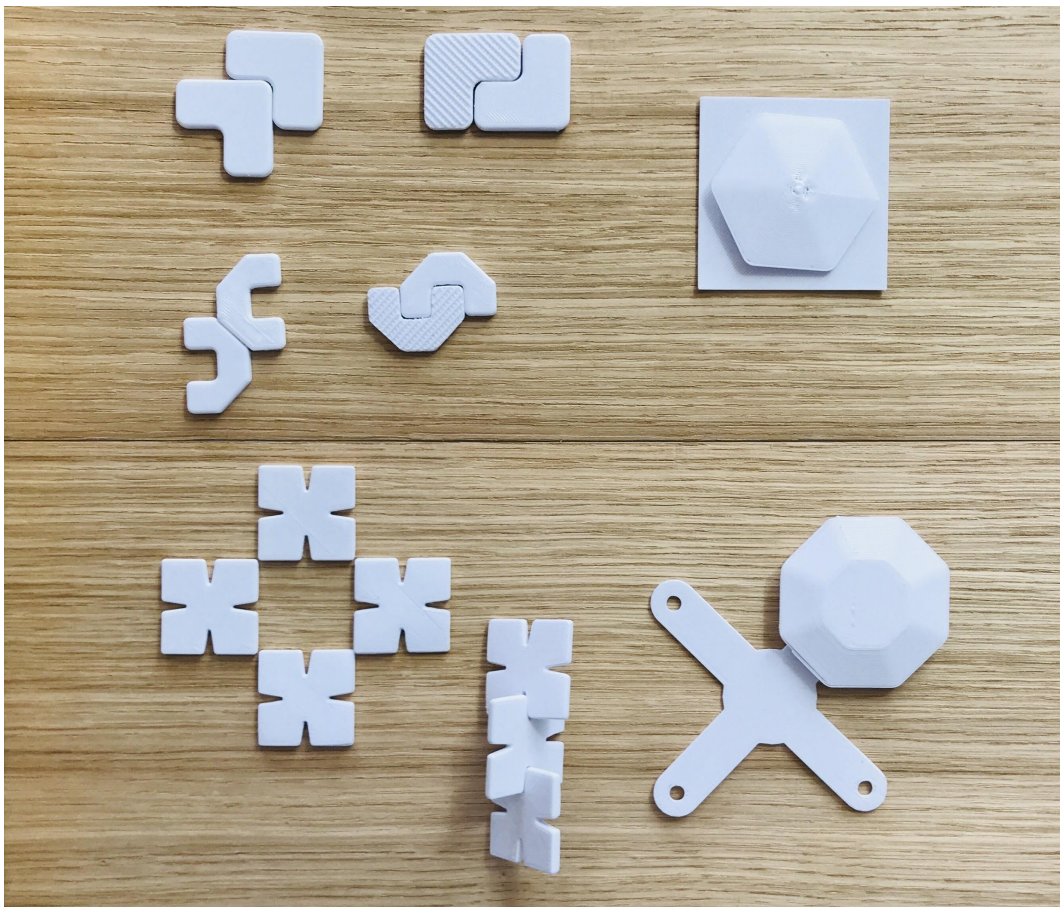


Figure 49. 3D Prints.

### 8.3.3 Selection

Once these five concepts were more defined, and after presented them to Kinnarps, a selection of three main concepts was made by some members of the company. The main purpose of this selection was to continue developing them, make prototypes and evaluate them. Concepts one, two and four were the ones selected based on their potential functionality, aesthetics and mounting easiness.

## 8.4 Prototyping

Quick-and-Dirty Prototypes of the selected concepts were developed in order to have a better perception of their size, their manufacturing process, viability, and appearance. (IDEO, 2003). The absorbent material used was the one the company currently uses, it was provided by the them.

Concept one mock-up was developed in a simple way (*Figure 50*), the MDF structure and the absorptive material were cut in scale 1 to 1 in order to observe the real dimensions and the composition possibilities. The feedback from the company design manager and the supervisor of the University was positive .



*Figure 50. Concept 1 mock-up.*

The mock-up of the concept 2 was developed by the company (*Figure 51*). The acoustic material was rolled over a metallic tubes and put inside ovens. The final shape was not completely achieved, the thickness and the folding radius were not the appropriate ones, although the length and width were correct. In this case it was decided that the manufacturing process should be studied deeply during the development, in order to achieve a better result by folding the acoustic material.





Figure 51. Concept 2 mock-up.

The prototypes for the concept 4 were made as well by cutting an MDF structure and absorptive material in scale 1 to 1. These prototypes were tried to be covered with fabric and some problems were found. The interior angles hindered the process of stapling the fabric and gave a bad aesthetic result (Figure 52). Thus, the shapes were changed, the corners were rounded and other mock-ups were developed, achieving a better result (Figure 53). Despite this good result it was suggested by the company's supervisor to stop the development of this concept in order to focus on the concept 1 and 2, that were considered more attractive for the company.



Figure 52. Concept 4 mock-up problem.

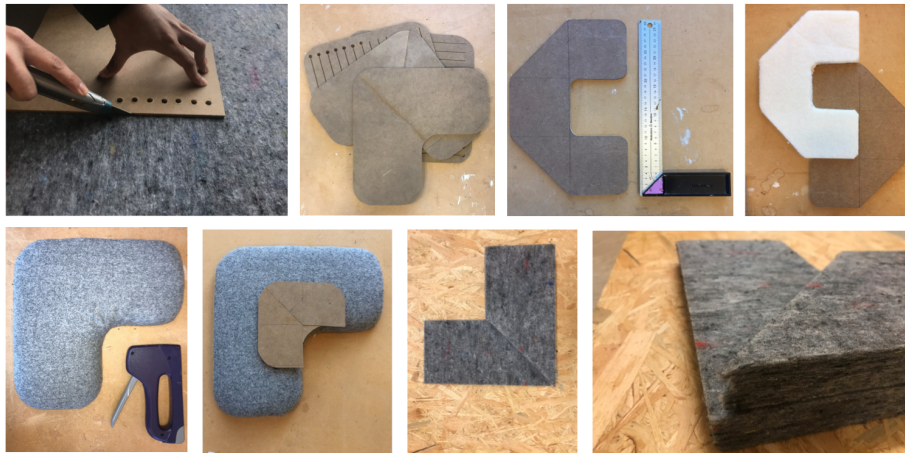
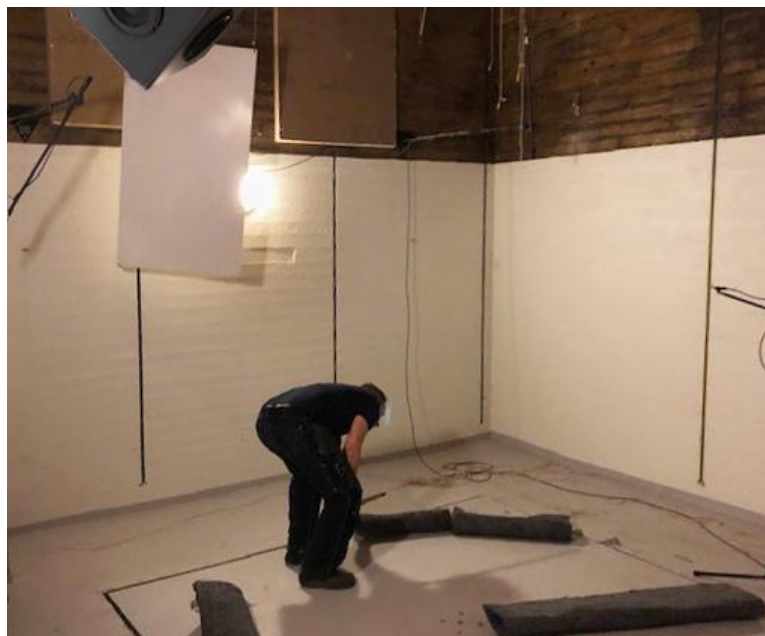


Figure 53. Concept 4 mock-up process.

## 8.5 Evaluation

An acoustic test of the prototypes of the concept two (*Figure 51*) was done by Kinnarps staff, taking the opportunity that they had rented the acoustic lab (*Figure 54*) for the evaluation of other products. The results obtained were not as good as expected,  $N_{10}=25$  for four acoustic panels. Even though it was possible to get some conclusions from this test in order to achieve better results with the next prototypes:

- The thickness of the prototype (20 mm) was not appropriate, it should be bigger(40 mm).
- The number of panels tested were not enough to achieve 100% proper results (according to the tester).
- The interior space of the concept should be bigger in the whole product.
- It should be covered by fabric, that is also an absorptive material.
- There should be an airspace between the panel and the surface behind.



*Figure 54. Concept 2 test in Akustikverkstan*

## 8.6 Final prototypes

Prototypes were developed in detail in order to select the final concept and have a closer similarity with the final products. These prototypes helped to make an appearance evaluation and to continue developing specific characteristics for each concept.

Thanks to this stage some solutions for specific parts of the prototypes were developed, in the case of the concept 1, create a way of putting the same panel in two different positions on the base with the same ironwork and type of assembly (*Figure 55*). The panels for this concept were weighted and it was found that they did not fulfil the requirement of weight (*Section 6.1*), due to each panel exceed it by having a total weight of 2.1 kg each. The solution proposed for the excess of weight was to have a small square of MDF in the middle of the panel, instead of the complete shape of the panel in MDF. This solution was tried and the resulting weight was 750 g per each panel (*Figure 55*).

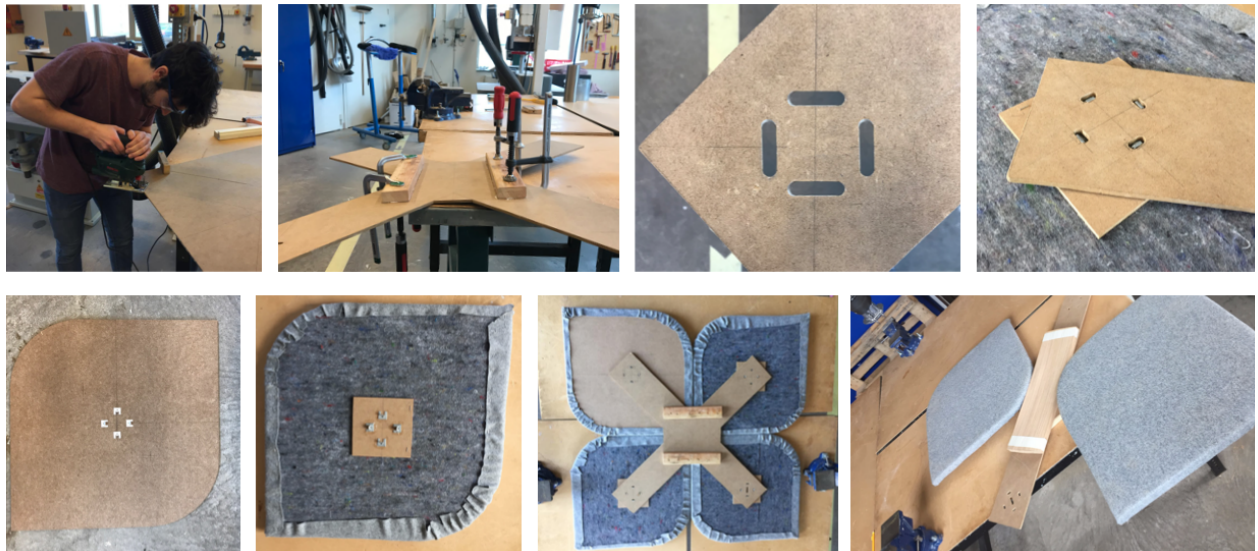


Figure 55. Concept 1 prototype process.

