DESIGNING SUSTAINABLE ACOUSTIC PANELS USING CORN COB WASTE: A STEP TOWARD CIRCULAR DESIGN

MASTER GRADUATION REPORT

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Abstract

Noise pollution is a growing concern in homes and workplaces, making acoustic solutions more important than ever. This project explores the potential of corn cobs (an agricultural by-product) to create sustainable acoustic panels. The goal is to offer an alternative to conventional soundproofing materials that is both eco-friendly and practical for real-world use.

Traditional acoustic panels are often made from synthetic materials like mineral wool, foam, or fiberglass. While effective, these materials come with environmental downsides, including high carbon footprints, waste generation, and, in some cases, the release of volatile organic compounds (VOCs) that can affect indoor air quality. This project takes a different approach by repurposing agricultural waste into a functional and circular product.

To test the concept, a prototype panel was developed. It measures 260 cm long, 30 cm wide, and 3 cm thick, designed to fit into U-profiles that attach to a floor-to-ceiling frame. The sound absorption coefficient was measured at approximately 0.35, meaning it provides some noise reduction but still has room for improvement. Mechanical tests revealed that the panel's bending and tensile strength are lower than standard requirements, highlighting the need for a stronger or more suitable binder.

Despite these technical challenges, the project has promising advantages. Corn cobs are widely available and inexpensive, making them a cost-effective raw material. The panels support a strong sustainability narrative, helping brands improve their eco-friendly positioning. They also do not emit VOCs, making them safer for indoor use. Aesthetically, they have a neutral, modern appearance that can suit various interior styles, and their customizability allows for different design possibilities.

However, there are still some limitations. The natural inconsistencies of the material, along with its sensitivity to moisture, could affect long-term durability. Some users might also question its strength, especially compared to established alternatives. The texture of the panels may not appeal to everyone, and while the production process is scalable using hydraulic pressing, setting up large-scale manufacturing could be costlier than expected. Additionally, competing with well-known brands will require strong market positioning.

To make the product commercially viable, key aspects such as cost, regulations, and consumer demand need further evaluation. The main target audience includes first-time homebuyers and renovators who prioritize sustainability, but the panels could also be applied in commercial spaces. The next steps will focus on improving strength and moisture resistance while maintaining environmental benefits.

This project demonstrates how agricultural waste can be transformed into useful, sustainable materials. While further refinements are needed, corn cob acoustic panels have the potential to become a real alternative to conventional options. By balancing sustainability, function, and design, they could contribute to a more circular and environmentally responsible construction industry.

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1: Introduction

1:1 Problem statement

The world is facing a challenge because of the rapid growth for needing new resources. The global population is expected to grow to around 8~~.~~ b~~i~~llion by 2030 and 9.7 billion by 2050, (United Nations Department of Economic and Social Affairs, 2021) from which globally 55% of the population live in urban areas which is projected to be increasing up to 68% by 2050. This rate is already higher in Europe with a rate of 74% (“World Urbanization Prospects 2018: Highlights,” 2018). This growing population and urbanization is pushing more and more challenges on our environment and on our lives.

One major issue is noise pollution, which impacts health and well-being in significant ways. Short-term effects include sleep disturbances and irritability, while long-term exposure can lead to neurological damage, cognitive issues, and even physical symptoms like tremors and increased pain sensitivity (Kim & Van Den Berg, 2010; Fietze et al., 2016). According to WHO guidelines, noise levels should stay below 30 dB(A) at night for quality sleep and under 35 dB(A) during the day for effective learning and focus (World Health Organization, 2010), (Eurostat, 2021). Despite this, many people, especially those living in urban areas with shared walls, are regularly exposed to noise levels above 55dB(A) day and night. This shows a clear need for more effective and sustainable soundproofing solutions.

Currently there are around 120 million residential buildings in the EU. This number is expected to be raised by 25% by 2050, (Boza-Kiss, Bertoldi, & Della Valle, 2021) which shows a growing demand for new building materials. And of course, like every industry, construction is generating waste. Today, the construction industry is responsible for around 37% of the global emissions, although with proper management of bio-based materials these compound emissions could be reduced by 40% by 2050 (United Nations Environment Programme, & Yale Center for Ecosystems + Architecture, 2023). And while acoustic tiling is taking only 0.8 % of the total waste production of a building, (Minnesota Pollution Control Agency, 2020) the EU has generated 807.17 million metric tons of construction waste in 2020 (Statista, 2024a). This is roughly 6.5 million metric tons of waste is generated from acoustic tiling alone.

Looking at this from an end-of-life perspective, the waste coming from the construction industry can be generally recycled to inferior products, (Schut et al., 2015) like aggregate in the road. But in the circular economy the main goals are to eliminate waste and emissions by reusing and recycling products and materials while maintaining their performance and functionality. Biobased materials offer more recovery pathways than traditional building materials (Ritzen et al., 2023), with especially incineration and composting (in the case of biodegradable materials) as additional options.

Exploring the use of biobased waste materials for acoustic panels is interesting for reducing CO2 emissions and for providing new recovery pathways.

The idea for this project started with exploring corn stover as a potential material for acoustic panels. Corn stover seemed promising because of their abundance and the sound-absorbing properties of lignocellulosic fibers. This study is about exploring the idea about finding out if corn husks, stalks and cobs can be turned into sustainable, high-performing acoustic panels that could replace traditional materials like Rockwool, polyester felt, or polyurethane foam.

The goal is valorizing a waste stream from agriculture and creating new products for the lignocellulosic waste to create a low-impact product that fits within circular economy principles. The panels should have a smaller carbon footprint at the end of their life and provide a more sustainable alternative to current acoustic materials. At the same time, using agricultural waste could benefit farmers by creating additional income streams and making the panels more affordable than petroleum or wooden based alternatives for end-users.

My design vision is focused on providing a simple and effective alternative to people who suffer from noise pollution in their own homes, without compromising on product quality and performance while keeping the environment in consideration. This product aims to enable people to customize their environment according to their liking while improving their quality of life by providing a calmer, quieter environment for living and relaxation. This vision leads to the following research questions.

1.2 Research questions

- How to make an eco-friendly acoustic wall panel from agricultural waste materials, that is attractive to customers?
- Sub questions:
    1) Which types of agricultural waste have a good potential (based on their availability and acoustic performance) for being used as an acoustic panel?
    2) How well does the chosen material absorb sound compared to traditional acoustic materials?
    3) Which binder alternatives are suitable for making an effective sound absorption panel based on performance and end-of-life considerations?
    4) What do people look for when choosing acoustic wall panels for their homes?

5) What design features would make acoustic panels more attractive and practical to use?
6) How big is the environmental impact of the new alternative compared to the traditional ones?
7) How feasible is it to manufacture the panels by existing machinery?

1.3 Approach and Methodology

Starting with an analytical approach, the background of the problem area is discovered regarding the needs of the environment, the people and the economy. To fulfil the need for a circular product the focus is put on the potential of creating value from waste, precisely agricultural waste as a resource. To get a deeper understanding of the existing sound absorption materials and technologies and the potential of the corn stover as a new alternative, extensive research will be leading the ideation process. The main research question is broken down into seven sub-research questions, that focus on different aspects of the project. The methods include literature reviews, data collection, user surveys and testing. Below there is a summary of how I approached each question. (see Table 1 below)

	Research question	Approach	Chapter
1)	Which types of agricultural waste have a good potential (based on their availability and acoustic	To answer this, scientific papers were reviewed from databases like, Google scholar, and Scopus. Keywords included “agricultural waste,” “acoustic material” #, “acoustic materials,” and “lignocellulosic waste.” Also, there was some investigation into grey literature from organizations like the UN, UNEP, and WHO as they are reputable sources of information. All sources were limited to studies from the past 15 years written in English. I focused on the materials with high lignocellulosic content. Especially the ones with great availability and possibly good sound absorption properties. This helped me to narrow down the list of potential materials for further investigation. Finally, three scientific publications and four publications of grey literature sources were used.	3.1.1
2)	How well does the chosen material absorb sound compared to traditional acoustic materials?	I compared the sound absorption properties of three existing materials with the results coming from two scientific papers about the acoustic properties of corn cobs as new alternative. The existing materials are Rockwool, polyester felt, and polyurethane foam, later named as traditional sound reduction materials. The acoustic properties of these alternatives came	3.1.2

		from scientific papers and manufacturer’s specifications. The results of these studies and manufacturer’s specifications provided a clear comparison between the effectiveness of sound absorption of the corn cob compared to the other alternatives.	
3)	Which binder alternatives are suitable for making an effective sound absorption panel based on performance and end-of-life considerations?	To answer this, scientific papers were reviewed from databases like Google scholar, and Scopus. Keywords included “biodegradable glue,” “biodegradable adhesive”, “lignin-based adhesive,” and “biodegradable thermo-plastics.” All sources were limited to studies from the past 15 years written in English. And then I created samples with the selected binders and performed acoustic testing on them.	3.1.3
4)	What do people look for when choosing acoustic wall panels for their homes?	To find out how potential users would approach this project, I conducted surveys with potential users and interviews with manufacturers. The goal was to understand their priorities when buying acoustic panels for their homes. Whether it is affordability, eco-friendliness and/or aesthetics.	3.2.3
5)	What design features would make acoustic panels more attractive and practical to use?	I used the surveys to also get more information about the design requirements. This included finding out the preference of the people when it comes to customizable options, textures, styles and practical matters like installation. Comparing this information helped me ensure that the design meets user expectations.	3.2.4
6)	How big is the environmental impact of the new alternative compared to the traditional ones?	I used tools like The Big Climate Database (CONCITO, 2021) , IdematLight, and Idemat2024 (Sustainability Impact Metrics, 2024) to estimate the environmental impact. This included analyzing the carbon footprint from raw material sourcing to manufacturing and transport. By comparing the CO2 emissions of my product with traditional panels, I could highlight the environmental benefits of using agricultural waste.	3.1.5
7)	How feasible is it to manufacture the panels by existing machinery?	First, I researched the techniques and industry guidelines of producing similar products (particle board) and then I compared that with case studies that is very similar to this project in terms of the core material, the board made of corn cobs. This helped to identify challenges and assess whether the product is compatible with the current manufacturing methods.	3.1.4

Table 1: Methods of answering the research questions

The outcome of this research leads to further exploration. With the direction gained from the research, multiple prototypes will be created. The next step is the iterative process of creating an effective sound absorption panel. The goal is to find the best ratio of fibers and binder and select the most appropriate binder for this application. Benchmarking the existing solution and the prototypes based on the absorption values and carbon footprint will determine the positioning of the product on the market. Benchmarking products based on their performance and via surveying potential customers will help determine whether this new alternative product would be compared to or even preferred to the other market alternatives. Each iteration of the user research will be shaped to the end-user's needs and preferences.

2 Background

This paragraph reviews all the relevant theoretical information that is related to this project. It discusses the most important definitions which will play an important role in further research. Starting from the human perception of sound to laying down the basics of acoustic measurements and material properties.

2.1 Sound Theory:

2.2.1 Human perception of sound:

The following definitions are used for sound and noise.

Sound: The energy that is transferred through the air, creating small pressure changes that are detected by the ears. The more energy a soundwave has, the louder it will be (Federal Aviation Administration, 2022).

Noise: The unwanted sound that one listens to. Even sounds that can be pleasant at a certain volume can become annoying on a higher volume. So, in the recognition of noise, there is an objective physical component, and a subjective one that considers an individual's perception (Federal Aviation Administration, 2022).

The human ear is capable of hearing frequencies of sound between 20 Hz-20KHz (Errede, 2002). The following diagram shows the audible range of the human ear. The human auditory area is limited by the lower threshold of hearing and upper threshold of pain indicated in Figure 1. The threshold of the sensitivity of human hearing at each frequency is different. The human ear is most sensitive between 2000 and 5000 Hz. In this middle range our ability to detect the sound needs the smallest amount of sound intensity and the pain threshold stays around 120 dB.

In regards to the project, the two most typical areas in an interior living environment are speech and music (the most common noise sources). See in Figure 1 which shows the range of sounds most commonly appearing during the processing of human voice (Latinus & Belin, 2011). And as an exterior source of common noise pollution the road traffic noise is measured in Figure 2. Where the noise is generated by the engine, typically between the range of 50-100Hz and a rolling sound that reaches a maximum of 1000 Hz. A typical spectrum of noise of a light vehicle is shown in Figure 2 (Gjestland, 2008).

In Figure 1, the intensity of sound that the human ear can process has a dynamic range from 0dB (threshold) to 120-130 dB (Latinus & Belin, 2011) .Although anything above 90 dB can cause some damage to the ears and above120 dB it can cause irreversible damage to the ears (Latinus & Belin, 2011).

As a conclusion, the aim is to develop a sound absorption panel that has a high absorption value in the range of 50 Hz to around 10000 Hz with a focus on the 500Hz- 2000Hz range and has the ability to lower with 10 db the intensity of the sounds that are transmitted through the walls. Since the 10 dB intensity reduction perceived as half as loud as originally the noise sounded (Sound Sea, 2025).

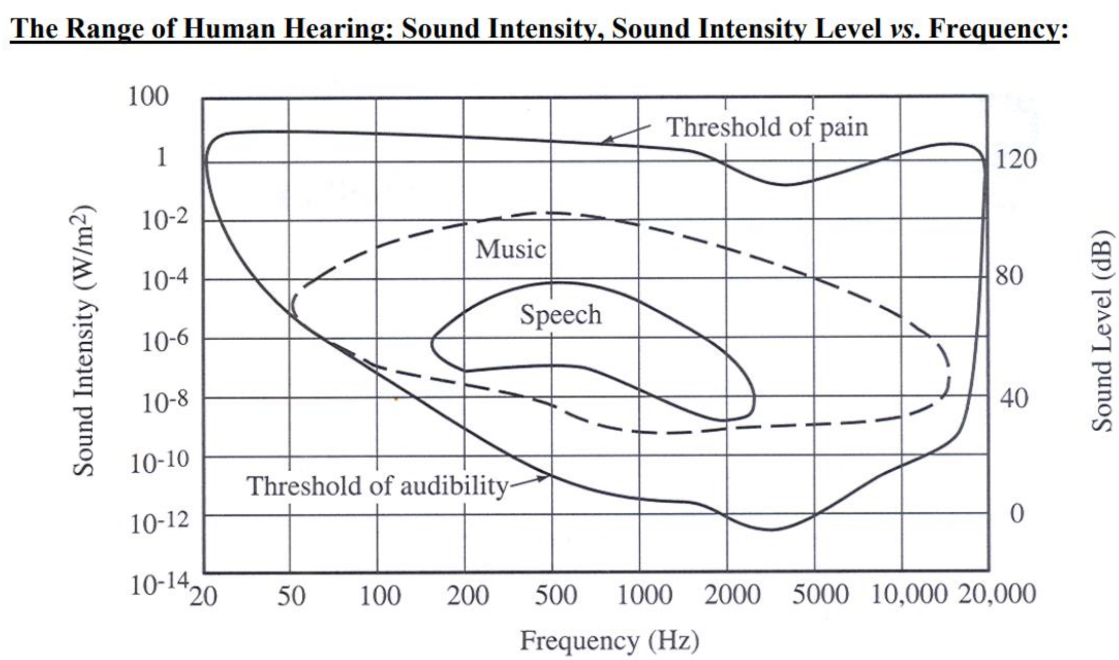


Figure 1: The human range of hearing (Vaisberg et al., 2017)

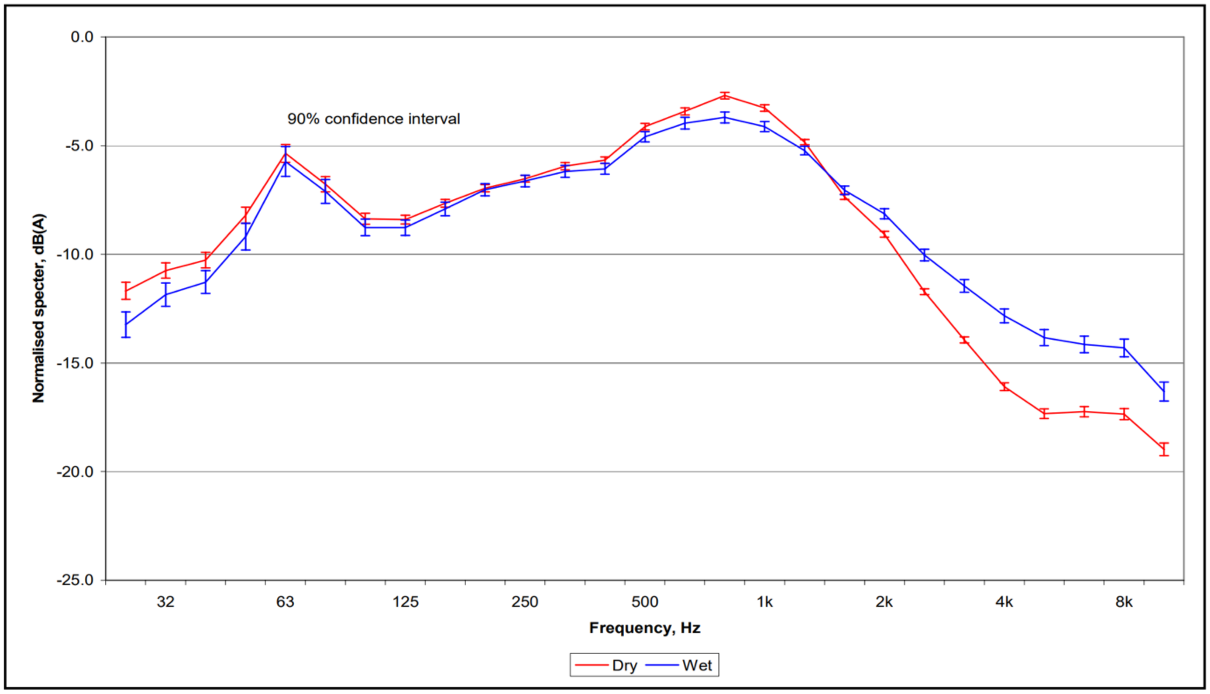


Figure 2: Common spectrum for road traffic noise (Gjestland, 2008)

2.1.1. Acoustics

To have a better understanding of the material properties, features and performance, we need to have a look into some basic terminologies.

Acoustics is the science that deals with the creation and transmission of sounds through solid or fluid materials and examines the effects of sound both non-living and living materials (Raichel & CUNY Graduate Center and School of Architecture, Urban Design and Landscape Design The City College of the City University of New York, n.d.). An acoustic signal can come from different sources, such as the movement of gasses, an object passing through fluids or the impact of two solids (Raichel & CUNY Graduate Center and School of Architecture, Urban Design and Landscape Design The City College of the City University of New York, n.d.).

When a sound wave hits the surface of an object, it gets partially reflected and partially absorbed. The rest passes through the material (transmission) (Li & Ren, 2011).

- Sound absorption: The sound absorption coefficient (α) is a measure which helps to evaluate the sound absorbing performance of a material. Mathematically it is the ratio between the energy that gets absorbed by the material and the energy that was impacting on the material. $\alpha = E_{abs}/E_0$. Where E_{abs} is the energy absorbed and E_0 is the starting amount of energy (Li & Ren, 2011). This value is in the range of 0-1 and does not have a unit. The following terms are important.
- Noise reduction coefficient (NRC) is a single number rating representing the average sound absorption coefficients (α) of a material at 125 Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000 Hz frequencies (Surfaces, 2024). This rating represents a simplified value of the percentage of the sound absorbed by a product. 1 represents 100% of the sound being absorbed. An NRC rating of 0.6 will absorb 60 % of the sound passing through (Snider, 2024).
- Sound reflection is the measurement of the reflected sound from a surface of an object. The reflection coefficient (R) measures the ratio of the reflected sound to the emitted sound. It is a unitless measure with a value between 0-1 (Deschamps & Dyson, 2002).
- Transmission coefficient (T) is a measurement of how much sound wave is passing through a material compared to the total amount that reaches it (Deschamps & Dyson, 2002). The formula to calculate transmission is $T = 1 - \alpha - R$ Where α is the absorption coefficient and R is the reflection coefficient. Which describe the ratio of sound waves that get absorbed or reflected.

2.2. Material properties that affect the acoustic properties

Generally, hard, smooth, and heavy materials are more suited for reflecting sound, while a loose, porous material will have a better absorbing power (Li & Ren, 2011). A material with high porosity will have a greater sound absorption effect compared to a denser material (Li & Ren, 2011) as the micropores help to dissipate the energy within the material. Although increasing the density of the same material can improve the absorption of the lower frequencies. The key is finding a balance between high and low-density materials to find a favourable solution for the application (Li & Ren, 2011). Also increasing the thickness of an absorbing material can improve the absorption of lower frequencies while it is not making significant change in the higher frequency range (Li & Ren, 2011).

The minimum requirement for a material to be called a sound absorbing material is to have an NRC value greater than 0.2. To find out if the corn stover can perform the minimum requirement and compete with the traditional alternatives materials multiple tests and configurations are performed.

3: Research phase

In this chapter the most important questions of the project are researched. Starting from material research to people and organizational questions. To finding answers to all relevant topics, the research is broken down into sub-research questions. The list, including the methods are shown in Chapter 1.4, Table 1. Chapter 3.1, (technological research) is concentrating on research related to the physical product and Chapter 3.2 is focusing on the people and organizational aspects.

3.1: Technological research

The research in this chapter is about discovering whether which materials and what technologies are suitable for creating an acoustic panel. This includes literature reviews, and acoustic testing to verify the results coming from the desk research.

3.1.1 Which types of agricultural waste have a good potential (based on their availability and acoustic performance) for being used as an acoustic panel?

To answer this question, the methods shown in Chapter 1.4 (Table 1 point 1) were used.

Only considering the European Union, there are 7 major agricultural waste types that are high in lignocellulosic mass, such as wheat, rape plant, corn, barley, sunflower, oat and rye plant. These produce a large quantity of unutilized organic waste (Searle et al., 2013).

Crop	Net availability of residues (million tons)
Wheat	48
Corn stover	21
Barley	22
Rapeseed	6

Sunflower	3
Oats	3
Rye	4

Table 2: The amount of unutilized crop waste in the EU (Searle et al., 2013)

From Table 2, we can see the three most abundant agricultural waste streams, which are wheat, maize and barley. The focus has been shifted to these materials. Upon further investigation, it turned out that the wheat and barley have only long fibrous structure (Kapoor et al., 2016a) while corn cobs (as large part of the maize waste) have a very porous microstructure (Kapoor et al., 2016a). Scanning a sample under electron microscope and energy dispersive spectroscopy showed that the chemical composition of the corn cob is very similar to the extruded polystyrene (XPS) or cork (Faustino et al., 2012). This implies that the corn cobs are more suitable for absorbing sound than the other two alternatives. Although when the particles are more compacted, and without the internal structure, the panel could not maintain high porosity for optimal sound absorption and mechanical strength.

Besides corn cobs lack nutrients to be used as feedstock for animals, and it is difficult to treat (Choi et al., 2022). So often it is considered an agricultural waste that is necessary to burn (Faustino et al., 2012). But the cobs contain the same fiber components as wood, so it seems to be suitable as a kind of building material (Choi et al., 2022).
Further research will focus on corn stover. Which means corn cobs, husks and stalks. The research will focus on optimizing the mixing ratio of these components to maximize the sound absorption value of the finished panels while they stay mechanically stable and safe as a non-load bearing construction material.

3.1.2 How well does the chosen material absorb sound compared to traditional acoustic materials?

To answer this question, the methods shown in Chapter 1.4 (Table 1 point 2) were used.

In the literature review there are three traditional types of materials being compared with corn cobs. Rockwool, PET felt, and Polyurethane foam. Table 3 shows the overview of the properties of the traditional materials that are compared to the corn cob panels.

Product name	Material category	Material type	Material thickness (cm)	NRC (noise absorption coefficient)	Global warming potential (CO_2-eq/ kg)	Health risk	Cost (€/m²)
Comfortboard 80 Rockwool	Mineral	rock wool	3.81	0.9	1.27	Skin and eye and respiratory irritation in contact with fibers	Approx.: (sales price) €17.27/m2
Cyatco PET Acoustic Panels Polyester	Fully synthetic	PET polyester	0.9	0.64	3.32	Concern is microplastic shredding	Approx.: (wholesale price) €5.79/m2
FOAM STOP ™ Polyurethane	Fully synthetic	PUR, flexform	3.5	0.82	3.18	Additional blowing agents and fire retardants can be harmful. Irritation of skin, eyes and respiratory system. Headaches and nausea	Approx.: (sales price) €61.3/m2
Corn cob board	Organic with synthetic binder	Corn cobs + wood glue	3	0.32	2.03- 6.37	N/A	N/A

Table 3: Overview of the example products used in this study (Sidharta et al., 2022), (Faustino et al., 2012) (GUANGZHOU CHUANGYA ACOUSTIC TECHNOLOGY CO., LTD., 2023), (Rockwool, 2022), (Acoustical Surfaces, 2024).

For more details about what these materials are, see Appendix 1. By reviewing and comparing the noise reduction capabilities of these materials, we get a better picture of what acoustic requirements the new product should meet.

Regarding corn cobs, the results of two scientific studies were used in this literature review.

In the first review, (A) “Corn Cob Absorption Rate As Acoustic Material” (Sidharta et al., 2022) The study was performed on unprocessed, dry corn cobs. A 3 cm diameter cylindrical prototype was made by gluing cobs together, an cutting them into shape. Then they were attached to a plywood board. Low and high frequency sound testing was performed using an impedance tube. Where the sound is travelling through the tube in the positive direction (from the speaker to the sample), towards the panel and 2 microphones are placed in front of the sample pieces that measure the reflection coming backwards from the negative direction. See more in Appendix 2.

In the second study, (B), Impact sound testing of corn cob particle board "(Faustino et al., 2012) the noise reduction capabilities of a 3 cm thick board were measured. Where a 21.75 dB impact noise reduction was achieved between two rooms (Faustino et al., 2012). Although the study claims this value is even higher (30dB) when the panel is placed on the floor of the emitting room (Faustino et al., 2012) (see more in Appendix 3).

Summarizing these data, we can compare the potential of the corn cobs as an acoustic absorber compared to the traditional alternatives.

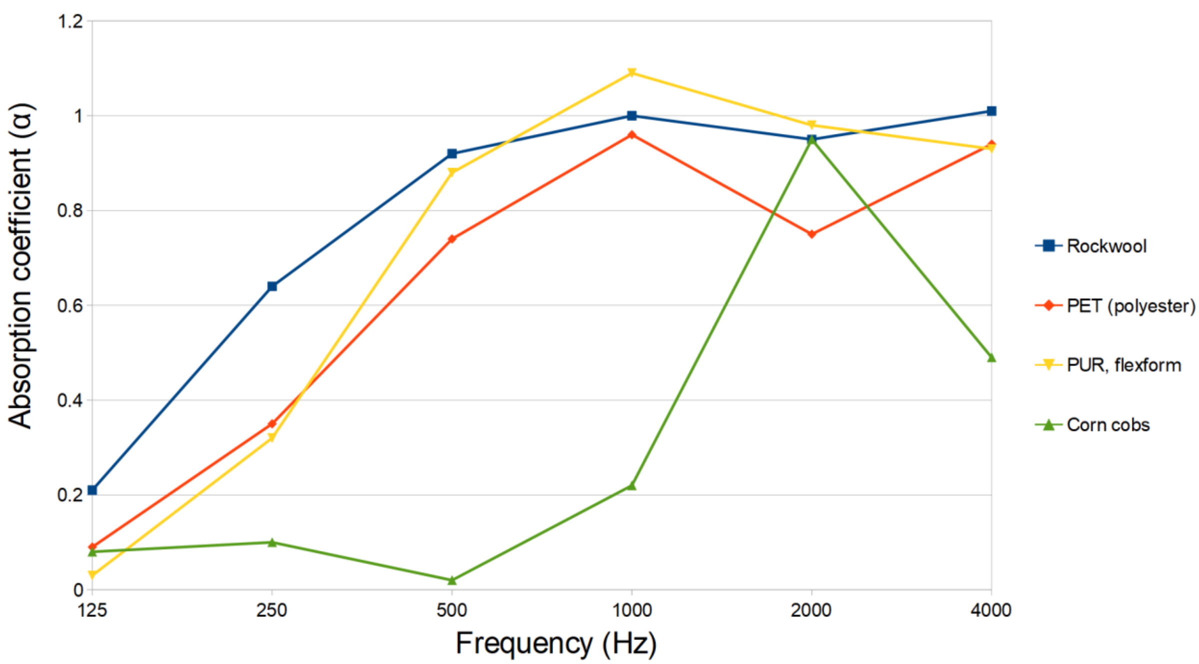


Figure 3: Sound absorption values of corn cob compared to the traditional materials

	Thickness (cm)	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	NRC

Rockwool	3.81	0.21	0.64	0.92	1	0.95	1.01	0.9
PET wool	0.9	0.09	0.35	0.74	0.96	0.75	0.94	0.64
Polyurethane foam	3.5	0.03	0.32	0.88	1.09	0.98	0.93	0.82
Corn cob board	3	0.08	0.10	0.02	0.22	0.95	0.49	0.32

Table 4: NRC values of corn cob compared to the traditional alternatives (Sidharta et al., 2022), (Faustino et al., 2012), (GUANGZHOU CHUANGYA ACOUSTIC TECHNOLOGY CO., LTD., 2023), (Rockwool, 2022), NOISE STOP POLYURETHANE FOAMS, n.d.)

Table 4 shows a comparison of the absorption values of the corn cobs compared to the traditional materials (the sound absorption values of the materials are referenced from the information provided by the companies). While in the lower frequencies the cobs underperformed compared to the other alternatives, in the higher frequencies (approximately around 2000 Hz) it shows some positive results. The limitations of the study were the fact that unprocessed cobs were used for testing, leaving large air gaps. But despite this fact, the result of the NRC value being around 0.32 was found to be positive (Sidharta et al., 2022). In the study of Sidharta et al., it is stated that, with further testing and optimization, it may be possible to improve the characteristics of a corn cob-based panel.

When it comes to improving the acoustical experience of a room, we need to consider also the incoming sounds that come from external sources. The ability of a material transmitting sound is described with the sound transmission class (STC) that is based on the intensity of sound (in decibels) passing through a wall.

According to the second study (Faustino et al., 2012) the sound transmission value of the corn cob board is relatively close to the rockwool. Although the transmission is also heavily dependent on the wall structure (“ROCKWOOL Acoustic Wall Assemblies Catalog,” 2023), so these values might differ based on which type of wall it is applied to. Also, when it comes to rockwool its primary function is thermal insulation, but solely for improving the acoustic of a room from the mid to high frequencies, the addition of the corn cob panel can be more space saving rather than adding additional rockwool to the walls.

Material:	NRC (absorption)	STC (sound transmission class)	Notes

Comfortboard 80 from Rockwool	0.9	Approx.: 35 dB	Value depending on the wall structure
Cyatco 9mm PET felt	0.64	N/A	
FOAM STOP ™ Polyurethane	0.82	Approx.: 10 dB	The main function is absorbing echoes not to block transmissions
Corncob test A	0.32	N/A	
Corncob test B	N/A	Approx.: 21.75 - 30 dB	

Table 5: Summary of sound absorption and sound transmission class values found in the different studies and resources (ROCKWOOL, 2023), (Green Insulation Group, 2024), (Faustino et al., 2012).

While the studies about the corn cobs need further research, it shows potential in both absorption and the reduction of the transmitted sound. With the optimization of the materials (cobs, husk, stalk and binder) and manufacturing method it appears to be possible to create an effective acoustic panel. However further experiments are needed to prove this concept, creating an adequate product.

3.1.3 Which binder alternatives are suitable for making an effective sound absorption panel based on performance and end-of-life considerations?

To answer this question, the methods shown in Chapter 1.4 (Table 1 point 3) were used.

When it comes to producing the corn cob board it is important to consider the type of binder that will be used in the process as it will define the manufacturing process and the end-of-life. It would be an added value to the product if it does not contain harmful substances like formaldehydes and is recyclable at the end of life it could be recyclable, or it will not emit harmful gases like methane to the environment during degradation. Multiple scientific publications (Basu et al., 2021),(Cano-Barrita & León-Martínez, 2016) (Vandi et al., 2018), (Reddy et al., 2003), (Bugnicourt et al., 2014), (Vandi et al., 2018b), (Song et al., 2022), (Trinh et al., 2021), (Ingrid Calvez et al., 2024) , (Mohamed Hasanin et al., 2022) , (Manjula Puttaswamy et al., 2017) , (Russell Li et al., 2018), (Amélie Tribot

et al., 2018), (Samira Moradi et al., 2020), (Gabriela Balea (Paul) et al., 2022) , and more have been reviewed about the use of biodegradable binder alternatives as potential options and a few have been selected for testing. This includes materials that are derived from natural sources and vary in terms of mechanical properties. This can help to determine whether it is feasible to use a biodegradable option. Also, as a synthetic alternative PVA wood glue was used for the comparison.
S
Sample creation:

The research was based on the following materials:

- Cellulose acetate
- Dealkaline lignin
- PLA
- PHA
- PBAT
- Colophony
- Bone glue
- Wood glue (PVA)

During the research, it has been discovered that plastics and resins can be created from the cellulose and lignin parts from lignocellulosic mass. Cellulose acetate is a modified natural polymer (Samiris Côcco Teixeira et al., 2023). It is a fairly hard plastic material type that is currently used for smaller items such as glass frames and accessories (Jiao Tan et al., 2023). At disposal, natural biodegradation can be achieved in microbial enzyme rich soil, (Oskar Haske-Cornelius et al., 2017). It can be dissolved in common solvents asl well like tetrahydrofuran, methyl acetate, and acetone. Tetrahydrofuran has a low potential for bioaccumulation but it is inherently biodegradable (Fowles et al., 2013), methyl acetate is readily biodegradable and not considered to have a harming effect on the environment (Fowles et al., 2013), acetone (can be cause cell membrane damage to plants when exposed to large quantities although it naturally degrades in days (Department of Climate Change, Energy,the Environment and Water, Australia, 2022) for re-use.

