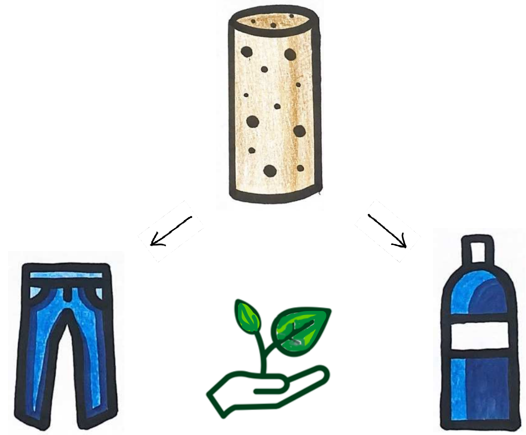
INTRODUCTION

Acoustic panels are sound-absorbing boards designed to control reverberation and absorb sound within a space.
The use of acoustic panels made from recycled materials offers advantages including, environmental friendliness, cost savings and a unique design finish.

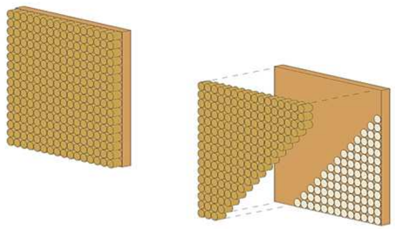


AIM

The aim of this thesis is to explore the acoustic and environmental benefits of using recycled corks for sound absorbing acoustic panels.

MOTIVATION

- High noise level in office and studio workspace
- Could I find an environmentally friendly solution to this ?
- Waste in Ireland
- Sustainable material options ?



OBJECTIVES

- Investigate and test the natural sound absorbing properties of cork stoppers.
- Analyse the environmental impacts of the chosen recycled materials.
- Test and compare the acoustic performance of using cork stoppers for acoustic panels.

METHODOLOGY

1

Make acoustic panels from:

- Recycled Cork stoppers
- Recycled Plastic
- Recycled Denim

→

2

Test their sound absorption properties
+
Compare against one another and use fiberglass panel to contrast

→

3

Evaluate the environmental elements of each panel
+
Evaluate LCA results on the chosen materials

ACOUSTIC AND ENVIRONMENTAL BENEFITS OF USING RECYCLED CORK STOPPERS IN

ACOUSTIC PROPERTIES

Cork stoppers offer natural acoustic benefits due to their unique properties :

- Previous studies show that just 3 millimetres of cork can block up to 10 decibels of sound.

↓

- Cork is a non-transmitting material, meaning it does not generate sound when struck or impacted, instead it absorbs and disperses sound energy.

↓

- Due to corks cellular structure composed of millions of air-filled pockets, it has the natural ability to absorb and dampen sound vibrations.

SOUND ABSORPTION PROPERTIES

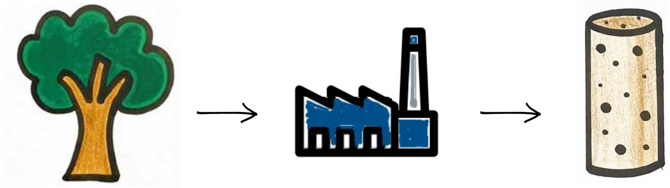
- **Insulation**
Cork is an excellent natural acoustic, thermal and vibration insulator.

- **Lightweight**
The average cork weighs 3.5g which makes it a very light raw material.

- **Impermeability**
Due to corks suberin content, it is impermeable to liquid and gases.

- **Flexibility and Compressibility**
Each cork is made up of 800 million watertight cells. This allows it to be compressed to half its size, while not increasing volume on the other side. This characteristic allows it adapt to variations of temperature and pressure without losing its abilities.

WHY CORK STOPPERS ?