A second prototype was developed for the concept 1 (Figure 56), the base that has three arms with circular panels. For this version it was decided to try a different way of mounting using magnets, which might facilitate the mounting for the installer and also make the product easier and faster to produce. In this way it is not necessary to attach four hangers to each panel nor make four holes in each arm of the structure.

The magnet system is composed by a metal sheet glued on the backside of a square hole in each arm of the main structure. The acoustic panels have a magnet glued to a MDF square in the middle back part that fits in the hole of the structure's arms, allowing the attachment of both parts.

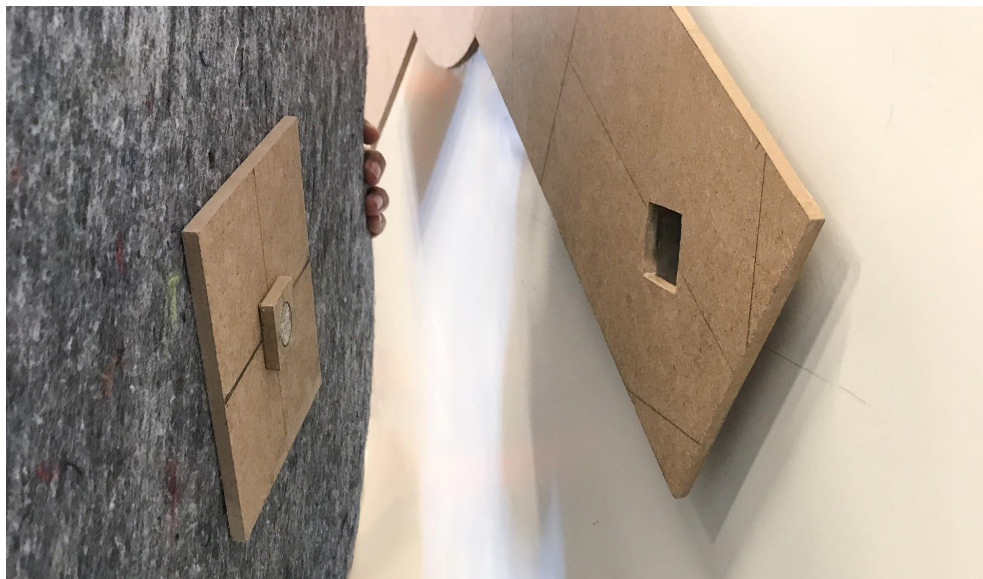


Figure 56. Concept 1 prototype 2, magnet system.

In the case of the concept 2, side MDF structures were made to keep the desired shape. Other type of solutions were tried and did not work as expected, like some grooves in the absorptive material to facilitate the folding without heat (Figure 57).

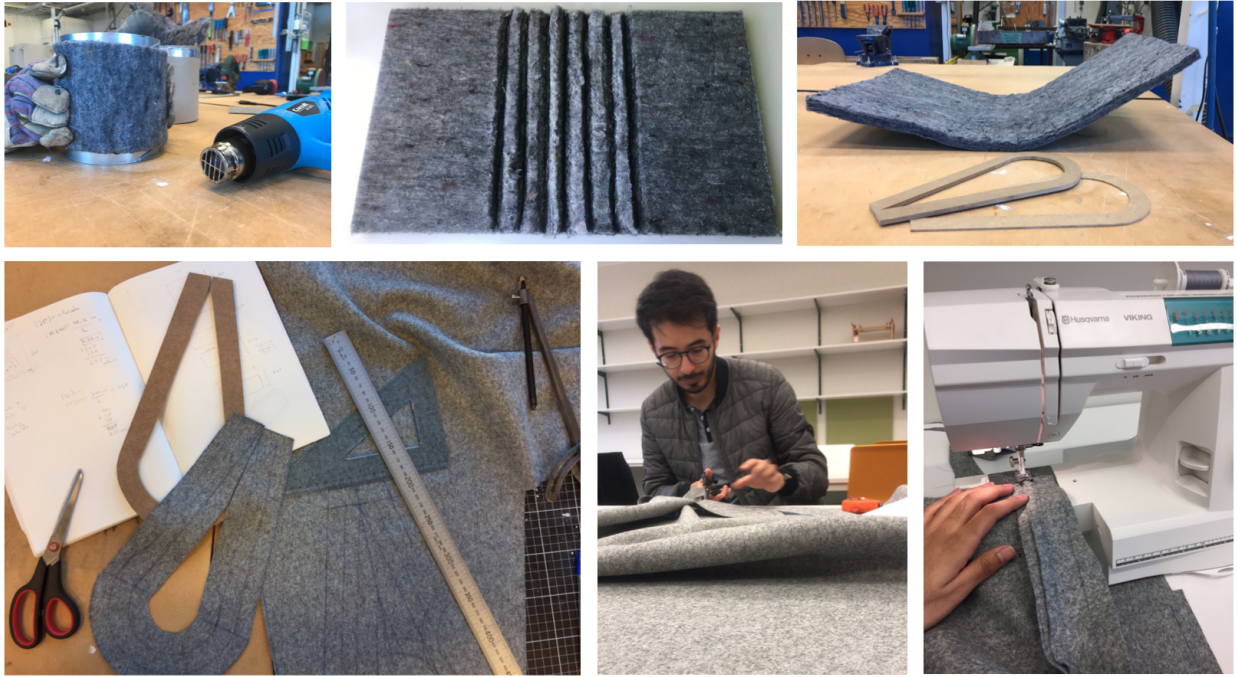


Figure 57. Concept 2 prototype process.

A material exploration was also done in this stage with the purpose of finding one foldable acoustic material that make possible to achieve the desired radius of concept two and at the same time may increase the absorptive properties of the panels. Some samples of different materials were requested from different suppliers in order to know more about their properties and test their flexibility. Three absorptive materials were provided by the company Horda Stans AB: Airfelt TK, Soundfelt Rec and Soundfelt Rec White (Figure 58). After trying to fold each of them was found that the Airfelt TK was easier to fold than the other two options, even though as its absorption coefficients were not provided by the supplier, it was decided not to continue further with these materials.



Figure 58. Horda Stans AB samples (Airfelt TK, Soundfelt Rec & Soundfelt Rec White).

As in the literature review (*Section 3.5*) was founded that the sheep wool had interesting high absorption coefficients, a sample of an acoustic textile felt made of this material was requested to the Danish company Really, discovered in the market research. Also a sample of a cotton acoustic textile felt (*Figure 59*) was requested due to the high absorption value (NRC=0.95 with 40 mm of thickness) available on their website. This value was tested with the standards ISO 354: 2003. (Really, 2019).The flexibility of this samples was not appropriate for the folding. Even though they had a variant with some cuts that could be applied for the concept 2 (*Figure 60*).



Figure 59. Really Acoustic Textile Felt.

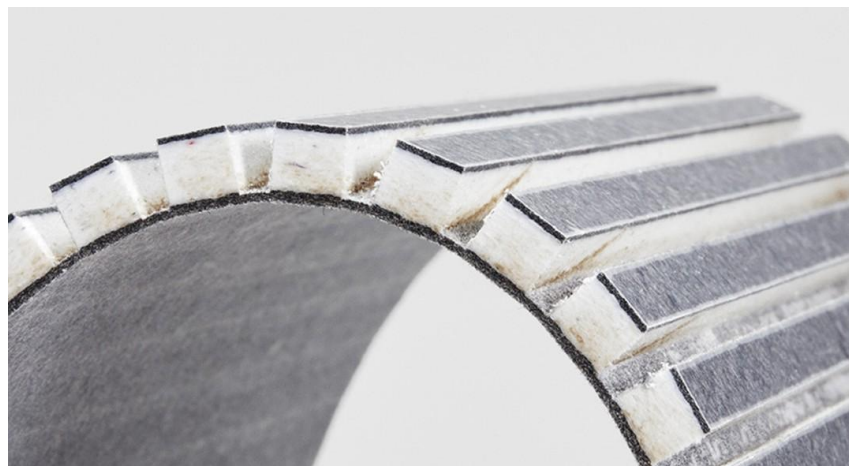


Figure 60. Really foldable Acoustic Textile Felt (Really, 2019).

The resulting prototypes (*Figure 61 and Figure 62*) received feedback from the supervisors at the university and at the company. The screws in the middle of the panel were decided to move 70mm higher in order to hide them with the acoustic panel, also it was suggested to edit the pictures to show different possibilities of colours (*Appendix 4*).



*Figure 61. Concept 1 prototype.*



*Figure 62. Concept 2 prototype.*

## **8.7 CAD modelling and rendering**

For having a better understanding of the shapes and being able to choose the appropriate appearance for each concept, some CAD models were done using Rhinoceros 3D software (*Figure 63* and *Figure 64*). It was interesting to explore shapes that it was difficult to explore with the materials available for the prototypes. Pyramidal shapes that help to diffuse the sound (*Section 3.1.2*) and bigger fillets were modelled.

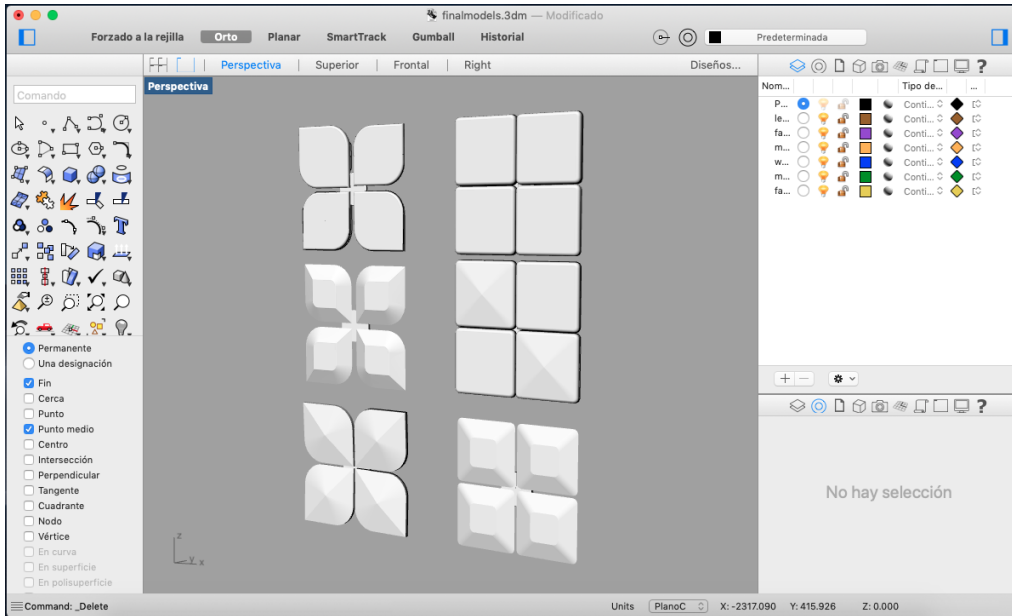


Figure 63. 3D Modelling concept 1.