Lignin, which is a natural polymer that holds the cell membranes of the plants together, is a byproduct of paper making and has a great potential in many areas creating bio-degradable resin out of it (Gabriela Balea (Paul) et al., 2022).

Biodegradable thermoplastic options seemed an alternative to test. One is the commonly used PLA (polylactic acid), which can degrade the most effectively in an enzyme rich composting environment under 58 ± 2 °C (Kale et al., 2007b; Kalita et al., 2019) in a composting environment which first breaks the carbonyl groups into carboxyl and hydroxyl groups which can be broken into CO_2 and water by the microorganisms in the compost (Kalita et al., 2021). Less common biodegradable thermoplastics such as PHA which is made by microorganisms and has the ability to degrade at 60 °C in a microorganism rich environment, into water, CO2 and methane (Zwawi, 2021). And the PBAT which is a bio-based polyester type thermoplastic that has similar biodegradability as the PLA (Fu et al., 2020).

From the natural sources, colophony, made of the resin of pine trees, was reviewed. It has great strength and adhesive capabilities, but it is highly toxic to the waters and aquatic life (Basu et al., 2021). From the end-of-life perspective it would be difficult to handle and most likely pose a danger to the environment. As a result, it was discarded as an idea. Regarding the bone glue which is made from animal bones (which could raise ethical concerns), the problem is mainly that it has a melting point at 60 °C and over time with temperature fluctuations the material can lose bonding strength. And it is sensitive to moisture which could lead to swelling in the panel and overall deterioration of the end-product.

All these materials need to be processed with heat. To have another alternative, that has a less energy intensive processing, the common PVA wood glue was selected. Even though it is not bio-degradable, it can give valuable insight into the production of the samples and overall efficiency of the acoustic insulation properties of the acoustic panels.

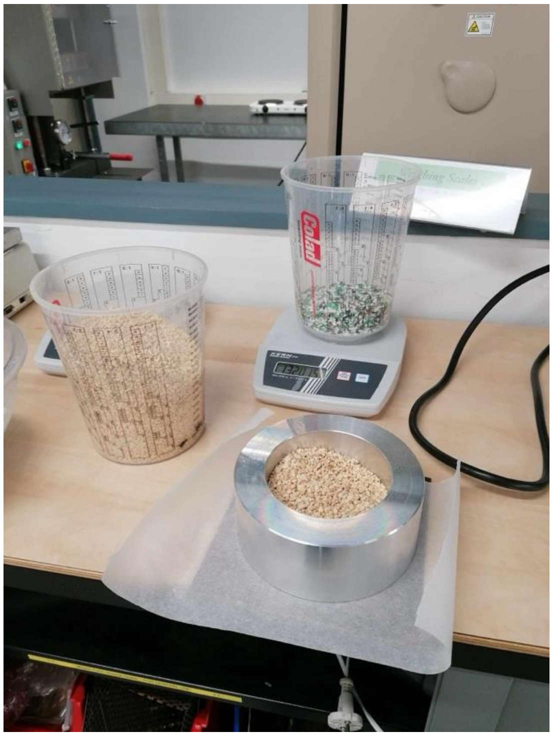


Figure 4: Measurement of corn cobs and PLA

To simplify the testing, only the dealkaline lignin, cellulose acetate, PLA and wood glue samples will be tested as the melting temperature and mechanical properties of the PHA and PBAT are very similar to PLA.

This project is focusing on the absorption quality of the material only due to the limitations of the measuring equipment. The measuring tool, the impedance tube used for testing gives accurate information only about the sound absorption of the material. The different prototypes were created to examine how the different kinds and proportions of materials behave.

The samples are designed to fit to an Impedance tube (testing machine) (see Appendix 4 Figure 70 and 71) which will examine the sound absorption properties of samples. The samples are 10 cm diameter disks with varying widths. For finding out which binder in which percentage can produce the most solid and most sound absorbing panels, 4 batches of samples were created.

The first set of samples includes five samples where the percentage of binder content was examined. Corn cobs with PLA were mixed in different ratios to find out what is the best ratio for the acoustic purposes but on the other hand creating a durable panel. To find out how much material each sample needs, a calculation was made using desired volume, and the average density of the materials see Appendix 5.

Table 6 shows used materials in grams and the result of how thick the samples become.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Material proportions Cobs + PLA	50-50 m-%	60-40 m-%	70-30 m-%	80-20 m-%	90-10 m-%
Weight cobs	112.16 g	128.81 g	150.3 g	171.75 g	193.22 g
Weight PLA	112.16 g	72.998 g	64.43 g	42.94 g	21.47 g
Thickness of sample	2.5 cm	2.55cm	2.6 cm	2.65 cm	2.8 cm

Table 6: Corn cob and PLA processing

Figure 5: First set of samples with varying PLA content

The second set of samples included two alternative types of binders, such as lignin and cellulose acetate. The percentage of corn cobs and binder were set to be 70-30, 70% being the corn cobs and 30% being the binder. The exact manufacturing method is shown in more detail in Appendix 6.

A summary of the materials used to create the samples can be found in Table 7.

	Sample 6	Sample 7
Material proportions	Cobs- dealkaline lignin 70-30 %	Cobs – cellulose acetate 70-30%
Weight cobs	**59.86 g**	**59.04 g**
Weight binder	**25.66** g	**25.3 g**

Thickness of sample	0.9 cm	1cm
Processing temperature	180 °C	160 °C

Table 7: Corn cob other and binders

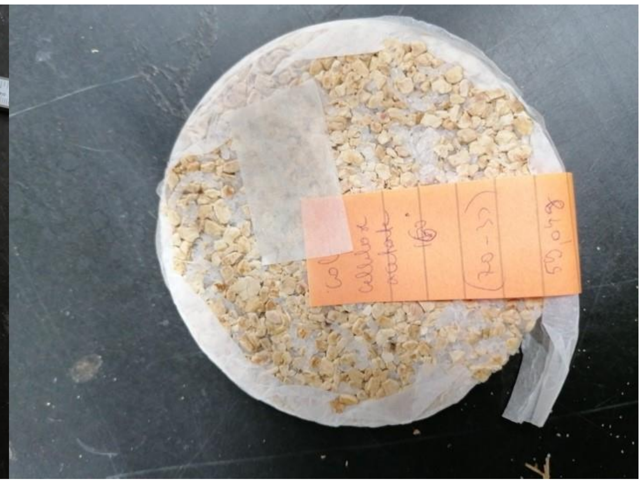


Figure 6: Corn cob and dealkali lignin. Figure 3: Corn cob and cellulose acetate

The samples shown in Figure 6, did not meet the requirements of a stable board. The lignin although melted between the particles, acts as a weak brittle bond, while the cellulose acetate did not melt at the given temperature. These samples then were discarded from further research.

In the third set of samples the ratio between corn cobs and corn stalks was examined. Dry corn stalks were ground up to a particle size of maximum 5mm.

Figure 7: The raw dried corn stalk

In Table 8 the summary of the samples can be found. In Appendix 7 a detailed calculation can be found about the materials

	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12
Material weight ratio Corn cobs + corn stalk + PLA	70-0-30 wt-%	52.5-18.67-30 wt-%	35-35-30 wt-%	18.67-52.5-30 wt-%	0-70-30 wt-%
Weight cobs	**58.87**	**47.18**	**33.47**	**17.74**	**n/a**
Weight stalks	**n/a**	**15.73**	**33.47**	**53.2467**	**30**
Weight binder	**25.24**	**26.96**	**28.7**	**30.42**	**32.15**
Thickness of sample	0.92 cm	1.11cm	1.15 cm	1.15 cm	1.2 cm

Table 8: Corn cob, corn stalk and PLA used for the different samples

Figure 8: Finished corn cob, corn stalk and PLA samples

Lastly, a more experimental approach was taken. The corn cobs were mixed with wood glue in a ratio of 85-15 %. For this process, a cold pressing technique was selected.

The first one was a mix of 200 g of corn cobs and 35.5 g of wood glue. But it did not fit the mold. After fitting as much material into the mold as possible, the mixture was pressed under 13.8 MPa pressure. After 30 minutes of curing, the sample was removed and weighted. The result was around 83% of the original mass measurement that was calculated. Surprisingly the sample was thicker than anticipated. It got compressed to a 3.5 cm disk. The adhesion of the 15% glue did not seem sufficient.

Figure 9: 3.5 cm corn cob and wood glue (15%)

Therefore, the second (corn cob and wood glue) sample was made to have 1 cm thickness. 60g of cobs and 14g of glue was used (23% wood glue) for better adhesion. The curing time was 30 minutes and only hand clamping was used, meaning that negligible force was applied.

Figure 10: 1 cm corn cob and wood glue (23%)

The acoustic measurement:

To find out which binder option is the most suitable in terms of sound absorption, an acoustic test needs to be performed on the samples.

The test was performed in a B&K4206 impedance tube. This machine determines the sound absorption coefficient and surface impedance by making measurements in accordance with ISO 10534-2 and ASTM E1050 –12 standards.

The machine was set up to measure the absorption between 0-1600 kHz. See Appendix 8 and 16.

Figure 7 shows the sound absorption of the 1st batch of samples. The straight blue line is indicating the average behavior of a porous material. Looking at the results, the version with 90-10 ratio (cobs-PLA) performed the best. (For detailed results see Appendix 8)

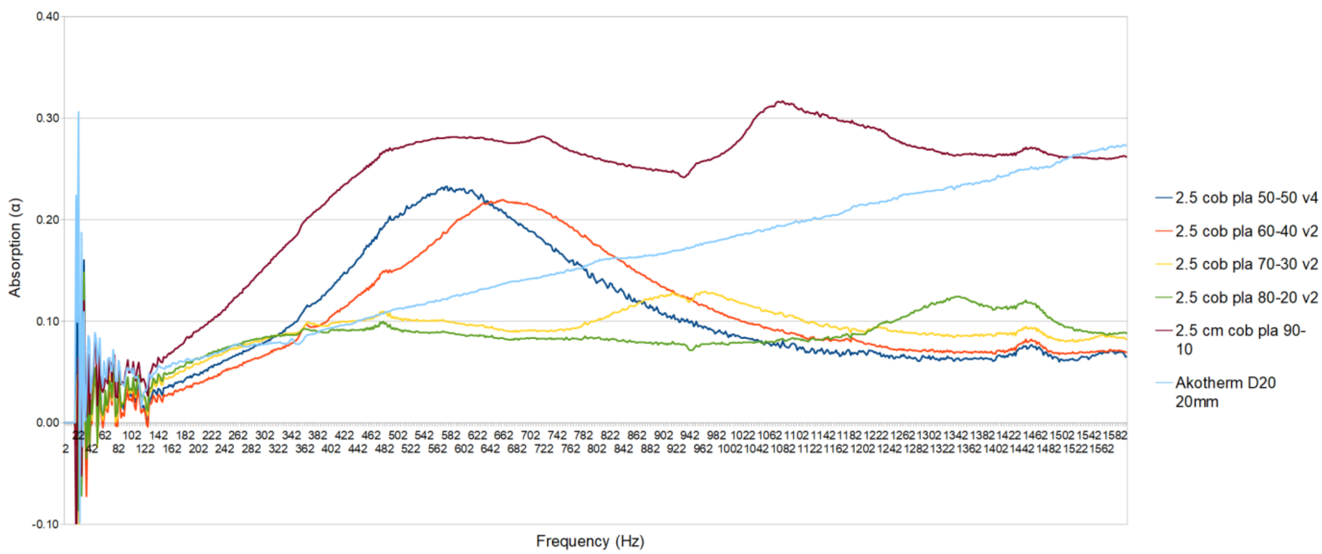


Figure 11: Sound absorption values of the 2.5 cm wide batch

The samples made with PLA and wood glue were used for the study. As the result shows the light blue line (version with wood glue) indicates high performance at the higher frequencies, and the version with only corn cob and PLA was the closest to the measurement of the example (Akotherm D20 20mm) provided by the testing machine as a baseline for how a good sound absorption material behaves

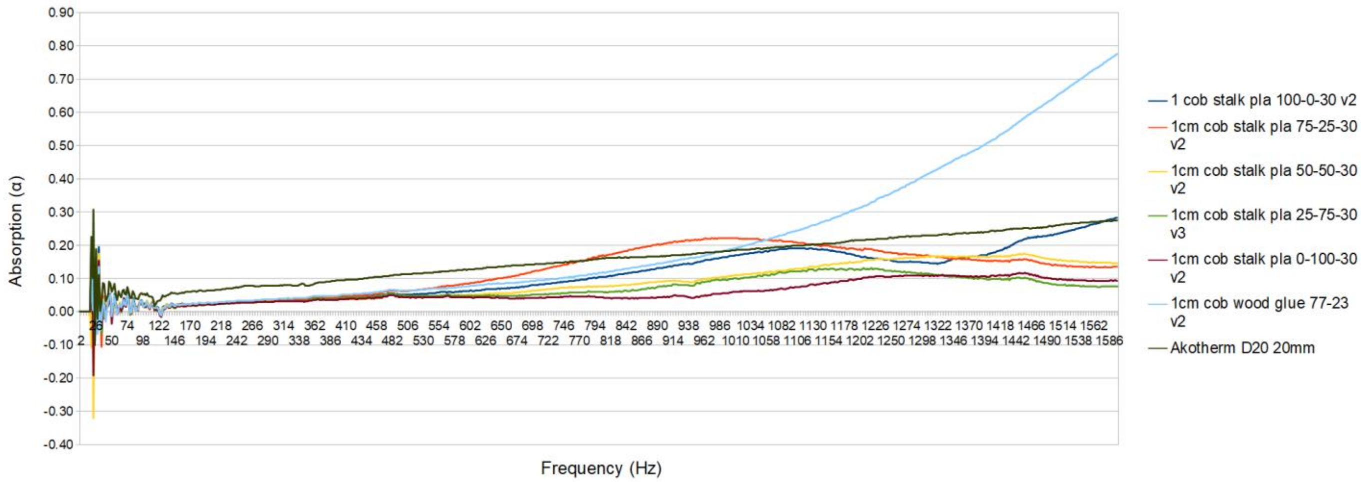


Figure 12: Sound absorption values of the 1 cm wide batch

In the case of sound absorption, the distance that the sound wave travels in the material matters. So, this is not only relating to the thickness of the materials but also to the porosity of it. As the sound wave bounces in the air gaps, it travels a longer distance. During this travel the sound energy is dissipated by thermal loss caused by the friction of air molecules with the pores (Cao et al., 2018).

But to have a better understanding if the material behaves as expected and showing high absorption capabilities, a comparison with thicker materials, the 3.5 cm wood glue- cob mix was (blue line) measured against the example measurement Akotherm D20 40 mm (see red line). Although errors can be accommodated in the reading of these measurements, the sample shows a similar behavior to the example material, which is very positive for the project.

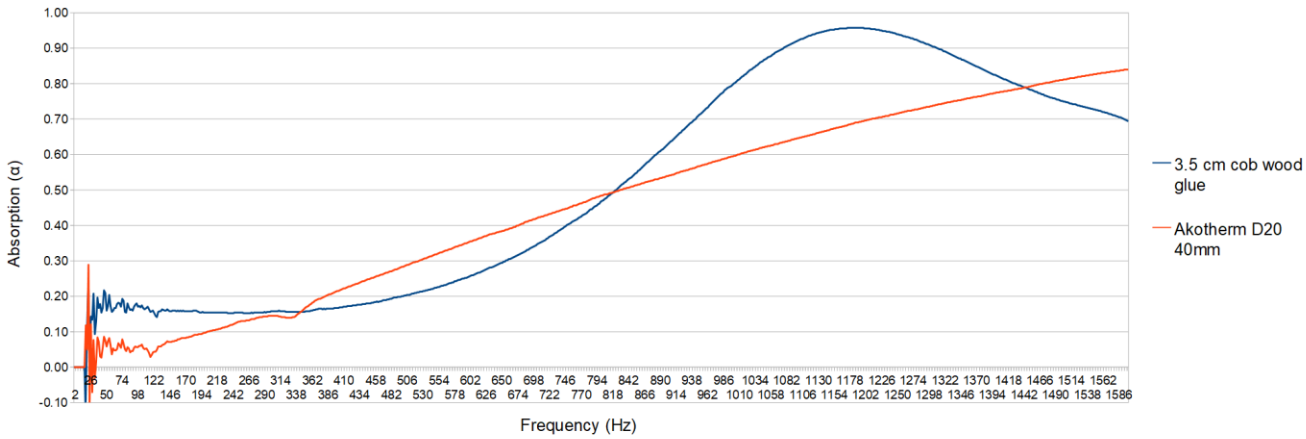


Figure 13: Sound absorption values of the 3.5 cm wide wood glue-cob composite version

The results show that the porosity of the panel needs to be maintained for having good sound absorption properties. A relatively good result came from the version with 10% PLA and corn cob mix. Although strong physical properties cannot be achieved with PLA using only 10% as it is not a sufficient amount to fill the gaps between the granules like fibers of the cobs and act as a reinforcement. Although this version showed the highest sound absorption result from the heat pressed samples, precisely because there were still pores within the material. On the other hand, even improved acoustic properties can be seen in the mix of cobs and wood glue with cold processing. It shows great potential for further experimentation. Seemingly it has good bonding strength and in all measured width (1cm thick samples (2), around and 3.5 cm versions) this version got higher result. Likely due to the cobs not compressed as much as with the hot pressing, the more porous microstructure could be maintained, and a promising sound absorption result was generated in the range of 1-1600 Hz.

Conclusion

The main objective, finding the highest performing variation, the wood glue-based composite outperformed all the other versions. The cold pressing helps to pack the granules tightly for the glue to bind the particles together but at the same time it maintains the porosity of material. The 1 cm version outperformed the example material that has 2 cm width, and the 3.5 cm version gave a relatively good result compared to the 4 cm wide example material. This means that the samples made out of corn cobs and wood glue seem to achieve better sound absorption result compared to its thickness than the baseline material.

From the project's perspective to improve the internal acoustics of a room but also block the incoming sounds from external sources, it is worth exploring a multi layered product. Where a porous layer and a dense layer of materials are stuck together, forming one panel. Further tests will determine the validity of this ideation.

The wood glue gave an interesting alternative for the first measurements, but further investigation is needed in binders that can spread evenly as a coating on the surface of the cob particles and do not need heat for binding.

3.1.4 How feasible is it to manufacture the panels by existing machinery?

When it comes to designing something that is made of new types of materials, it is important to assess whether it is feasible to produce. To find out whether this acoustic board project can be accomplished, the production of similar products and research project will be analyzed.

First of all, the product needs to be categorized to be able to relate it to other products. The idea is that corn cob particles are bound together with a binder to form a special acoustic panel. And according to the US Environmental Protection agency, the definition of the particle board is defined as a panel product made from lignocellulosic materials in the form of particles, that are combined with resin or other suitable binder and bonded under heat and pressure (U.S. Environmental Protection Agency, 2002). So, the foundation product concept is a special particle board.

Common wood-based particle boards go through several steps during the manufacturing process (see Figure 14). First, the raw material, primarily wood particles, need to be collected, and then screened and sorted by size to ensure uniformity in the material. Then the drying process follows where the moisture content of the particles needs to be reduced to 2-8%. For this, commonly rotary dryers are used. Then the dried particles are blended with resin. After that the mixture is shaped into a form using a forming machine and with hot pressing the resin is activated to bon the wood fibers together into a solid panel. Finally, the boards need to cool down and can be sent to post processing, like sanding and trimming to size (U.S. Environmental Protection Agency, 2002).

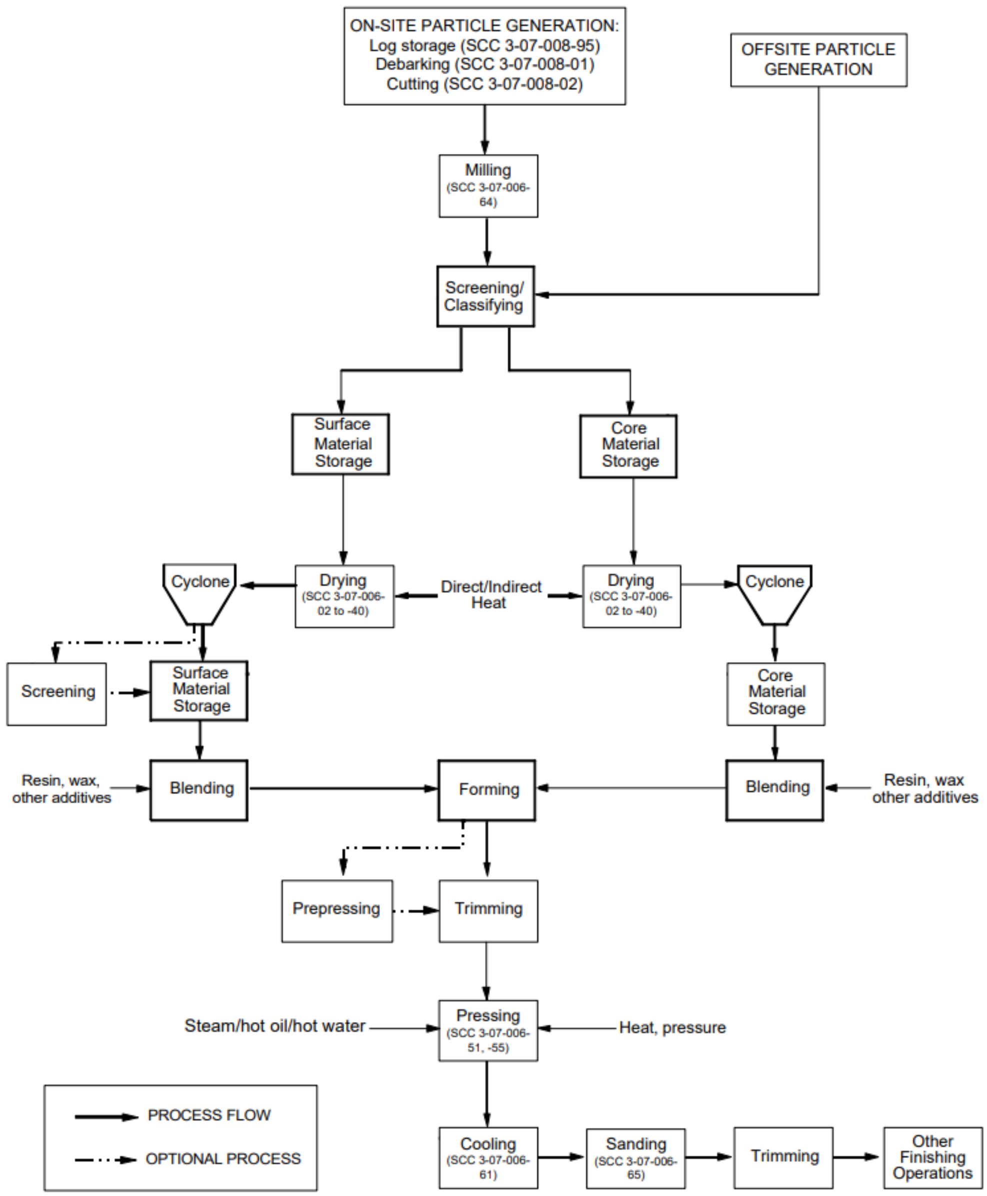


Figure 14: Process flow diagram for particleboard manufacturing (U.S. Environmental Protection Agency, 2002).

Figure 15 summarizes the production of a panel made of particles and heat reactive resin. To find out how feasible it is to make the acoustic board, the process will be compared with an experimental study (Abetie, 2021), where the particle board is made of corn cobs, starch-based adhesive and wood glue (Abetie, 2021). According to the researcher, the process goes as follows: The corn cobs are collected and sun dried to reduce the water content below 4.5%. After that, it is ground up to particles to 1 to 2 mm particle sizes and then sorted by size. Then, the particles are mixed with the modified starch adhesive and wood glue in a ratio of approximately 4.5:1:1. Next, the mixture is poured into a mold and pressed in it, using a hydraulic press. After pressing the board is allowed to cure and then removed from the mold, it is let to dry completely and sent for post processing (Abetie, 2021).

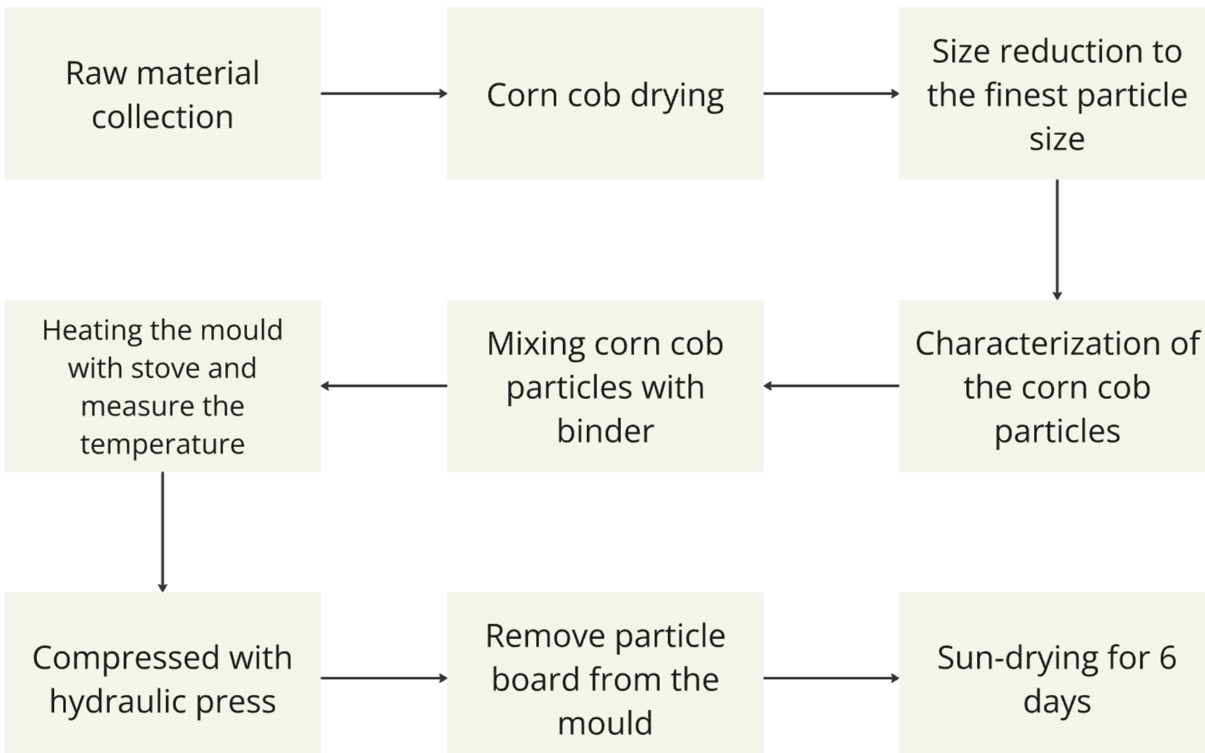


Figure 15: Experimental flow sheet of the corn cob particle board production (Abetie, 2021).

Comparing the experimental study made with the mixture of corn cobs and wood glue, with the general process of particle board production, it can be concluded that there is no need for extra, or new equipment to produce the base panel compared to a traditional particle board. There is not much difference in the processes. Only the processing temperature and time varies, which completely depends on the binder used in the process. Even though it needs to be established whether the acoustic board is going to be made with heat reactive resin or water-soluble glue, it is safe to say that it is feasible to make the final product.

3.1.5 How big is the environmental impact of the new alternative compared to the traditional ones?

To answer this question, the methods shown in Chapter 1.4 (Table 1 point 6) were used.

To have a better understanding of how the different products affect the environment, first the life cycle assessment of the rockwool by Flumroc, PET felt acoustic panels called Archisonic by Impact Acoustic, and polyurethane panels are being reviewed. Then a comparison can be made with a study analyzing the impact of a corn cob-based particle board as a reference for this project. This comparison can serve as a guide for further optimization of the new acoustic panel to minimize the environmental impact of the final product.

For an easier comparison, the Global Warming Potential (GWP) will be examined in each material.

The functional unit of this study is the material needed for 1 m^2 area to achieve 0.35 NRC value.

- The volume required for achieving 0.35 NRC value, 0.025 m^3 material is needed. The density of the rock wool is around 40 kg/m^3 therefore 1 kg of material is needed to achieve this value. For this reason, the LCA made by the ESU-services can be used as a reference as the reference unit of this study equals with the impact of 1 kg of rock wool.
  The reference unit is 1 kg of packed rock wool at the plant. The study includes the steps from the production, the infrastructure, the packaging and transportation and the waste streams. Now they are not producing directly from the basalt and dolomite pieces, but they are sourcing briquettes as the raw material and then process it into its final form.

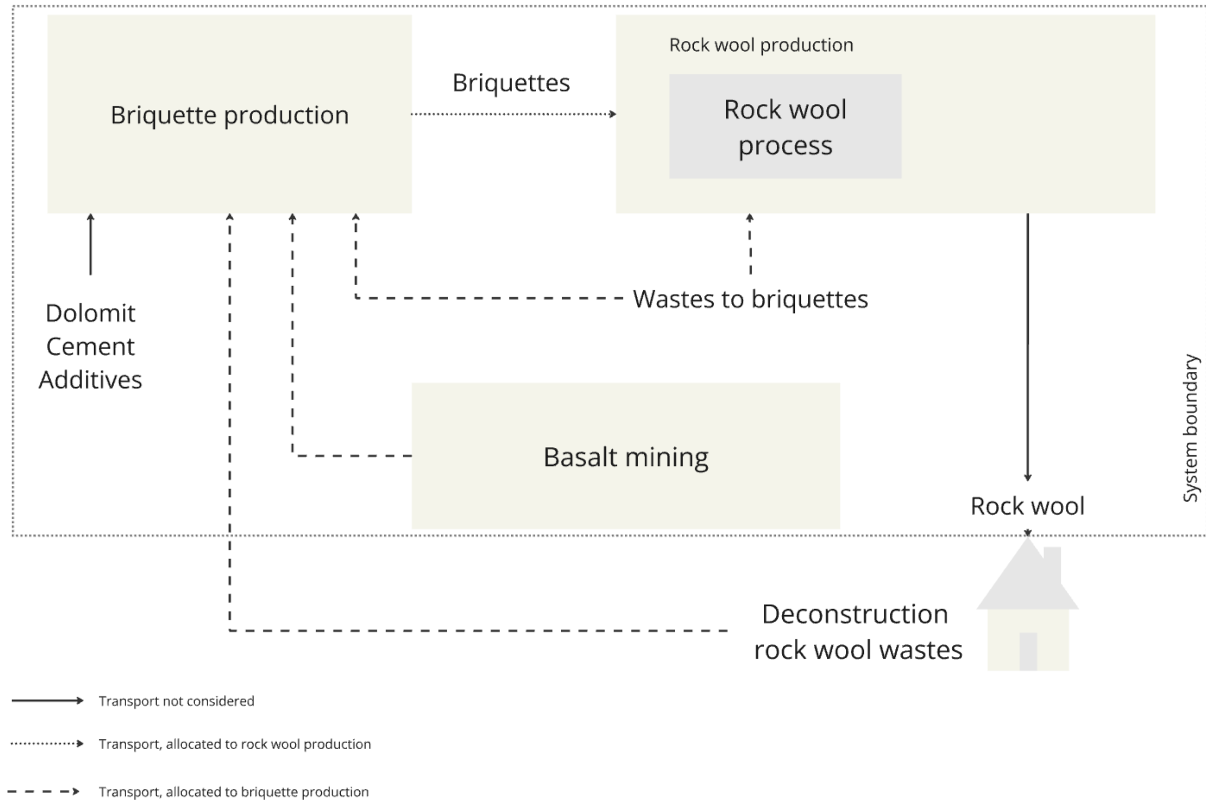


Figure 16: Basic schematic visual of the material flows between basalt mining, briquette production and rock wool production (Flury & Frischknecht, 2012).

The production of the rockwool itself is the greatest contributor to the overall greenhouse gas emissions the product generates in its life cycle. The total production accounts for 60% of the emissions, which is equal to 1.03 kg CO2-eq (carbon dioxide emissions). Including the sourcing of other materials needed (like coal for burning) and the transportation, the rockwool generates 1.68 kg CO2-eq/kg emissions (Flury & Frischknecht, 2012).

- ARCHISONIC® Felt is an acoustic absorber, which comes in two thicknesses. One in a 12 mm and a 24 mm version. The company claims that they are using recycled plastic, making it more environmentally friendly (Impact Acoustic, n.d.). But the life cycle assessment provided by Impact acoustic can clarify these claims (SRF testing and certification (Changzhou) Co., Ltd., 2022).