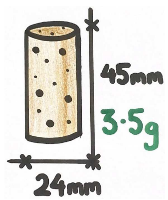


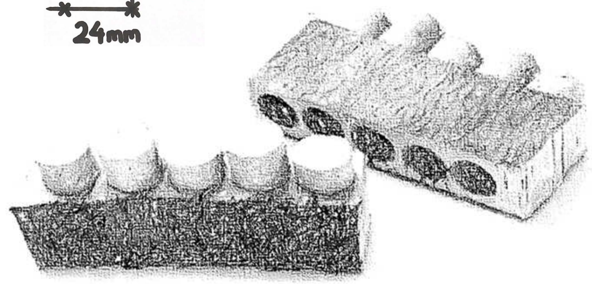
Cork is a natural raw material which is 100% biodegradable, recyclable and renewable.

It is sourced from the bark of the Cork Oak tree.
The bark is stripped into planks, then processed into cork stoppers.
This process is done without harming the tree itself, making it a renewable resource as its harvested without depleting natural resources.

ABOUT CORK

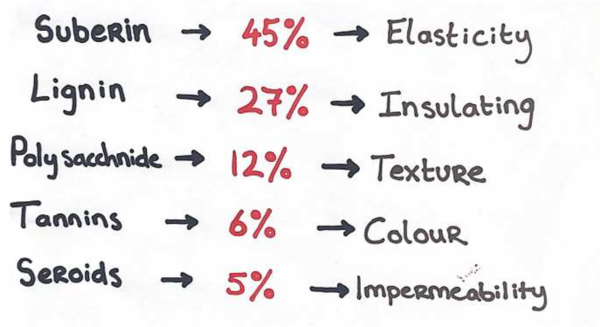
- 12 billion cork stoppers produced globally each year.
- 80% of the worlds cork is produced in Portugal due to the Mediterranean climate needed for the cork oak tree to grow.
- 66,700 cork stoppers can be sourced from 1 tonne of cork plank.
- Cork stoppers have millions of cell cavities filled with air, this is what gives cork its natural qualities.





CORK COMPOSITION

The chemical composition of cork is primarily made up of organic compounds. The following are the key components of cork and the qualities of their chemical composition :



FIRE RESISTANT PROPERTIES

- **Ignition Temperature**
Cork has a high ignition temperature of around 400 degrees Celsius. This means that it requires a significant amount of heat to ignite, reducing the risk of fire initiation.

- **Smoke Emissions**
Cork produces minimal smoke when exposed to fire. The smoke emitted does not release harmful gases or pollutants, contributing to a safer environment during fire incidents.

- **Self Extinguishing**
When the heat source is removed, cork has the ability to self-extinguish. It stops burning once the external flame is no longer present.

- **Protective Layer**
When exposed to fire cork forms a protective layer of char on its surface. This charred layer acts as a barrier, insulating the inner cork material while also slowing down the combustion process.

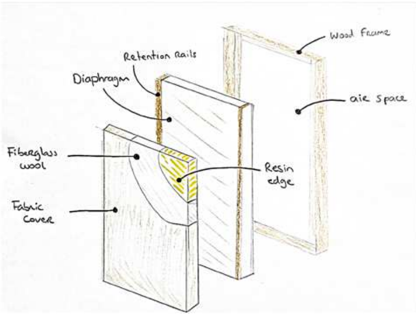
ACOUSTIC PANELS

CONOR O'CARROLL

STANDARD ACOUSTIC PANELS

The materials commonly used for standard acoustic panels offer great sound insulating and absorption properties, however, they have many environmental negatives. Below are the most commonly used materials for panels and some of the key environmental concerns associated with them.

- FIBERGLASS
- MELAMINE FOAM
- MINERAL WOOL
- POLYURETHANE



Fiberglass panel elements

ENVIRONMENTAL NEGATIVES

- **Energy Consumption**

The production of fiberglass and mineral wool panels requires the extraction of non-renewable resources such as:

- Glass
- Limestone
- Petroleum

- **Waste Disposal**

Most acoustic panels end up in landfills or incinerator plants at their end of life cycle. They release harmful chemicals and do not decompose.

- **Product Emissions**

Energy intensive production processes which lead to harmful greenhouse gas emissions.