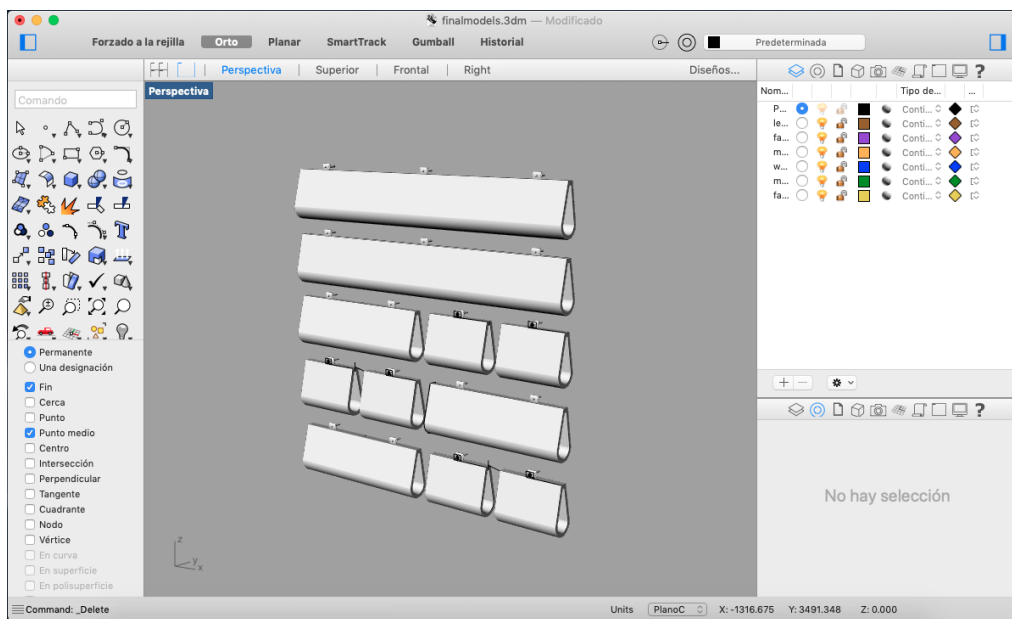


Figure 64. 3D Modelling concept 2..

With these models it was possible to develop some realistic renders with Cinema 4D. (Figure 65). It was possible to download the company material samples library to configure renders with Kinnarps materials and give the concepts the proper appearance.

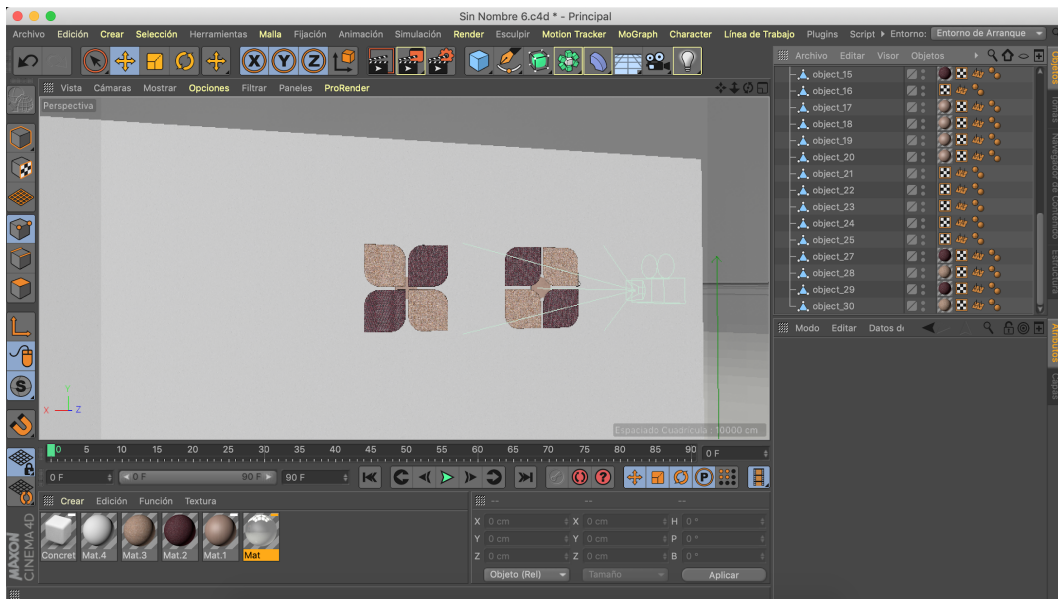


Figure 65. Rendering in Cinema 4D.

## 8.8 Appearance Test

The main goal of the appearance test was to select the final concept according to the company aesthetics. To achieve it, compositions in Kinnarps furniture environments were done to show the concepts possibilities. Adobe Photoshop was used to edit the prototype pictures and to integrate the renders into Kinnarps environments downloaded from the company website (*From Figure 68 to Figure 71*). The colour palette chosen for the test was based on the new colour combinations of the company, presented on the Stockholm Furniture Fair (*Figure 66*).



Figure 66. Kinnarps colour palettes



The appearance test was developed in the Kinnarps showroom in Skövde. The people evaluated were the sales workers in charge of choosing the acoustic panels for the interior design of several companies. *Figure 56* was shown to explain the shape and mounting system of each concept and from *Figure 68*, to *Figure 71* showed the possibilities of both concepts integrated in offices environments.



*Figure 67. Final prototypes shown in the concepts explanation.*



*Figure 68. Concept 1 square panels.*



Figure 69. Concept 1 circle panels



Figure 70. Concept 1 leaves panels.

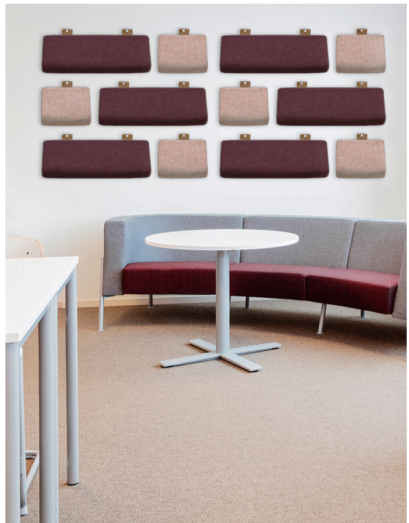


Figure 71. Concept 2.

Once all the possibilities were shown, they shared their opinions and preferences, being concept one the best for them, with specific emphasis in the variant 2 and 3. They decided to choose these ones because of the following aspects:

- Nice looking
- Considered easy to sell
- Easy mounting system
- The panels give a luxury plus to the environment
- The combination of fabric and veneer is a good idea because the customers can play with colours and combine with the rest of the furniture of the offices

Concept two received a positive impression regarding how it looked, creating a big difference from what is already on the market, even though it was not considered as easy to sell as concept one. One important comment of the manager was that this concept should have an interesting story to justify its shape and make it attractive for the clients.

## 9 Results

The final concept of a family of acoustic panels is described, regarding its main distinctive characteristics, sound absorption, materials, mounting system and the manufacturing processes needed. The selection of the following chosen concept was based in the appearance test and intuition of the designers.

### 9.1 Description of final concept

The final concept of family of acoustic panels consists in three different types of MDF structures, that work as bases where two, three or four acoustic panels can be easily attached with magnets. This concept seeks to:

- Give the customer the possibility to choose and combine different types of panels in different positions, depending on the type of environment they have.
- Reduce the number of holes on the wall per panel in comparison to the one that the company currently has (four per panel).
- Generate an air backing space between the panels and the wall in order to catch the sound at a higher speed and increase the sound absorption. (*Section 3.3*)

The panels shown in *Figure 72* have the same mounting system, which enable them to be fixed in the three different types of structures designed (*Figure 73*).



*Figure 72. Panel versions.*

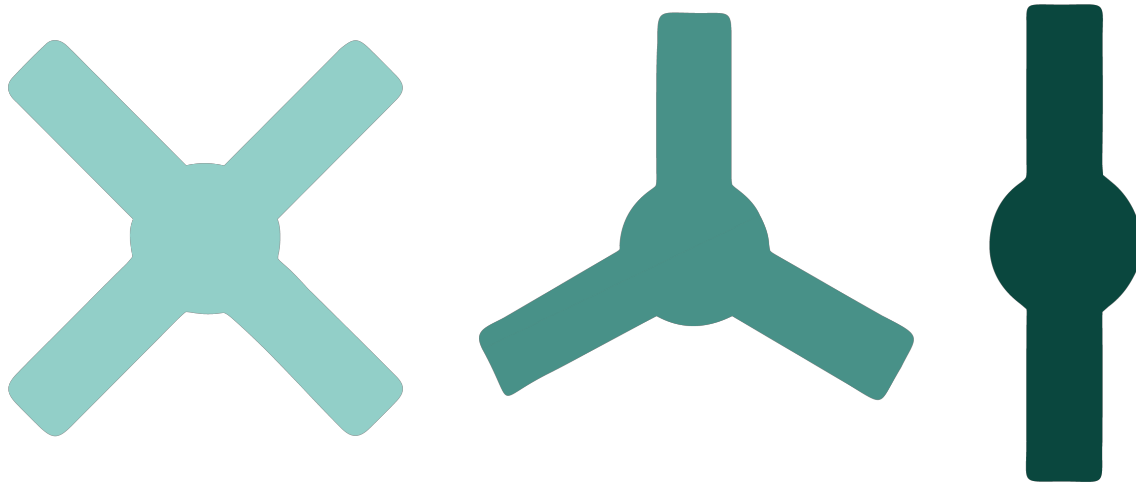


Figure 73. Structures versions.

## 9.2 Mounting test

Two mounting systems were developed and tested. The first system (*Figure 74*) consisted of two wall hooks where the structure would be hanged, the hooks were fixed to the wall using one screw for each. The second system (*Figure 75*) consisted of two perforations on the structure where two screws would be placed directly in the wall. The magnet system to attach the panels to the structure was also tested in order to know its effectiveness.

The mounting test was developed to observe if the mounting process was intuitive, and fast for the mounter in comparison with the company's previous acoustic panels. The evaluation was divided into two parts: the first one where two Kinnarps mounters tried to mount two types of systems without any information provided and the second one with the instructions of the installation. Both of them were video recorded and time measured. Surprisingly, the mounters did not need any instructions for mounting the two systems. There was a small conversation after the installation, in order to receive some feedback regarding the aspects with possible improves. The preferred mounting system and the fastest was the one with two holes in the structure (1,5 minutes). The main inputs received by the mounters were:

- The system of the two hangers would need an extra screw on each hanger of the wall to be more stable.
- They preferred the system of the holes because it is a more stable system.
- The combination of the structure and the magnet system was considered a big improvement for them in the current panels' mounting system. They consider this combined system would make faster to mount a big number of panels.