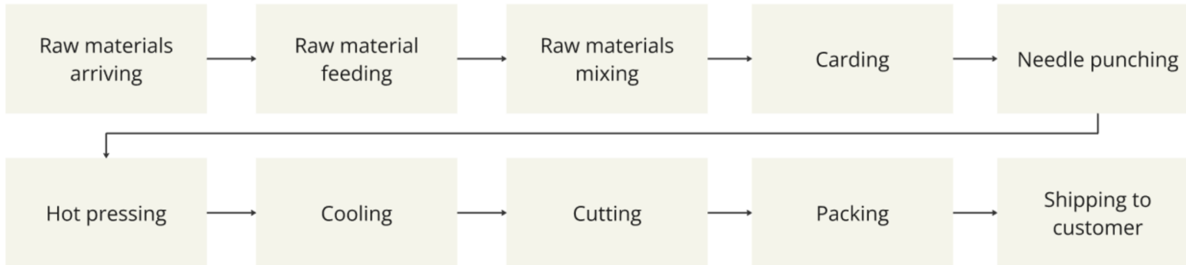


Figure 17: Production flow of felt production

The production takes place in China, where they transport the goods oversees by cargo ships to Europe, North America and Japan.
The 12 mm thickness panels come in from 2.4 to 4 kg/m^2 weight, and with an NRC value of 0.45. It can be assumed that with thinner panels this value would change. Approximately a 9 mm thick panel would weigh 3 kg/m^2
(SRF testing and certification (Changzhou) Co., Ltd., 2022).

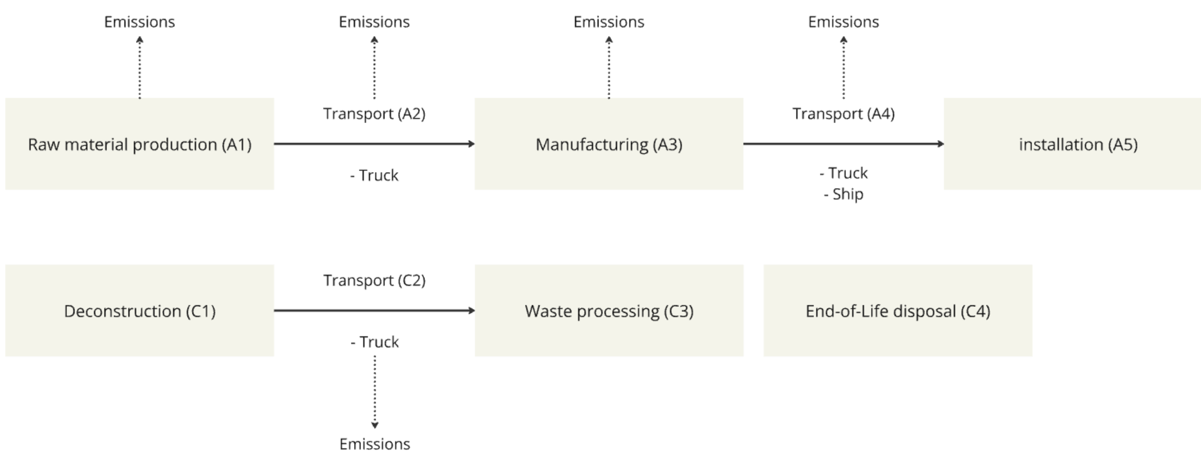


Figure 18: System boundary of (SRF testing and certification (Changzhou) Co., Ltd., 2022).

The schematic drawing represents the steps where the emissions occur (see Figure 18). And from an end-of-life perspective, it is estimated that 26.3% of the panels go the recycling, 61.2% goes to landfill, and 12.5% goes to incineration (SRF testing and certification (Changzhou) Co., Ltd., 2022).

Using the data from the EU impact assessment result, (SRF testing and certification (Changzhou) Co., Ltd., 2022) it can be calculated that the 3 kg material was calculated (see Appendix 9) and it is approximately between 10.7 CO_2 eq and 17.76 kg CO_2 eq.

- And as a final example from the traditional variations, a Life Cycle Assessment of Polyurethane Foams from Polyols Obtained through Chemical Recycling was reviewed (Marson et al., 2021) The LCA study refers to 1 kg of foam when analyzing the results. The required volume to achieve 0.35 NRC value is approximately 20 mm thick panel. The density is approximately 30kg/ m^3 so roughly for 1 m2 area 0.6 kg of material is needed.
-

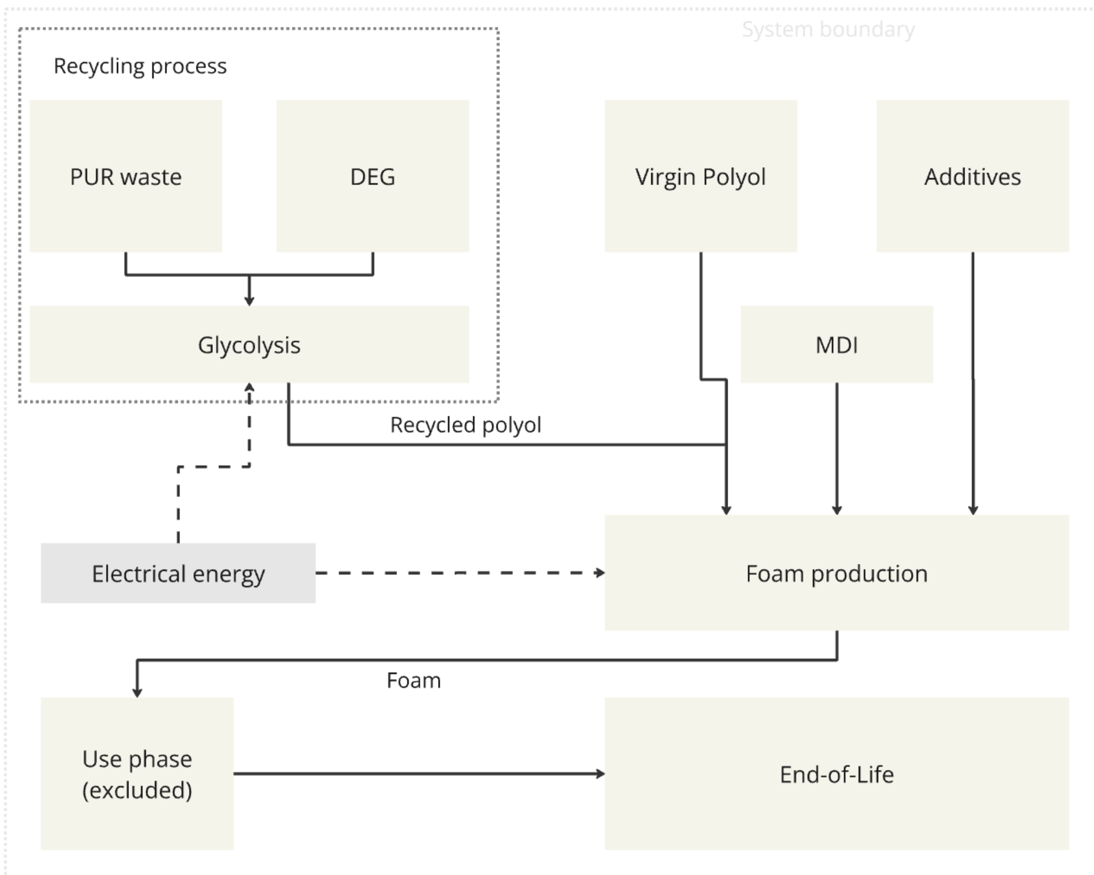


Figure 19: Production flow of polyurethane foam from partially recycled sources (Marson et al., 2021)

In the study the system boundary explains the whole process of creating the polyurethane foam from the recycled material till the disposal. The study gives a detailed explanation of all the quantities of materials and energy used in the process giving a comprehensive overview of polyurethane foam production. Using the data from the study (Marson et al., 2021) approximately 3.9 kg CO_2 eq is generated until the end-of-life of the product.

- From the study of "Thermal performance and life cycle assessment of corn cob particleboards" (Ramos et al., 2021) we can get an idea of the environmental impact of the new product. The study examines two scenarios. One with a binder referred to as Fabricol agglutinative 222 (FAG222) and the other one with PVA glue (Ramos et al., 2021). According to this study, the functional unit of the study refers to amount of materials used to create a panel with 1 m^2 area. While the study is about the investigating the thermal performance of a corn cob-based particle board, but it includes the different stages from the production to disposal, including two disposal scenarios (landfill or incineration) which are applicable for the current project (see table 9) (Ramos et al., 2021).

Process	Elements	Unit	Cob + FAG222	Cob + PVA
-	Corn cob	kg	26.2	13.31
-	Agglutinative	kg	4.62	4.99
-	Thickness	cm	8.8	5.2
Energy	Energy consumed	MJ	46.2	23.5
Production	Mixer	MJ	1.76	1.04
Transport	Diesel	kg	0.097	0.0493
	Distance	km	100	100
Incineration	Energy produced	MJ	0.0198	0.010
	Auxiliary materials	kg	-	-
Landfill	Fuel	kg	0.078	0.0399
	Cover system	kg	0.026	0.0133

Table 9: Inventory data for the LCA study (Ramos et al., 2021)

The study shows in detail the values of the global warming potential in each phase of the corn cob particle board (see more in Appendix 10). With the information of the cob board sample created in this project and the available information from the LCA study (Ramos et al., 2021), It can be calculated that with incineration and landfill options how much CO_2 gets generated. See Table 10.

Bind	Landfill (kg CO_2 eq)	Incineration (kg CO_2 eq)

er		
FAG222	36.96	5.32
PVA	37.50	116.03

Table 10: Amount of CO_2 generated by the disposal of a 1 m^2 corn cob panel (Ramos et al., 2021)

The study concludes that the corn cob particle boards have the potential to be used as a sustainable construction material (Ramos et al., 2021). While the aim of the study was to find the highest thermal performing material, which is the cob board mixed with the PVA, there is no information regarding the acoustic performance of the variations. So, the options are open for further research whether the FAG222 or the PVA glue board perform better. Which could give us a more conclusive idea about the emissions or trade off-s that the project will have.

As a conclusion, we can see from Table 10, that the impact of the corn cob board highly depends on the use of the binder. The cob board could have potentially smaller environmental impact compared to the synthetic felt materials. Although further investigation is needed for more accurate comparison. Also, it is worth investigating whether with the use of a biodegradable binder it would be possible to gain back any sort of raw material that could be used for new products instead of disposal.

Product	Version	Emission (kg/CO_2 eq)		
		Incineration	Landfill	Not considered
Rockwool	-	-	-	1.68
ARCHISONIC® Felt	-	-	-	17.8
Polyurethane Foams	-	-	-	3.9
Corn cob board	FAG222	36.96	5.32	-
	PVA	37.50	116.03	-

Table 11: Summary of the emissions of the materials (Changzhou) Co., Ltd., 2022), (Ramos et al., 2021), (Marson et al., 2021), (Flury & Frischknecht, 2012)

From this summary it can be suggested that the cob when incinerated has the lowest CO_2 emission, and the impact of the final product will depend heavily on the impact of the type of binder used. With further research it can be evaluated what can happen with the product at the end-of-life. Whether it can be recycled or disposed of in a landfill or incinerated and used to generate electricity.

3.2 Research about people and organizational questions

In this chapter, the question related to the stakeholders and the needs of the stakeholders are discussed. First the most important stakeholders and their needs are identified. Then the current markets and opportunities are discovered.

3.2.1 Stakeholder analysis

Mind map:

With the first mind map (see Figure 20), the most critical questions have been collected, for further exploration. To understand the needs of the customers, we need to be asking the right questions first.

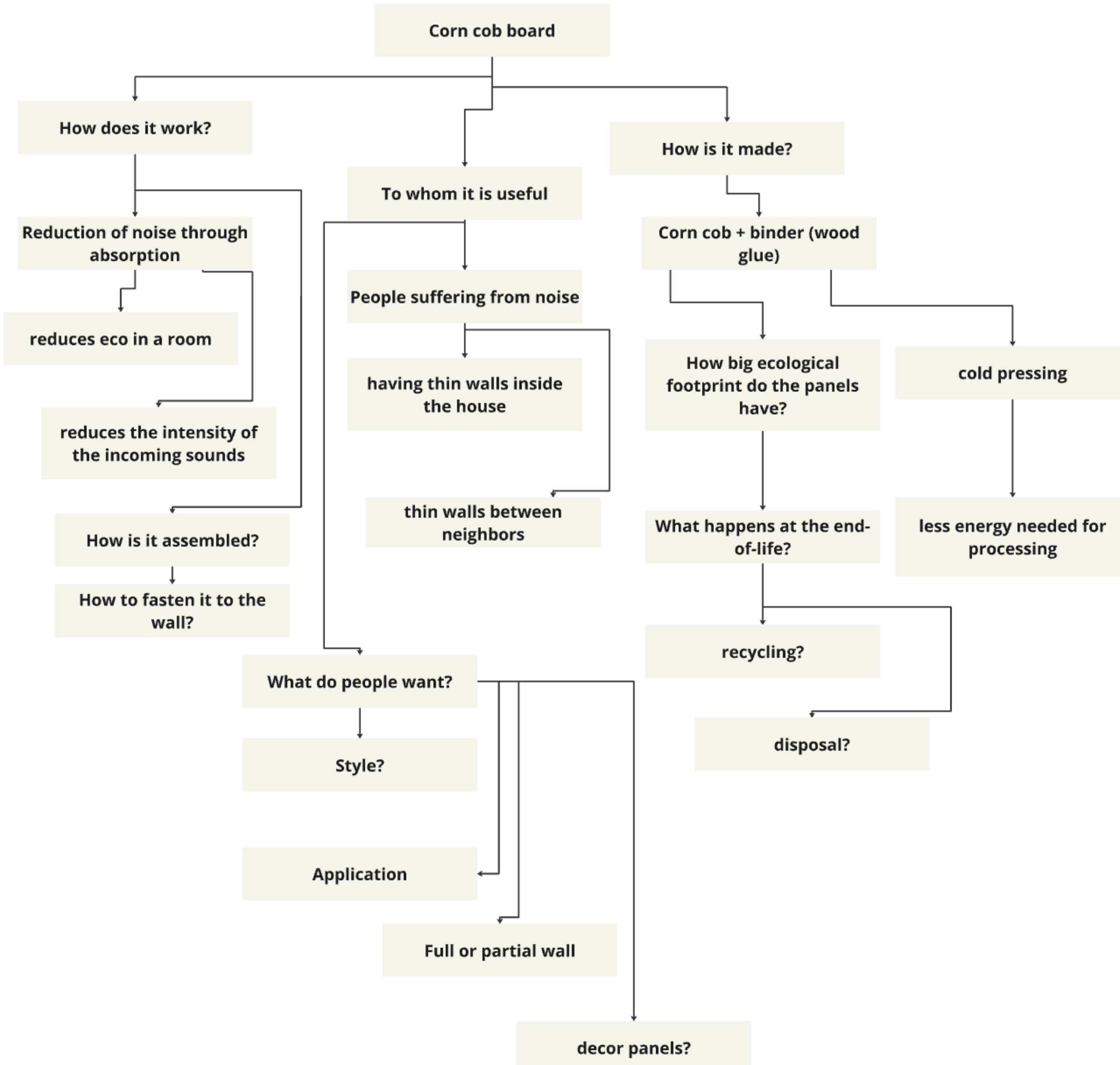


Figure 20: Mind map about finding direction in the project

But in a project, there are many parties that are potentially interested or involved. To discover who these parties are and to what extent they are involved in the project a stakeholder analysis is performed.

Stakeholder analysis:

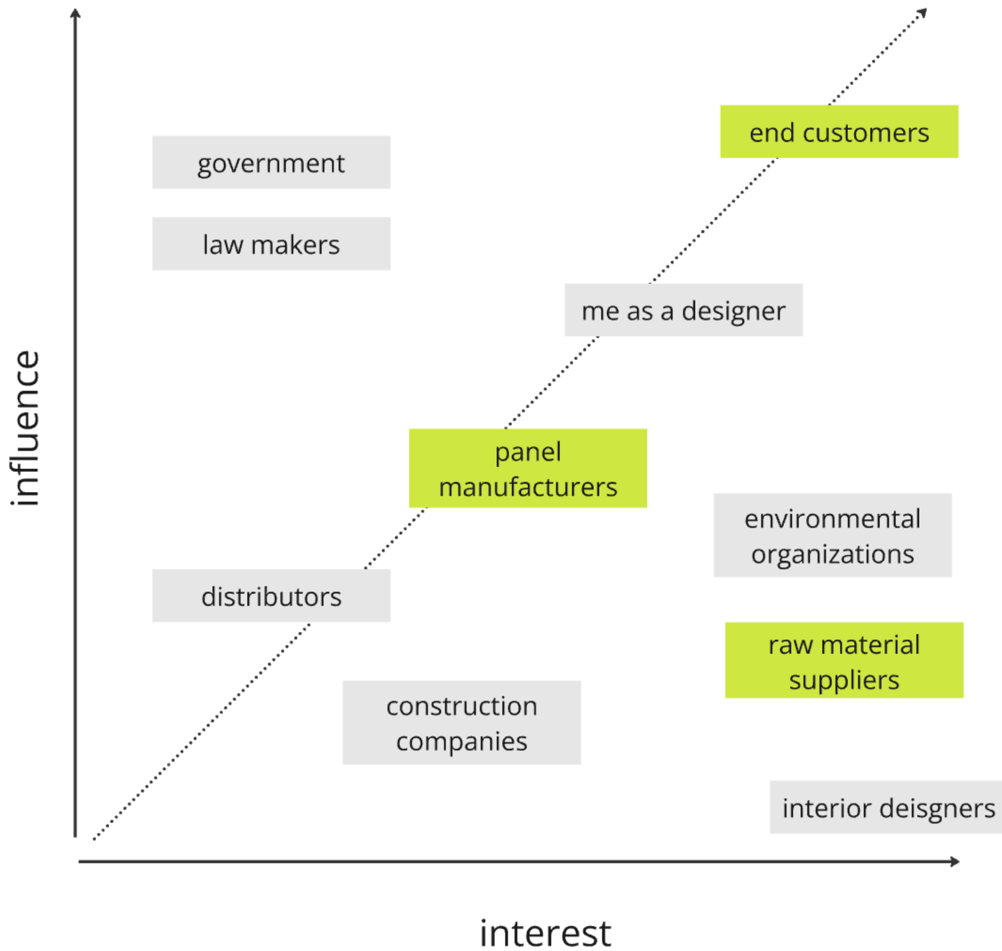


Figure 21: Graph of the stakeholders based on their interest and influence

The scope of this project is to focus on the end-customers, they are the main target. The aim of the product is to provide the end-customers with a product that is easy to install by themselves, without the need for a specialist. The most important stakeholders are listed and placed in a graph, depending on their level of influence and interest (see Figure 21) in accordance with the scope of this project. This gives an overview of all the parties involved in the creation of the panels. And the most important 3 are selected for further exploration, as the project stands on them as pillars of the project. Steady supply from the raw material suppliers, efficient manufacturing and market demand are the most important aspects of this project to be successful.

In Table 11, the wants and needs of these 3 main stakeholders are discussed.

	Who are they?	What do they want?	How will they get it?
End customers	Eco conscious people who suffer from noise pollution in their home. Target: first-time buyers, or those who want to renovate their homes. Age between 25-45.	Simple solution. Easy to install. Affordable solution with high performance. They want undisturbed work hours and sleep. Aesthetically pleasing solution.	They can change the windows to improve the sound insulation partially, and improve the insulation of the walls.
Panel manufacturers	Particle board manufacturing company that works with different kinds of lignocellulosic materials. Having the capability of creating custom shaped boards from the cob particles and binder.	Stable supply. Reliable material properties. Clean dry material. The product must fit to existing machinery. Low production cost and low set-up cost.	Work only with stable suppliers. Contract for set batch production. Work only with materials that their existing machinery can handle.
Raw material suppliers (cobs)	Farmers who produce corn.	Increase their income. Finding use for the excess waste they generate.	Sell waste as animal feed and burn the rest.

Table 12: Needs and approaches of the three main stakeholders

3.2.2 Competitor analysis

The different market landscapes are examined in this analysis to find out how to position the acoustic panel on the market. The analysis is going to examine traditional synthetic product and natural / bio-based alternatives.

First, a list of examples in Table 12 is going to show the most common types of traditional materials. Including the type of business and the acoustic products they sell. Following a “SWOT” (strength, weaknesses, opportunities and threats) analysis (see Figure 22), to find out generally what are the strengths and weaknesses of these traditional materials on the market.

	Organizational structure	Product	Application	Thickness	NRC value
Acoustical Surfaces, Inc	Distributor company	Fiberglass based, fabric covered decorative panels.	on wall	0.9 cm	0.9
Acoustical Surfaces Stop Noise	Small scale manufacturer	Lightweight foam panels specialized for music studios	on wall	3.5 cm	0.82
CYATCO	Medium size manufacturer	Customizable polyester felt decorative panels	on wall	0.9 cm	0.64
Gyproc	Part of a large multinational organization	Plaster acoustic panels	build-in	1.2 cm	0.65
Quietstone	Medium size company	Glass particle based panels for industrial and commercial applications	on wall	5 cm	0.65
ROCKWOOL	Large-scale multinational organization	Mineral wool based panels for high-performance soundproofing	build-in	3.81	0.9

Table 13: Selected companies of conventional products

Figure 22: A general SWOT analysis of the conventional acoustic companies

As we can see in Figure 22, the traditional products/materials excel in terms of performance and price. Also, they dominate the market with established products with high reputation. Although the future is slowly shifting towards new, recyclable and sustainable alternatives which could pose potential challenges to these companies.

Then, the second list of competitors can be considered a direct competition for the project. Mainly bio-based materials with a certain degree of biodegradability or compostability come as attractive features. In Table 13 nine very different but interesting bio-based products and their businesses are listed. The “SWOT” analysis in Figure 23 shows clearly that these businesses suffer from high expenditure costs and scalability issues, but the current trends going towards to a circular economy and greener future help them to gain market share in this competitive environment.

	Organizational structure	Product	Application	Thickness	NRC value
AKUWOODPANEL	Small scale business with the focus on natural aesthetics	Wooden cladded panels for domestic and commercial purposes.	on wall	6 cm	0.6
Cyclin	Medium size manufacturer	Lightweight panels made of cellulose (recycled paper) for various application	build-in	3.5 cm	0.85
HempFlax	Medium size manufacturer	Biodegradable and durable acoustic panels made with mixing hemp with pla	build-in	3 cm	0.4
ISOLENA	Medium size manufacturer	Wool based insulation material for sound absorption and thermal insulation	build-in	5 cm	0.75
Linex Pro Grass	Small scale business	Flax plant based panels (marketed as sustainable alternative)	build-in	2.5-5 cm	~0.4-0.6
Mykofoam	Start-up	Compostable soundproofing panels made of cellulose and mycelium	build-in	5-10 cm	~ 0.7
Silentfiber	Small scale business	Peat-based acoustic panels	on wall	2 cm	0.5
Søuld	Small scale business	Eel grass based acoustic panels targeting high-end markets	on wall	1.8 cm	0.65
Zenfeel	Small scale business	Coco fibre based panels designed for residential use	build-in	5 cm	0.5

Table 14: Selected companies of more eco-friendly products

Figure 23: A general SWOT analysis of the more eco-friendly acoustic companies

To round up the analysis a price per square meter (see Table 14) is summarized to see what kind of price ranges the traditional and more eco-friendly competitors operate.

Competitor	**Price per € / m²**
Acoustical Surfaces, Inc.	22-65
Acoustical Surfaces Stop noise	22-54
AKUWOODPANEL*	54-108
CYATCO	32-54
HempFlax*	75-130
ISOLENA*	75-130
Quietstone*	65-108
ROCKWOOL	16-32

Table 15: (Acoustic Surfaces, 2020), (Acoustical Surfaces Inc., 2024), (Acoustical Surfaces, 2025) , (AKU Woodpanel NL, 2025), (GUANGZHOU CHUANGYA ACOUSTIC TECHNOLOGY CO., LTD., 202c), (*HempFlax*, 2020), (ISOLENA Naturfaservliese GmbH, 2025), (Quietstone, 2024) , (Zibo Soaring Universe Refractory& Insulation materials Co., Ltd, 2022)

These price ranges clearly indicate that even though there is a large variation in price between products, but the decorative (like AKUWOODPANEL) and high performing products (like HempFlax Quietstone, and ISOLENA) cost significantly higher than the build in versions. Although it is worth to consider all aspects and additional costs of the installation of the different types of panels.

3.2.3 What do people look for when choosing acoustic wall panels for their homes?

To find out what the people are looking for, questionnaires for manufacturers and potential customers were sent out. The initial customer survey was filled out by 47 people aged between 18 to 56, of which the largest age groups of responders were 25-34 and 35-45 (see more in Appendix 11).
68% of the respondents find it important to be in a quiet environment, but often day and night they need to endure different kinds of noises. Like traffic noise, human speaking from the neighbors, and other mechanical noises. Around 20% of the responders expressed some skepticism about the current products. And an interview participant highlighted, they are *“either thick, expensive or useless.”* Important factors seem to be that people are deciding on are the effectiveness of sound reduction and the price. Appearance and longevity are just coming afterwards as decision making factors. From an appearance standpoint, the responders preferred a minimalist, modern look with the chance of some customization. Although from the summary of their answers, it seems they are looking for options with more earthy neutral tones with a smooth surface and but possibly modular design. From a manufacturer's standpoint the pricing seems to be the biggest barrier. As the initial cost of an eco-friendly product tends to be higher, and scaling up can be an issue as well.
Besides, the interest in sustainable building materials is increasing, according to an interview participant, *“there are also a lot of greenwashers who are spoiling the market”.* And competing in this market is difficult with eco-friendly products, due to their higher costs. Therefore, it is difficult to compete for many start-ups that offer different solutions. The scale of their production line is smaller, and the costs are higher, which discourages a wider audience from adopting it. According to the survey 34% of the responders are willing to pay between approximately 16.5-33.5 € for 1 m² and 12.8% of them are willing to pay

up to 66.5 € per 1 m². This information can serve as guidance in finding the right pricing for the target audience.
Altogether, people are in need of an effective acoustic panel that is affordable and of course appeals to their aesthetic taste.

3.2.4 What design features would make acoustic panels more attractive and practical to use?

Nearly half of the respondents find aesthetics very important, although some design decisions may depend on the place of application. People might have different preferences in their living room than in their bedrooms. And 68% of the respondents considered their bedroom the most important to isolate.

Nearly 2/3rd of the respondents prefers a minimalist and modern style. And 58% of all respondents would prefer neutral tones and 27% would prefer earthy shades. Regarding the surface finishing it is important to have a smooth surface for aesthetic reasons and also not to collect dust, but the boards could possibly retain their original fibrous texture look as well.

2/3rd of the respondents also prefer standard modular panels that are easy to install with adhesive to the wall, making the installation easy, practical and without the need for professional help.

These aesthetic and practical combinations provide guidance for concept development, which will allow me to provide an acoustic panel for a large audience with desirable options.

3.2.5 Current market trends

The acoustic panel industry has grown significantly in the last few years as people are more and more aware of the harmful effects of noise pollution. The global acoustic panel market is projected to grow at a compound annual rate (CAGR) of 4.3% from 2022 to 2030. The market size is expected to surpass 14 billion USD (Architectural Acoustic Panels Market Size, Share | Report [2032], n.d.). The main drivers for this expenditure are the rapid urbanisation, where people are closed in smaller and smaller places. This has increased demand for soundproofing for not only residential but commercial and industrial buildings as well. The calmer, quieter environment can improve the focus and productivity of employees for all who work from home or work from offices. And overall people are more and more aware of health implications of noise pollution such as stress, hearing damage or loss.

Even though until today the synthetic sound proofing materials have been dominating the market, there is a growing interest in sustainable materials due to environmental concerns and strict regulations on non-renewable resources. In the European Union the new policies are driven to achieve the goals of the circular economy, promoting the adoption of sustainable building materials to the construction industry. As an example, panels made of hemp, wool and straw have been gaining some attraction recently (Global Growth Insights, 2023) and wooden and wood wool products even achieved popularity in architectural applications (Globenewswire, 2023). Lastly polyester felt panels have gained popularity as well even though they are not bio based, but highly recyclable alternatives when looking for a cost-effective solution (QY Research, 2023).

3.2.6 New market opportunities

As consumers and businesses shift towards more environmentally friendly solutions, there are some market opportunities that can give competitive advantage to products on the market. Such as biobased solutions or promoting a product with a cradle-to-cradle solution, offering modular or customizable solutions for all kinds of applications, or even add additional value to the product by improving for example the thermal insulation of the products.

3.2.7 Opportunities of the corn cob panel

The sustainable aspect of the panel can be used as a differentiator on the market. The raw material comes from the waste source of another industry (agriculture) which reduces the resource extraction and emissions. And unlike fully synthetic panels, the cob particles are able to decompose naturally in case the product ends up in a landfill. If the panels are made of corn cobs and biodegradable binder, they could offer a more sustainable solution overall compared to the synthetic alternatives.

Design innovation such as modular and easy to install designs can cater to both renters and homeowners in the domestic market and can offer commercial areas more unique customizable options to express their own corporate image and identity through the designs.

This product is targeted at eco-conscious consumers, architects and businesses that are looking for sustainable acoustic panels. The panels are envisioned to be a mid-price range (€25-€50/m²) to compete with the bio-based alternatives. Modular design with various sizes and finishes can attract a broad range of customers, according to the customer review. And as a future recommendation it is worth considering the thermal insulation capabilities of the panels and improve them, providing additional value to the customers.

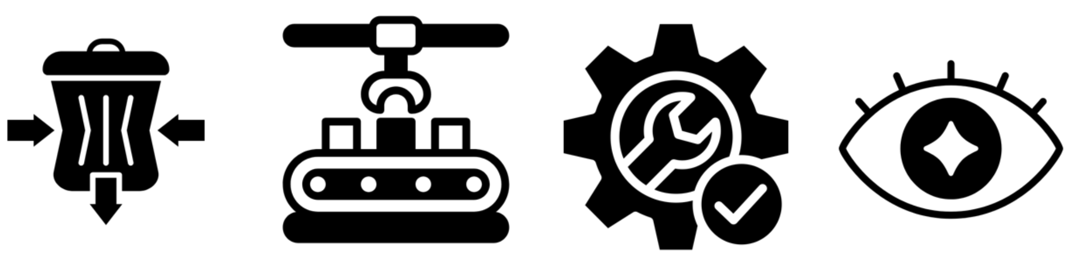
If all these are considered, the corn cob panels have the potential to enter in the market by addressing the growing demand for eco-friendly, modular, customizable acoustic solutions. Aligning with the market trends and leveraging a strong value proposition, the panels can enter in the competitive landscape of the acoustic panel market.

4. Conceptualization phase

4.1. Design Vision:

My vision is to provide people with an environmentally friendly acoustic panel solution, that creates a calmer, and quieter environment that improves their wellbeing while it meets their aesthetic requirements.

4.1.1 Design drivers:



Waste reduction - Easy to manufacture - Easy to install - Aesthetically pleasing

The project is driven by these four drivers. It is important to reduce the generation of waste not only with the sourced raw materials but through production as well. The product needs to be simple enough to be manufactured in an existing particle board factory and simple enough for the end consumers to feel confident about installing it. And finally, the design must be desirable by the consumers and fit into many different environments.

4.2 Ideation

4.2.1 Mind map- Discovery of areas of opportunity

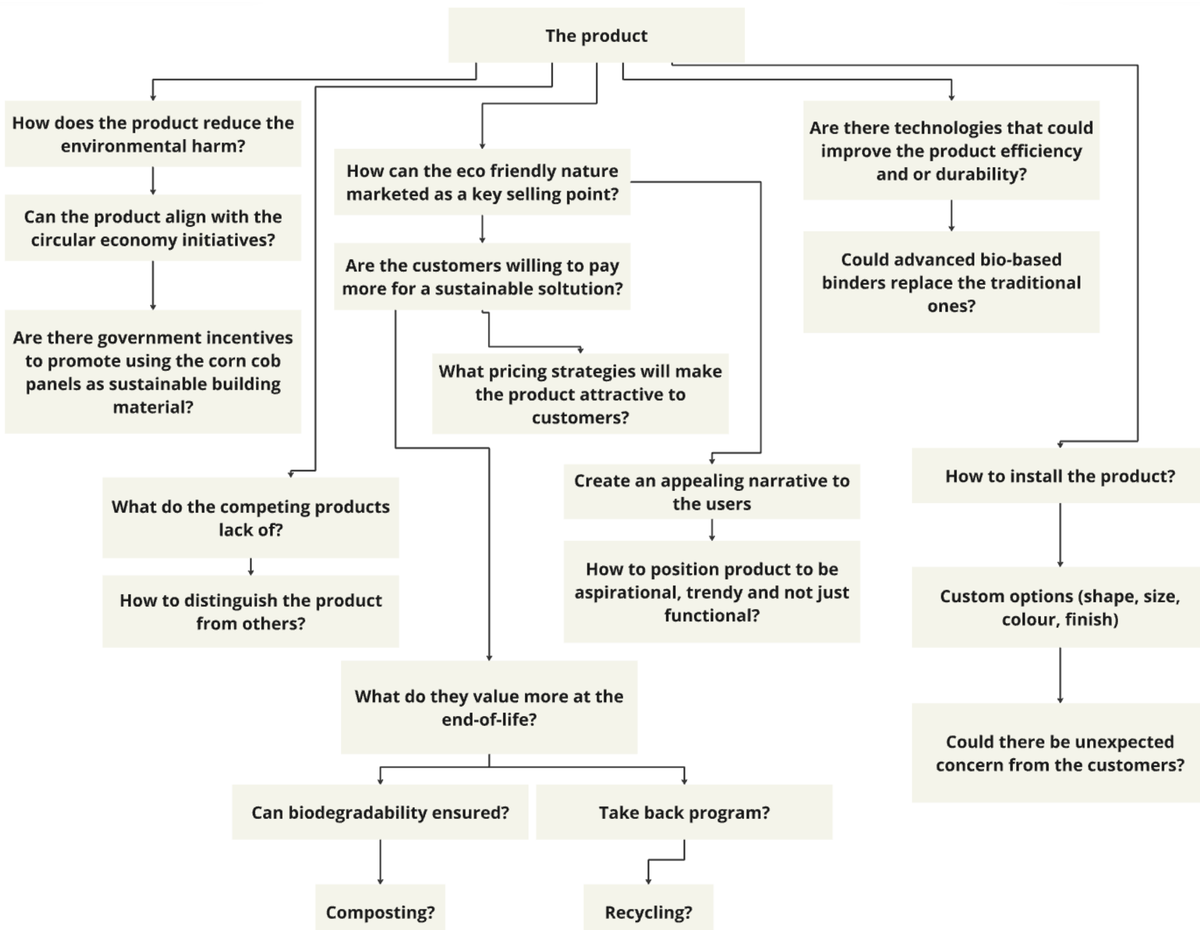


Figure 24: Mind map: Finding the direction of the unanswered details

A more in-depth thinking process led to raising questions about the values of the corn cob that it could offer. The creation of the mind map (see Figure 24) was followed with the initial list of criteria, which the project needs to follow.