WASTE IN IRELAND

33,000
Tonnes of Cork waste each year in Ireland
(8 million corks)

225,000
Tonnes of Textile waste each year in Ireland
(47% RECYCLED)

300,000
Tonnes of Plastic waste each year in Ireland
(60kg per person)

WASTE PERSPECTIVE

How many panels could be made from Irish Cork waste ?

Weight = 2.8 kg per panel

33,000 tonnes → 11 million panels

1 tonne → 357 possible panels

How many panels could be made from Irish Textile waste ?

Weight = 3.1 kg per panel

225,000 tonnes → 72 million panels

1 tonne → 322 possible panels

How many panels could be made from Irish Plastic waste ?

Weight = 2.9 kg per panel

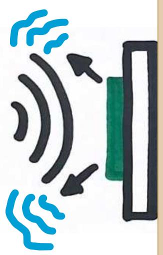
300,000 tonnes → 100 Million panels

1 tonne → 345 possible panels

WHAT ARE ACOUSTIC PANELS

The primary function of acoustic panels is to absorb sound energy. Acoustic panels are made from sound-absorbing materials that help to absorb and dampen sound waves.

Without panel
vs.
With panel



When sound waves strike the panel's surface, the core material converts the sound energy into heat through friction and internal reflections. This process reduces the amount of sound that is reflected back into the room, thus improving sound quality.

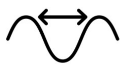
SOUND WAVES

Sound is a type of wave that travels through a medium such as air, water or solid objects.

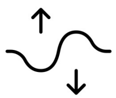
Sound waves are characterized by the following:

- Frequency
The no. of cycles per second measured in Hertz. →

- Wavelength
The distance between two corresponding points on the wave. →



- Amplitude
The height of the sound wave. →



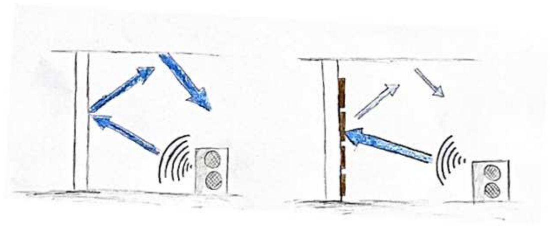
SOUND ABSORPTION

Sound absorption is the process of reducing sound energy through a panels ability to convert the sound waves into heat energy.

As the sound waves pass through the panel, they are absorbed and lose energy, reducing the intensity and preventing them from bouncing back into the room.

Sound absorption is a process that depends on five factors. →

1. Thickness
2. Material
3. Density
4. Shape
5. Size

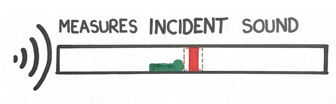


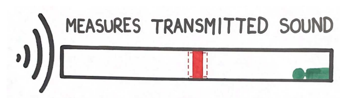
This is a measure of how well a panel absorbs sound across different frequencies. →

Coefficient ranges from 0 to 1
0 = Complete Reflection
1 = Complete Absorption

An impedance tube test is used to calculate the two measures below. The formula is then used to calculate the coefficient of an acoustic panel.

- Measures sound BEFORE passes through panel
- Measures sound AFTER passes through panel





$$a = I_a / I_i$$

→

a = SOUND ABSORPTION COEFFICIENT
I_a = SOUND INTENSITY ABSORBED (W/m^2)
I_i = incident sound intensity (W/m^2)

ISO STANDARDS

Due to all acoustic panels varying on application and build-up, the ISO standards do not provide specific acoustic panel requirements.

They do however provide guidelines for testing methods. For the impedance tube test performed to calculate the sound absorption coefficient, standards state that the tube should be 3 times the diameter of the panel.