Figure 74. Mounting test hangers-system.



Figure 75. Mounting test two holes-system.

### 9.3 Final mounting system

Six fittings are necessary for mounting each panel: two wall plugs, two flat M6 washers and two M6 screws (60mm long). An storyboard (Evans et al., 2010) was done for explaining how the mounter will interact with the product (*Figure 76*).

1. The mounter measures and marks the distance between screws on the wall.
2. The mounter makes the holes in the wall with a hand drill.
3. The mounter inserts the wall plugs on the wall.
4. The mounter inserts the washers and the screws in the structure holes.
5. The mounter screws the structure to the wall.
6. The mounter attaches the panels in the desired position by aligning the magnets to the holes in the structure.

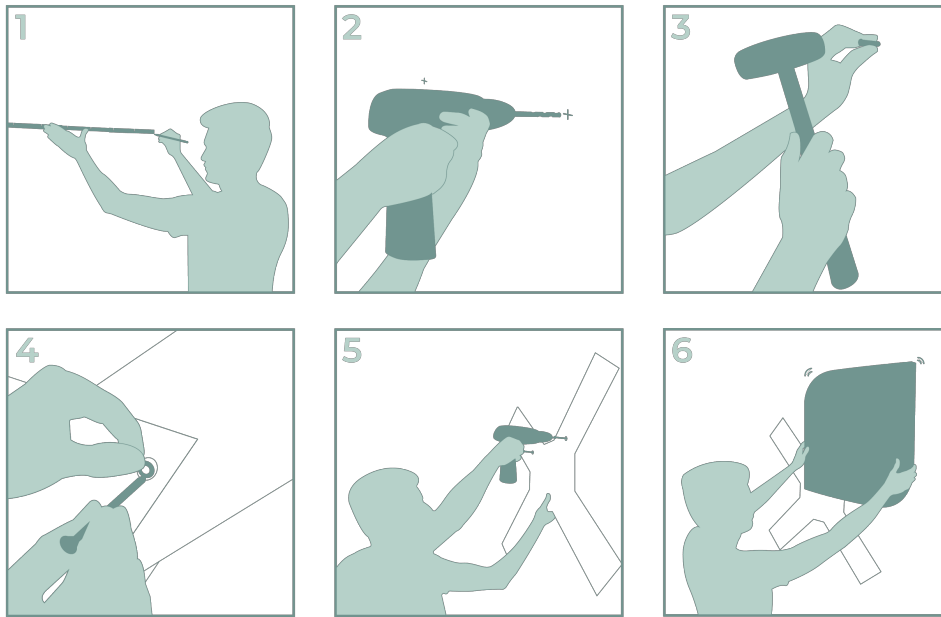


Figure 76. Mounting graphic process.

## 9.4 Aesthetic results

The aesthetics of the panels is based on regular and simple forms (circle, square, and a “leaf”), that mounted on the bases can create attractive compositions. All the panels have the edges rounded and are symmetrical in one direction. The style is mainly based on the keywords of the brand Kinnarps (*Section 5.4* and *Section 7.2*), in analogical thinking and in moodboards of the environments designed by the company (*Section 7.3*). One of the panels has a pyramidal volume because this type of geometries diffuse the sound waves (*Section 3.1.2*).

A rendered visualization of the final structure of three arms with circular panels is shown in *Figure 77*, and an integration in one of the Kinnarps’ environments is shown in *Figure 78*. Other visualizations of the rest of the panels are available in *Appendix 5*.

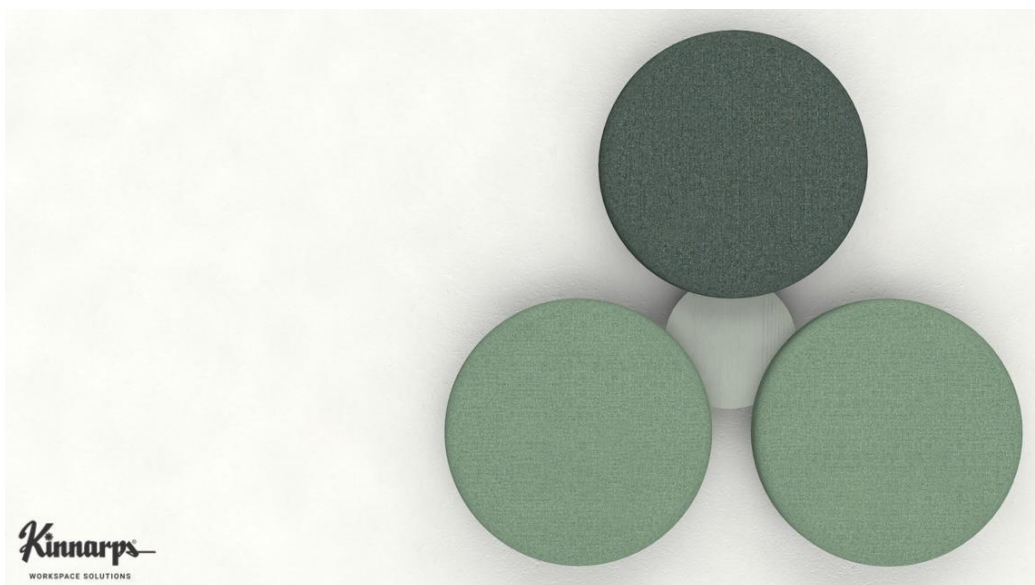


Figure 77. Three arms version.



Figure 78. Integrated panels in a Kinnarps designed office environment.

## 9.5 Absorption

It is proposed to have two layers of different absorptive materials (*Figure 79*), combining 20 mm of Kinnarps acoustic filler made of their recycled polyester fibres that has shown efficient acoustic properties in their current products (See *Section 3.6*), with the Wool Acoustic textile felt of 20 mm of thickness from the company Really, wool was founded to have one of the highest Noise Reduction Coefficient of natural fibres (NRC=0.70). This proposed combination and the use of might improve the absorption results for the panels. Even so, to verify that this solution provides an optimal absorption and fulfil the requirement, it would be necessary to test them in the Acoustic Room. Unfortunately, the company is not going to test any of their products before this project ends and it is too expensive to rent the laboratory just for the evaluation of the prototypes generated on this project.

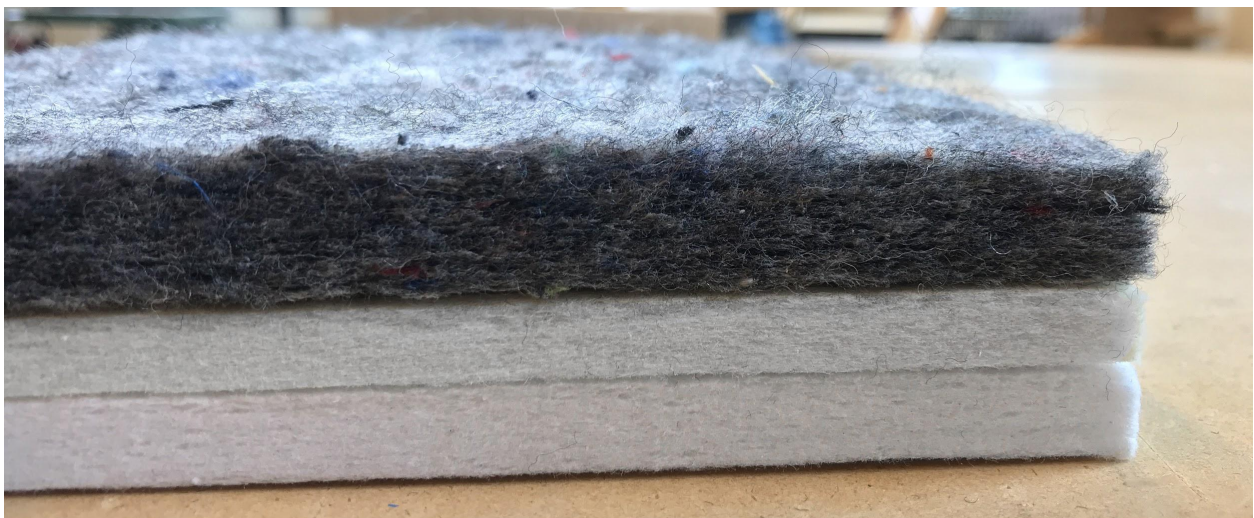


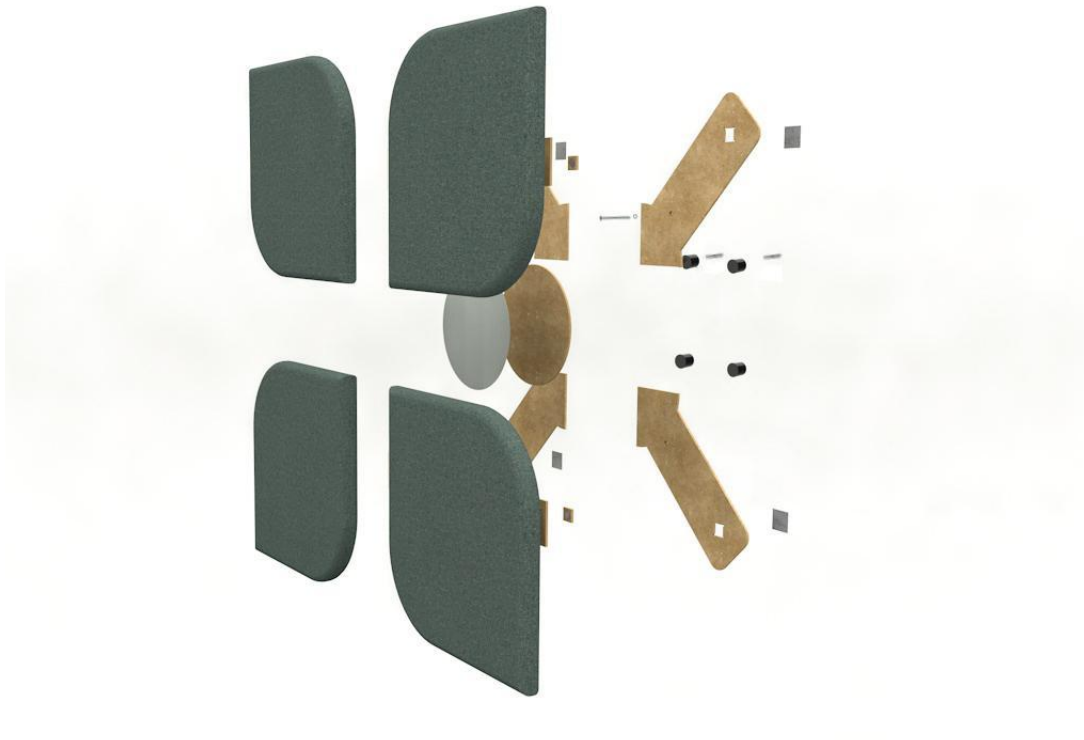
Figure 79. Absorbent material composition inside the panels.