4.2.2 List of requirements:

Acoustics	- Creating a healthier, calmer environment for the end-users. - Reduce incoming sound to a room and improve the acoustics by reducing the internal echo. - Certification of the NRC (noise reduction) value. Product needs to comply with NEN-EN-ISO 10534-2 standards.
Sustainability	Offer an eco-friendly and healthier alternative to the customers compared to the traditional alternatives
Aesthetics	Alignment with the aesthetic needs of the end customers whether individuals or companies.
User Requirement	Alignment with the functional needs of the end customers (whether individuals or companies) in regard to installation.
Feasibility	Product needs to be resource efficient in the use of raw materials. (The corn cob and binder). The manufacturing process should be energy effictien and scalable for mass production. Product should be done via existing production methods
Cost	Make it comparable to traditional alternatives and more affordable than the direct competitors (other bio-based acoustic panels) (€25-€50/m²)

Table 16: List of criteria

4.3 Concept Design directions

4.3.1 Hanged-up panels:

The first idea is based on standard size panels that could be hung on a metal rail that is directly attached to the wall. The rails must be secured with screws. Depending on the size of the panels, many rows of rails would be needed to cover an entire wall. The panel from the top would be hanging from the rail and in the bottom, it would be supported by the rail below.

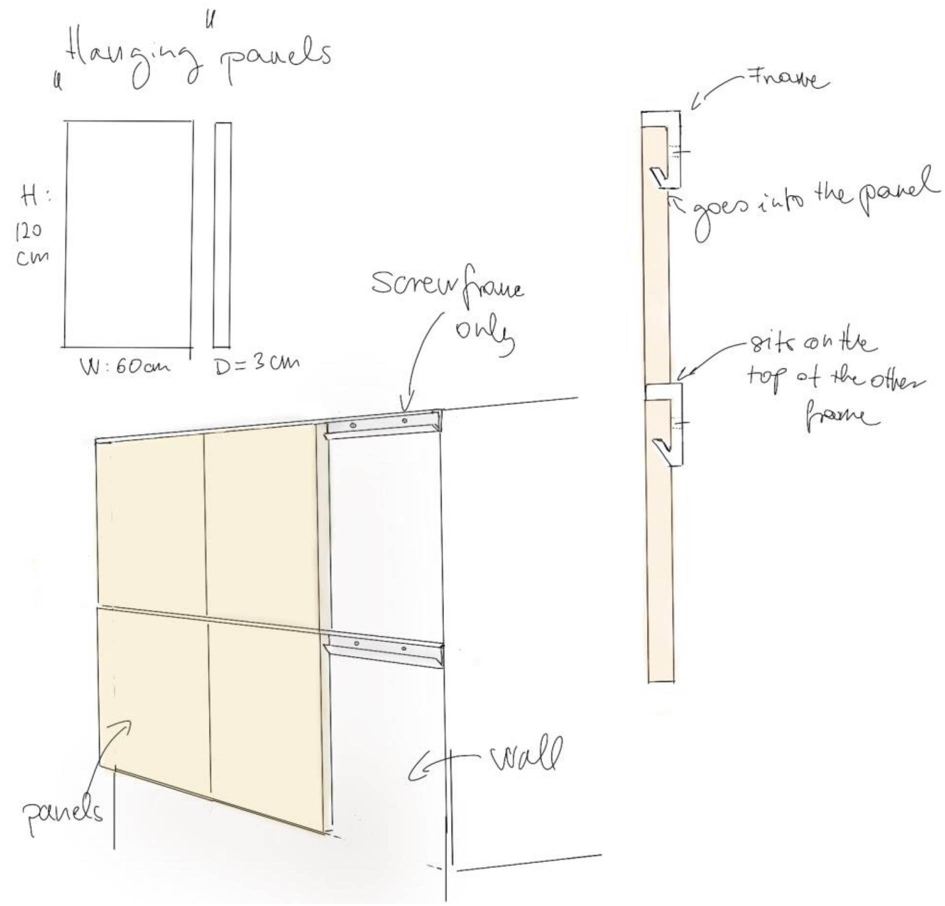


Figure 25: Illustration of the hanging panel idea

4.3.2 Expandable rod system

This idea came from the need not to harm the wall. This is tailored to the people who are renting apartments. The base of the idea is similar to the Hanged-up panel idea with a differentiation in the suspension system. A network of expandable rods should be fastened to the walls by force. This network would serve as the support for the panels. Then individual panels could be hung up on it.

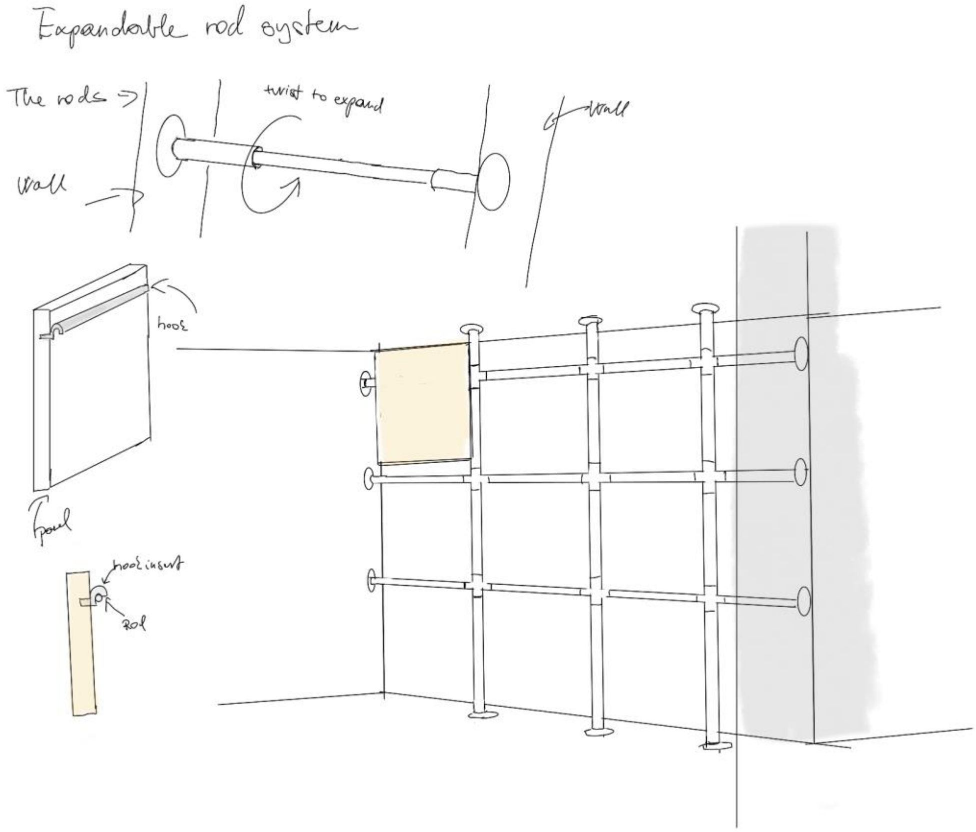


Figure 26: Illustration of the expandable rod idea

4.3.3 Glue-on

One of the simplest ideas is the use of glue for installation. This idea does not need the end-customer to use machinery or any specific skills.

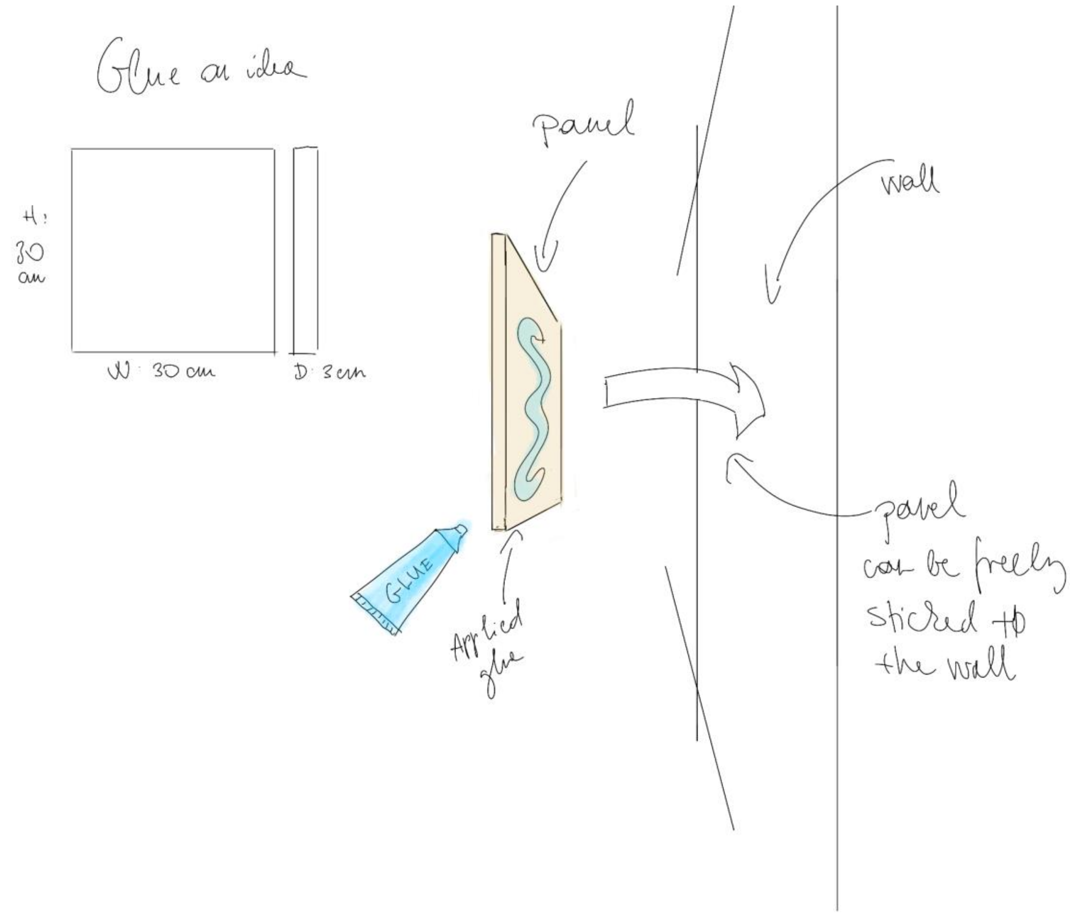


Figure 27: Illustration of the glue on idea

4.3.4 U-profile system:

This idea is an optimized version of the Hanged-up panel idea (Chapter 4.3.1). The U-profiles are laid down on the floor and attached to the ceiling. In between the panels would be placed beside each other.

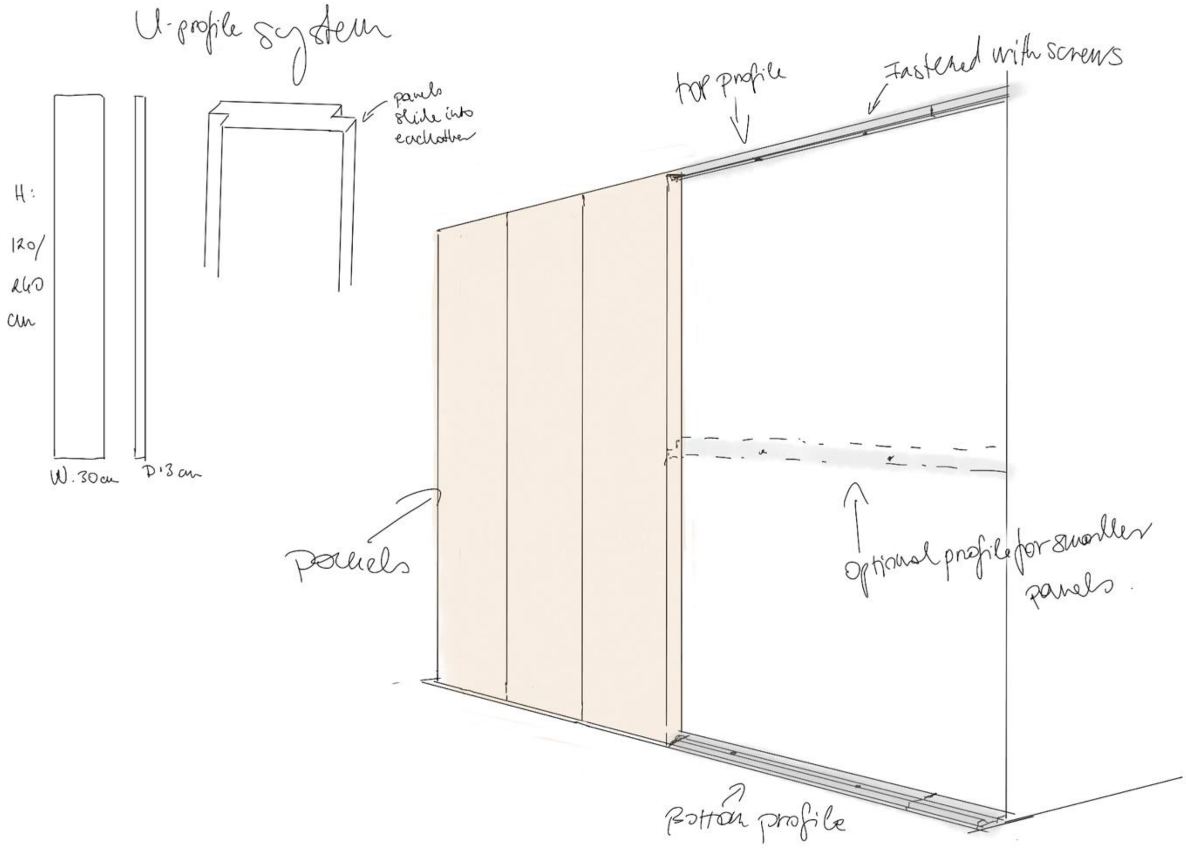


Figure 28: Illustration of the U-profile idea

4.3.5 Panel with stick on frame

This idea is a variant of the simple Glue-on idea (Chapter 4.3.3) but in this case the system is based on gluing a frame to the wall that holds the individual panels. This way the panels would not be contaminated with the adhesives at the end-of-life. If a heat reactive glue was applied, then it would be easier to remove the frame from the wall if needed with the heat gun.

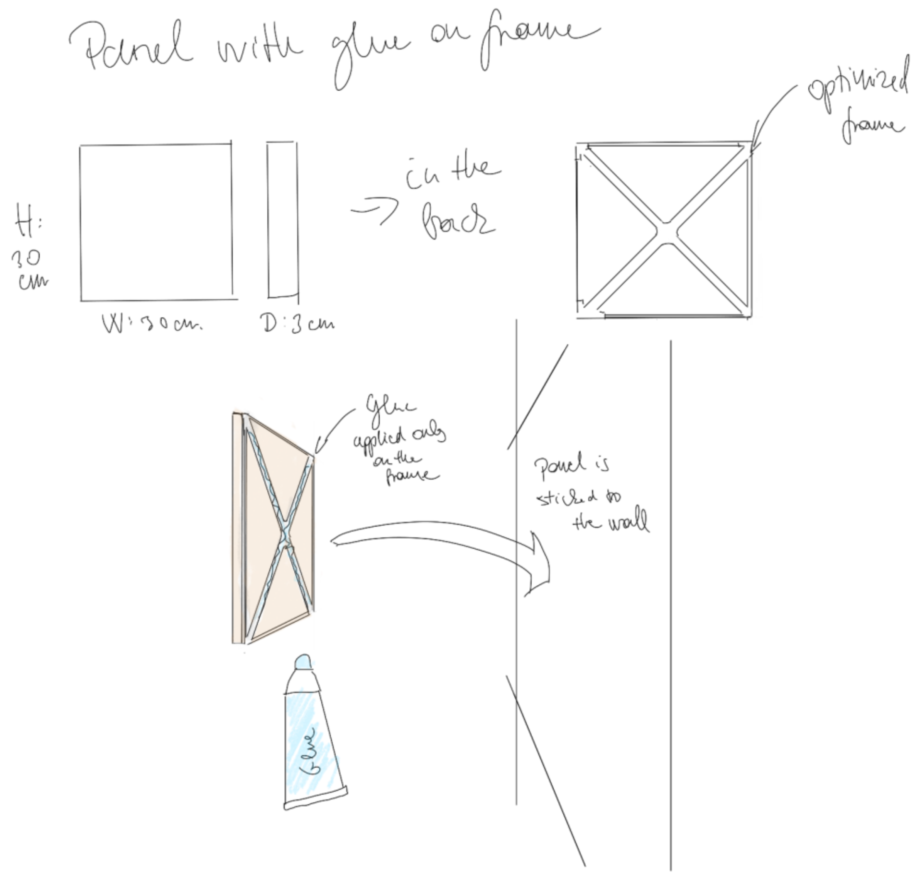


Figure 29: Illustration of the glue-on frame

4.4 Initial concept evaluation

With the aid of a Harris profile, the concepts were evaluated, and the strongest design is selected, where the definition of the points came from the list of requirements. In the selection process all aspects are broken down further into feasibility, viability and desirability are considered.

Figure 30: My evaluation of the designs direction based on feasibility, viability and desirability

According to the evaluation shown in Figure 30, the idea with the U-profile seems to be the strongest. The alternatives with adhesive could be difficult to recycle as most of the industrial grade, construction adhesives are not biodegradable, therefore it could contaminate the corn cob panel that potentially could be biodegradable. And the expandable rod system is not only using more raw material than any other options, but it seems a bit complicated to fasten a network of support to the walls. To validate this hypothesis, a cognitive user test was performed with simplified mock-up prototypes. See figure 31.

Figure 31: Mock-up models of the ideas

The research participants received the basic information about the product and instructions for the assembly of the 5 different set-ups were given to them. At the end their experience is summarized with the aid of the same Harris profile that was filled by me. From the analysis of the answers of the group, we were able to find out which alternative would be deemed most suitable for the customers and that Direction 4 idea (U-profile) is the one to follow.

User evaluation	10 participants

Feasibility

Viability

Desirability

	Direction 1				Direction 2				Direction 3				Direction 4				Direction 5			
	Hanging panels				Expandable rod system				Glue on				U-profile				Stick on frame			
	--	-	+	++	--	-	+	++	--	-	+	++	--	-	+	++	--	-	+	++
Reuse or recyclability			xxxxx	xxxxx		x	xxxx	xxxx	xxxxxxxxx	x				x	xxxxxxx	xx	xxxxx	xxxxx		
Technical feasibility		xx	x	xxxxxxx	x	xxxx	x	xxx	x	xxxx	xx	xxx	x	xxx	xxxxx	x	xx	x	xxxxx	x
Ease of application		xxx	xxxxxx	x	xx	xxxx	x	xx	x	xx	xxx	xxxx	x	xxxxxx	xxx		xx	xx	xxxxx	x
Scale of the project / difficulty		xxxx	xxxx	xx		xxxxxxx		xx	xxx	xxxx	x	xx	x	xxxx	xxx	xx	xxx	xxx	xx	xx
Resource efficiency		xx	xxxxx	xxx	xx	xxx	xx	x	x	xxxxxxx		xx	x	xxx	xxx	xxx	xxxx	xxx	xx	x
Investment needed -- large, ++ small	x	xx	xxxxxxx		xxx	xxxx	x	x	x	xxxx	xxx	xx	x	xx	xxxxxxx		xx	xxxx	xxxx	
Align with customer's functional needs		x	xxxxx	xxxx		xxxx	xxx	xx	xxx	xxxx	xx	x	xx		xxxxxx	xx	xxx	x	xxxx	xx
Align with customer's aesthetic needs		xx	xxxxx	xxx	xx	xx	xxx	xx	x	x	xxxxx	xxx	x	xxxx	xxx	xx	x	xx	xxxxxx	x
Probability to be adopted by end customers		xx	xxxxxxx	x	x	xxx	xxx	xx	xx	xxx	xxxx	x	x		xxxxxxxx	x	xx	xx	xxxxx	x
Probability to be adopted by companies		xxx	xxxxx	xx	x	xxx	xxx	xx	xxx	xxxx	xx	x		xxx	xxxxxx	x	xxx	xxx	xx	xx

Figure 32: Evaluation of the ideas of the interview participants

From the two Harris profiles (see Figure 30 & 32), the most promising ideas are the hanging panels and the U-profiles. According to the participants the hanging panels and the U-profiles options seemed to be the most reliable and to the point that the product should be well secured to the wall. Also, the glue ideas are not only lacking reliability, but they are highly questionable from the sustainability point of view, as the plastic frame in the Stick on frame idea could be possibly recycled but with less efficiency than metal (in case of the Hanged-up panels, Expandable rod system and U-profile ideas), as conventional plastic degrade with each recycle round. On the other hand, the metal parts (in the case of the hanging panel and U-profile) can be either re-used or recycled 100%. During the interviews it was highlighted that with the rail option the installation might seem slightly difficult, but it requires the least amount of labor and potential damage during installation, compared to the hanging panel idea. One participant expressed also that the long panels can increase the sense of space in a room rather than using smaller cassettes that seem busy and would rather compress the space.

So the final decision has fallen for the rail idea, and further development continues in this direction.

5: Embodiment phase

At the start of the embodiment phase, it is important to consider the details of the project. What is missing, what are the unanswered questions. For this reason, a more detailed mind map was created. See Figure 72 in Appendix 12. The questions arose mostly around the technical feasibility and how to make the product more attractive to the end-customers.

5.1: Experimental characterization of the corn cob as a panel

To understand the potential users of this acoustic panel, it is important to understand what effect it creates in people, but first and most importantly what they associate the material with. With that in mind, we can get guidance on how to make this product valuable and desirable to the end customers. For this task, partially the Material Driven design (Karana et al., 2015) method was used.

The interview was performed with ten participants. With two young professionals and eight students from the industrial design faculty. During the interview the participants received samples of the product, and they were asked for their impressions. First and foremost, the participants were given 5 minutes to have a look and experience the product without knowing what it is made of. Then they were asked questions like “What do you think this block is made of? What function might it have? What might it be good for? “The participants on a performative level were pressing, compressing and sort of rubbing the material (see more in Appendix 13, Figure 73) to understand the material. They were asked to express their perception of the material on a scale from –2 to +2, to find out how they feel about the material (see more in Appendix 13, Figure 74).

Surprisingly, the interview participants considered a sample (13 cm x 20 cm x 3 cm) of a panel lighter than it appears, while it seems strong and solid. And at the same time, it felt rather warm to the touch.

And finally, the participants were asked how they could describe the sample, and the participants mostly referred to the product as natural, calm and either manufactured or hand crafted (see more in Appendix 13, Figure 75).

Overall, the perception of the participants aligns with the intention of the product. Being an acoustic panel that is warm and welcoming, that creates a cozy, peaceful atmosphere not only by reducing the noise in the house, but by its aesthetics as well.

5.2: Mood board:

From the majority of the answers of the survey participants and from the in-person interviews. Then a mood board was created to find out what kind of visual direction the panels should follow (see Figure 33).

Figure 33: Mood board

Colours are a crucial element in a design. While individual color preference can affect the product selection, the message they try to convey with colours, can influence the customers to make purchasing decisions (Chu et al., 2024). For example, warm colours can lower negative emotions like loneliness and bring positive feelings like warmth and pleasure. And neutral colours have a calming effect on people (MasterClass, 2021). Neutral colours are defined as colours without high intensity or saturation. These colours tend to mix well with others (Missouri City, 2021) . Pure neutrals are considered colours made of the mix of black, white and brown (MasterClass, 2021). And near-neutrals are colours that are made by mixing the pure neutrals with a primary colour and they tend to have less saturation than pure neutral colours (MasterClass, 2021). Neutral colours are popular in interior design as they complement true colours of other objects, that is why they are a great choice as backgrounds (Lewis, 2023). Also, they are timeless, and they radiate the sense of peace (Lewis, 2023).

As the answers of the interview participants align with the underlying goal that the product wants to represent, the neutral, earthy shades seem the most suitable for this product.

5.3 Concept refinement

5.3.1 Colour, material, finish (CMF)

The base material of the panels is given by the corn cob. But the overall look and feel can be transformed significantly by choosing the right finishing of the material and defining the frame, that is going to encompass the panels.

The panels:

The panels are sanded down to have smooth surface and coated with natural lineseed oil-based varnish to change the colour and protect the panel from water absorption (Rubio Monocoat, 2025). Rubio Monocoat Oil Plus 2C does not emit volatile organic compounds. It is food and toy safe (E 71-3) and it improves the heat and water resistance of the surface of the product (*Oil Plus 2C - Houtolie Voor Binnenshuis*, n.d.).

The surface will have a satin finish in “White", "Pure", "Walnut”,” and “Charcoal” colour versions (Rubio Monocoat, 2025)

Figure 34: Colour selection (Rubio Monocoat, 2025)

The frame:

Figure 35: Colours of the frame (Eagle Aluminum, 2022)

The material choice fell on aluminum due to its high resistance to corrosion, easy to work with and lightweight compared to steel. The aluminium can be coated in various ways, and it is a highly recyclable material. Even though it is less cost effective than steel, it has greater durability which may justify the initial higher investment.

The surface of the U-profiles is envisioned to have a medium rough surface finish, to follow the smoother, natural aesthetics of the panels. Grade N6 according to the ISO 1302:1992 standards (AN Precision Engineering., 2025) .

The frame needs to be coated to follow the neutral aesthetics and offer multiple choices to the end-customer for customization. Powder coating is being selected as a method of finishing the surface as other methods such as anodizing can be more costly and have a higher environmental impact. For small batch production it is more viable to powder coat parts as the set-up cost is minimal compared to anodizing, and the rails can be estimated to have a 32 euro/m (FIXR, 2025). Although for future reference it is worth investigating after how large batch production would it worth turning to anodizing, as bulk anodizing can be more cost-effective solution (Zintilon, 2024) . But for now, with powder coating it can be ensured that the custom colours can be achieved and uniformly maintained on the aluminium U-profiles. From the recyclability perspective the side effects of the coating is negligible as it can be burned-off during the re-melting process. The coatings generally can be burned off between 450-600 °C, and the metal recovery in the recycling process lowers the environmental impact of this process than primary metal production creates (Vallejo-Olivares et al., 2022).

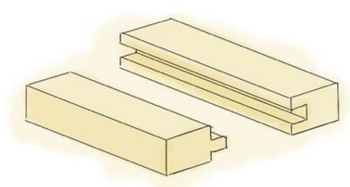
5.3.2 Concept iterations

To optimize the design for the users, it was considered whether to add more rails to the wall, so individuals can install smaller pieces that are lighter at the time, or the panels should fit from floor to ceiling. But according to the calculations from the material density (606.7kg/m^3 in chapter 6.3.2) of a panel with the standard height of 260 cm, the panels weight approximately 14.2 kg (See more about the physical properties in Chapter 6.3). This is safe to handle by an individual with proper precautions and instructions. For more details about the safe handling instructions see chapter 5.3.4.

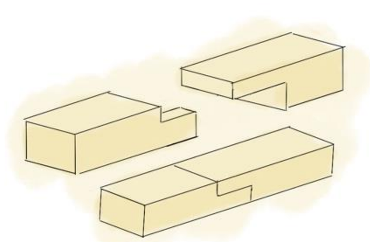
During the research on which installation system would be most suitable for the users, 6 out of 10 participants highlighted, that they preferred the longer panels as they optically make the space looking taller, more spacious and one of them even highlighted that the panels could touch one and the other in a flush creating the effect that the whole wall is consciously covered with the panels.

For this reason, three kinds of prototypes are created (Toolstoday, 2025)

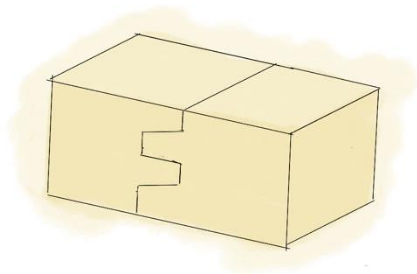
1st Tong and groove



2nd Half lap joint



3rd Edge joint



Prototypes of the Panel closures

As the panels are stacked beside each, it is important to make sure that there is minimal or no open-air gap in between. The following ideas are referenced from wood working joinery ideas (Toolstoday, 2025). For this reason, three different profiles were designed and evaluated, which type of profile suits the best for this acoustic panel application.

1 Tongue and groove

Figure 44: Tong and groove sample

2 Half lap joint

Figure 45: Lap joint sample

3 Edge joint

Figure 46: Edge joint sample

The prototypes of these joints were fabricated from 3 cm thick samples.

During the creation of the samples, it turned out that the material can tolerate cuts only, that does not leave the part with less than 1 cm thickness. On the attempt of creating the edge joint, the smaller cutouts just broke out from the sample. And in the case of the tongue and groove option, the connection also got weaker than expected, leaving the tongue part likely to break during a smaller load.

The half lap joint seems to offer the strongest structural integrity to the parts while they can connect in a flush. With higher accuracy cutting, the joining line could be barely visible.

Prototypes of the U-profiles

The idea behind the U-profile system is that the U-profiles minimize the use of fastening point that needs to be secured. But there are different ways to fasten the U-profiles to the floor and to the ceiling. So, it is important to find out where to fasten them. To the walls on the side, or to the floor and to the ceiling. Which option seems possible due to the materials the walls, floor and ceiling made of, which gives higher stability, and which options would the end-customer prefer?

The prototypes are designed in Solidworks and with the use of a Bamboo P1P filament 3D printer, they are printed 20 cm long and 1:1 scale.

The ideas of the custom profiles came from the shapes of the standard U-profile extrusions used in construction. There are simple U-profiles on the market, but the profiles need to be customized specifically for the application, so that they can be either attached to the walls or the floor/ceiling. And provide sufficient support for the panels. The 2 pairs of profiles were designed with the idea that where the individual profiles can be interchangeable.

First, the profiles could be sitting on the floor and touching the ceiling, but they should be fastened to the wall (see Figure 36).

Secondly the rails are directly attached to the floor and to the ceiling (see Figure 37).

Testing the different profiles with users can give an insight into all the above-mentioned questions.

Figure 36: Initial profile version 1

Figure 37: Initial profile version 2

Further improvement of the U-profiles

After the user research (see Chapter 5.4.1) some modifications had to be applied to the profiles. First the floor profile that can be attached to the walls needed optimization. So, the individual panels would not need to have a groove cut, maintaining their structural integrity, and reducing the risk of breaking.

The thickness of the rails should be ± 3mm thickness to better the load-bearing properties (ZP Aluminum Co. Ltd., 2022).