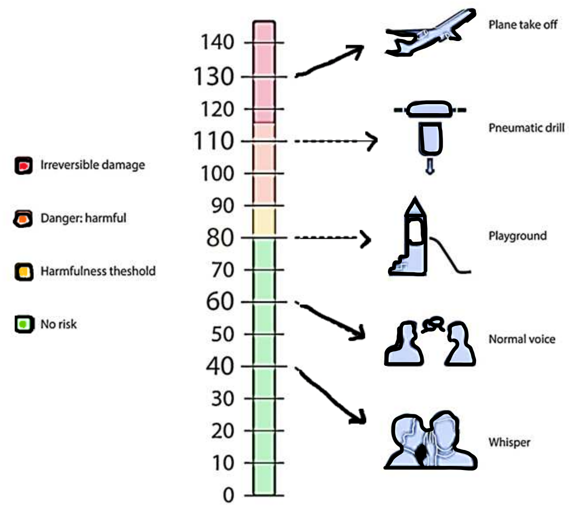
The performance classes for sound absorption according to EN 13964

- Class A → ≥ 0.90
- Class B → ≥ 0.70
- Class C → ≥ 0.50

WHAT ARE DECIBELS ?

Decibels (dB) are the unit of measurement for the intensity of sound. Sound pressure level (SPL) is a measure of the intensity and level of sound.

The decibel scale is based on the threshold of human hearing, which is defined as 0 dB. The scale extends in both positive and negative directions to accommodate a wide range of sound levels as seen below:



CORK (1)

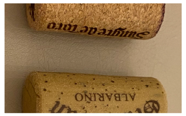


MATERIALS

- Cork stoppers
- MDF board panel
- Soy-Based Adhesive
- Scissors


1. First, the cork stoppers were glued to the MDF panel base using soy-based adhesive.
2. Next, a strip of recycled denim was wrapped around the MDF base using soy-based adhesive. This was done so there would be no sound leaks around the panel during testing.

CORK (2)


MATERIALS

- Cork stoppers
- MDF board panel
- Soy-Based Adhesive
- Scissors


1. Each cork stopper was cut in half using the scissors. They were then glued flat face down to the MDF panel base using soy-based adhesive.
2. Finally, a strip of recycled denim was wrapped around the MDF base using soy-based adhesive. This was done so there would be no sound leaks around the panel during testing.

PANEL PRODUCTION

MDF board was used as a base for each of the four panels. A Computer Numerical Control machine (CNC) was used to cut four 100mm diameter acoustic panel bases.

One problem encountered during the production of the panels was that there was a 1mm gap present when the panels were placed inside the impedance tube.

To fix this, a strip of denim was glued to the edge of each panel to fill this gap. This gap would allow sound to travel through, which would have a huge effects on the test results.

WHY MDF ?

- Reduced Waste

MDF is made by compressing wood fibers and resin, which results in a very dense material. This results in less waste during the manufacturing process.

- Recyclable

MDF can be recycled, which means that it can be reused or repurposed at the end of its useful life. This reduces the amount of waste that ends up in landfills and helps to conserve natural resources.

- Emissions

MDF is made using formaldehyde-free binders, which means that it emits low levels of volatile organic compounds (VOC's) compared to other wood based products. This makes it a safer and healthier choice for indoor environments.

SOY BASED ADHESIVE

The soy flour and water was heated in a saucepan until paste consistency, then glycerine and vinegar was added. The mixture was stirred for 20 minutes then cooled before use.

This is an adhesive made from soybeans. It is an eco-friendly alternative to traditional adhesives that are petroleum-based which have negative environmental impacts when disposed of as they are non-biodegradable.

Ingredients:

Equal cup of soy flour
Equal cup of water
1/4 cup of white vinegar
1 tablespoon of glycerine

DENIM TEXTILE



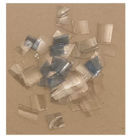
MATERIALS

- Denim jeans
- MDF board panel
- Soy-Based Adhesive
- Scissors


1. First, a 100mm circle of denim was cut and glued onto the top of the panel.
2. Next, recycled denim textile was cut into 1 inch strips. A thick strip of denim was then cut and glued onto the panel in a circle shape to act as a wall for the shredded denim.
3. Next, the 1 inch strips were dispersed into the panel. The adhesive was used to bind the strips together to prevent them from falling out.

