3D printed mycelium based sound absorbing panels

- Daphne de Bruin –

Tutors:

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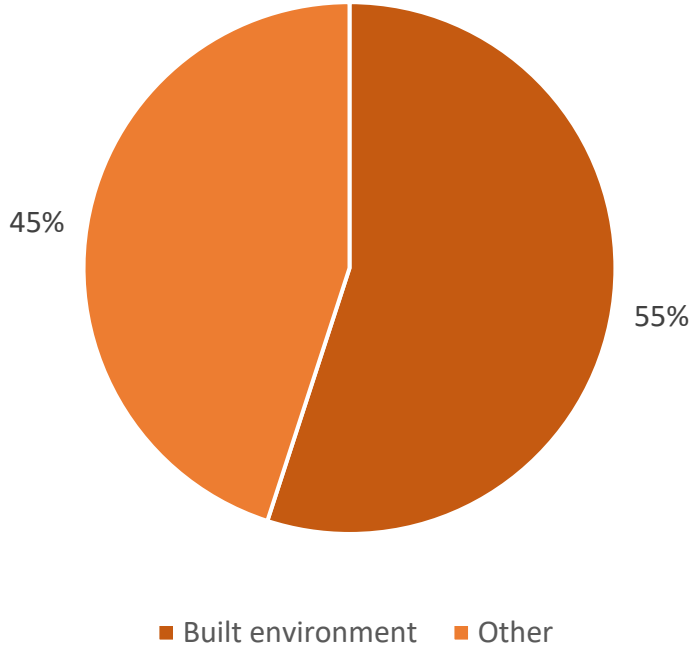
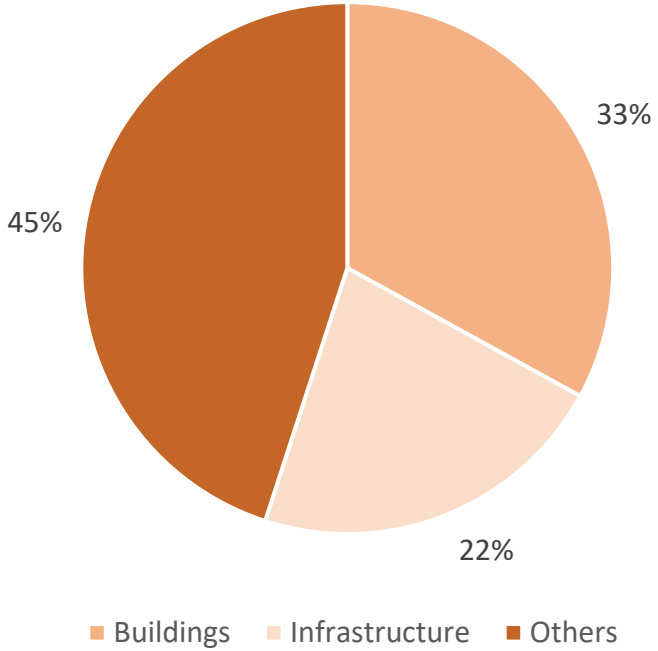
CONTENT