## 9.6 Manufacturing process

Two main goals were sought in the manufacturing process: achieve a good sustainable value according to the Kinnarps rating and ensuring the operators safety. To fulfil them, Kinnarps materials and currently used processes are proposed to be continued because the company pays special attention to the high standards of them, and this will fulfil their sustainability requirements and also ensure the safety of their manufacturers.

The manufacturing processes required for the development of the product will be divided in the manufacturing of the structures and the panels:

- Structures:
  - CNC router for creating the pieces of each structure. As it is shown in *Figure 80*, dividing the main structure into separate arms which are glued to each other's thanks to a central part. It increases the full use of the MDF boards, avoiding the waste of material. Also small parts attached to each panel and holes for the screws are cut with the router.
  - One operator station: for gluing the arms and the veneer to the central piece, and the separators to the backside.
  - For creating the air backing space was decided to put four rubber pieces on the back.
- Panels:
  - A mould to manufacture the acoustic panels by pressing the fabric to the acoustic materials with heat.
  - Another operator will glue the MDF central pieces with the magnets to the panel.



*Figure 80. Exploded view.*



## 10 Discussion

After the development of this project some conclusions and discussion regarding the whole process were done. It was taken in consideration all the stages and make a special emphasis in the fulfilment of the product specifications, methodology chosen, results and learning from the whole process.

### 10.1 Requirements

The requirements fulfilled are marked in green, and the ones that require further development and testing are marked in orange in the *Table 6*.

Table 6. Fulfilled requirements.

Högskolan i Skövde - Kinnarps	Requirements List		Issued on 02/27/19
	Project: Family of acoustic panels		Responsibles: Julián Soria de la Torre Gabriel Juárez Mejía
Changes	D/W	Requirements	Evaluation method
02/13/19 02/27/19	D	Geometry: Thickness 35-80mm	Measurement (50mm)
	D	From wall to top of panel > 80mm	Measurement (81mm)
	D	Kinematics: Easy to mount	Time and user test
	W	Fast to mount	Time (2 minutes)
	W	Adjustable position	Yes/No
	W	Attachable modules	Yes/No
	D	Forces: Weight <1 kg + attachment parts	Measurement (0,9 kg)
	D	Function: $N_{10} \leq 6$ (6 wall panels or 1 standing panel) (Sound abs)	SS-EN ISO 354 and SS 25269
	W	Encourage concentration	Users test
	W	Improves workspace atmosphere	Users test
	D	Material: KCS Fabrics (If fabric is used)	Yes/No
	W	Recycled polyester filler	Yes/No
	W	Partly recycled	Yes/No
	D	Sustainable Value >2	"The Better Effect Index" by Kinnarps
	D	Safety: Operator safety	Swedish Work Environment Laws
	D	Mounter safety	Swedish Work Environment Laws
	D	User safety	Yes/No
	D	Manufacture: According to the industry standards	Yes/No
	W	Use existing facilities	Yes/No
	W	10.000-25.000 pieces per year	Yes/No
	D	Appearance: Brand colors	Yes/No
	D	Follow Brand aesthetics	Aesthetic analysis (Kinnarps keywords)
	W	Attractive to users and customers	Users/ <u>Customers questionnaire</u>
	W	UX: Consider user studies conclusions	Yes/No
	D	Time: 5 months in development	Yes/No
	W	Price: 750 SEK	Yes/No
	W	Maintenance: Easy to clean	Users questionnaire

The project fulfils the requirements that were demands, even though some fields are debatable. In the case of the functionality, formal tests with proper equipment are still needed to corroborate this feature with the proposed dimensions, shapes and materials but a  $N_{10} < 4$  is expected due to the materials used show good absorption levels with official results that follow the SS-EN ISO 354. Regarding the sustainability, a deeper study taking into account the six different areas of the “better index” rating should be performed to achieve the mentioned punctuation. Besides this, the project suggested another material that do not have a high negative impact on the environment, and the parts of the structure were developed to avoid the waste of material. As well, further testing for the mounter and users should be done in the next stages.

The literature review and preliminary studies gave the main base for the decisions taken along the whole project, and justify the features of the proposed final concept. The literature review of sound absorption and materials influenced the choice of materials proposed, the use of a backing space in the panels to increase the absorption and the pyramidal geometry of one panel to diffuse the reflected sound waves. Regarding the user studies. The type of chosen panel to develop (wall panel) was the most popular from the users web questionnaire. The customizable feature of choosing different shapes, positions and colours was found as an interesting and attractive characteristic for the target group in the interviews and in the web questionnaire. The appearance was based on simple forms with a modern style, due to they were repeated words that influenced the decision of the target group at the moment of choosing a panel. The aesthetics of the brand were taken into account by using as reference the moodboards of the environments created by Kinnarps with their products and the keywords at the moment of defining the shapes. Providing an easier and faster mounting system was one of the main requirements of the project and thanks to the structures proposed this requirement is fulfilled by reducing the number of holes in the wall to only two of them for each type of structure instead of four per panel. Using a lower amount of screws also reduces the risk of having different disorders (explained in *Section 3.6.1*) of the mounter.

This final concept presented is the proposal that was possible within the time limit. Therefore if the project continued it can still be developed more in detail to get closer to a production phase. More evaluations and refinement in detail of the product would be done, for instance, the functionality evaluation and a focus on the manufacture of all the pieces, considering how the materials should be combined in the mould, the viability of this manufacture processes, a Failure Mode & Effects Analysis to examine potential failures (Ginn et al., 2004) and an analysis of all the costs involved.

## 10.2 The project, the company, the process and design by itself

- From the project in general it was learnt how to apply to the development of a real company's product some of the methods and strategies obtained from the education of product design engineers. It was also understood that the planification of the project is as essential as any other stage of the process because it marks a work rhythm, with stated goals that have to be achieved every certain time.

As in all the projects several difficulties were found, for instance, in the creation of the web survey's questions, sometimes leading questions were done without noticing. In the case of the literature review, it is considered that it took a lot of time due to a not structured planification, first a lot of information of the main fields were collected, then filtered and at last structured, resulting in a big amount of data that was not completely relevant and in time wasted. From this situation was concluded that it would have been better to make a more structured planning of this stage before collecting all the information. In addition, it was difficult to deal with some limitations founded on the development of the project such as depending on the material suppliers in order to do the prototypes, or not being able to test the final results on a proper lab.

To work in a team was considered an advantage in this project because all the parts were involved equitably, thinking with an open mind, being critics, helping each other, and seeking to achieve the best possible result. It was really useful to have another point of view during the entire product development process because it helps to cover the main problem from a wider perspective and also to generate a discussion and complement the knowledge and abilities of each other.

- From the company besides the overview of how a big company as Kinnarps works, including the factory, manufacturing processes, and logistics, it was learnt that is important not to restrict the project too much since the beginning in order to leave some freedom and enhance creativity during the whole process. As well that the communication between the people involved in the project is really important. The constant feedback from the company (a weekly meeting) was considered a really good strategy to keep working on the right track and do not forget the main objectives of the project.
- From the process it was considered that the methodology followed “Design thinking” was a good tool to work with product design projects that seek an innovative result, due to the mix of divergent and convergent thinking it suggests, that gives an appropriate mix of exploration and selection of ideas. Developing a wide variety of solutions with sketches and prototypes helped to gain input to continue working, for instance, shapes, different assemblies, dimensions, proportions, and pieces were evolved by using as reference these previous ideas created. The involvement of the users that the approach followed suggested is considered really useful in two main stages of the project, at the initial phase because it gave important design opportunities and concrete characteristics of the target group to work in the concept generation, and in the evaluation of concepts, because it has as outcome relevant feedback that guided the decisions made to select the final concept that best fulfil their needs. On the other hand, it was found that the iterations that characterized “Design thinking” had positive and negative aspects. It was really useful for evolving the concepts and go back to develop a specific part that it was found that had to be fixed, even though this process may be a risk if there is not a limit, sometimes it seems to be infinite and it involves a lot of time.

The prototypes developed helped to refine the solutions and to have a better perception of the proposed solutions, even though developing prototypes for three concepts was not considered a good decision because of the amount of time that this process required, it would have been better to make the prototypes for two concepts.

The combination of different methodologies was considered effective for this project because their different approaches complemented each other. For instance the Ulrich & Eppinger's engineering approach suggested to state more concrete and technical data, while the IDEO method cards, and "Design thinking" suggested tools more focused in the user, and in the iterations of the process.

- From design in general it was concluded that developing all the areas of a product is a really complex activity. The process of keeping in mind the investigated information, the requirements, user studies, and other relevant data can overwhelm the designer, even though for the team in charge of this project was helpful to decompose the problem in order to have a better understanding of what had to be solved and also to not forget the main objectives every time that a decision has to be made.

Design is considered by this team an activity that requires constant practice to gain experience and keep obtaining more knowledge from every project.

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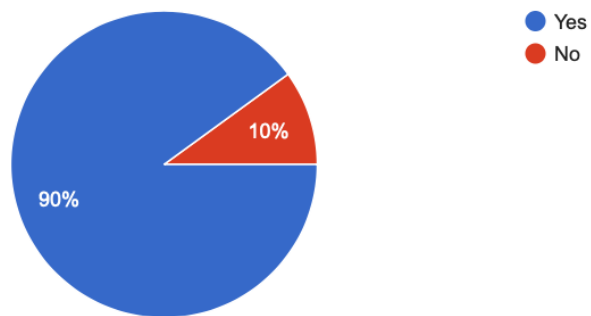
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## 12 Appendices

### 12.1 Appendix 1. Web questionnaire

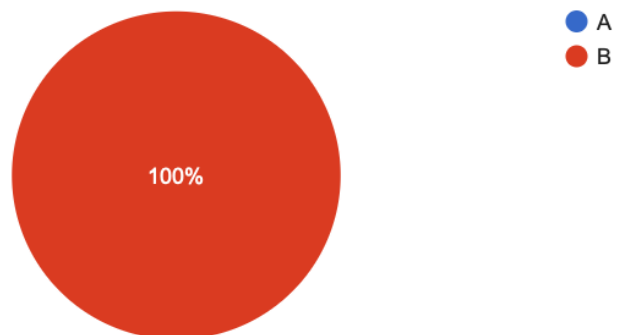
Do you know what an acoustic panel/sound absorber is?