PLASTIC





MATERIALS

- Plastics scraps
- MDF board panel
- Soy-Based Adhesive
- Scissors


1. First, recycled plastic bottles were cut into one inch square shapes.
2. Next, using a layer of plastic was glued around the edge of the MDF to create a basin for the plastic scraps.
3. Finally, a plastic netting from oranges was wrapped around the panel to keep the plastic scraps intact with the panel..

IMPEDANCE TUBE TEST

In order to calculate the sound absorption of each panel, two separate test were conducted.

Test (1) measures transmitted sound level

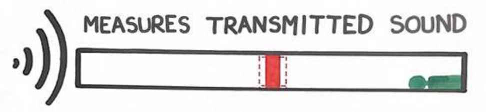
Test (2) measures incident sound level

- (1) The transmitted sound level is tested to measure the sound level after the sound waves have passed through the panel.
- (2) The incident sound level is tested to measure the sound level before the sound waves have passed through the panel.

TESTING METHOD

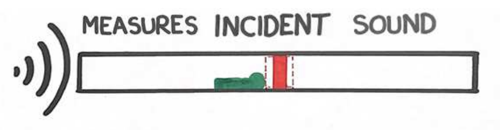
Test (1) – Sound Transmission

1. Set up all apparatus needed in the chosen testing room.
2. Attach speaker to one end of the PVC tube (impedance tube).
3. At other end of the PVC pipe, place the decibel meter.
4. Play a white noise at 85dB through the PVC pipe and record the decibel reading.
5. Next, place the Cork panel in the centre of the PVC pipe.
6. Play the same white noise sound through the pipe and record the decibel reading.
7. Next, do the same for the PET plastic panel, Textile panel and Fiberglass panel.
8. Repeat this test three times for each of the four acoustic panels and evaluate the results.



Test (2) – Sound Incident

For this test, it is the same process as above however the decibel meter is placed on the sound source facing (speaker) side of the panel.



SOUND ABSORPTION TEST

An Impedance tube test is a standard method used to measure the sound absorption characteristics of an acoustic panel.
The acoustic panel is placed in the middle of the impedance tube (PVC pipe), a sound device is placed at one end and a decibel reader at the other.

The ISO standards state that the length of the impedance tube should be three times the diameter. The diameter of the panels are 100mm, therefore the tube length for this test is 300mm.

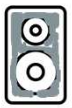
White noise is used for this test as it contains all frequencies across the audible sound spectrum, which range from 20–20,000 Hertz (Hz).

TESTING APPARATUS

 → Acoustic panels

 → PVC pipe (300mm)

 → Testing room

 → Speaker

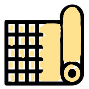
 → Phone

 → Decibel meter

Impedance Tube test

IMPEDANCE TUBE

	MDF	
	Lowest (dB)	Highest (dB)
Test 1	64	65
Test 2	63	64
Test 3	64	65



	Fiberglass		Fiberglass (Reversed)	
	Lowest (dB)	Highest (dB)	Lowest (dB)	Highest (dB)
Test 1	52	53	53	54
Test 2	51	54	52	54
Test 3	52	53	53	54

	Cork 1*		Cork 1* (Reversed)	
	Lowest (dB)	Highest (dB)	Lowest (dB)	Highest (dB)
Test 1	57	58	58	59
Test 2	56	57	57	58
Test 3	56	57	58	59

	Cork 2*		Cork 2* (Reversed)	
	Lowest (dB)	Highest (dB)	Lowest (dB)	Highest (dB)
Test 1	57	58	58	59
Test 2	56	57	57	58
Test 3	56	57	58	59

	Plastic		Plastic (Reversed)	
	Lowest (dB)	Highest (dB)	Lowest (dB)	Highest (dB)
Test 1	60	61	63	64
Test 2	59	60	64	65
Test 3	59	60	63	64