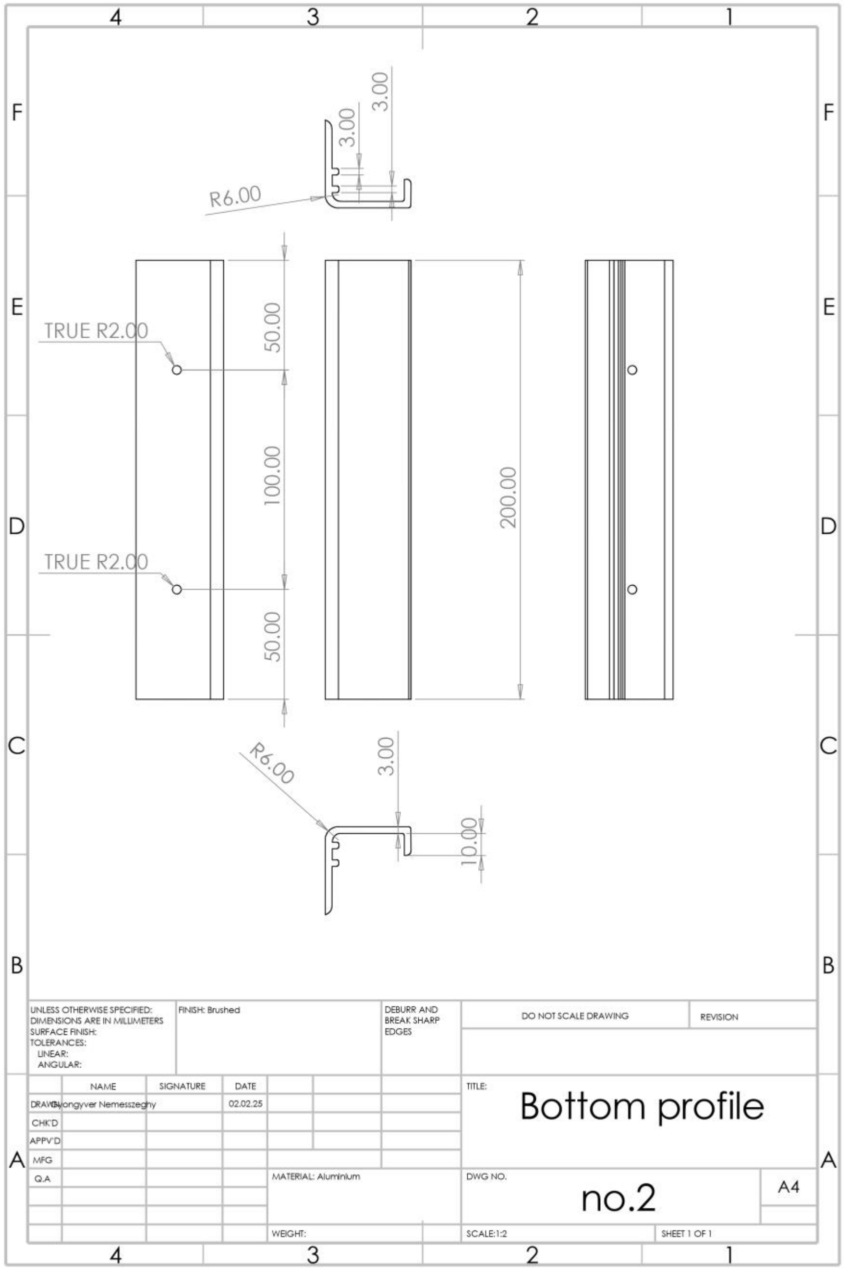


Figure 47: Improvement of the design of the bottom profile

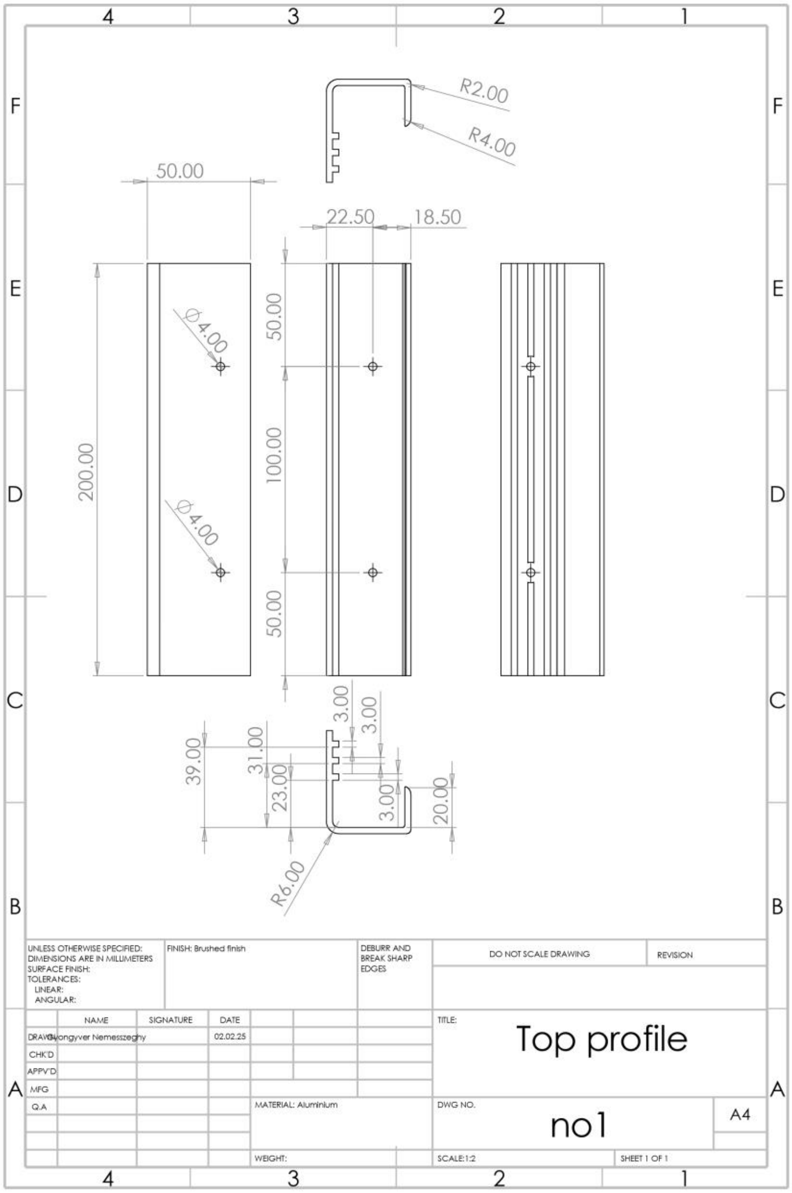


Figure 48: Improved design of the top profiles

Then the top rails are a copy of the bottom frame with a slight adjustment. The wall on the right (see Figure 48) is 1 cm long in the bottom frame and 2 cm long in the top frame. This version the profile has screw holes on the sides and on the (respective) top and bottom which allows the U-profiles allow the end-customers to choose whether they want to install the rail on the wall or on the ceiling.

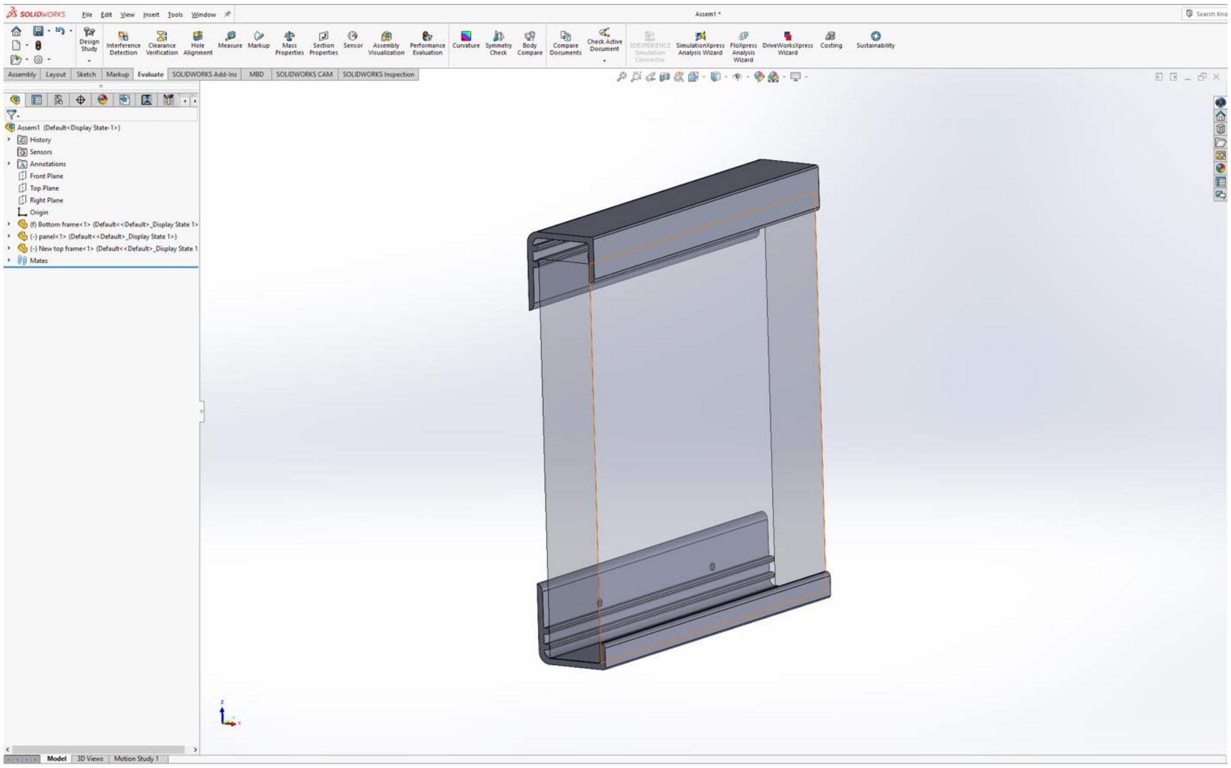


Figure 49: Final profile design

The profiles are designed to come in standard sizes of 1.2 and 2.4 m length. They are designed to be aligned when tightly fastened next to or to the wall.

5.3.3 Scenarios: Installation

Knowing the proper way of installation of this product is important as it can potentially cause strain and accidents for the end-user. The installation process needs to be designed in accordance with consideration of safe handling of the panels. During the installation it is important to handle the product correctly to avoid any accidental strains on the body. In Figure 38 the journey is presented with the consideration of how the panels should be safely lifted and installed. While the exact weight of the panels depends on the height of the room. It is calculated with the Dutch standard. Which is 260cm for newly constructed buildings) (Van Overveld et al., 2020)

Therefore, the dimensions of a panel are length x width x depth 260 cm x 30cm x 3 cm. And with these dimensions one panel weights 14.2 kg. The installation process shown in Figure 38 considering human ergonomics (Health and Safety Executive, 2025).

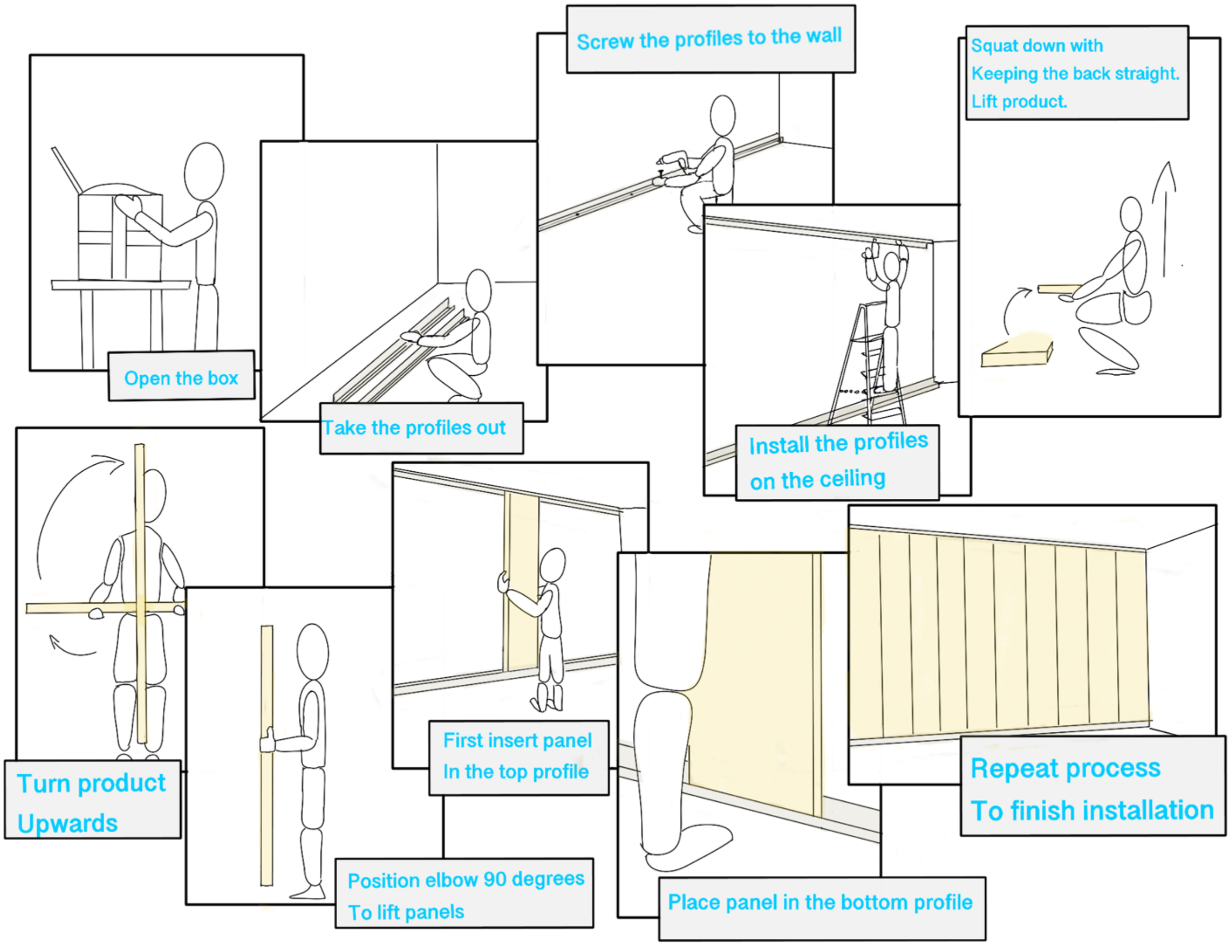


Figure 38: Journey of installation (illustration)

5.4 Concept validation

5.4.1 User research

One of the crucial aspects of the project is the installation. More importantly, how the rails are going to be fastened to the wall. To find out what the users may have as concerns, the prototypes of the profiles were tested with five end-users aged between 25 to 40 was performed. The participants were asked what they think about the rail system overall, and which combination of the rails seems most suitable for them. The participants were given the prototypes and approximately five minutes to think through how they could imagine installing the rails in their own home.

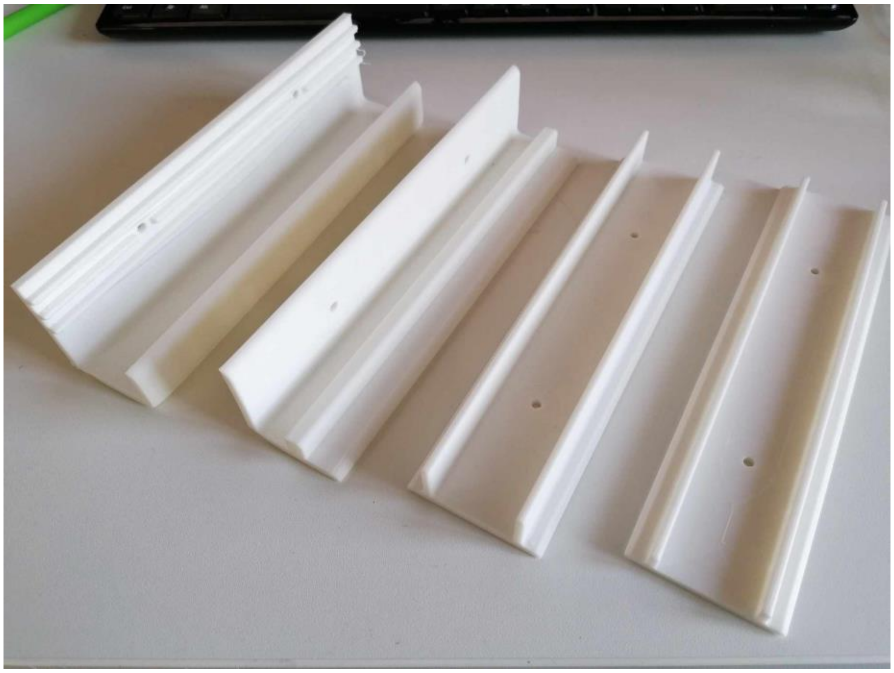


Figure 39: The initial profiles for user tests

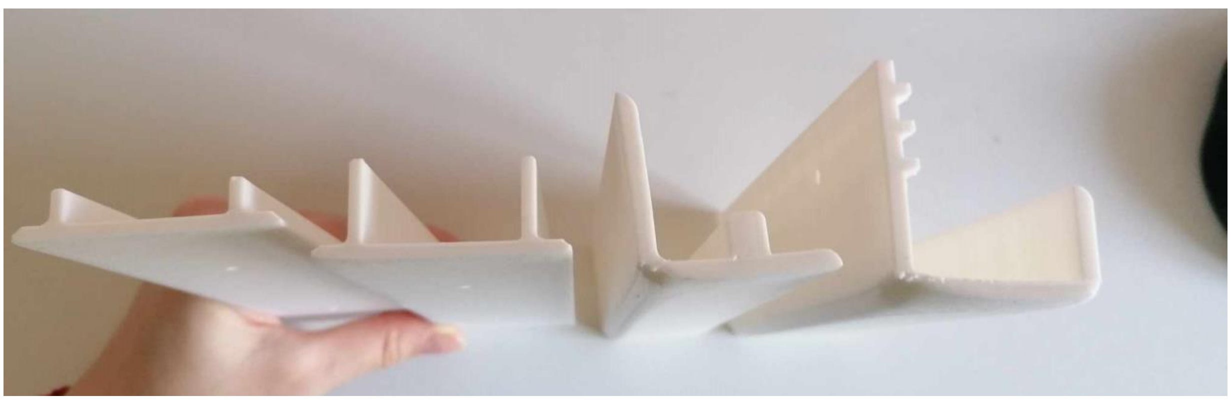


Figure 40: The initial profiles for user tests

The participants were more in favor of the version which is fastened to the wall on the floor level and attached to the ceiling as they were concerned about damaging the floor which is covered by laminated sheets, while it is easier to repair the wall which can be filled with plaster filler and painted. The rail that would be attached to the top, seems also bulkier than the simpler version that is just simply attached to the ceiling.

Then the participants were asked questions about the general experience of the product on a scale from 1-5. Which gave some insight into how to make fine adjustments to improve the product.

In conclusion, the design needs to adhere to its natural beauty to emphasize the natural patterns that it has. The neutral earthy colour tones are represented in the panels and carried to the supporting U-profiles, to show a coherent aesthetic together. With the available variety of colours, the customers can customize the design according to their taste, to fit in with the environment they place it in.

6. Final testing and evaluation

In this chapter, the final test and their evaluation are presented.

6.1 Final sample preparation

In this chapter, the methods of how the samples were created for different tests, are going to be discussed. Samples are made for acoustic testing, to measure the physical strength of the composite material such as tensile and bending strength, and to decide which type of closure between the panels is suitable for the application.

In chapter 6.2 and 6.3 an in-depth measuring process is shown with an evaluation of the respective results.

6.1.1 Test-samples for acoustic testing

From the initial experimentation to the final composition of materials, multiple iterations needed to be done. The iterations were created to find out which ratio of corn cobs, corn stalks, and binder was the most appropriate in terms of acoustical properties, while it stayed stable, without structural failure.

From the result of the initial acoustic testing, it was suggested that the panels that were made of the mixture 70% corn stalk and 30% PLA, had the least amount of sound transmission. While the mixture of 77% of corn cobs and 23% wood glue achieved the highest sound absorption values. (See more in Appendix 14)

To validate these suggestions, a series of panels were created, that were used to make acoustic measurements. The idea was to create a “sandwich” panel that incorporates the positive attributes of both types of panels. The denser panel is made of corn stalks and PLA (see Figure 42), and the more porous one is made of corn cobs and wood glue (see Figure 41).

The idea is to measure which combination of panels could provide the highest absorption value. Table 16 shows the individual panels that were created for testing in the same impedance tube that was used in the initial testing. The machine is again set to measure the absorption of the material from 0Hz to 1600 Hz. The panels were created in a circular shape with 10 cm diameter to fit in the testing machine. See more information in Appendix 13.

Figure 41: Corn cob and wood glue samples with varying thickness

Figure 42: Corn cob and PLA samples

Base material	Binder	Mixing ratio	Thickness (cm)
Corn cobs	PLA	7:3	1
Corn cobs	Wood glue	≈ 4:1	1.2
Corn cobs	Wood glue	≈ 4:1	2.3
Corn cobs	Wood glue	≈ 4:1	2.7

Corn cobs, corn stalk	Wood glue	3:7:3	3
Corn stalk	PLA	7:3	0.5
Corn stalk	PLA	7:3	0.8
Corn stalk	PLA	7:3	1.2

Table 18: The mixing ratio of the different samples

6.1.2 Test-samples for Tensile and Bending test

For the tensile and bending tests, also, multiple samples were created.

The samples were created the same way as the circular versions. The only difference is that they were created in a mould that produces a maximum of 13 x 20 x 5 cm samples. The cob and wood glue mixture were loaded in the mould and then cold pressed at room temperature, under 8,6 MPa pressure. First, the thickness of the sample was calculated and matched with the required thickness by the standards of NEN En 310 and the sample then was cut to match the length and width requirements.

Volume of the desired rectangular sample: 13 cm* 20 cm* 1cm = 260 cm^3, and the final mass of the materials needed for 1 cm thick rectangular sample 190 g of corn cobs and 43.9 g of wood glue.

To test better the structural integrity of the end products, also 3 cm thick samples were created. Simply 3 times the weight of the materials needed to be mixed and loaded in the mould. Each sample was pressed under 8,6 MPa pressure for 30 minutes until the wood glue hardened enough to keep the shape. Then the test samples were cut out in accordance with the NEN EN 310 standard.

Figure 43: Samples created for the bending test

6.1.3 Density of the material:

From a sample created, the density of the final composite can be estimated. The dimensions of the sample: 12.6cm *6.2cm*3.1cm (L*W*D)

From these numbers the volume of the block can be calculated. Which is:

V=L*W*D= 242 cm^3

Then the sample was measured on a scale.

M=147g

Knowing these values the density of the material can be calculated:

D=M/V = 147g/242.17= 0.607 g/cm^3 which is equal to 607kg/m3.

6.2 Acoustic testing

6.2.1 A series of sound absorption tests were run on the samples mentioned in point 6.1.1.

The individual test pieces were laid out (see Figure 50) and then measured in multiple combinations in stacked-up, layered structures in the impedance tube (see Figure 51).

Figure 50: Samples created for the “sandwich” acoustic testing

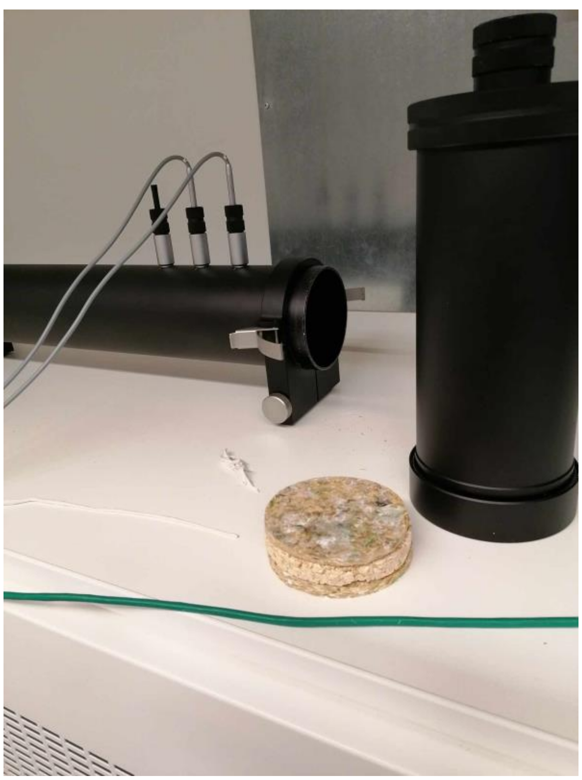


Figure 51: Example of a test sample made for the impedance tube

16 different combinations of samples were tested (see more in Appendix 21). From all these versions first, the best performing 6 options were

selected (See Appendix 21 figure 78) although the versions that exceeded the 3.5 cm maximum limit of the thickness criteria, were excluded from further study. Then the versions that had overall higher absorption capacity for lower frequencies, were selected (see Appendix 21, Figure 79 & 80) for further analysis. From this it turned out that the sample with 3.5 cm thickness made of corn cob and wood glue performed the best.

To find how does it relate to other products, the available absorption values at 125 Hz, 250Hz, 500 Hz 1000 Hz and 2000 Hz were compared. As the sample was measured only until 1600 Hz, an approximate value of the 1600 Hz in the case of the other products was calculated using the values given at 1000Hz and 2000Hz for the comparison.

It is important to compare the traditional and eco-friendly alternatives it is important to know how well the corn cob competes with the traditional materials, and the more eco-friendly solutions in case of performance. Therefore, first the sample was compared separately to three traditional acoustic materials, (see Figure 52) and then it was compared to eco-friendly alternatives separately, that are more direct competitors. (see Figure 53)

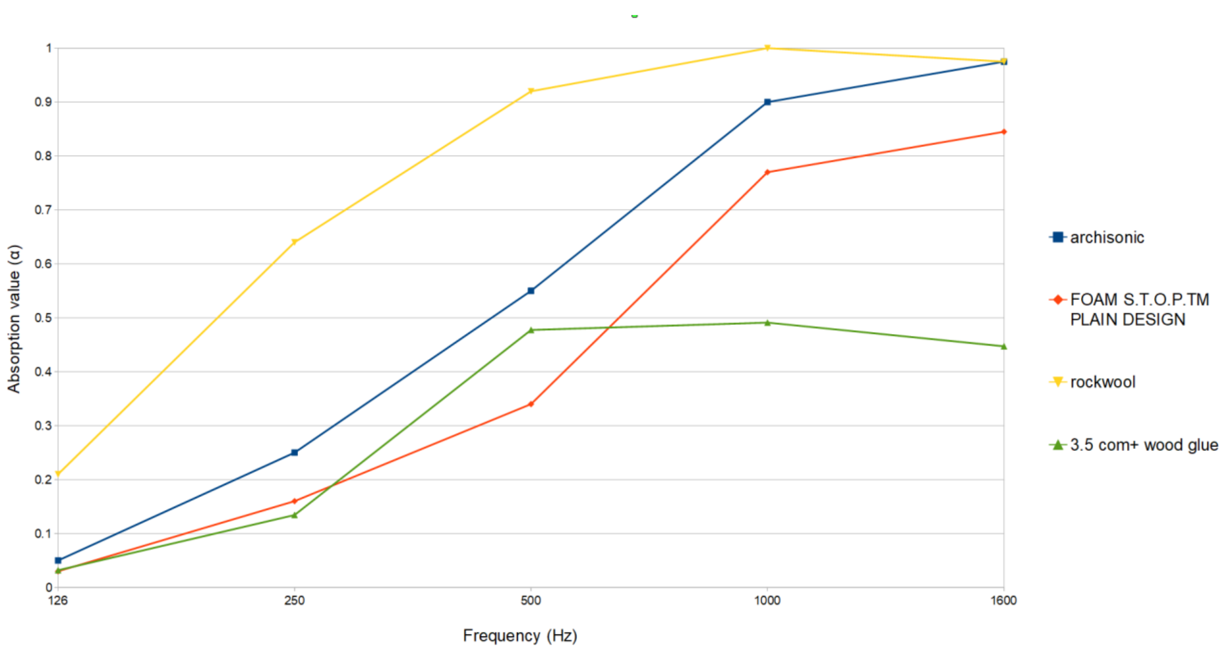


Figure 52: Sound absorption values of the conventional materials compared to the corn cob sample

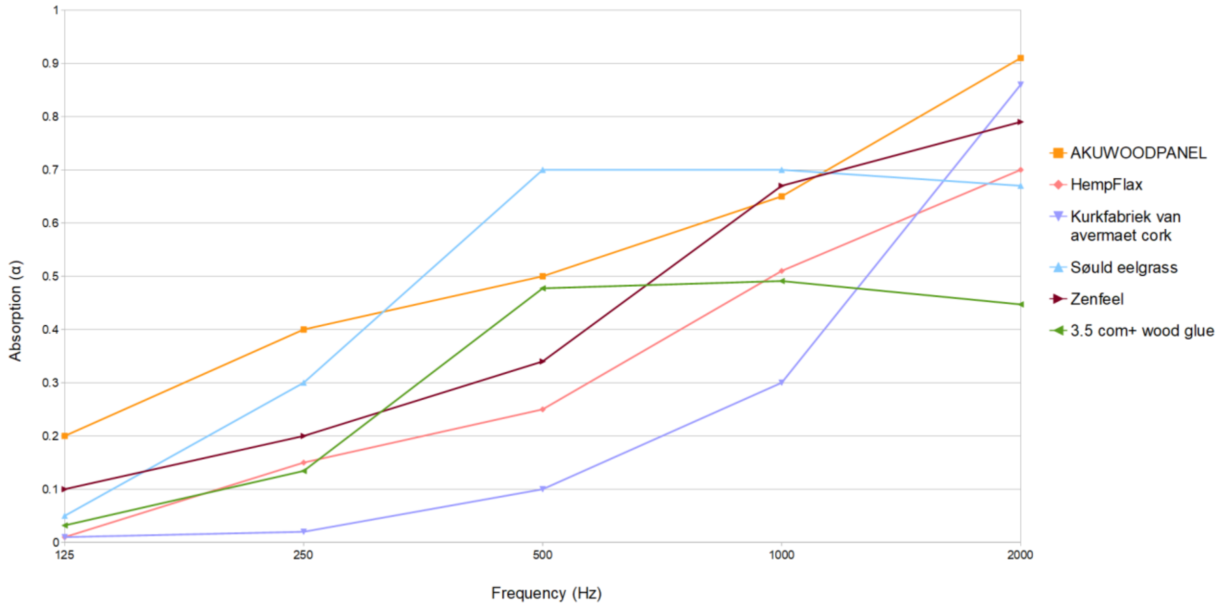


Figure 53: Sound absorption values of the more eco-friendly materials compared to the corn cob sample

Even though these measurements do not cover all the standard spectrum noise frequencies, they provide a comparable view on the performance of the different products at lower frequencies.

Low frequencies are generally more difficult to absorb as they have longer wavelengths (Institute of Acoustics, Chinese Academy of Sciences, 2015). Protecting ourselves from these frequencies is more difficult, therefore needs more attention. Mainly low-frequency noise is considered to be the most annoying (Henry & Henry, 2020), therefore the higher absorption value we get from a material, likely to have better overall user experience.

The sample seemingly underperformed compared to the traditional acoustic materials, but considering the more eco-friendly alternatives, it has achieved comparable results. Therefore, it is worth exploring the corn cob panel further and completing the absorption test from 0 Hz to 6400 Hz.

6.2.2: Final acoustic test.

To get a complete overview of the capabilities of the corn cob panels, the measurements needed to be done in the complete range possible. From 0Hz to 6400Hz.

The measurements were done with the impedance tube.

First the test was repeated with a new sample, with the sample size 10 cm diameter version to see if the newly measured result would match with the previous results. Then with the new sample (2,9 cm diameter and 3 cm thick) an extended measurement was performed until 6400 Hz.

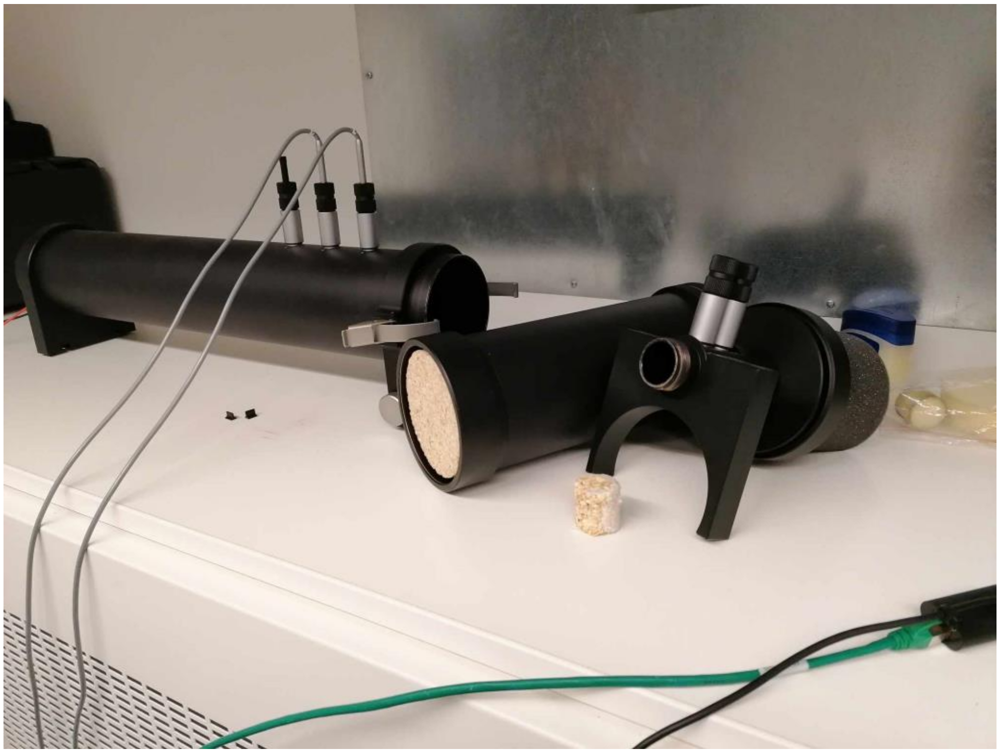


Figure 54: Test preparation for the large and small tubes

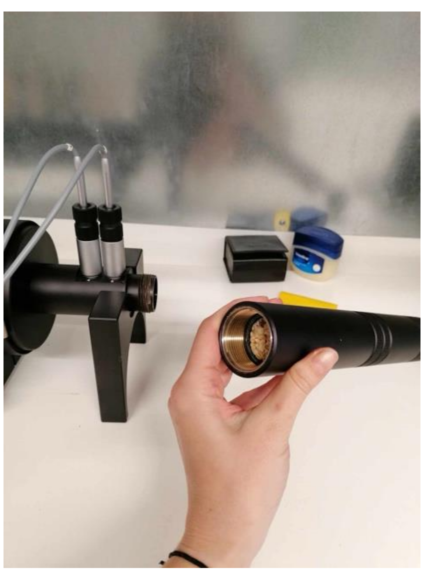


Figure 55: Small sample in the impedance tube

The measurements were repeated 5 times, and the samples were flipped to see if there is any deviation in the measurements.