30 responses



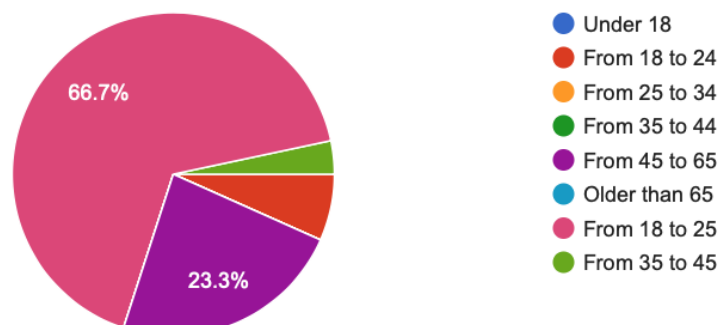
Select the correct option

30 responses



Age

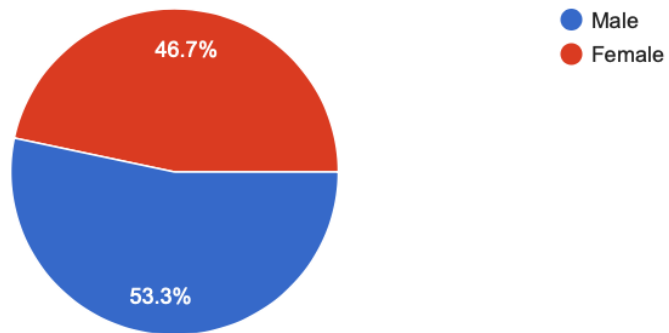
30 responses





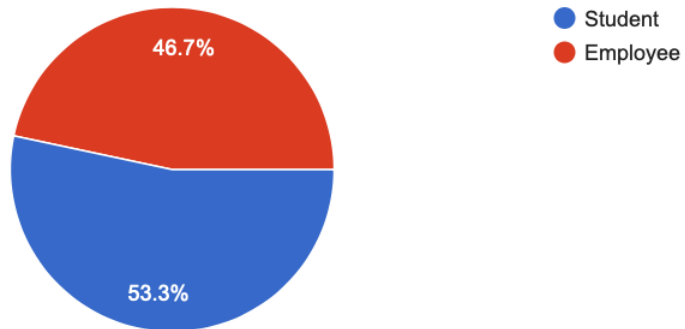
## Gender

30 responses



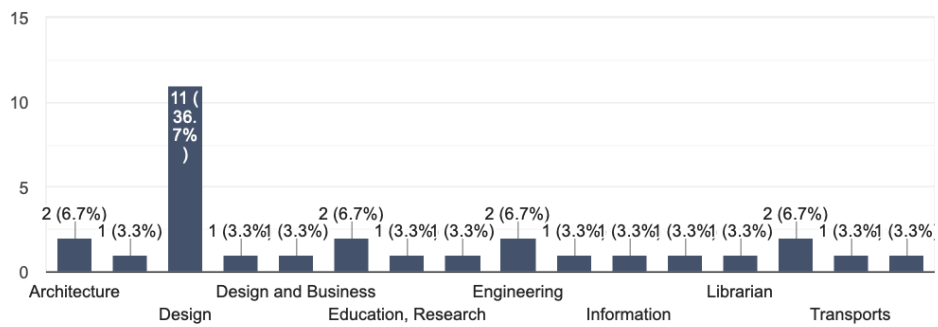
## Employment Status: Are you currently...?

30 responses



## Specify your field (Business, Science, Architecture, Design, Education, etc)

30 responses



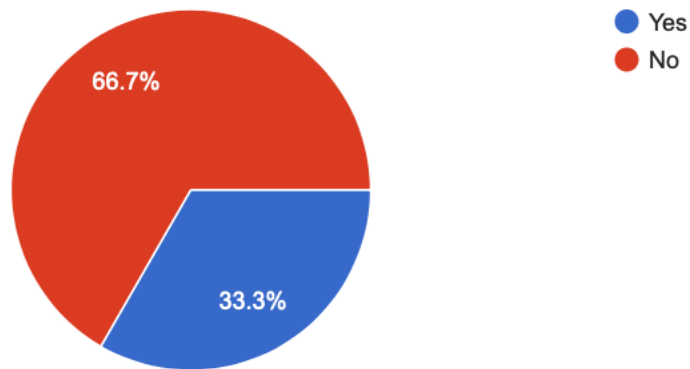
Specify your type of work space (Open office, home office, co-working space, single room office, classroom, library, etc)

30 responses

Single room office
Co-working room
Classroom and library
Biblioteca
Three room office
Studio/Co-working space
Open office
Single room
Classroom, library, home office
Single room office
Home studio
Cockpit

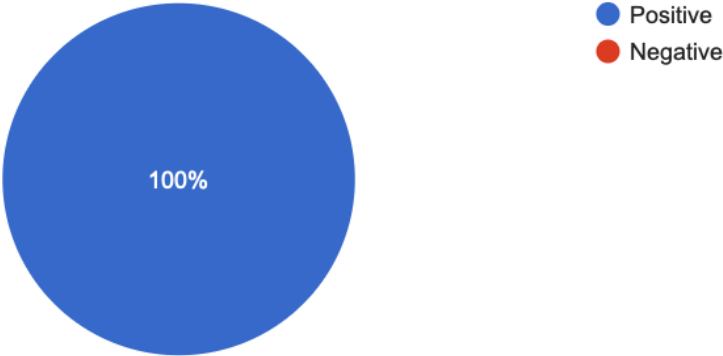
Do you have acoustic panels in your workspace ?

30 responses



# Do you think acoustic panels affect in a positive or negative way the work environment?

30 responses



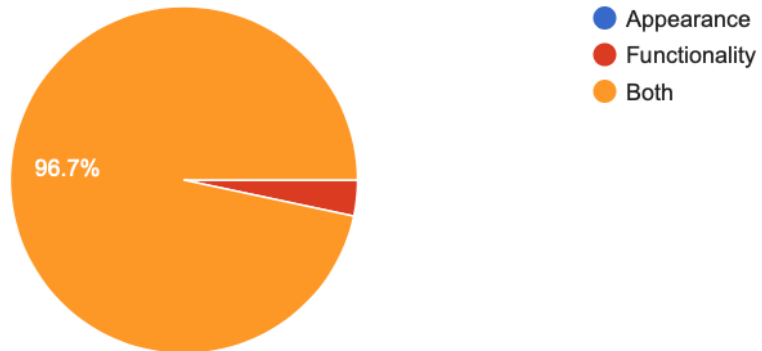
## Explain briefly why

25 responses

- The place will be more quiet, then peaceful. In my area that gives you more opportunities to be creative
- Helping the work environment by making it easier to concentrate in a quieter space
- There are panels in the roof of my office room, which may reduce echoes a bit.
- Reduce noise level, better concentration
- Because them helps to have better conversations and work space
- More quiet to the people outside the zone and more comfort for the people inside
- Because of noise reduction improves co-working environmental team and helps brain concentration
- Obviusly in the library to create environments which allows people or groups to produce some noise but keep areas as undisturbed as possible and create more calmness, in the (in our) library also much as a design element to supply the library with positive colours
- Man låta det bli en del av gestaltningen och förstärka uttrycket
- Positive - they keep down the noise, Negative - they're ugly
- it makes a more friendly and colorful environment to work, and reduces the noise

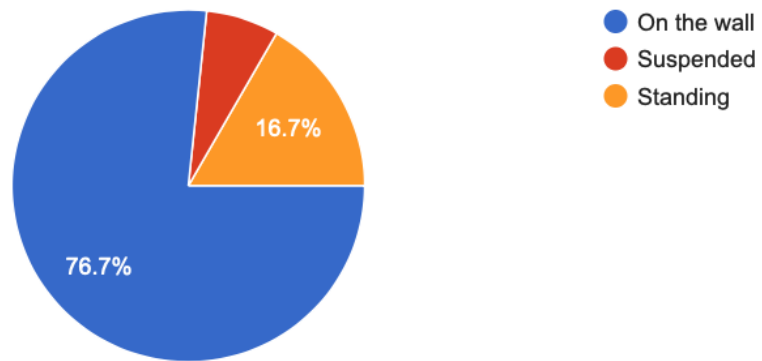
## What do you think is more important for an acoustic panel?

30 responses



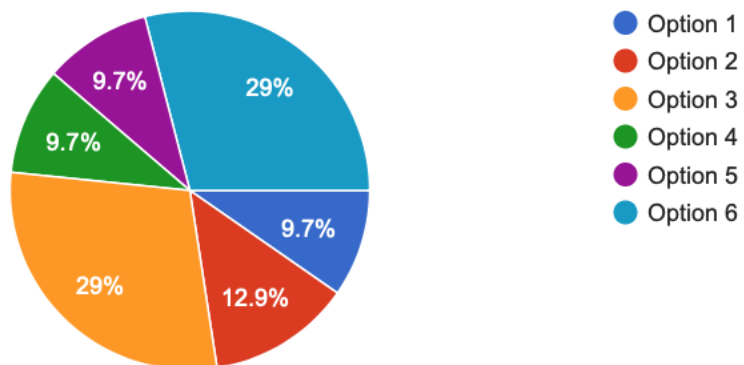
## Which type of panel do you prefer?

30 responses



## Which of these wall panels do you prefer?

29 responses



## Brief explanation of your choice

25 responses

Because this panels have design and you can removed to different places that helps to have different rooms with panels or improve rooms.

Depends on the location and function needed

More creative, better integration with the wall

Modular panels in hexagons can be adapted to many types of walls, plus mixing colors can create great patterns.

Multifunctional panel

I would prefer option 6 because I think it is colorful, subtle and smart at the same time.

It is also a good decorative method

Great and simply design

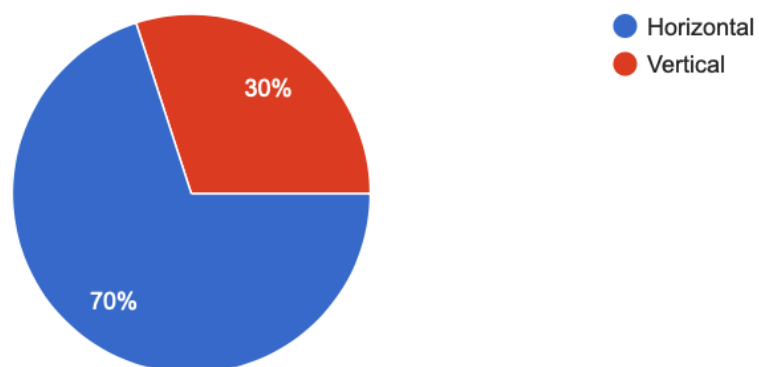
Is simple, modular, conservative and good looking

Very simple yet nice design, not distracting

It is possible to add images to the panels in a less limited way.

## Which of these suspended panels do you prefer?

30 responses



## Brief explanation of your choice

23 responses

Horizontal panel does not block the view of the room, also they would bring a nice dynamic to the space and would bring a perception of height and three dimensionality especially to large open spaces if suspended on varying levels.

It is not felt as a wall

Me parece menos invasivo

Because the sound expands and stops at the top with this type of panels.

Looking better and to avoid collisions with other objects or your upper body

Horizontal panels must be difficult to clean, while verticals seem to be easier.