	Denim		Denim (Reversed)	
	Lowest (dB)	Highest (dB)	Lowest (dB)	Highest (dB)
Test 1	60	61	63	64
Test 2	59	60	64	65
Test 3	59	60	63	64

The average decibel reading values:

Material	Average dB
MDF	64
Fiberglass	53
Fiberglass (Reversed)	54
Cork 1	56
Cork 1 (Reversed)	57
Cork 2	57
Cork 2 (Reversed)	58
Plastic	60
Plastic (Reversed)	64
Denim	59
Denim (Reversed)	60

SOUND ABSORPTION

The focus in this project is reducing sound levels in the workplace.
The decibel is a better measure of how we perceive sound than intensity as it refers to the sound intensity level.

In professional tests the absorption coefficients are calculated using the formula:

$$a = I_a / I_i$$

a = SOUND ABSORPTION COEFFICIENT

I_a = SOUND INTENSITY ABSORBED (W/m^2)

I_i = incident sound intensity (W/m^2)

- The sound level and intensity are related through the formula:

$$dB = 10 \log\left(\frac{I}{I_0}\right)$$

I = SOUND INTENSITY (W/m^2)

$I_0 = 10^\wedge(-12)(W/m^2)$

I_0 = REFERENCE INTENSITY (W/m^2)

$$I_0 = 10^\wedge(-12)\, W/m^2$$

- This is used as it is the lowest intensity of sound that a person with normal hearing can perceive.
- The sound intensity can be calculated from the sound level through the formula:

SOUND INTENSITY CALCULATED THROUGH FORMULA:

$$\left(I = I_0 10^{dB/10}\right)$$

This gives, for example, the intensity for 85dB as :

- I_85=3.16×10^(-4)W/m2

Decibels and sound intensity are not linearly related. For example, using the formula above a reduction of noise by 10dB corresponds to a reduction in sound intensity by a factor of 10.

IMPEDANCE TUBE RESULTS

- The decibel is a better measure of how we perceive sound than intensity as it refers to the sound intensity level.
- Decibels and sound intensity are not linearly related. For example, using the formula above a reduction of noise by 10dB corresponds to a reduction in sound intensity by a factor of 10.
- The level of (85dB) chosen as the input for the test is because this is the internationally accepted maximum threshold level for all workplace and studio environments.

All of the panels would be effective in reducing noise as the results are well below the threshold of 85db and most in the normal conversation range of 50dB-60dB.

The results for cork show that is the best and differs significantly from plastic. This is not obvious but is clear when converted to intensity. because the difference between them of 3dB implies a halving of the intensity.

$$3 = dB_{plastic} - dB_{cork} = 10\log_{10}(I_{plastic}) - 10\log_{10}(I_{cork})$$

$$3 = 10\log_{10}\left(\frac{I_{plastic}}{I_{cork}}\right)$$

- Giving the ratio of the two intensities as:

$$\frac{I_{plastic}}{I_{cork}} = 2.0$$

- Cork outperforms plastic with a sound intensity 1.58 times less.

This means that the sound intensity with the cork panel is half that of the plastic panel. This is a significant result as it demonstrates the effectiveness of cork stoppers in absorbing sound.
For the case of denim and cork it is:

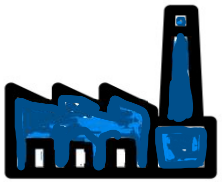
$$\frac{I_{denim}}{I_{cork}} = 1.58$$

- Cork outperforms denim with a sound intensity 1.58 times less.

A difference of 10dB corresponds to a reduction in the sound intensity by a factor of 10. For cork, the difference between 85dB and 57dB is almost 30dB. This means that the reduction factor of the sound intensity in this case is almost a 1000.

All of the materials tested showed good sound absorption but cork was the most effective.

RAW MATERIAL



MANUFACTURING

PURPOSE

DISPOSAL/RECYCLING

LIFE CYCLE ASSESSMENT

A Life-cycle assessment (LCA) is a process of evaluating the effects that a product has on the environment over the entire period of its life.