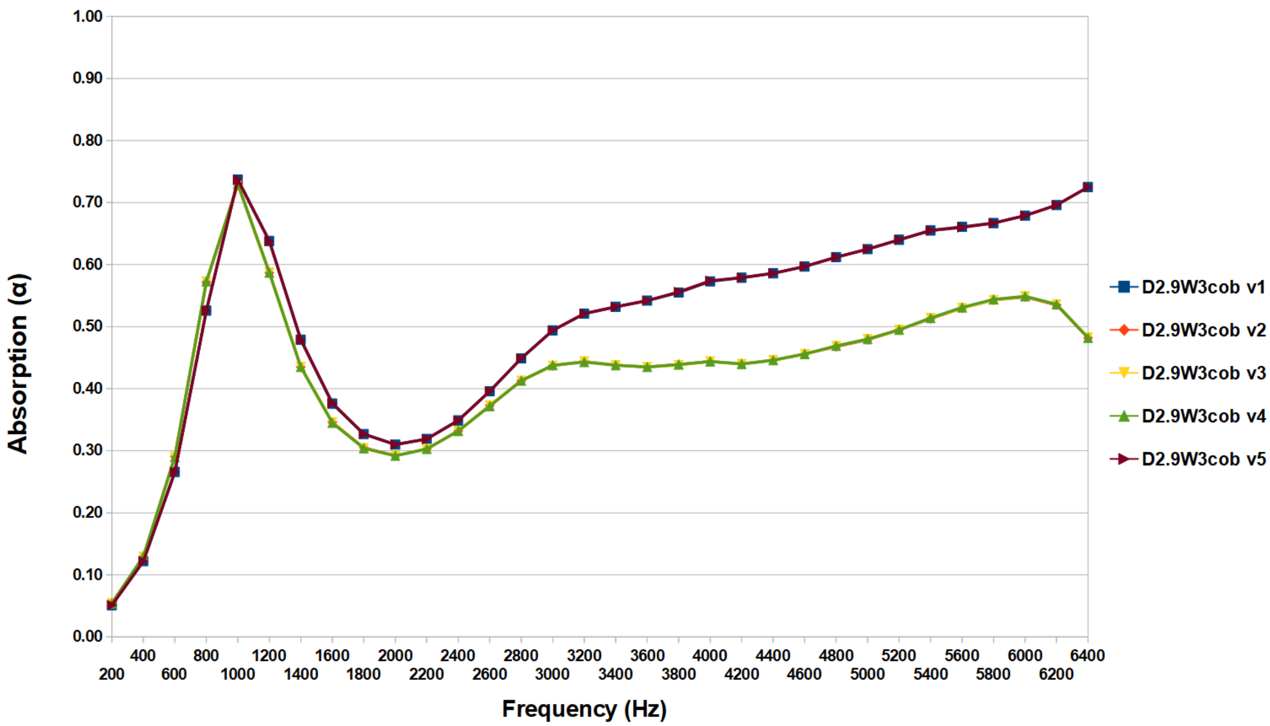


Figure 56: Graph of the sound absorption of the corn cob panel from 0 to 6400 Hz.

Name	Frequency							NRC
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	6000 Hz	
D2.9W3cob v1	0.05	0.07	0.11	0.73	0.29	0.45	0.55	0.32
D2.9W3cob v2	0.06	0.12	0.28	0.73	0.29	0.45	0.55	0.35
D2.9W3cob v3	0.02	0.09	0.29	0.73	0.29	0.44	0.55	0.34
D2.9W3cob v4	0.02	0.10	0.30	0.74	0.31	0.57	0.68	0.39
D2.9W3cob v5	0.02	0.09	0.29	0.74	0.31	0.57	0.68	0.39

Table 18: NRC values of the five measurements taken

It can be concluded that the NRC of the material is approximately 0.36.

This is especially interesting because the material seems to be quite effective in the noise range of average human speaking. While the results show a medium result, it is worth further investigation to experiment with other thicknesses and manufacturing processes to optimize the sound absorption capabilities of the panel.

6.3 Tensile and bending test

6.3.1 Tensile test

The tensile test is needed to find out how the material will perform under use. The test measures the force required to break the composite and to which extent the sample elongates to until it breaks (Singh, 2011). This helps to find out how strong the material is and how much it can stretch before it breaks.

Methods:

Dimensions:

The samples were prepared to fit in the measuring tool. The test piece is rectangular, measuring L*W*H: 50mm±1* 50mm±1*12mm±1

Tools:

The measuring instrument is called the Zwick Z010 testing machine with a 10 kN loadcell, where the tensile test was performed.

The test piece was clamped in the loadcell and from zero position the sample was pulled upwards. The machine was set up to pull the material with 2 mm/minute and measure the length of deformation and the force applied.

Figure 57: Tensile test on the corn cob sample

From the measurements taken, knowing the cross-sectional area the stress can be calculated the following way:

Tensile strength= F/A where A is the cross-sectional area of the sample (see Figure 58)

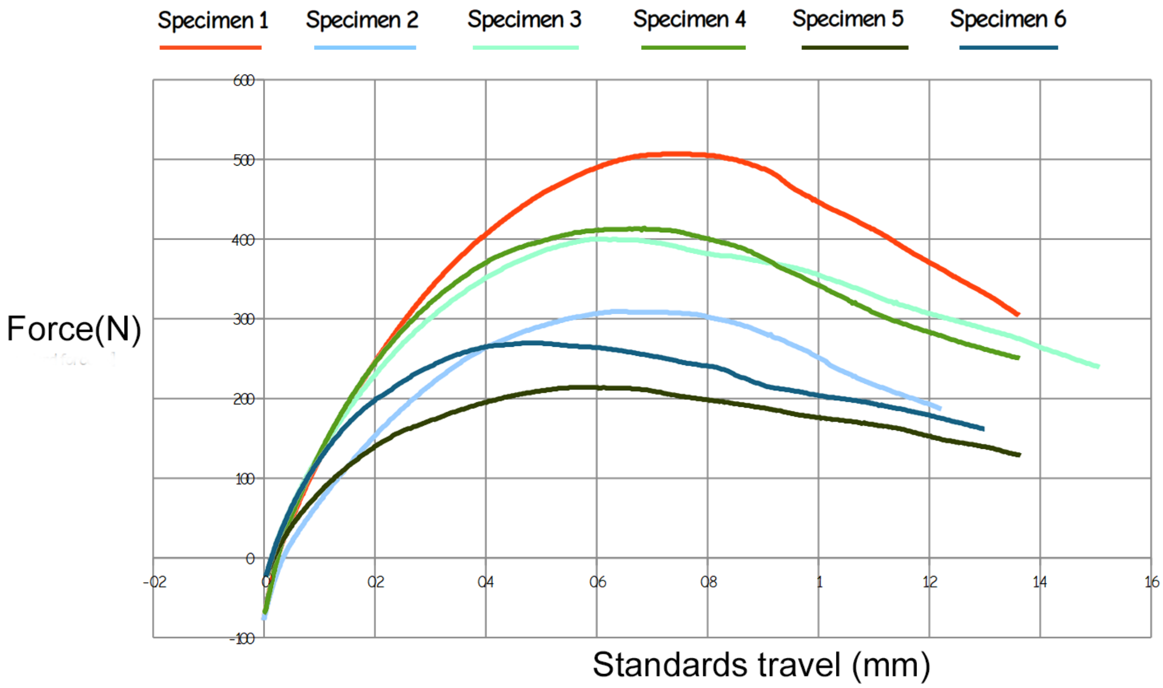


Figure 58: Results of the tensile test performed

The average value of the Tensile strength is approximately 0.53 ± 0.16 N/mm^2. Table 18 summarizes the test performed on the six samples in detail. Including the dimensions of the samples and the measurements taken. The result suggests that the material is relatively weak in tension, but this low-level strength is sufficient for a non-load bearing construction material. Also, there is high variation in the mechanical properties of the samples which suggest material defects or manufacturing inconsistencies (see Table 18).

Series	Maximum extension	Test speed	Pre-load	Specimen no.	h	b	A0	Peak detection	Date/Clock time	L0 CH
n = 6	mm	mm/min	N		mm	mm	mm²	N		mm
x	3	2	0.1	3.500	12.797	51.862	663.689	352.378	45677.598	19.214

s	0	0	0	1.871	0.636	0.552	34.301	107.269	0.007	0.127
n [%]	0	0	0	53.452	4.967	1.065	5.168	30.442	0.000	0.662

Table 19: Summary of the data of the tensile test

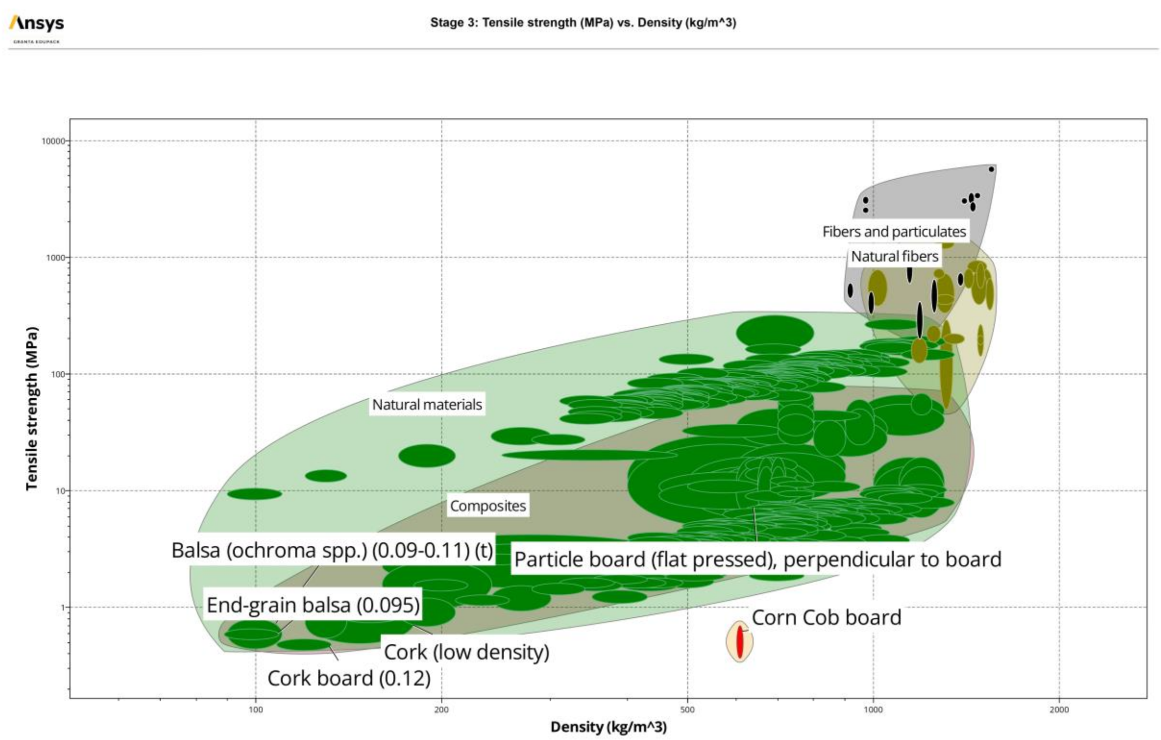


Figure 59: Graph of the tensile strength of the cob panel compared to wooden and natural fibrous materials, created in Granta EduPack 2024 R2 (ANSYS Inc,2024)

According to the database in Granta EduPack 2024 R2 (see Figure 59) the corn cob board is amongst the least strong materials, like cork and balsa wood. Although it proved to be strong enough to use it as a non-structural acoustic material.

6.3.2 Bending test

The goal of the three point bending test is to determine the stresses and strains within a material. The Young's modulus can be calculated from values of stress and strain, and it shows the ability of the material to withstand changes in length under tension or compression (The Editors of Encyclopaedia Britannica, 1998). The Young's modulus of this material can be compared to others to determine whether it is suitable for its intended application.

Methods:

The samples follow the standards defined in NEN-EN 310 (Wood-based panel Determination of modulus of elasticity in bending and of bending strength)

Dimensions:

According to the standards, there must be six samples. The test piece must be rectangular. Width must be 50±1mm. The length must be 20 times the thickness plus 50 mm, with a minimum of 150 mms to a maximum of 1050 mm.

The test pieces are L*W*H: 240 mm±1* 51±1mm * 12±1mm

Tools:

The measuring instrument is called the Zwick Z010 testing machine with a 500N loadcell, where the three-point test was performed.

A force moves from the starting position towards the bottom, while it bends the material in the middle. The machine was set up to bend the material with 2 mm/minute and measure the length of deformation and the force applied.

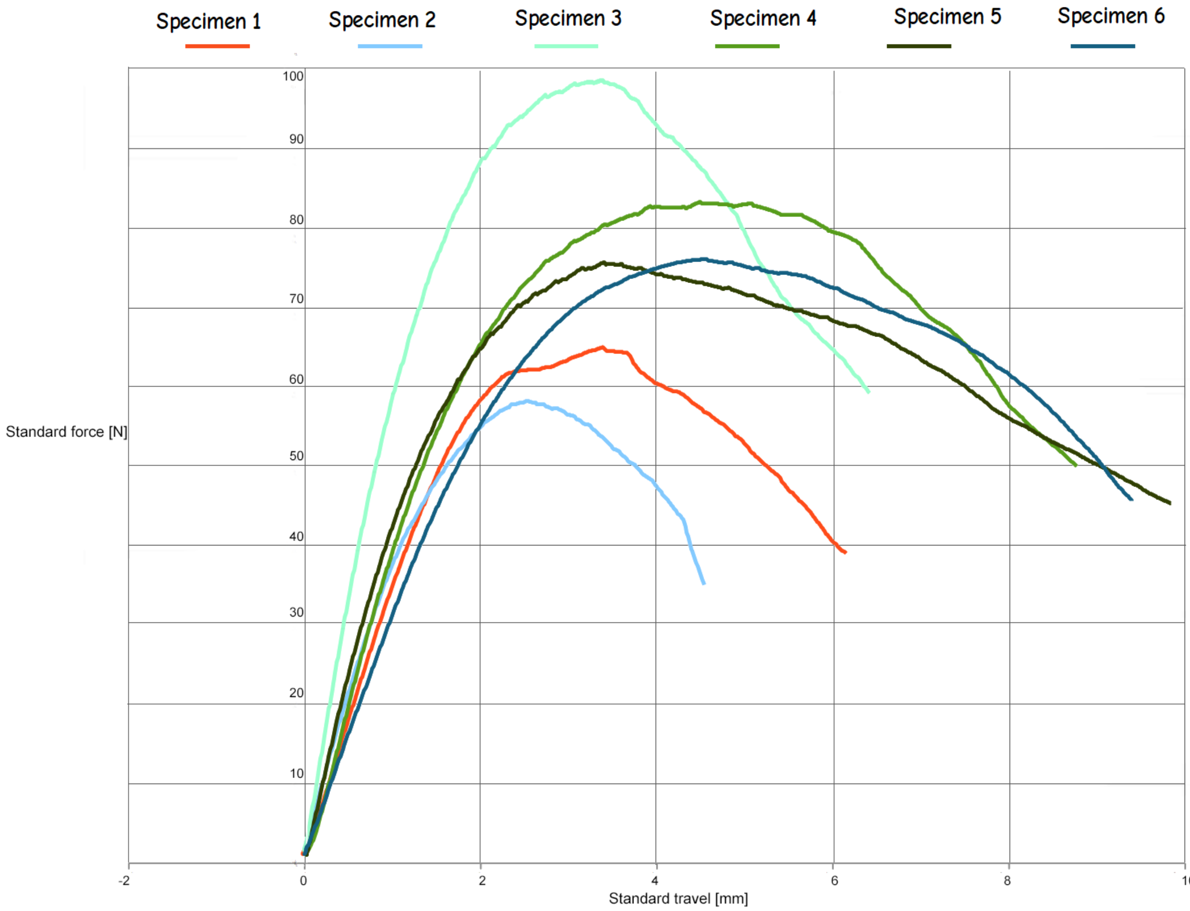


Figure 60: Results of the bendingt test performed

Even though the curves show large differences between the measurements, we see similarities between specimen 4 and 5. All these measurements indicate that the strength of the material is heavily dependent on the consistent application of the binder to create a solid matrix within the material. Table 19 summarizes the results of the measurements of the bending tests performed. From the results of the measurements a moderate flexural strength can be suggested, although not as strong as traditional structural materials like wood or MDF. The high deformation length (dL) suggests that the material can bend significantly before breaking. Although there are high variations in the measurements which indicate problems with distribution of the binder within the panels.

Series	Fmax	dL at Fmax	FBreak	dL at break	W to Fmax	a0	b0	S0	tTest
n = 8	N	mm	N	mm	Nmm	mm	mm	mm²	s

x	104.334	3.717	62.597	7.307	256.568	17.255	52.225	782.688	44.835
s	55.973	0.683	33.584	1.845	127.410	9.089	1.095	379.302	11.062
n [%]	53.647	18.367	53.651	25.243	49.659	52.673	2.097	48.462	24.674

Table 20: The average results of the bending test

See the individual results of the measurement in Table 39, Appendix 24
The average Young's Modulus across all specimens is approximately 0.761 ± 0.313 N/mm^2

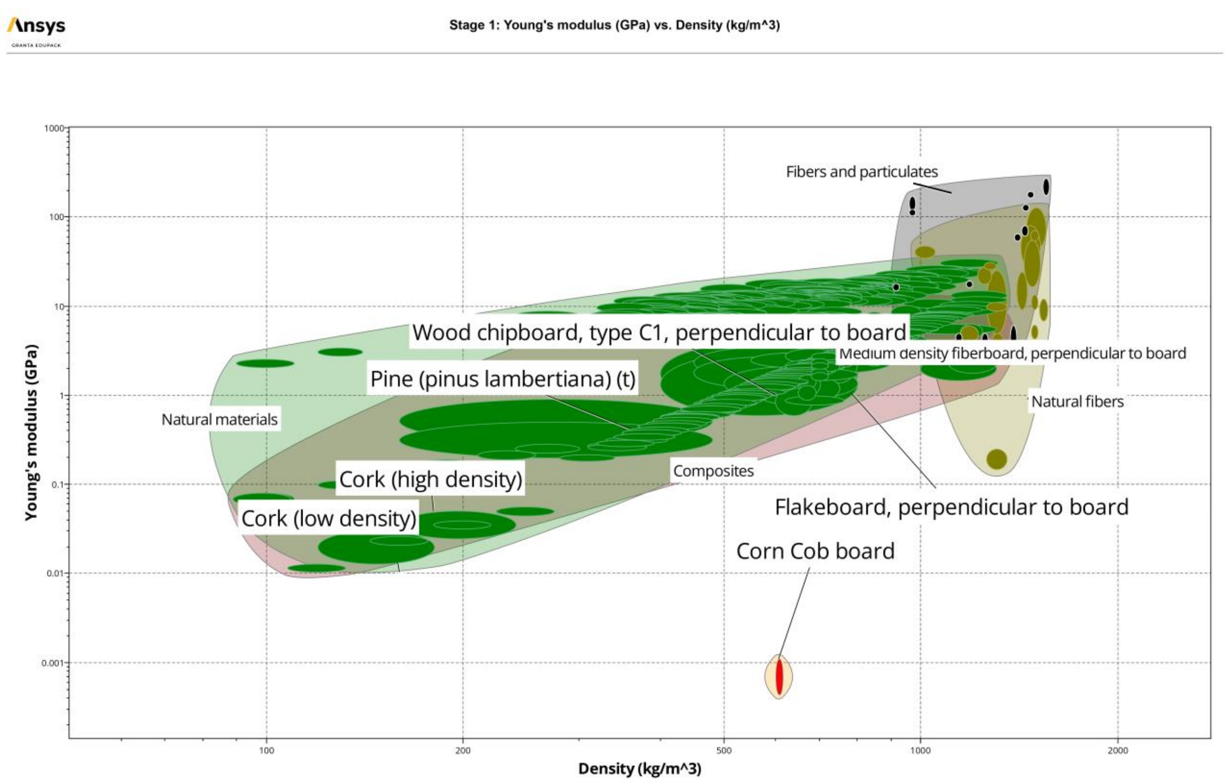


Figure 61: Graph of the Young's Modulus over the density of the cob panel compared to wooden and natural fibrous materials, created in Granta EduPack 2024 R2 (ANSYS Inc,2024)

Based on Young's modulus of the material, the material seems to have a very low strength, which implies that further optimization to the composite is necessary. Currently the material seems to be too weak for the application. The panel is prone to high deflection, approximately 5.5cm which could lead to failure. (See more in Appendix 25). Although with improving the strength by increasing the thickness of the panels or decreasing the length or changing the binder to a stronger adhesive, the panel could be amongst the low-medium density fiber boards.

6.4 Final design

In this chapter the final prototype of the current design is shown with an evaluation respective to the feasibility, viability and desirability criteria. At the end of this chapter the conclusions are drawn whether the design has potential for further development.

6.4.1 Proposal

The final product is envisioned to encompass the custom U-profiles (see 6.1.4) which give support to the acoustic panels, and the panels themselves.

Figure 62: Final design visualization

Figure 63: Prototype of the final design (3 panels framed)

Finally, the panels measure 260 cm * 30 cm * 3 cm* (length * width * depth) for easier assembly and option for customization (colour variations).

The start and end pieces can be ordered separately, so the entire wall can be covered tightly without the gap the half lap joints would cause. So, it would have   finished look.

The Panels come in an initial four-color version Pure", "Walnut”, “White” and “Charcoal (Rubio Monocoat, 2025).

Figure 64: Final colour samples: From left to right, white, pure, walnut and charcoal

6.4.2 Final concept evaluation

The corn cob acoustic panels present a compelling alternative with focus on sustainability, functionality and aesthetics. To have a better overview of the product, the positives and negatives of the project are listed in consideration of feasibility, desirability and viability aspects (see Figure 65). The panels are designed to create a calmer and quieter home environment. Its strength relies in the raw material (corn cobs) which is a widely abundant, inexpensive agricultural waste making the sourcing both cost-effective and environmentally responsible. This reduces the reliance on virgin materials and promotes resource efficiency. The manufacturing process is scalable which allows for potential mass production without the need of extra resources. Unlike synthetic materials these panels do not emit VOCs (volatile organic compounds), contributing to healthier indoor air quality.

The growing demand for eco-friendly products further supports the business viability of the project. Its modern, neutral appearance can complement many different interior design styles, while offering an organic feel that differentiates it from the conventional alternatives. Customizability in colours adds another layer of appeal allowing the end-customers to find a tailored solution to their needs.

However, there are still significant challenges to solve. The use of wood glue provides sufficient adhesion but undermines the possibility of biodegradation at the end-of-life. This raises concerns about the end-of-life disposal, which needs further investigation. Exploring other more sustainable binders could align the product more with the circular design approach. Inconsistencies within the tested material also raise concern affecting the overall mechanical performance of the product. And the moisture and fire resistance need further investigation.

While the natural aesthetic is an asset, it is unique which may not suit all design preferences, limiting the appeal in certain markets. Also, skepticism around durability and longevity may create resistance among consumers in acquiring it.

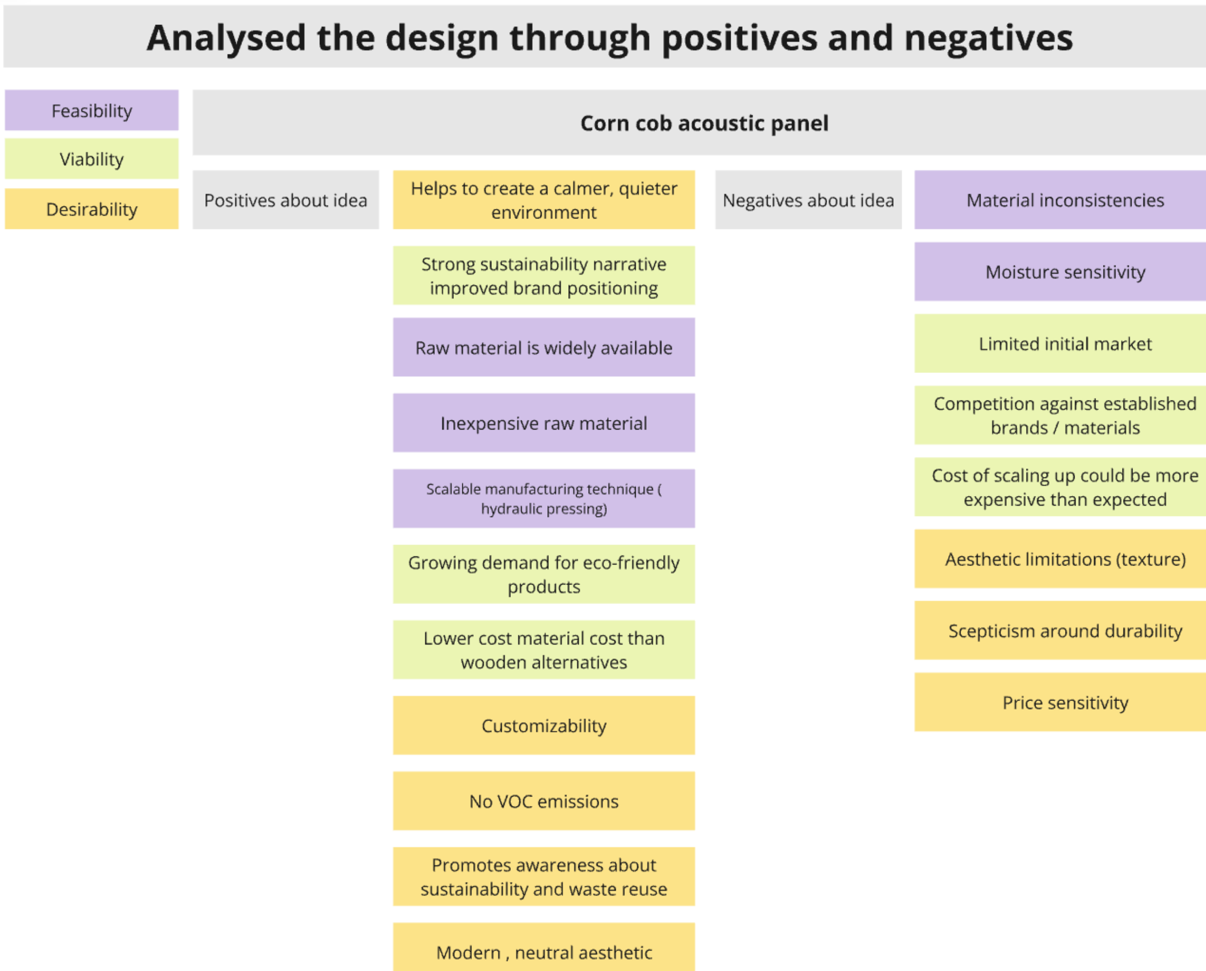


Figure 65: List of positives and negatives of the project based on feasibility, viability, and desirability criteria

As a final evaluation, the corn cob board is rated based on the project criteria, (See figure 66) that reflects on the strengths and the weaknesses of the project. The evaluation table gives an indication whether the project seems to meet the criteria or not in a visual way.

Starting at the top, the project has reached its purpose as it addresses a growing need for sustainable construction materials that reduce the environmental impact. The project aligns well with the circular economy principles by repurposing the agricultural waste. However, there is plenty of space to improve the product from a sustainability perspective. The use of wood glue compromises biodegradability and therefore compromises the natural extraction of potential material / mineral for further use.

Aesthetically the boards are presenting a modern natural look that is generally liked by the consumers, and its natural texture creates a distinctive appearance that can be appealing to eco-conscious consumers. However, the product may not suit all consumer preferences, limiting it from wider adoption.

Regarding the sound absorption capabilities of the product, there were some inconsistencies during the testing phase. But it seems to meet the requirement for the application.

Figure 66: Table of the evaluation

The cob panels at this stage of development meet the minimum criteria of the consumers, but further improvements in structural strength, moisture and fire resistance are necessary to make it a successful product. The cold pressing as manufacturing method provides a feasible production method but the overall process still needs to be optimized to ensure consistent quality through the whole production process.

The cob boards made with wood glue do not emit hazardous levels of volatile organic compounds, which aligns with indoor air quality standards, but full certification and compliance would need further testing and validation. Further testing of the moisture and fire resistance is also required.

The production cost of these panels seems low as materials are inexpensive and the production method is not an energy intensive type. However, there is a potential for the expenses to be higher with the optimization of the product to ensure high quality, and the use of an alternative binder could pose some financial uncertainties.

Ultimately the corn cob panel has a strong potential as a sustainable acoustic solution, but further refinements are needed to address all the concerns raised. By improving the material composition, optimizing the production process and showing the customers the benefits of this product, this project could gain an entrance into the eco-friendly materials market.

7. Discussion

7.1 Results summary

The findings of this project demonstrate that the corn cob board can be used as an acoustic panel. And it offers significant potential to the traditional sound proofing materials. The boards were successfully fabricated using wood glue as an adhesive. Although further studies about the type of adhesive used to create a biodegradable acoustic panel are needed. The density of the material was calculated at around 606.7 kg/m^3. Through mechanical testing, including tensile and bending tests, the material showed unsatisfactory results it has the potential to be a non-load bearing construction material with further material improvement. The panel being relatively lightweight contributes to both ease of transportation and efficiency of installation. Although the variability in mechanical performance of the samples indicates that the material needs further improvement.

Overall, the project has met its core objective to explore the opportunities to whether it is possible to create a functional acoustic panel from corn stover.

7.2 Processing

The processing of the corn cob boards relied on the combination of hot or cold pressing with a binder. The development process included extensive experimentation with different types of biodegradable and non-biodegradable binders, material ratios and pressing parameters to optimize the structural integrity and acoustic properties of the panels. The use of high-pressure and heat binding proved to be very effective in terms of mechanical strength, but it raised challenges in exploiting the natural absorption capacity of the material. In the end a cold pressing method with wood glue as a binder provided adequate bonding strength and sound absorption capabilities.

During production, one of the main difficulties was achieving uniform distribution of the binder throughout the matrix, which impacted the consistency of the boards. The variations in density and mechanical performance between the test pieces suggest that further refinement of mixing and pressing stages are needed.

While the wood glue used for the experiments is not bio-degradable, further studies could explore a bio-based biodegradable adhesive to replace or even enhance the flexibility and durability of the material.

Overall, the processing approach validated the potential of using agricultural waste in industrial applications but also revealed many areas for improvement manufacturing.

7.3 Sustainability

Sustainability remains a central focus of this project, aligning with the goal of creating an eco-friendly acoustic panel that can reduce environmental harm throughout its lifecycle. The use of agricultural waste, namely corn cobs, not only diverts waste from landfills or incineration, but capitalizes on a widely available, underutilized natural resource. This supports the circular economy principles by transforming waste into valuable materials.

However, so far biodegradability as an extra positive feature could not be implemented in the product yet, due to the lack of available binder alternatives.

On the positive side, the energy consumption needed for production is minimized with the cold pressing method. Also, when the panels are compared to the traditional alternatives, the panels present a compelling case for reduced toxicity. While a rigorous life cycle assessment (LCA) is needed to provide further evidence, the panels seem to have a strong potential to contribute to greener building practices.

7.4 Limitations and Recommendation

While the project achieved many of its objectives, several limitations must be acknowledged. Starting with the limited availability of high-performance biodegradable binders. The optimal binder alternatives are not yet commercially available and expensive, which could have highly impacted on the viability of the product. Also because of the lack of materials tested, the results of this research become limited. Inconsistencies in mixing and pressing techniques could have led to the varying material properties during the tensile and bending testing. Addressing these limitations will require cooperation with companies with equipment that provides precise control over the preparation of the samples.

Another limitation was the lack of more comprehensive long-term testing. While the initial results are promising, further testing is needed to evaluate the durability of the panels in different environments, e.g. varying humidity, temperature levels and physical wear.

The recommendation for future research is to explore alternative natural binder that could replace the current adhesive and make the product 100% biodegradable, while it improves the physical strength without compromising the acoustic properties of the material. Furthermore, the scope of sustainability assessment could include assessments related to eutrophication and toxicity related parameters (related to fertilizer and pesticides), the water usage, carbon emissions and energy consumption throughout the entire supply. This could strengthen the adoption of these boards on a commercial level.

Lastly, engaging more with stakeholders like manufacturers and end users could help to identify practical challenges and make further improvement on the product.

7.5 Reflection

This project has been a significant learning experience, highlighting both the opportunities and challenges of developing a sustainable product. The process of designing and testing the corn cob board provided insights into material science and sustainability and about the realities of the industrial production process. While the project achieved many of its goals, it also showed me where my assumptions about the behavior of the material were overly optimistic.

One of the most enjoyable parts of this journey was to see the corn cobs (as waste) turned into a functional product. The iterative experimentation process, although it was time consuming, but gratifying as well. As I could see the panels perform and validate the feasibility of the concept.

Although there were many struggles. For example, with understanding the different material properties and complexities of the binder chemistry required. It was a steep learning curve. There were moments of frustration when the results did not align with expectations. But these challenges taught me to be patient and view setbacks as opportunities to grow from.

This project has not only deepened my understanding of the material science aspect of this project, but I gained valuable knowledge in understanding the relationship between the product and the stakeholders. And about the necessity of understanding the interconnected relationship in serving all stakeholders to make a successful product.

This project has been an interesting journey that has strengthened both my technical and personal skills. This experience has reinforced my passion and belief in sustainable design development. While there is still work to be done on this project, the results can serve as a foundation for further exploration in this area.

8. Conclusion

In conclusion, this project has explored the potential of a corn cob-based acoustic panel as a functional and aesthetically appealing alternative to traditional acoustic materials. The panels achieved sufficient sound absorption to be called an absorbing material (NRC value 0.36) and with further mechanical improvement the concept proves that agricultural waste can be transformed into a valuable resource.

Beyond the technical aspects, the panels have a great aesthetic value with their natural texture and organic appearance, providing a unique design element that aligns with the preferences of the potential end-users. This distinctive visual appeal enhances their desirability for customers who seek sustainable yet stylish materials.