The roof space is used

Horizontal panels bothers less to me

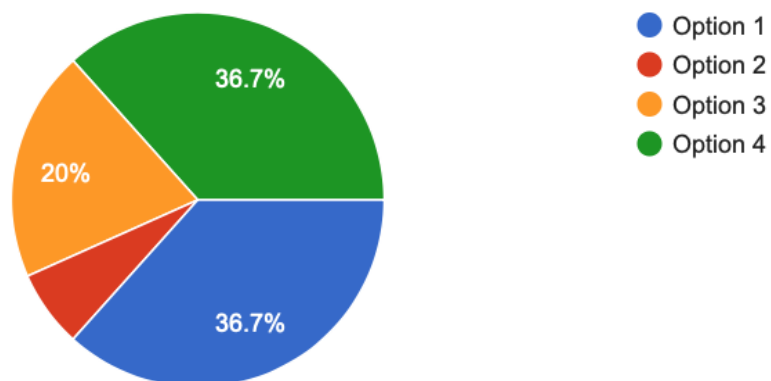
It creates an open apace

More space, it is more practical

You can create different atmospheres with compression of the space, but vertical can be used as a dividers of

## Which of these suspended panels do you prefer?

30 responses



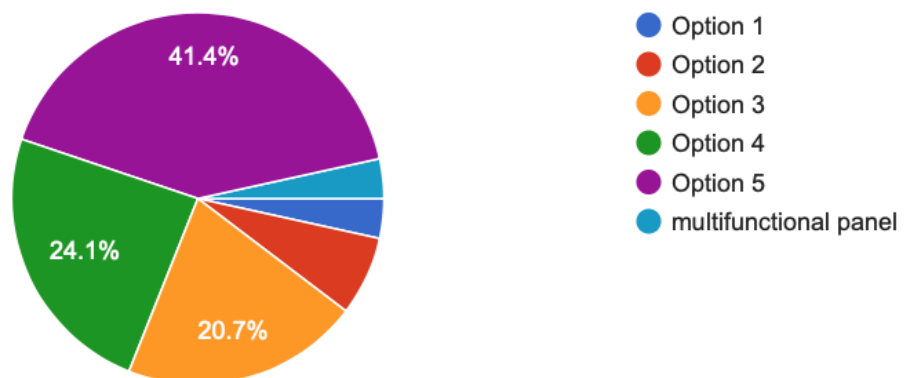
## Brief explanation of your choice

24 responses

Because you can use it to divide the rooms and continue the visual at the room space
Looks most interesting
You can see through
They look a decorative object instead of a panel.
Type of emotional panel
Option 1 lets the light go through it
It is also a good decorative method
Great design
I chose this option more based on my design likes and also because the modulation of the panels, I also like the lattice, but I guess cannot be really useful in acoustic absorption focusing
Dividing the room, not distracting, better design than the others
The horizontal panel 4 does not act as a barrier, and it is visually attractive.
Seems light and lively

## Which of these standing panels do you prefer?

29 responses



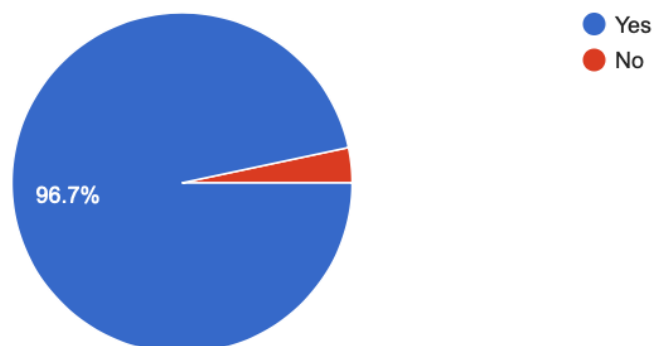
## Brief explanation of your choice

21 responses

It seems to be a other fitmet at the house and not a panel
Original and movable
I like the natural shape of these panels.
Because of its organic shape and
It could be used also for separating the space into diverse areas
Modular form
If you want to use more space into the room you can hide part of the panels
Nice eye catcher without being too overwhelming in a workspace
It can be use more like a wall, but still flexibly it seems.
enjoyable
Is more organic, similar to a nature space
I love the modular design

## Do you consider interesting to be able to choose the position, color and pattern of the acoustic panels for your work space?

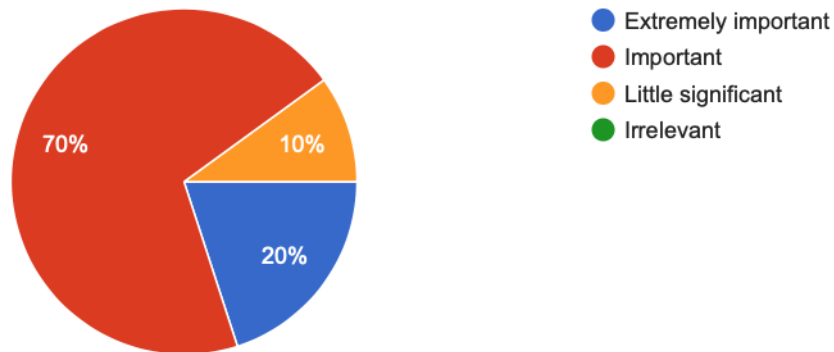
30 responses





## How important sustainability is for you, when you are choosing one of this products?

30 responses



### 12.2 Appendix 2. Interviews

Interview 1.

Interviewers: Julián Soria and Gabriel Juárez

Interviewed: Architect of Ritningen Arkitektbyrå AB

1. **What did you consider to choose the acoustics panels for the University of Skövde's library?**

A: The freedom to choose the fabrics colour, and the prize.

2. **Do you consider important to have a big amount of acoustic panels in order to absorb the sound?**

A: It is better not to have so many, it depends in how many people will be there and other things, and also it depends if you can put something in the ceiling or not. We are not fan of the 60x60 cm "pladur" for the roof, although they are useful for the installations but not for the aesthetics of the space.

3. **What type of acoustic panels do you prefer, wall, standing or hanged from the ceiling and why?**

A: It depends on the project and the type of space. Acoustic panels are our last resource because you can also use other type of objects, as carpets, open shelves with books, furniture, etc.

4. **If acoustic absorption represents a 10 and aesthetics a 0, which would be the balance/proportion between them for you?**

A: It also depends on the project but In this case, in a library is very high the proportion for the acoustic absorption, 70-30 approximately.

5. **From 1 to 10, being 1 irrelevant and 10 extremely important, how do you think acoustic panels could improve a working environment?**

A: 8, yes it improves the working environment

6. **What kind of shapes do you consider are more appropriate for an acoustic panel, simple and regular, based on basic forms or more complex ones?**

A: Mostly Very simple, discrete, where you can put your stamp on it.

### **Extra comments**

In general architects, we first look in the room, in what we want to create, which absorbents we are going to use, so we can build a room that will have proper acoustics.

And we depend on the acoustic panel measures that the company provides but sometimes is an issue, and it could be useful to have a wider variety of sizes or be able to customize them.

### Interview 2.

Interviewers: Julián Soria and Gabriel Juárez

Interviewed: Sales employee "A" Kinnarps showroom Skövde

1. **Have you been involved in choosing acoustic panels for interior design projects?**

Yes

2. **What did you consider to choose the respective panels?**

Price, How big the problem of acoustics is for the customer, the thickness, the interior material, but it depends in the project.

3. **Where did you look for possible acoustic panels for your designs? (websites, catalogues, fairs, etc).**

We have contacts in the companies, representatives come and talk about their products.

4. **Do you consider important to have a big amount of acoustic panels in order to absorb the sound?**

Yes, it depends in how much the sound bounce between the walls, and if they have a textile floor, or a hard roof.

5. **What type of acoustic panels do you prefer, wall, standing or hanged from the ceiling and why?**

I think that the hanged from the ceiling is the nicest looking one, but you should have both types at least to make the sound not bounce so much, often is not enough with one type. Maybe wall and standing or wall and roof.

Horizontal panels are more for personal dinners, where many people interact, and the vertical are more for offices.

6. **If acoustic absorption represents a 10 and aesthetics a 0, which would be the balance/proportion between them for you?**

70% aesthetics, 30% functionality

7. **From 1 to 10, being 1 irrelevant and 10 extremely important, how do you think acoustic panels could improve a working environment?**

8

8. **From 1 to 10, how important you consider is to have different size panels ?**

8

9. **From 1 to 10, how important you consider is to have the possibility of customize the composition with different shapes, patterns and colours?**

The colour and textile are the most important for me. There are many different shapes, and if you have to come with a new panel, it must be something quite spectacular, and with new thinking.

10. **Do you consider interesting to let the workers customize the office acoustic panels?**

That would be great, a problem is that is not flexible today, you need to screw them on the wall.

11. **What kind of shapes do you consider are more appropriate for an acoustic panel, simple and regular, based on basic forms or more complex ones?**

I think that both are great depending on the type of project.

12. **What company do you think is currently doing a great job in acoustic panels?**

Glimakra, Abstracta and Zilenzio

### **Extra comments**

We work with different companies that sell acoustic panels, but mainly three big companies, sometimes there's a request from the customer to have one type of panel or of a company has a product that is more unique.

Interview 3.

Interviewers: Julián Soria and Gabriel Juárez

Interviewed: Interviewed: Sales employee “B” Kinnarps showroom Skövde

1. **Have you been involved in choosing acoustic panels for interior design projects?**  
Yes
2. **What did you consider to choose the respective panels?**  
The roof and the floors, I choose the colours looking through Kinnarps and other companies and of course the preferences of the client.
3. **Where did you look for possible acoustic panels for your designs? (websites, catalogues, fairs, etc)**  
Websites of different companies.
4. **Do you consider important to have a big amount of acoustic panels in order to absorb the sound?**  
Yes
5. **What type of acoustic panels do you prefer, wall, standing or hanged from the ceiling and why?**  
I prefer wall panels because it is nicer than a white wall, but it depends on the client.
6. **If acoustic absorption represents a 10 and aesthetics a 0, which would be the balance/proportion between them for you?**  
6
7. **From 1 to 10, being 1 irrelevant and 10 extremely important, how do you think acoustic panels could improve a working environment?**  
8
8. **From 1 to 10, how important you consider is to have different size panels?**  
I think it depends on the project and how many absorption you need in the room, but I like to work with different sizes.
9. **From 1 to 10, how important you consider is to have the possibility of customize the composition with different shapes, patterns and colours?**  
It is important for me to customize composition and colours.
10. **Do you consider interesting to let the workers customize the office acoustic panels?**  
Yes it is very interesting, we also work with a company that prints pictures in acoustics panels' fabric.
11. **What kind of shapes do you consider are more appropriate for an acoustic panel, simple and regular, based on basic forms or more complex ones?**  
Simple and regular combining different sizes in order to create a composition.
12. **What company do you think is currently doing a great job in acoustic panels?**  
Zilenzio and Glimakra.

Interview 4.

Interviewers: Julián Soria and Gabriel Juárez

Interviewed: Manager of Trängens förskola

1. **Can you notice the difference between being in a room with the children that has acoustic panels and in a room that has not?**

Yes, of course. There are a lot of children, so we need them.

2. **What kind of shapes do you consider are more appropriate for acoustic panels, simple and regular, based on basic forms or more complex ones?**

In big rooms we prefer this one ( point rectangular standing wood panel), and in smaller rooms we prefer the wall ones.

3. **Do you think this objects distract the children? Why?**

Yes but we prefer this one for smaller rooms (points a fabric wall panel) because the children can attach paintings and other things in the panels.