It can be used to study the environmental impact of either a product or the function the product is designed to perform. LCA is commonly referred to as a "cradle-to-grave" analysis.

Cork

- Cork has a major environmental advantage over plastic and textiles in that it is a carbon sink.

A single natural cork stopper can retain up to 268g of CO2.

- sparkling wine cork stoppers it is 589g of CO2
- micro agglomerated cork can retain up to 323g of CO2.

Cork is an environmentally friendly product on a number of measures. In the comparison of cork and plastic stoppers :

Environmental Indicator

- Non-renewable energy consumption
- Water consumption
- Emission of greenhouse gases
- Contribution to atmospheric acidification
- Contribution to the formation of photochemical Oxidants
- Contribution to the eutrophication of surface water
- Production of solid waste

Environmental Indicator	Cork Stopper	Plastic Stopper
Non-renewable energy consumption	1	5
Water consumption	1.88	3.07
Emission of greenhouse gases	1	10.23
Contribution to atmospheric acidification	1	1.63
Contribution to the formation of photochemi	1	1.49
Contribution to the eutrophication of surface	1	1.52
Production of solid waste	1	1.58

As can be seen above, cork is considerably more environmentally friendly than plastic.

MDF

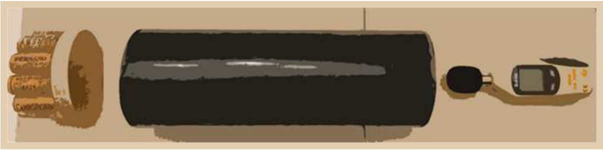
- 632 kg CO2e were released in the production of 1 m3 of MDF. However the same 1 m3 of MDF stores 1,364 kg CO2e.

Plastic

- The energy used to make and process plastic bottles is equivalent to 3,800kg of CO2 per 1000 kg of plastic. / 1kg = 3.8kg CO2

Cotton/ Denim

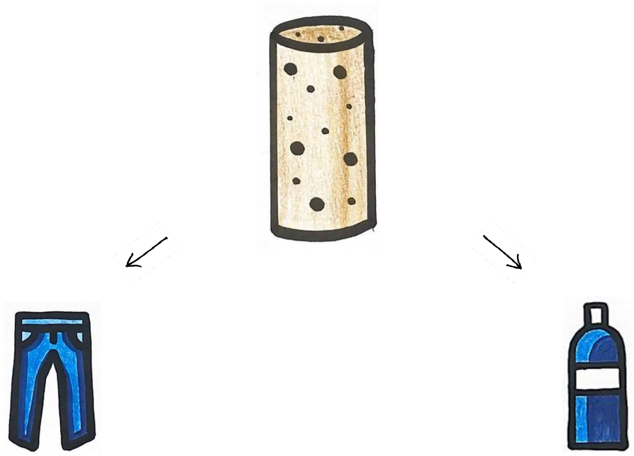
- A 1000 kg of organic cotton fibre's production produces GWP 978kg CO2. / 1kg = 0.978kg CO2
- While cotton is a natural fibre its production requires significant amounts of water and creates greenhouse gases in the process.
- Traditional cotton is 2446kgCO2.
- This is before the material is processed to deliver the final fabric.



CONCLUSION

Cork stoppers have been investigated and shown to display excellent sound absorption properties when used for acoustic panels. This is a very effective way of re-purposing a product that would otherwise end up in a landfill for decades.

Out of the three recycled materials chosen, both recycled plastic and recycled denim showed very good sound absorbing properties, with the recycled cork stopper panel displaying the best sound absorption properties.



The use of cork stoppers as the sound absorbing material for acoustic panels gives a significantly more positive environmental impact compared to commonly used non-biodegradable materials like fiberglass.

Fiberglass has better sound absorbing qualities of the cork panel which was expected, however, this must be balanced against the significant difference of environmental impacts.
With further research into cork stoppers there is no doubt the results of this comparison could improve.