INTRODUCTION

Global Greenhouse Gas Emissions

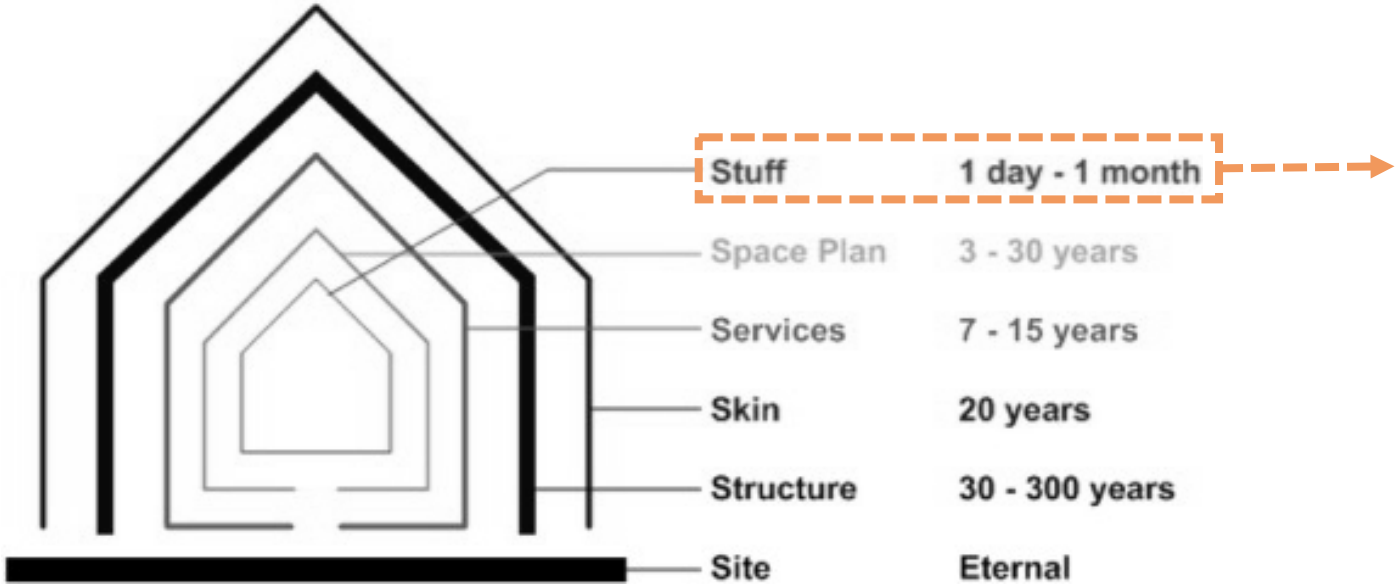




Circular Economy

Eliminate	Circulate	Regenerate
Eliminate waste and pollution	Circulate products and materials (at their highest value)	Regenerate nature

Shearing Layers of Change



- Layout
- Furniture
- Light
- Greenery
- Controls
- Noise

Shearing Layers of Change (Brand, 1995)

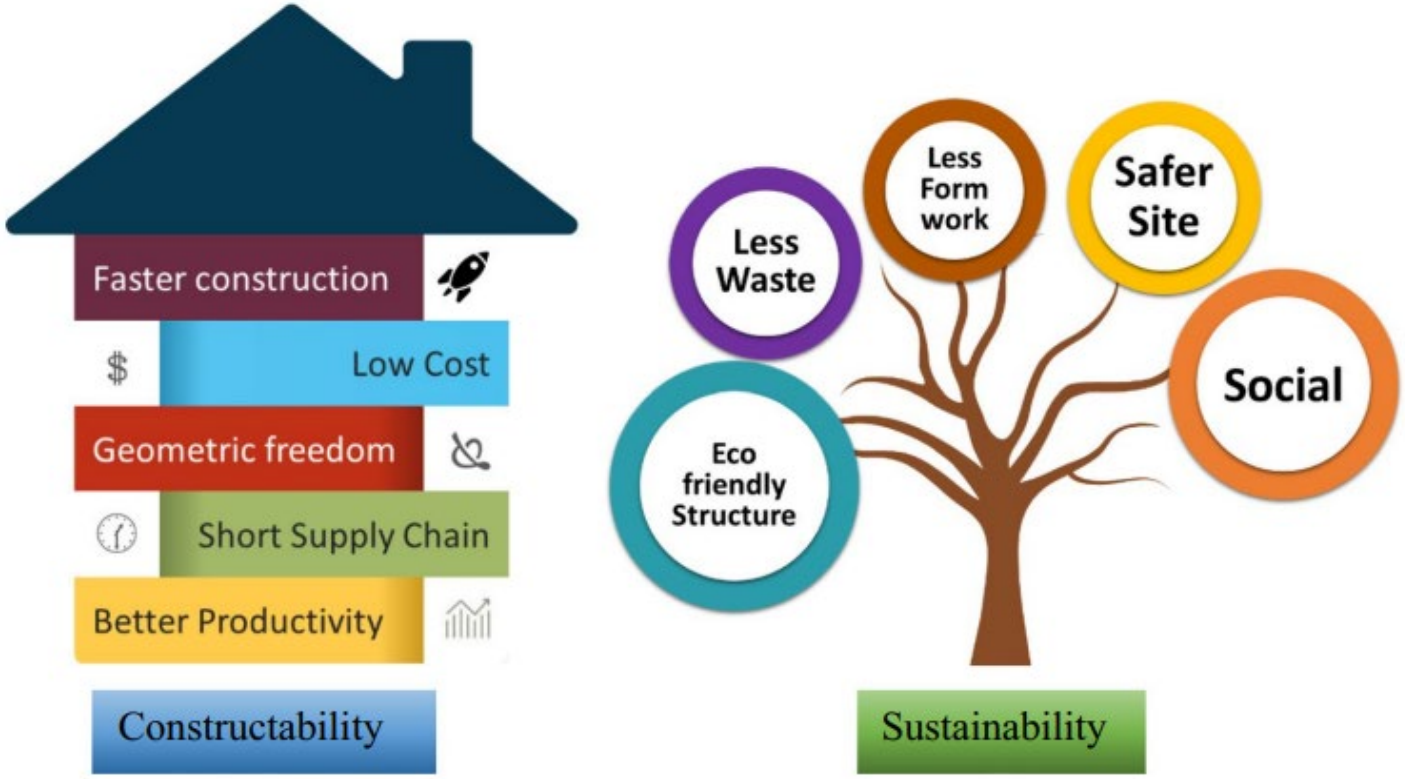
Noise

Wall based sound absorbing panels

Circular product

Eliminate	Circulate	Regenerate
Eliminate waste and pollution	Circulate products and materials (at their highest levels)	Regenerate nature
Biobased materials	Reuse urban waste	Grow Mycelium

3D printing



Benefits of 3D printing (El-Sayegh et al, 2020)

Objective

Create a bio-based sound absorbing panel made from mycelium with 3D printing as the production method, which meet the requirements of a circular economy.