4. **From 1 to 10, being 1 irrelevant and 10 extremely important, how do you think acoustic panels could improve a working environment?**

While more acoustic panels in the place it improves the concentration in a better way. I work here so I need a concentration environment

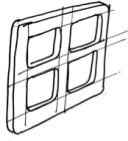
5. **What do you consider more appropriate, to have acoustic panels, or to have acoustic absorptive furniture as sofas, carpets, etc?**

We need to have both kind of sound absorbers, panels and furniture.

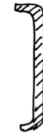
6. **Do you consider interesting to have interactive customizable acoustic panels for the children? Why?**

Our panels could not be moved from the walls or ceiling, so it would be interesting to make them softer as toys for children but the pieces should not be noisy when they fall on the floor, as the plastic box that we have to put the toys inside them.

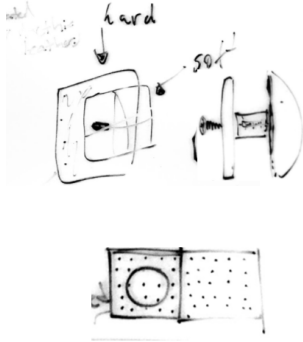
## 12.3 Appendix 3. Interior parts and mounting system alternatives



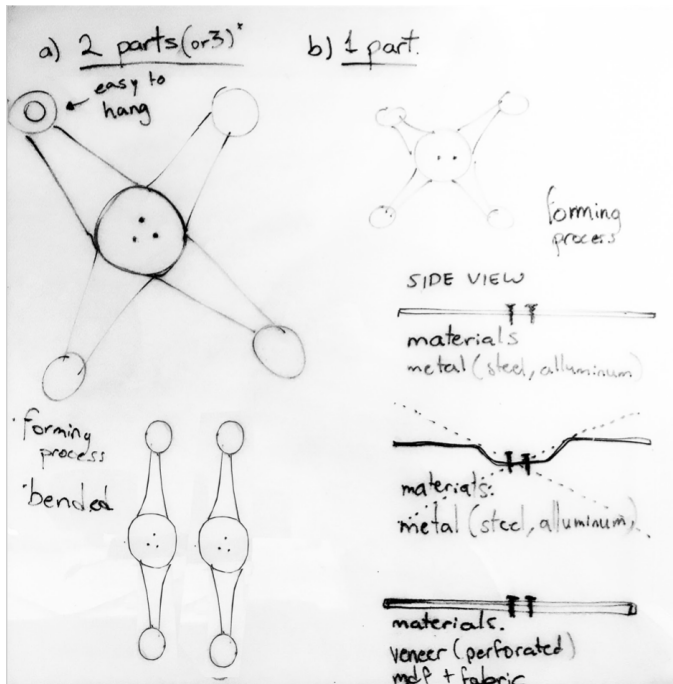
A frame in the back part of the panel that lets the air go through it.



A panel that has a space in the back due to its shape. Similar to a "shell".



A double panel that has a central union that creates a space between them. The back panel could be a perforated veneer panel or a mdf panel covered with a fabric. While the front panel could be the one with the absorbent material and have different shapes.



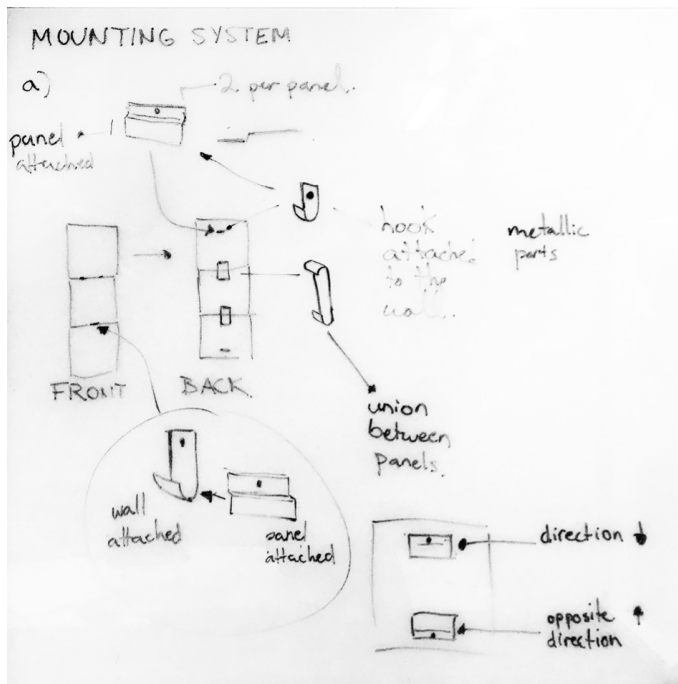
### Base for hanging the panels

It can be a **4 "arms"** module or a **2 "arms"** module (as it is shown in the left side of the picture).

#### Possible **materials**:

- metal (steel or aluminium)
- Perforated veneer panel
- MDF + fabric

The acoustic panels are attached to each arm with a hook, velcro, or ironworks.



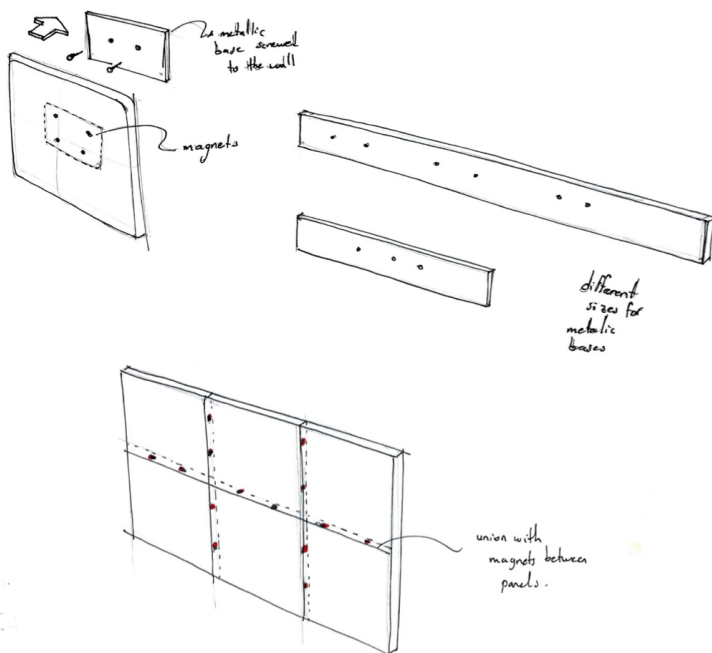
**Attaching 1 panel to the wall**, and the others are hung from it with metallic parts.

The system is composed by **3 pieces**.

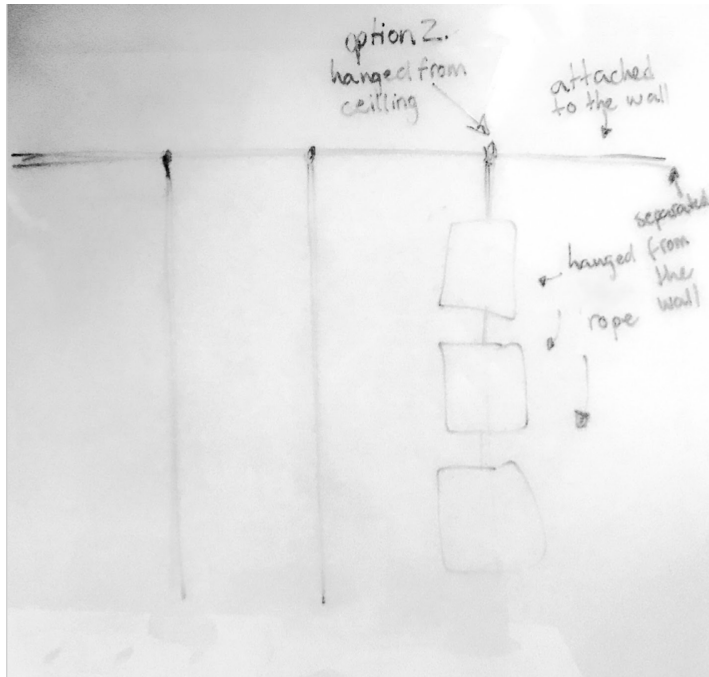
**Two** of the **first type** are **attached to every panel**.

The **hook** is attached to the **wall**.

The **double hook joins** the panels vertically.



**Magnets system** for hanging the panels



**Rope system** for hanging the panels

**Bar** separated from the wall

The panels and/or the rope had the union mechanism to hang them.

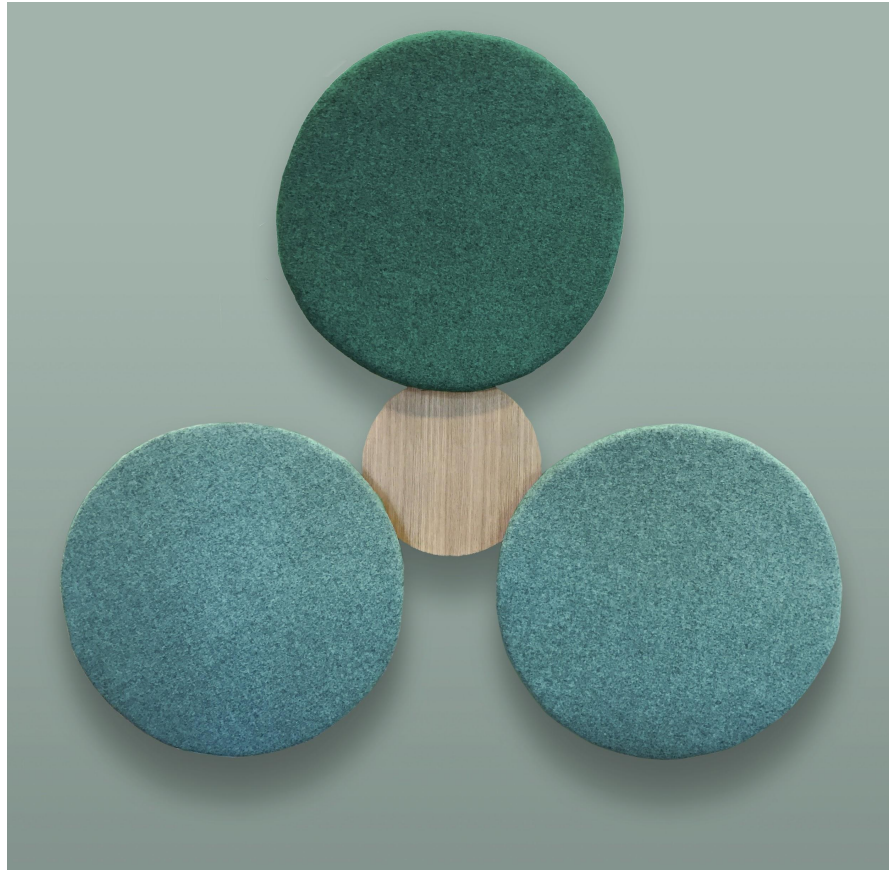
## 12.4 Appendix 3. Prototypes versions











## 12.5 Appendix 5. Integrated final results