Besides, the panels offer a non-toxic alternative for soundproofing homes, as they do not emit toxic volatile organic compounds (VOC). This project contributes to the circular economy by involving farmers to supply the raw materials and potential end-users who value sustainable design innovations.

While there are still many challenges related to optimizing the material, the project has laid a strong foundation for further development. By merging functionality, sustainability and aesthetics, these panels have the potential to show the way for future design developments where designs not only meet human needs but also respect the environment.

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10. Appendices

Appendix 1:

Traditional acoustic materials:

Rockwool:

Background of the material

Rock wool is made from volcanic stones, like basalt. They are crushed and mixed with limestone and coke. Then it gets loaded in a cupola furnace and in the presence of oxygen, the mix is melted at around 1500 oC. Then the molten rock is fed into machinery which creates fibers (Gallyer, 2001). Resin based binders, water repellent materials and mineral oil are sprayed onto the fibers. Then they are layered in thin sheets on top of each other, pressed and cut-in size. Generally, the density can range between 23-200 kg/m3 (Gallyer, 2001) In the case of the following example this number is 128 kg/m3 (Rockwool, 2023).

Example: Comfortbard 80 from Rockwool (Rockwool, 2022)

Image : Rockwool (ROCKWOOL, 2022)

Material composition: basalt rock and slag (Rockwool, 2022)

Environmental impact: While they claim the product is 100% recyclable (“SECTION 07 21 00 MINERAL WOOL INSULATION,” n.d.) , there is only 40% recycled content in the new products (Rockwool, 2022).

Polyester felt:

Background of the material:

Hollow polyester staple fiber and 4D low-melting point fiber are combined to make the PET nonwoven fabric. Then the fibers are a range of procedures, like blending, lapping and needle-punching. Then multiple layers are layered and bonded together with further needle-punching (Huang et al., 2014).Generally the density can range between 120-250 kg/m3 (GUANGZHOU CHUANGYA ACOUSTIC TECHNOLOGY CO., LTD., 2023)

Example: Cyatco 9mm PET Acoustic Panels Polyester

Image: (CYATCO, 2025)

- Material composition: non-woven PET fabric
- Environmental impact: The product can be made from 60% of recycled content (GUANGZHOU CHUANGYA ACOUSTIC TECHNOLOGY CO., LTD., 2023).

Polyurethane foam:

Background of the material:

This material is made by mixing different kinds of resins and catalysts to create an exothermic reaction which releases the foaming agent in the material that causes it to expand. Generally, they are made in large blocks in a batch production or continuously laid onto a paper or polyethylene substrate in a conveyor belt system. Generally, it has a density between 32-50 kg/m3n (Gallyer, 2001).

Example: FOAM STOP ™ Polyurethane

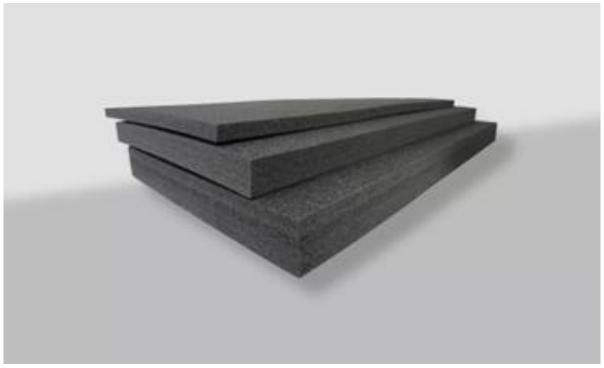


Image: Foam board (Acoustic Surfaces, 2020)

- Material composition: Polyurethane foam 100% percent (Acoustical Surfaces, 2024).

Acoustic performance of the example products:

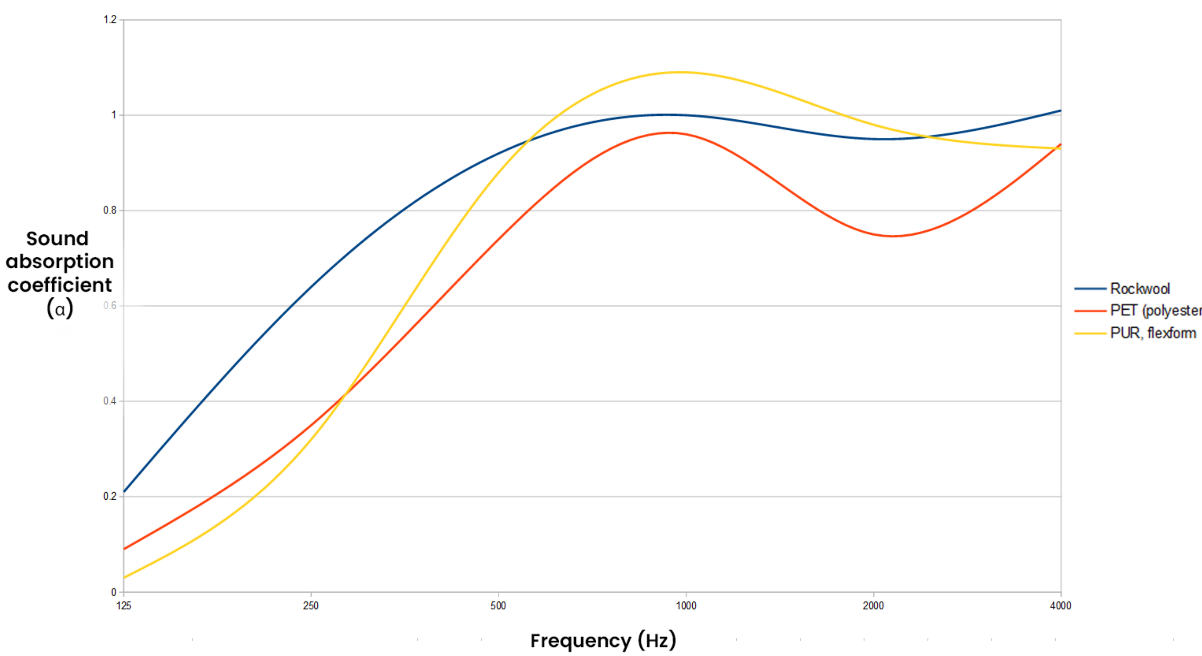


Figure 67: Sound absorption values of Rockwool, Pet polyester and Polyurethane foam

	Thickness	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	NRC
Rockwool	3.81 cm	0.21	0.64	0.92	1	0.95	1.01	0.9
PET wool	0.9 cm	0.09	0.35	0.74	0.96	0.75	0.94	0.64
Polyurethane foam	3.5 cm	0.03	0.32	0.88	1.09	0.98	0.93	0.82

Table 21: NRC values of different materials

Appendix 2:

Acoustic performance of the corn cobs:

Study A: Corn Cob Absorption Rate As Acoustic Material (Sidharta et al., 2022).

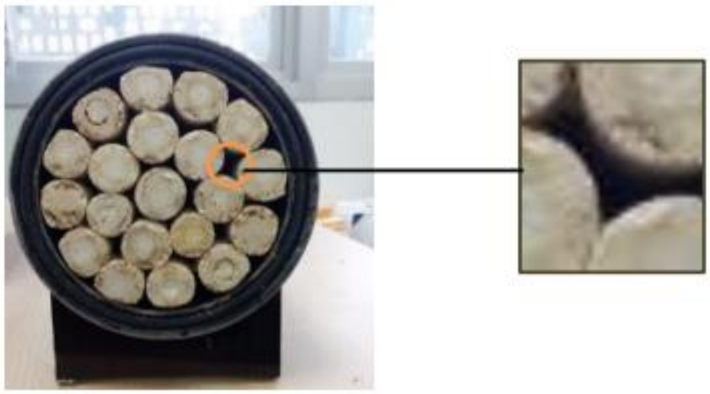


Figure 68: Corn cob samples for acoustic measurements, and the samples in the impedance tube

Thickness	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	NRC
3 cm	0.08	0.10	0.02	0.22	0.95	0.49	0.32

Table 22: NRC values of corn cobs (Sidharta et al., 2022)

Appendix 3:

In the second review (B) that is called: “Impact sound testing of corn cob particle board “(Faustino et al., 2012) Where the noise reduction ability of the material was measured.

Figure 69: Sample of the corn cob board

In this study a 3x100x50 cm board was created by mixing corn cob particles and wood glue in a 4:1 ratio in terms of weight. Then the mixture was molded and de-molded (Faustino et al., 2012).

This way the average density of the board was 334 kg/m3, which is similar to cork.

Two experiments were conducted.

Average impact noise in the receiving room with the panel. To measure the transmission of impact noise from room to room, another experiment was performed, where the Sound transmission class (STC) was measured by following the standards of NP EN ISO 140-7 (Faustino et al., 2012).

Thickness	Reduction value in (dB)						STC
	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	
3 cm	0.6	5.8	16.8	27.0	32.8	39.3	21.75 dB

Table 23: Noise reduction values of the corn cob board (Faustino et al., 2012)

By analyzing the numbers, I have calculated an average of 21.75 dB noise reduction, but the study claims a 30 dB gain in terms of impact sound insulation when the panel is placed on the floor of the emitting room (Faustino et al., 2012). The study also concludes that there is an acoustic potential of this kind of product and recommends further research in the subject (Faustino et al., 2012).

Appendix 4:

The measurements were performed with the aid of an impedance tube.

Figure 70: Impedance tube and the samples

The NRC value is calculated from taking the values of 125 Hz, 250 Hz, 500Hz, 1000 Hz, 2000Hz, 4000Hz and they calculate the average value of these numbers. In this experiment the measurements were taken until 1600 Hz, so the NRC value was calculated according to this limit. Therefore, the measurements represent only an approximation rather than a definitive value.

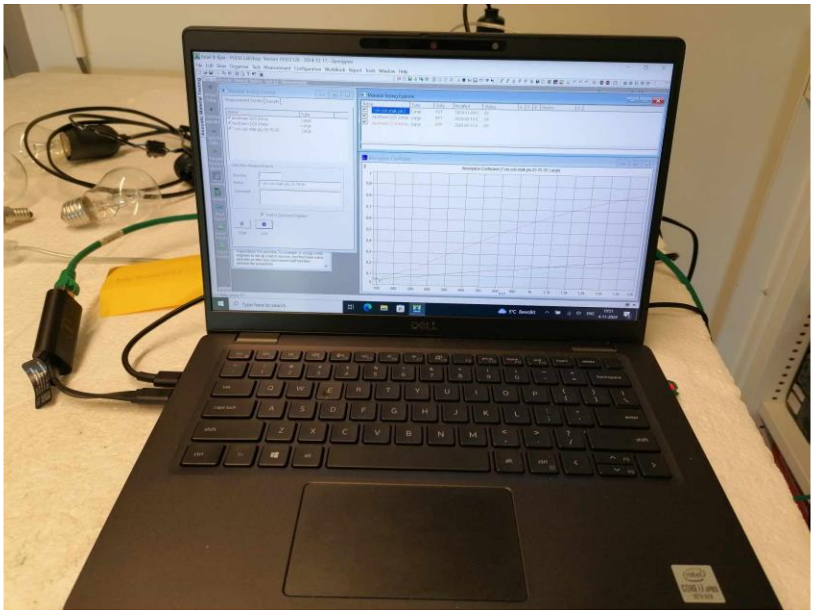


Figure 71: Laptop with the acoustic measuring software

The project set-up:

Tube	
Type	Large
Microphone Spacing:	0,05 m
Distance to Sample from Mic. B, Pos. 3:	0,1 m
Distance to Source from Mic. A, Pos. 2:	0,15 m
Diameter:	0,100 m
Lower Frequency Limit:	50 Hz
Measurement	
Lines	800
Span	1.6 kHz
Averages	150
Zoom	FALSE
Centre Frequency (Hz):	800,0
Generator	
Generator Active	TRUE
Waveform:	Random
Signal Level:	2,000 Vrms

Pink Filter:	Off
Environment	
Atmospheric Pressure:	1013,25 hPa
Temperature:	22,00 °C
Relative Humidity:	40,0 %
Velocity of Sound: 344,41 m/s	
Density of Air: 1,194 kg/m³	
Characteristic Impedance of Air: 411,2 Pa/(m/s)	
Options	
Signal-to-Noise Ratio below:	10,0 dB
Autospectrum (Max-Min) above:	60,0 dB
Calibration Factor exceeds:	2,0 dB
Calibration Factor exceeds:	2,0 degrees
Transfer Function Estimate:	H1

Table 24: Set-up of the impedance tube

The values at given frequencies:

Name:	1 cm cob stalk pla 0-100-30	1 cm cob stalk pla 100-0-30	1 cm cob stalk pla 25-75-30	1 cm cob stalk pla 50-50-30	1 cm cob stalk pla 75-25-30	1 cm cob wood glue 87-23 control
TubeType:	Large	Large	Large	Large	Large	Large
Date:	04/11/2024	04/11/2024	04/11/2024	04/11/2024	04/11/2024	04/11/2024
Time:	11:02	10:55	09:24	10:58	11:00	11:05
f (HZ)	Real Part	Real Part	Real Part	Real Part	Real Part	Real Part
0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
125	0.007347	-0.011492	0.023502	0.004679	-0.005273	0.000642
250	0.038592	0.029763	0.046153	0.042093	0.030799	0.040444
500	0.048630	0.069826	0.052422	0.095278	0.049276	0.068729
1000	0.102760	0.221750	0.126690	0.272700	0.134380	0.157640
1600	0.101860	0.246620	0.112970	0.086422	0.304310	0.607370

Table 25: Sound absorption values of the samples at given frequencies

Appendix 5:

The initial idea was to make a sample with 3 cm thickness.

Because of the volume of the particles before compression, the materials were reduced to 85% to fit the mould.

The chosen manufacturing process was heat pressing which involved pre-treating the mixture and warm it up to a 100 °C for 15 minutes and then placing it in the heat press for an additional 15 minutes at 170 °C under 8,6 MPa pressure.

The exact calculation of the material needed for the samples can be found in. Table 6 shows used materials in grams and the result of how thick the samples become.

The formula for the volume of a cylinder is:

Where:

is the radius of the base of the cylinder

is the height of the cylinder

is a mathematical constant

So, the volume of the sample needs to be:

V=r2* π*h

r= radius

h=height

V= 235.62cm3

To calculate the amount of materials needed, the material density of the two materials were considered.

Cobs: 1g/cm3

PLA: 1.24g /cm3

From this average density of the end product can be calculated: (1 g/cm3*X%)+(1.24 g/cm3*Y%)=Z g/cm3 where X and Y are defined values.

From the volume, the estimated total mass can be calculated. V* ρ =m where V is the volume of the sample, the ρ is the average density, and the m represents the estimated mass. This gave an indication of the mass of materials that are going to be needed.

Calculations of the individual samples.

Sample 1:

Avg density 70/30 = (1*0.5)+(1.24*0.5)= 1.12 g/cm3

Estimated total mass = 235.62 cm3 * 1.12 g/cm3= 263.9 g

cobs= 263.9 g * 0.5 = 131.95 g

PLA= 263.9 g * 0.5= 131.95 g

In ideal scenario, 131.95 g of cobs and PLA would be needed for the required volume, but this calculation does not account for possible air gaps within the sample. For this reason, 85% of the materials were used to create the sample.

85% - cobs: 112.16 g

- PLA: 112.16 g

Sample 2:

Avg density 70/30 = (1*0.6)+(1.24*0.4)= 1.096 g/cm3

Estimated total mass = 235.62 cm3 * 1.096 g/cm3= 252.58 g

cobs= 252.58 g * 0.6 = 151.55 g

PLA= 252.58 g * 0.4= 85.88 g

85% - cobs: 128.81

- PLA: 72.998

Sample 3:

Avg density 70/30 = (1*0.7)+(1.24*0.3)= 1.072 g/cm3

Estimated total mass = 235.62 cm3 * 1.072 g/cm3= 252.58 g

cobs= 252.58 g * 0.7 = 176.8 g

PLA= 252.58 g * 0.3= 75.8 g

85% - cobs: 150.3

- PLA: 64.43

Sample 4:

Avg density 70/30 = (1*0.8)+(1.24*0.2)= 1.048 g/cm3

Estimated total mass = 235.62 cm3 * 1.048 g/cm3= 252.58 g

cobs= 252.58 g * 0.8 = 202.06 g

PLA= 252.58 g * 0.2= 50.52 g

85% - cobs: 171.75

- PLA: 42.94

Sample 5:

Avg density 70/30 = (1*0.9)+(1.24*0.1)= 1.024 g/cm3

Estimated total mass = 235.62 cm3 * 1.024 g/cm3= 252.58 g

cobs= 252.58 g * 0.9 = 227.32 g

PLA= 252.58 g * 0.1= 25.26 g

85% - cobs: 193.22

- PLA: 21.47

Appendix 6:

With the use of lignin and cellulose acetate some additional considerations had to be done. The processing time in both cases were 15 minutes, but the processing temperature of the lignin was 180 °C where the lignin starts to melt and in case of the cellulose acetate, 160 °C was used as in the safety sheets it was highlighted that above 180 °C CO and CO_2 can be released which could be potentially dangerous. So, to avoid that, the temperature was lowered to stay in a safe zone. The aim was to find out how these materials could behave as a binder in this application.

Sample 6:

Volume = 235.62cm3

Cob + dealkaline lignin

Avg density 70/30 = (1*0.7)+(1.3*0.3)= 1.09 g/cm3

Estimated total mass = 235.62 cm3 * 1.09 g/cm3= 256.82 g

cobs= 256.82 g * 0.7 = 179.77 g

lignin= 256.82 g * 0.3= 77.05 g

To account for the air gaps, 85% of the materials were considered to fill the desired volume.

85% - cobs: 152,8045

- lignin: 65,4925

And to get a 1 cm thick 10 cm diameter disk, the third of the material had to be calculated.

33.3% - cobs: 59.86 g

- lignin: 25.66 g

Sample 7:

Cob + cellulose acetate

Avg density 70/30 = (1*0.7)+(1.25*0.3)= 1.075 g/cm3

Estimated total mass = 235.62 cm3 * 1.075 g/cm3= 253.3 g

cobs= 253.3 g * 0.7 = 177.31 g

cellulose acetate= 253.3 * 0.3= 76 g

85% - cobs: 150,7135

- cellulose acetate: 64,6

33.3% - cobs: 59.04 g

- Cellulose acetate: 25.3 g

Appendix 7:

To get an apporximately 1 cm thick disk, 1/3 of the materials needed compared to the original amount of material / volume. The corn cobs and corn stalks were pre-conditioned at 100 °C for 15 minutes and then the samples were processed at 170 °C for 15 minutes under 8,6 MPa pressure.

Sample 8

Volume = 235.62cm3

Cob+PLA

Avg density 70/30 = (1*0.7)+(1.24*0.3)= 1.072 g/cm3

Estimated total mass = 235.62 cm3 * 1.072 g/cm3= 252.58 g

cobs= 252.58 g * 0.7 = 176.8 g

PLA= 252.58 g * 0.3= 75.8 g

And its 33% is:

33.3% - cobs: 52.99

- stalks: 0
- PLA: 25.23

Sample 9

Volume = 235.62cm3

Cob+stalk+PLA

Avg density 75/25 = (1*0.525)+(1.42*0.175)+(1.24*0.3)= 1.1455 g/cm3

Estimated total mass = 235.62 cm3 * 1.1455 g/cm3= 269.9 g

cobs= 269.9 g * 0.525 = 141.7 g

stalks= 269.9 g * 0.175= 47.23g

PLA= 269.9 g *0.3= 80.97 g

33.3% - cobs: 47.18

- stalks: 15.73
- PLA: 26.96

Sample 10

Volume = 235.62cm3

Cob+stalk+PLA

Avg density 70/30 = (1*0.35)+(1.42*0.35)+(1.24*0.3)= 1.219 g/cm3

Estimated total mass = 235.62 cm3 * 1.219 g/cm3= 287.22 g

cobs= 287.22 g * 0.35 = 100.53 g

stalks= 287.22 g * 0.35= 100.53g

PLA= 287.22 g *0.3= 86.16 g

33.3% - cobs: 33.47

- stalks: 33.47
- PLA: 28.7

Sample 11

Volume = 235.62cm3

Cob+stalk+PLA

Avg density 25/75 = (1*0.175)+(1.42*0.525)+(1.24*0.3)= 1.2925 g/cm3

Estimated total mass = 235.62 cm3 * 1.2925 g/cm3= 304.54 g

cobs= 304.54 g * 0.175 = 53.29 g

stalks= 304.54 g * 0.525 = 159.9 g

PLA= 304.54 g *0.3= 91.36 g

33.3% - cobs: 17.74

- stalks: 53.2467

- PLA: 30.42

Sample 12

Volume = 235.62cm3

Stalk+PLA

Avg density 0/100 = (1.42*0.7) +(1.24*0.3) = 1.366g/cm3

Estimated total mass = 235.62 cm3 * 1.366/cm3= 321.85 g

Stalks= 321.85 g * 0.7 = 225.3 g

PLA= 321.85 g *0.3= 96.55 g

To adjust to the potential air gaps, 85% of the materials were taken into consideration. (85% - stalks: 191.5 g and PLA: 82.06 g)

And then the 3rd of the materials resulted in a 1 cm thick board to which 63.2 g of corn stalk and 27.08 g of PLA were used.

Appendix 8:

The machine was set up the following way:

Type	Large
Microphone Spacing:	0,05 m

Distance to Sample from Mic. B, Pos. 3:	0,1 m
Distance to Source from Mic. A, Pos. 2:	0,15 m
Diameter:	0,100 m
Lower Frequency Limit:	50 Hz
Measurement	
Lines	800
Span	1.6 kHz
Averages	150
Zoom	FALSE
Centre Frequency (Hz):	800,0
Generator	
Generator Active	TRUE
Waveform:	Random
Signal Level:	2,000 Vrms
Pink Filter:	Off
Environment	
Atmospheric Pressure:	1013,25 hPa
Temperature:	22,00 °C
Relative Humidity:	40,0 %
Velocity of Sound: 344,41 m/s	
Density of Air: 1,194 kg/m³	

Characteristic Impedance of Air: 411,2 Pa/(m/s)	
Options	
Signal-to-Noise Ratio below:	10,0 dB
Autospectrum (Max-Min) above:	60,0 dB
Calibration Factor exceeds:	2,0 dB
Calibration Factor exceeds:	2,0 degrees
Transfer Function Estimate:	H1

Table 20: Set-up of the impedance tube

Appendix 9:

The area of the panel is 0.093 m², thickness is 12 mm, GWP is 1.045 kg CO_2 eq per panel. If we add the surface weight of 1.9 kg/m², we can calculate the weight of one panel.

One panel (m)= 0.093m²×1.9kg/m²=0.1767kg

So, one panel weighs 0.1767kg. And knowing this value the total GWP emission could be calculated for 1 kg of material.

1.045kg CO_2 eq/ 0.1767 kg = 5.92 CO_2 eq

5.92 CO_2 eq * (2.4*0.75) = 10.7 CO_2 eq

5.92 CO_2 eq * (4*0.75) = 17.8 CO_2 eq

Appendix 10:

The global warming potential of the corn cob board was calculated in the study (Thermal performance and life cycle assessment of corn cob particleboards) (Ramos et al., 2021).

In the study they created two boards. The first was made with FAG222 resin and the second with PVA. The first weighs 26.2 kgs while the second weighs 13.31kg.

According to the study the version with the FAG222 binder when incinerated generates 7.66 kg CO_2 eq while it is disposed to the landfill it generates 53.2 kg CO_2 eq. And the version with the PVA glue, when incinerated it generates 84.9 kg CO_2 eq and when disposed to landfill it generates only 27.5 kg CO_2 eq. From this we can calculate how much CO_2 eq is generated by only 1 kg of the products by dividing the emissions with the weights of the boards.

Then we will get the result for:

- Corn cobs + FAG222 incineration: 0.292 kg CO_2 eq
- Corn cobs + FAG222 landfill: 2.03 kg CO_2 eq
- Corn cobs + PVA incineration: 6.37 kg CO_2 eq
- Corn cobs + PVA landfill: 2.06 kg CO_2 eq

For 1 m^2 and 3 cm thick board where the density is 607 kg/m^3 , the mass is 18.21 kg.

From this the following can be calculated:

Corn cobs + FAG222 incineration: 36.96 kg CO_2 eq

Corn cobs + FAG222 landfill: 5.32 kg CO_2 eq

Corn cobs + PVA incineration: 116.03 kg CO_2 eq

Corn cobs + PVA landfill: 116.03 kg CO_2 eq

Appendix 11:

Results of the online survey

1: What is your age range?

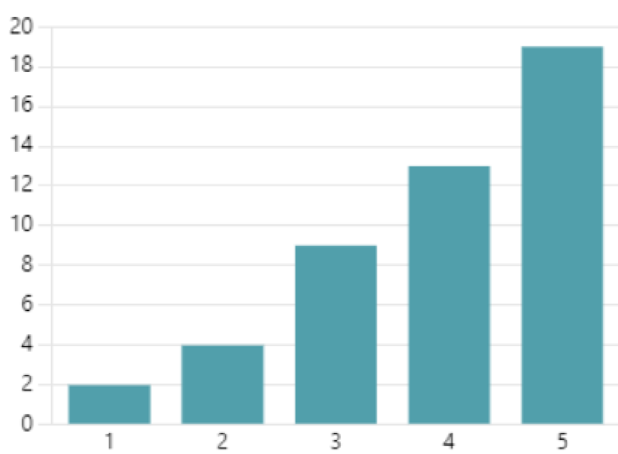
18-24	4
25-34	14
35-45	17
46-55	6
56+	6

2: What best describes your living situation?

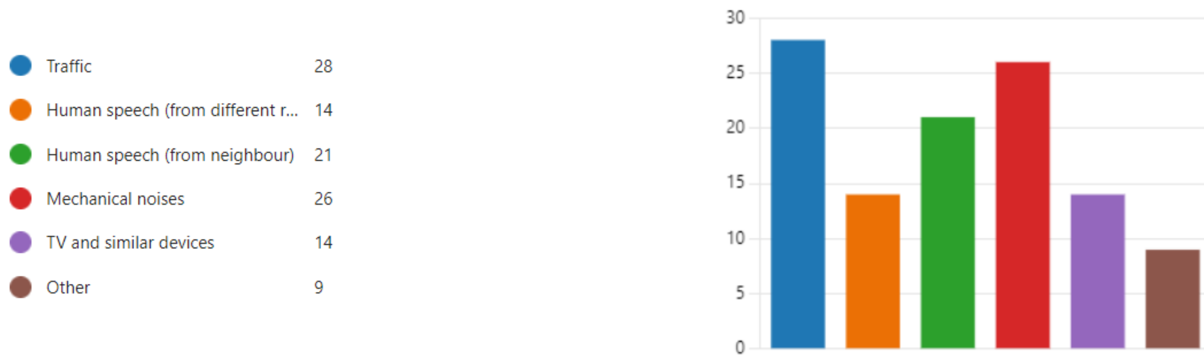
3: How often do you experience noise issues at home?

4: When do you experience most of the noise?

5: How important is noise reduction to you when it comes to your home? 1: Not important - 5: Very important



6: What kind of noises do you usually hear?



7: Have you considered buying acoustic panels to improve the acoustics and noise insulation of your living spaces?

8: If yes, what have you considered or bought already and why?

1	anonymous	i haven't bought any yet, because i haven't found any option i liked. and also the price is another factor i didn't like
2	anonymous	Considered to buy sponge panels
3	anonymous	Not jet. The air noise is to much next to wentillator.
4	anonymous	My husband bought them for his studio
5	anonymous	I bought a few for my music studio
6	anonymous	I've considered one or two times adding decorative soundproof panels to the walls of the bedroom, to blocking snoring noise a bit more
7	anonymous	We haven’t bought it because it is too expensive. But we were looking at the MuteBoard 4 panels.
8	anonymous	Not yet decided, probably wooden acoustic panels
9	anonymous	Working with insulation I use to do soundproofing in different ways/different products.

10	anonymous	Paneles
11	anonymous	Considere to buy, accustic wall , wood, grey colour , to avoid noise from other rooms for.ex kitchen bathroom
12	anonymous	I havent even get the amount of money that requires to start a proyecto like that.
13	anonymous	As a veteran Industrial Designer I feel like you're inventing a problem to solve. There are real problems in this world that you can focus on. Mio Design and Michael D2lo have done this project, and many designers before them. You should read Design for the Real World, if you haven't already. Or if you're set in stone, make it unique and actually useful. Maybe incorporate Biotechture. Like a living wall. ;-)

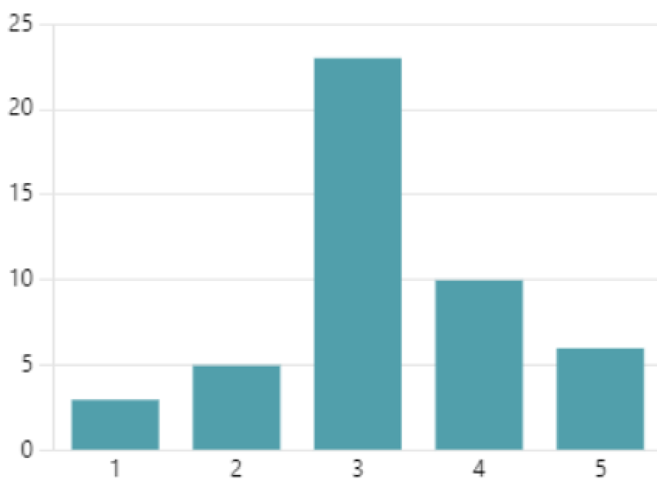
9: If you have disliked anything in the product what you bought. What was it?

1	anonymous	I didn't bought any
2	anonymous	Nothing at all
3	anonymous	N/A
4	anonymous	It's either thick , expensive or useless.
5	anonymous	Price
6	anonymous	I have hung a drapery, or an attractive blanket on the wall. Was slightly worried about flammability. Also, I believe that sustainability is designing something that is of a quality that last a long time. Maybe even something that can be passed down the family tree. Products that don't need to exist, even if they are so-called green usually have a lot of energy put into their production and quickly become waste. Read Cradle to Cradle & natural capital.

10: Which factors are most important to you when considering soundproofing solutions?

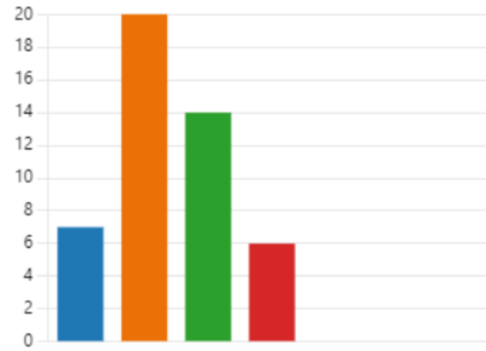
11: Would you prefer a product made from 100% biodegradable materials?

12: How willing are you to pay more for an eco-friendly product? 1: Not willing- 5: Very willing



13: What is the maximum you'd be willing to pay for an acoustic panel for one room (1 wall of 4 m long room. approximately 15 m^2)?

●	Less than 100 eur	7
●	100 - 250 eur	20
●	250 - 500 eur	14
●	500 - 1000 eur	6
●	1000 - 1500 eur	0
●	1500 - 2000 eur	0
●	More than 2000 eur	0



14: Where would you prefer to buy soundproofing products?

●	Home improvement stores (e.g.,...	15
●	Online (e.g., Amazon)	11
●	Specialty interior design stores	1
●	Direct from manufacturer (onlin...	20

15: How do you feel, what is your biggest challenge when it comes to soundproofing your home?

1	anonymous	probably noise coming from the street would be harder to reduce because of the windows
2	anonymous	Looking for a product that can convince me
3	anonymous	Money and space
4	anonymous	The options available only for musicians
5	anonymous	Money and space
6	anonymous	Making room for the job
7	anonymous	The surrounding noises don't bother me that much, to be fair, though sometimes I can hear the neighbor, so I assume he can hear us as well. The biggest challenges are probably the price and appearance.
8	anonymous	Budget
9	anonymous	I don't know how to install them properly
10	anonymous	All frequency destroying (white moise)

11	anonymous	exclude traffic noise
12	anonymous	Proper measurement and installation
13	anonymous	Cost and fear that it won't perform well enough vs. investement made
14	anonymous	It would be price if I need to get soundproofing.
15	anonymous	the whole job that it will involve
16	anonymous	That they really work
17	anonymous	Nice and silent
18	anonymous	Ours is the price
19	anonymous	Small space, extraordinary layout of apartment, price.
20	anonymous	Being certain about the result - will it meet the expectations
21	anonymous	Pricing / efficiency / Thickness of soundproofing
22	anonymous	Soundproofing is not always solved by walls but mostly floors, doors and windows. Acoustics would be something I would use these panels for. Less reverb in a room for example
23	anonymous	Lack of a decision to do it
24	anonymous	Peace
25	anonymous	real solution without thought through design
26	anonymous	Money
27	anonymous	I know nothing about it - I would need a good guidance when choosing the right fit for me and my home
28	anonymous	I’m not the owner of the flat where I live
29	anonymous	Just to have a basic understanding of the system, and to get know the market and the options.
30	anonymous	Money Is very expensive

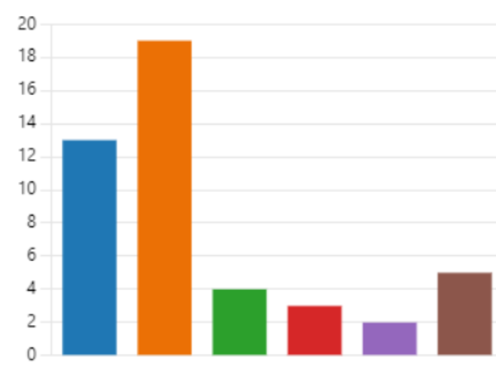
31	anonymous	To make it soundproof
32	anonymous	Most of the noize is coming through the window even if closed.
33	anonymous	Having my kids wear the sound proofing.
34	anonymous	Good materials available
35	anonymous	To find the best most effective product
36	anonymous	How to secure it without minimal ewuipmwnt and no knowledge

16: Where do you most need sound absorption in your home?

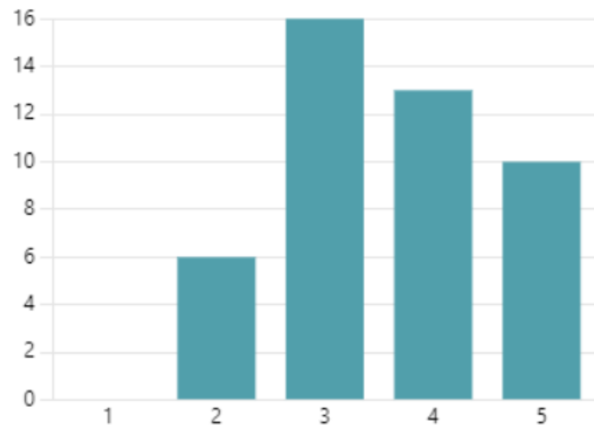
Living room	10
Bedroom	29
Home office	6
Shared spaces	1

17: What style best suits your interior design preferences for acoustic panels?

Modern	13
Minimalist	19
Rustic	4
Industrial	3
Romantic	2
Other	5



18: How would you balance the importance of aesthetics and functionality in your decision to purchase an acoustic panel? 1: More focused on aesthetics - 5: More focused on functionality



19: Which colour palette would you prefer for acoustic panels in your home?

Neutral tones	26
Bold (colours)	2
Bold colours (dark)	3
Earthy shades	12
Other	2

20: What surface texture would you find most appealing for an acoustic panel?

Smooth	17
Textured	9
Natural fiber appearance	14
Added pattern	1
Other	5

21: Would you prefer acoustic panels in standard rectangular sizes, or would you be interested in custom shapes or sizes

Standard sizes	14
Custom shapes	15
Modular panels	16

22: Do you prefer acoustic panels that require professional installation, or would you rather have a DIY-friendly option?

Professional installation	10
DIY installation	34

23: What type of installation method would you prefer for acoustic panels?

Wall mounting with adhesive	28
Wall mounting with frame attac...	16

Appendix 12:

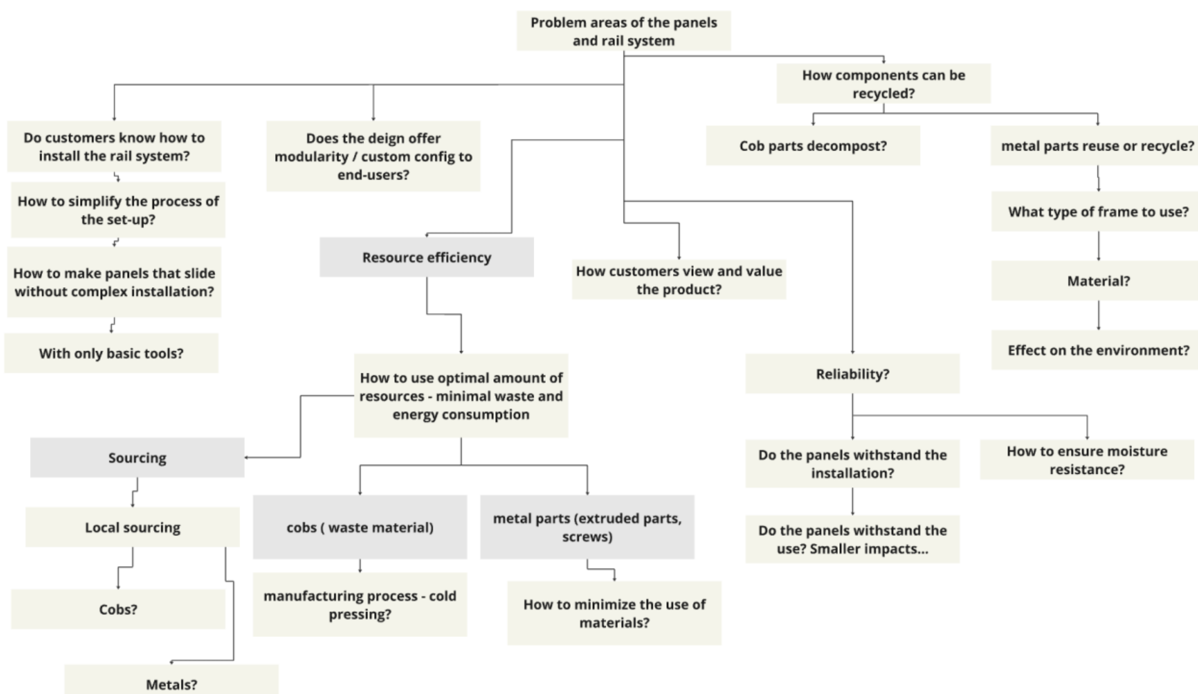


Figure 72: Mind map, identifying the problem areas

Appendix 13:

Experimental characterization	10 participants

Performative

How do you tough the material?		How do you touch the material		How do you hold the material?	
Pressing	xxxxxx	folding	x	holding	xxxxxx xx
rubbing	xxxxxx x	lifting	xxxxxx xx	seizing	
grazing	xxxx	weighing	xxxxx	pinching	
compressing	xxxx	bending		grabbing	xxxxx
poking	xx	flexing		grasping	
caressing		picking	xxx		
fiddling		squeezing	xxx		
pounding		smelling	xxxxxx		
pushing	xx				

Figure 73: Performative test results

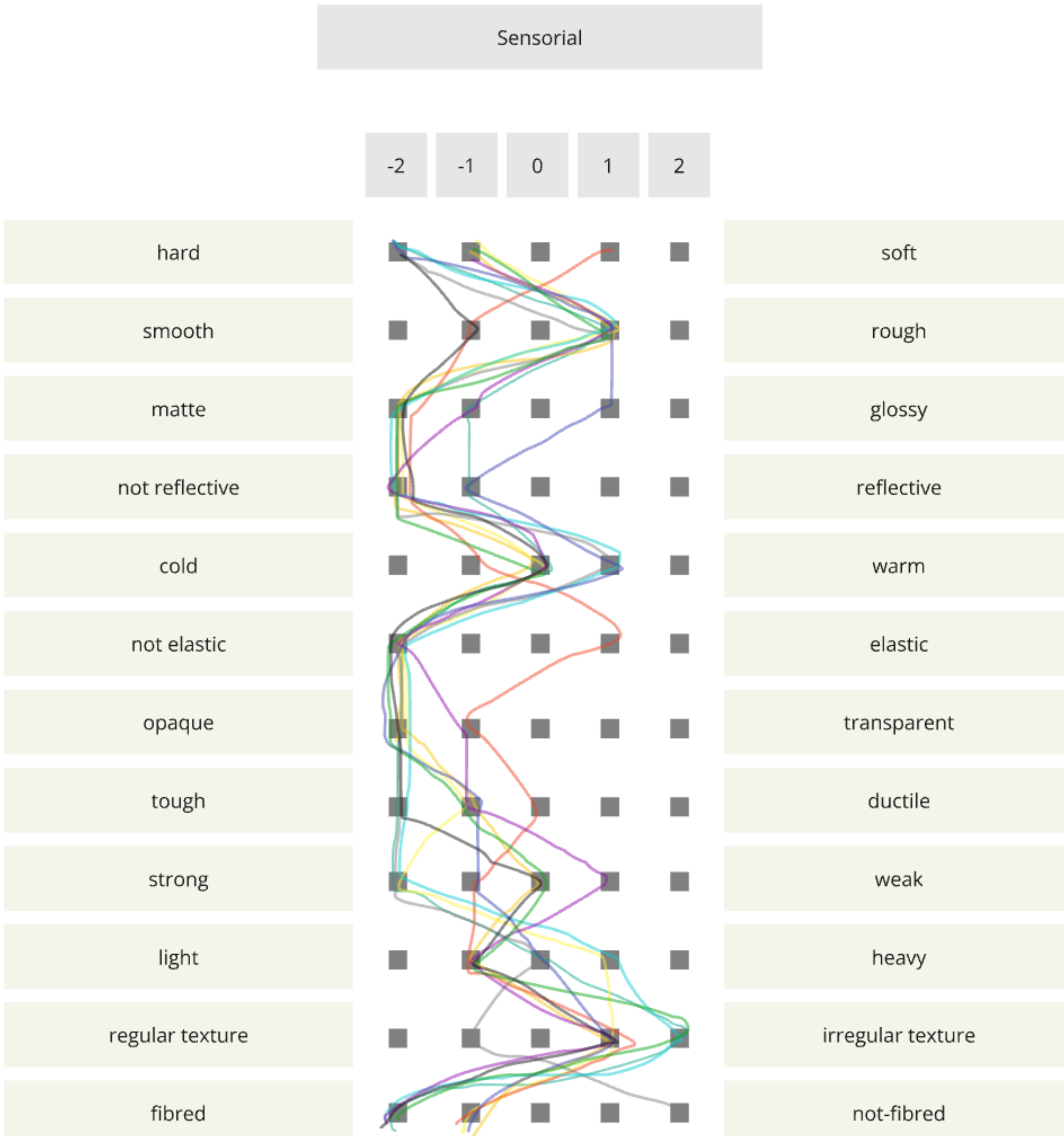


Figure 74: Sensorial test results

Interpretive	
How would you describe it?	
Natural	xxxxxxxx
Manufactured	xxx
thinking of food	x
calm	xxxx
hand crafted	xxxx
strange	x
nostalgic	x
aggressive	xx
sober	x
cosy	x
masculine	x
neutral	x
vulgar	x

Figure 75: Interpretive test results

Appendix 14:

To create the prototypes mentioned in Table 16, first the exact values of the individual materials needed to be calculated.

First the sample with the corn cobs and PLA.

To estimate the materials needed, the desired volume needs to be calculated. Then with calculating the average density of the mix, the total mass can be estimated in an ideal fully compressed scenario. The first calculations were tailored to a 3 cm thick sample.

Cylindrical shape (cobs + PLA)

Calculation

Volume = 5*5*pi*3= 235.62cm3

Cob+PLA

Avg density 70/30 = (1*0.7) +(1.24*0.3) = 1.072 g/cm3

Estimated total mass = 235.62 cm3 * 1.072 g/cm3= 252.58 g

cobs= 252.58 g * 0.7 = 176.8 g

PLA= 252.58 g * 0.3= 75.8 g

The material was pressed under 1250 psi pressure, on 170 °C degrees for 15 minutes.

Once the part was de-molded, it turned out that final volume was approximately 15% higher than the ideal scenario. This happened because the calculation was not accounting for the air pockets that possibly stay within the structure of the sample.

For this reason, 85 % of the materials were calculated and another test piece was created.

85% - cobs: 150,28 g

- PLA: 64,43 g

To get a 1 cm thick panel the 33.3% of the materials were calculated with are:

- Cobs: 49.95 g

- PLA: 21.26 g

Then the version with the corn stalks and PLA were created with the same manner. Only the calculation needed to be adjusted to the density of the corn stalks.

Cylindrical shape (stalk + PLA)

Calculation

Volume = 5*5*pi*3= 235.62cm3

Stalk+PLA

Avg density 0/100 = (1.42*0.7) +(1.24*0.3) = 1.366g/cm3

Estimated total mass = 235.62 cm3 * 1.366/cm3= 321.85 g

Stalks= 321.85 g * 0.7 = 225.3 g

PLA= 321.85 g *0.3= 96.55 g

To adjust to the potential air gaps, 85% of the materials were taken into consideration. (85% - stalks: 191.5 g and PLA: 82.06 g)

And then the 3rd of the materials resulted in a 1 cm thick board to which 63.2 g of corn stalk and 27.08 g of PLA were used.

Figure 76: Sample of a 0.5 cm corn stalk and PLA sample

For the 0.5 cm thickness sample 31.6 g of corn stalk and 13.54 g of PLA were used.

Then the versions with the use of corn cobs and wood glue come.

This version used a cold pressing method. The materials were mixed, loaded in the press, and under 1250 psi pressure it was compressed for 30 minutes, until the wood glue set strong enough to be able to remove the sample from the mold.

To find out the mixing ratio, first the volume of the corn cobs was calculated that in ideal scenario would fit into the desired volume.

Calculation

Volume = 5*5*pi*3= 235.62cm3

Cob + Wood glue

Density = 1 g/cm3

Estimated total mass = 235.62 cm3 * 1 g/cm3= 235.62 g

To account for the probable air gaps, 85% of the material was calculated, which is 200.3 g. As the wood glue is a fluid, and the water content that gives its volume is evaporating with the drying process, an additional approximately 23% of the weight of the cobs were calculated and added to the mix, which is 46.06 g.

When the prototype was ready, it turned out that with the cold pressing method the structure of the cob pieces was not shrinking as much as during the hot pressing. This resulted in an approximately 16.6% increase in volume or in other words 5 mm increase in thickness.

Considering these results, the measurements needed to be adjusted to achieve the results for 1 and 2 and 3 cm thickness samples.

3.5 cm -> 100%

1 cm-> X%

100/3.5= 28.57% of the materials are needed for a 1 cm thick sample.

200.3 g *0.2857= 57.23 g of cobs

46.06*0.2857= 13.24 g of wood glue was mixed.

For a 2 cm thick sample 114.46 g of cobs and 26.48 g of wood glue were mixed and for getting a 3 cm thick sample 171.7 g of cobs and 39.72 g of wood glue were mixed.

Due to the manual processing, and the fluctuating pressure during processing, the samples slightly varied from the expected results.

Figure 77: Corn cob and wood glue sample

The sample that intended to be 2 cm thick, became 2.2 cm thick, and the version that should have been 3 cm thick, ended up being 2.7 cm thick. The compression seems heavily dependent on providing constant pressure of 8,6 MPa, without fluctuation.

Appendix 15:

Measurements of the second batch at given frequencies:

Name:	1 cob stalk pla 100-0-30 v2	1cm cob stalk pla 0-100-30 v2	1cm cob stalk pla 25-75-30 v2	1cm cob stalk pla 25-75-30 v3	1cm cob stalk pla 50-50-30 v2	1cm cob stalk pla 75-25-30 v2	1cm cob wood glue 77-23 v2
TubeType:	Large	Large	Large	Large	Large	Large	Large
Date:	04/11/2024	04/11/2024	04/11/2024	04/11/2024	04/11/2024	04/11/2024	04/11/2024
Time:	12:35	12:51	12:45	12:48	12:42	12:38	12:56
f (HZ)	Real Part	Real Part	Real Part	Real Part	Real Part	Real Part	Real Part

0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
125	-0.007019	-0.016641	-0.013901	-0.014504	-0.008561	-0.013257	-0.013428
250	0.029506	0.025251	0.025630	0.025135	0.028456	0.027161	0.032089
500	0.050880	0.042989	0.046805	0.047609	0.043273	0.060945	0.062348
1000	0.164630	0.055487	0.105700	0.095008	0.105280	0.219450	0.185190
1600	0.282070	0.091265	0.073100	0.073448	0.142680	0.133930	0.776010

Table 26: Sound absorption values of the samples at given frequencies

Results of the first batch of samples

	NRC value
1 cob stalk pla 100-0-30 v2	0.110557
1cm cob stalk pla 75-25-30 v2	0.117984
1cm cob stalk pla 50-50-30 v2	0.085578
1cm cob stalk pla 25-75-30 v3	0.066199
1cm cob stalk pla 0-100-30 v2	0.055954
1cm cob wood glue 77-23 v2	0.206041
Akotherm D20 20mm	0.153654

Table 27: Summary of the absorption values

Appendix 16:

Measurements of the third batch at given frequencies:

Name:	2.5 cm cob pla 50-50	2.5 cm cob pla 60-40	2.5 cm cob pla 70-30	2.5 cm cob pla 80-20	2.5 cm cob pla 90-10
TubeType:	Large	Large	Large	Large	Large
Date:	04/11/2024	04/11/2024	04/11/2024	04/11/2024	04/11/2024
Time:	11:08	11:10	11:12	11:15	11:17
f (HZ)	Real Part	Real Part	Real Part	Real Part	Real Part
Name:	2.5 cm cob pla 50-50	2.5 cm cob pla 60-40	2.5 cm cob pla 70-30	2.5 cm cob pla 80-20	2.5 cm cob pla 90-10
0	0.000000	0.000000	0.000000	0.000000	0.000000
126	0.004792	-0.004919	0.013052	0.016661	0.026278
250	0.050729	0.051779	0.078075	0.090444	0.117300
500	0.127640	0.170390	0.129980	0.113080	0.270400
1000	0.285130	0.145710	0.136570	0.085721	0.268350
1600	0.088550	0.114000	0.113390	0.128980	0.261370

Table 28: Sound absorption values of the samples at given frequencies

Results of the third batch of samples

	NRC value
2.5 cob pla 50-50 v4	0.101121
2.5 cob pla 60-40 v2	0.101285
2.5 cob pla 70-30 v2	0.087201
2.5 cob pla 80-20 v2	0.081954
2.5 cm cob pla 90-10	0.228231
Akotherm D20 20mm	0.153654

Table 29: Summary of the absorption values

Appendix 17:

Measurements of the fourth batch at given frequencies:

Name:	3.5 cm cob wood glue - broken up sample-	Akotherm D20 40mm
TubeType:	Large	Large
Date:	04/11/2024	13/03/2020
Time:	11:36	09:57
f (HZ)	Real Part	Real Part
0	0.000000	0.000000
126	0.139820	0.047114
250	0.152960	0.126530
500	0.200020	0.282680
1000	0.796130	0.594440
1600	0.693120	0.839580

Table 30: Sound absorption values of the samples at given frequencies

Results of the fourth batch of samples

	NRC value
3.5 cm cob wood glue	0.5047896729
Akotherm D20 40mm	0.45354042

Table 31: Summary of the absorption values

Appendix 18:

Calculation of the materials needed to create the test samples:

From the material needed for the 1 cm thick 10cm diameter disk sample, the material for the rectangular sample was calculated.

Volume of the disk: 5 cm *5 cm* π*1 cm = 78.54 cm³

Final (wet) mass of the disk: 57.23 g of cobs

46.06*0.2857= 13.24

Ratio of mixing ≈ 4:1

Volume of the desired rectangular sample: 13 cm* 20 cm* 1cm = 260 cm³

260 cm³ -> X%

78.54 cm³ ->100 %

X= (260 * 100)/78.54 = 331.04 %

So the mass of the cobs and wood glue will need to be multiplied with 3.32 to get the desired amount.

Appendix 19:

Material type	Brand name	Product name	Material	Width (cm)	Sound absorption values						NRC value
					125 Hz	250 Hz	500 Hz	1 kHz	2 khz	4 KHz	
Traditional	Impact acoustic	ARCHISONIC® Felt	Synthetic felt	2.4	0.05	0.25	0.55	0.90	1.05	1.10	0.7
Traditional	Rockwool	Comfortboard 80	Mineral wool	3.8	0.21	0.64	0.92	1	0.95	1.01	0.9
Traditional	AcousticalSurfaces	FOAM S.T.O.P. PLAIN (FLAT)	Polyurethane foam	3.5	0.03	0.32	0.88	1.09	0.98	0.93	0.82
Eco-friendly	Akuwoodpanel	Akupanel	Wood +synthetic felt	6	0.20	0.40	0.50	0.65	0.91	-	0.6
Eco-friendly	Generic	Generic	Hemp + PLA	3	0.01	0.15	0.25	0.51	0.70	-	0.4
Eco-friendly	Generic	Generic	Cork	3	0.01	0.02	0.10	0.30	0.86	-	0.3
Eco-friendly	Søuld	Søuld Acoustic Boards	Eelgrass	1.8	0.05	0.30	0.70	0.70	0.67	0.75	0.65
Eco-friendly	Generic	Generic	Coco fibres	5	0.10	0.20	0.34	0.67	0.79	-	0.5
Eco friendly	Current project	Generic	Corn cobs + wood glue	3	0.15	0.15	0.20	0.80	0.69	-	0.4

Table 32: Table of the material put in comparison with the current project (Archisonic, 2025), (Rockwool, 2017), (Acoustical Surfaces Inc, 2020), (Berardi & Iannace, 2015) (Søuld, 2024).

Appendix 20:

Tube	
Type	Large
Microphone Spacing:	0,05 m
Distance to Sample from Mic. B, Pos. 3:	0,1 m
Distance to Source from Mic. A, Pos. 2:	0,15 m
Diameter:	0,100 m
Lower Frequency Limit:	50 Hz
Measurement	
Lines	800
Span	1.6 kHz
Averages	150
Zoom	FALSE
Centre Frequency (Hz):	800,0
Generator	
Generator Active	TRUE
Waveform:	Random
Signal Level:	2,000 Vrms
Pink Filter:	Off
Environment	
Atmospheric Pressure:	1013,25 hPa
Temperature:	22,00 °C
Relative Humidity:	40,0 %
Velocity of Sound: 344,41 m/s	
Density of Air: 1,194 kg/m³	
Characteristic Impedance of Air: 411,2 Pa/(m/s)	
Options	
Signal-to-Noise Ratio below:	10,0 dB
Autospectrum (Max-Min) above:	60,0 dB

Calibration Factor exceeds:	2,0 dB
Calibration Factor exceeds:	2,0 degrees
Transfer Function Estimate:	H1

Table 33: Set-up of the impedance tube

Appendix 21:

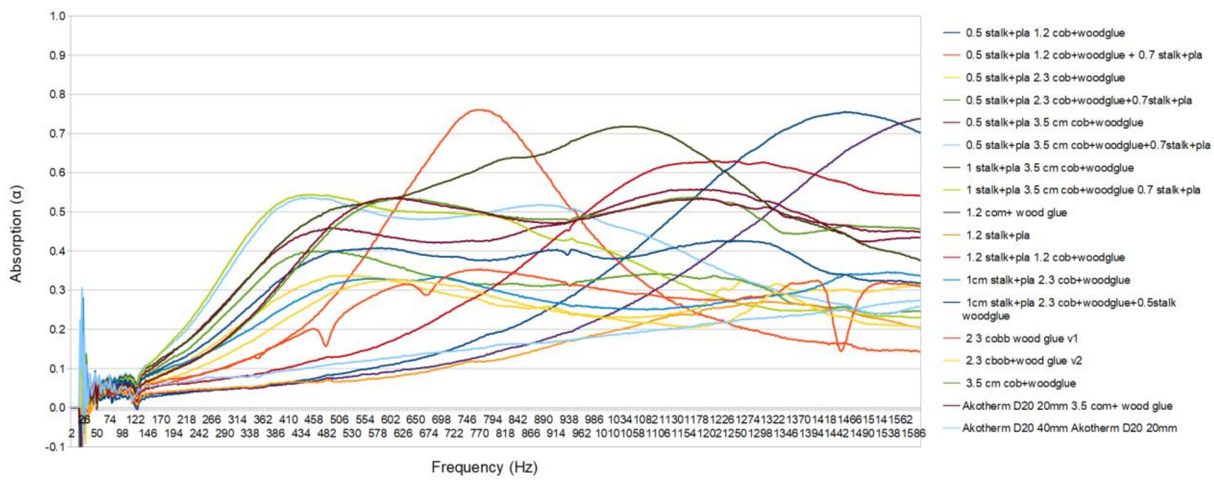


Figure 78: The results of all the measurements taken in the impedance tube

Measurement values at given frequencies:

Name:	0.5 stalk+pla 1.2 cob+woodglue	1.2 com+ wood glue	1.2 stalk+pla 1.2 cob+woodglue	3.5 com+ wood glue	0.5 stalk+pla 3.5 cm cob+woodglue	1 stalk+pla 3.5 cm cob+woodglue
126	-6.02E-03	3.10E-03	1.47E-02	3.19E-02	5.29E-02	5.96E-02
250	4.15E-02	4.31E-02	6.60E-02	1.34E-01	2.09E-01	2.05E-01
500	8.41E-02	7.43E-02	1.28E-01	4.77E-01	4.57E-01	5.08E-01
1000	3.37E-01	2.28E-01	5.29E-01	4.91E-01	5.03E-01	7.08E-01
1600	7.00E-01	7.38E-01	5.41E-01	4.47E-01	4.33E-01	3.75E-01

Table 34: Results of the samples at given frequencies

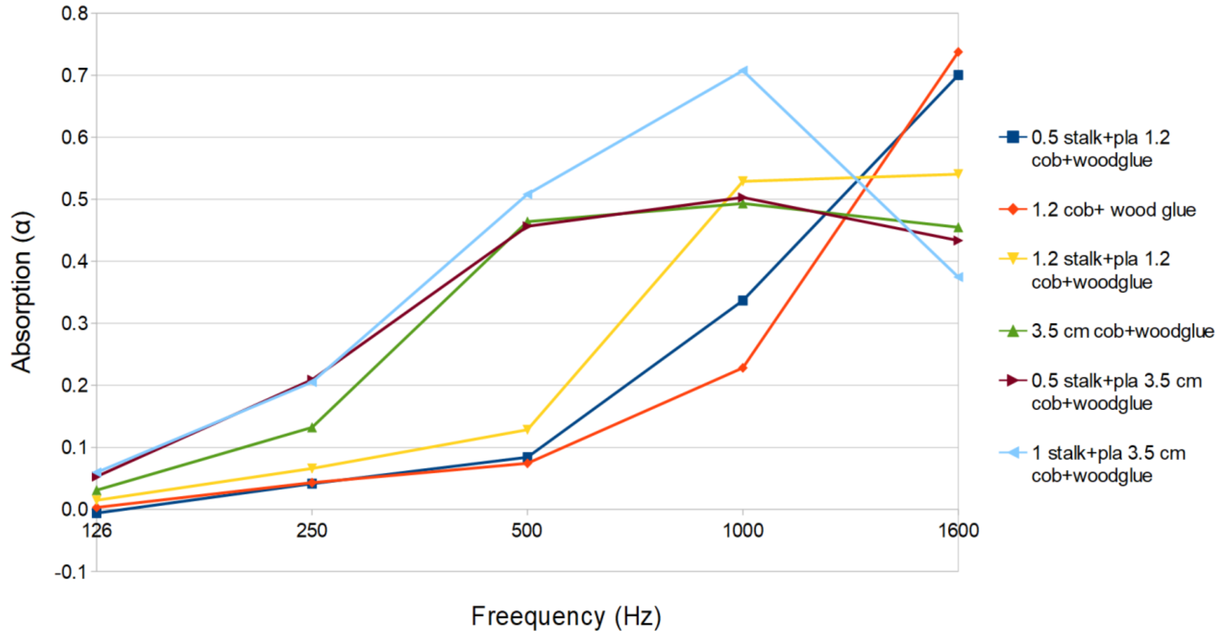


Figure 79: Results of the samples at given frequencies

Measurements values at given frequencies:

Name:	0.5 stalk+pla 2.3 cob+woodglue	0.5 stalk+pla 2.3 cob+woodglue+0.7s talk+pla	1cm stalk+pla 2.3 cob+woodglue	3.5 com+ wood glue
125	0.030707	4.42E-02	4.23E-02	3.19E-02
250	0.14387	1.84E-01	1.35E-01	1.34E-01
500	0.33584	3.97E-01	3.17E-01	4.77E-01
1000	0.23111	3.28E-01	2.54E-01	4.91E-01
1600	0.3137	2.45E-01	3.35E-01	4.47E-01

Table 35: Results of the samples at given frequencies

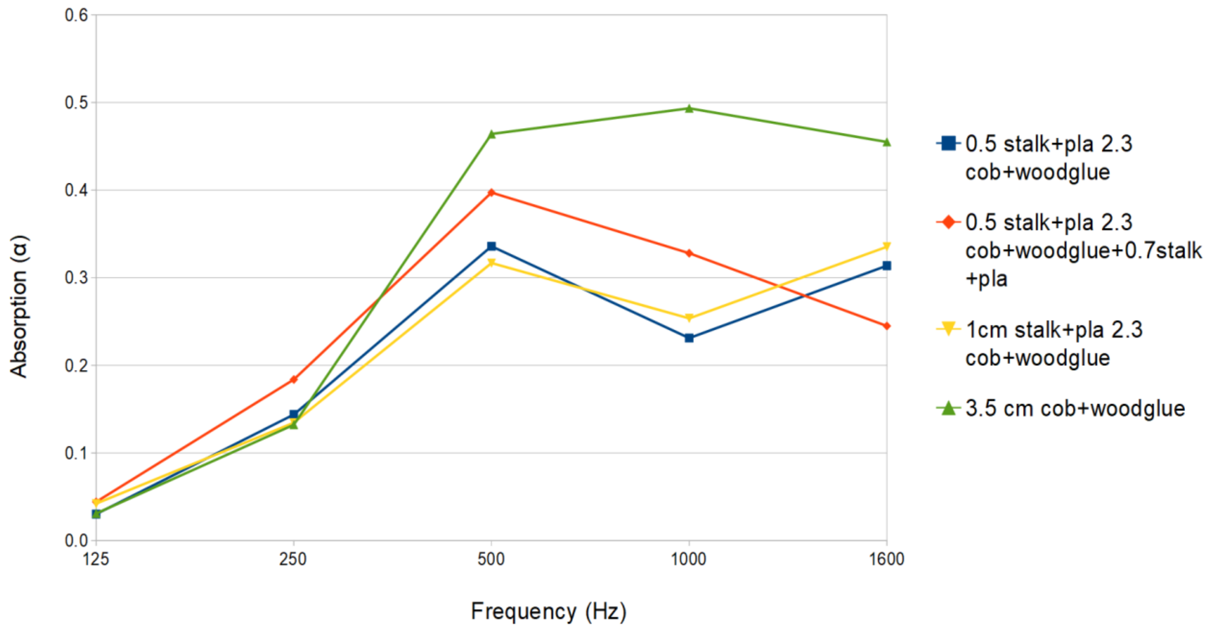


Figure 80: Results of the samples at given frequencies

Appendix 22:

Tube	
Type	Small
Microphone Spacing:	0,02 m
Distance to Sample from Mic. B, Pos. 5:	0,035 m
Distance to Source from Mic. A, Pos. 4:	0,37 m
Diameter:	0,029 m
Lower Frequency Limit:	500 Hz
Measurement	
Lines	800
Span	6.4 kHz
Averages	150
Zoom	FALSE
Centre Frequency (Hz):	3200,0
Generator	
Generator Active	TRUE
Waveform:	Random

Signal Level:	1,414 Vrms
Pink Filter:	Off
Environment	
Atmospheric Pressure:	1013,25 hPa
Temperature:	22,00 °C
Relative Humidity:	40,0 %
Velocity of Sound: 344,41 m/s	
Density of Air: 1,194 kg/m³	
Characteristic Impedance of Air: 411,2 Pa/(m/s)	
Options	
Signal-to-Noise Ratio below:	10,0 dB
Autospectrum (Max-Min) above:	60,0 dB
Calibration Factor exceeds:	2,0 dB
Calibration Factor exceeds:	2,0 degrees
Transfer Function Estimate:	H1

Table 36: Set-up of the impedance tube

Measurements values at given frequencies:

Name:	D2.9W3cob v1	D2.9W3cob v2	D2.9W3cob v3	D2.9W3cob v4	D2.9W3cob v5
f (HZ)					
125	4.84E-03	2.13E-03	5.85E-03	9.74E-03	1.17E-02
250	7.11E-02	7.09E-02	7.18E-02	6.87E-02	6.88E-02
500	1.96E-01	1.96E-01	1.96E-01	1.81E-01	1.81E-01
1000	7.29E-01	7.30E-01	7.30E-01	7.37E-01	7.37E-01
2000	2.92E-01	2.92E-01	2.92E-01	3.10E-01	3.10E-01
4000	4.44E-01	4.44E-01	4.44E-01	5.74E-01	5.73E-01
6000	5.48E-01	5.49E-01	5.49E-01	6.79E-01	6.79E-01

Table 37: Results of the samples at given frequencies

Appendix 23:

Specimen No.	Tensile Strength (N/mm²)
1	0.7116
2	0.4681
3	0.6464

4	0.6516
5	0.3226
6	0.3906

Table 38: Tensile test results

Appendix 24:

The stress and strain of the samples can be calculated as follows:

Stress σ = 3FL/2bh2

Where:

F: Applied force (N).

L: Span length between supports (mm).

b: Specimen width (mm).

h: Specimen thickness (mm).

While the strain is the distance of the deformation with can be calculated as:

Strain ε = 6dL/L2 where d is the distance of deflection at the center.

Given all these data, the Young's modulus of each specimen can be calculated as:

E= σ/ε

Specimen	Young's Modulus (N/mm2)
1	0.775
2	0.576
3	0.874
4	0.921
5	0.869
6	0.92

Table 39: Bending test results

Appendix 25:

Panel dimensions:

Length = 260 cm = 2.6 m

Width = 30 cm = 0.3 m

Thickness = 3 cm = 0.03 m

Weight: 14.2 kg

Young's Modulus (E): 0.761 ± 0.313 N/mm^2

Deflection:

δ_{max}-= $(5wL^4)/(384EI)$

w = weight per unit length (N/m)

L = effective span of the beam = 2.58 m

E = Young's modulus (N/m^2)

I = second moment of area (m^4), given by:

$I = (bh^3)/12$

Where:

b is the width of the panel.

h is the thickness of the panel.