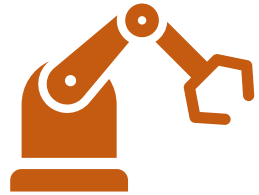
RESEARCH QUESTION

How can a sound absorbing panel for indoor use be 3D printed with a mycelium bound biomaterial which finds its origin in urban waste?

SUB-CATEGORIES

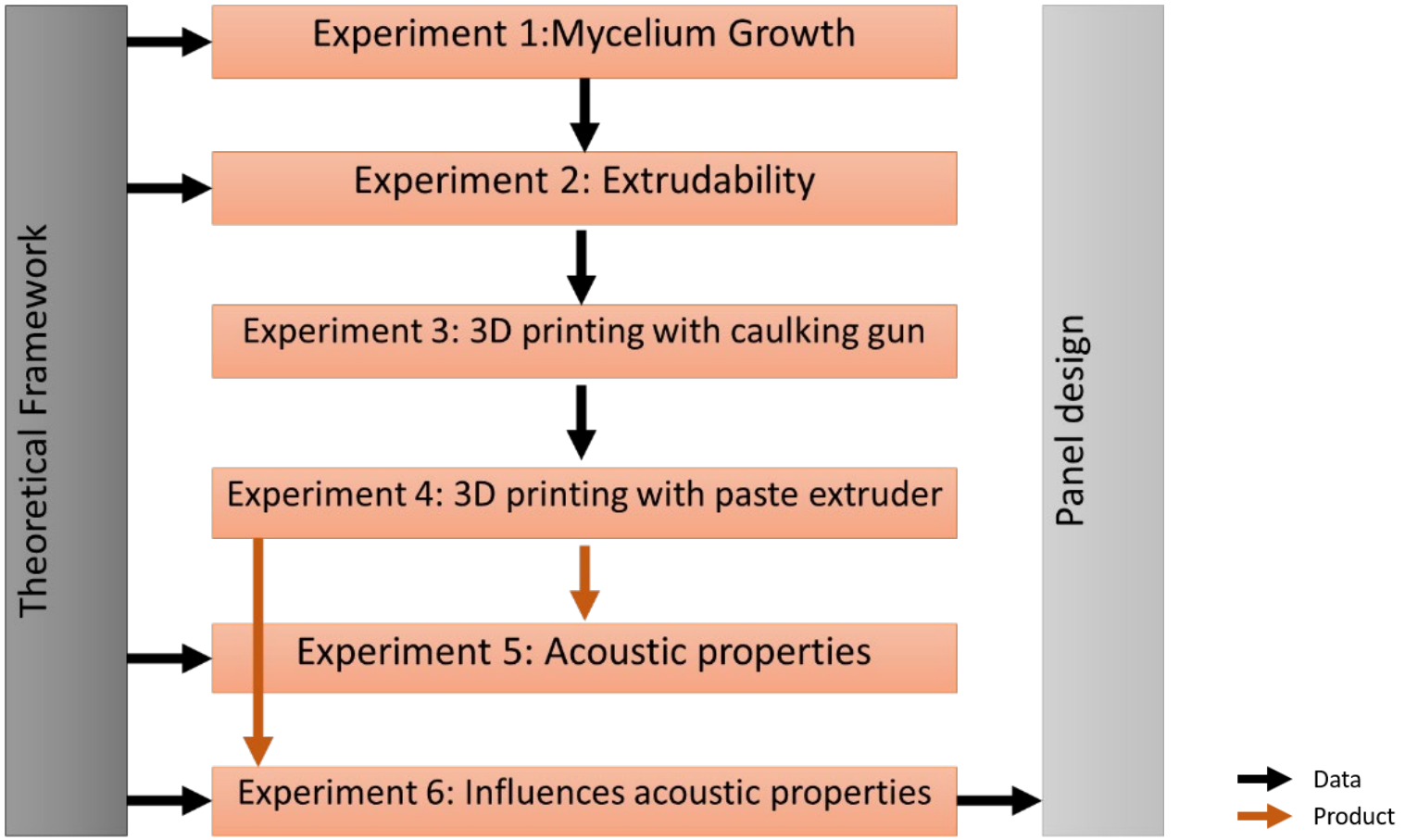
Material

Acoustic performances



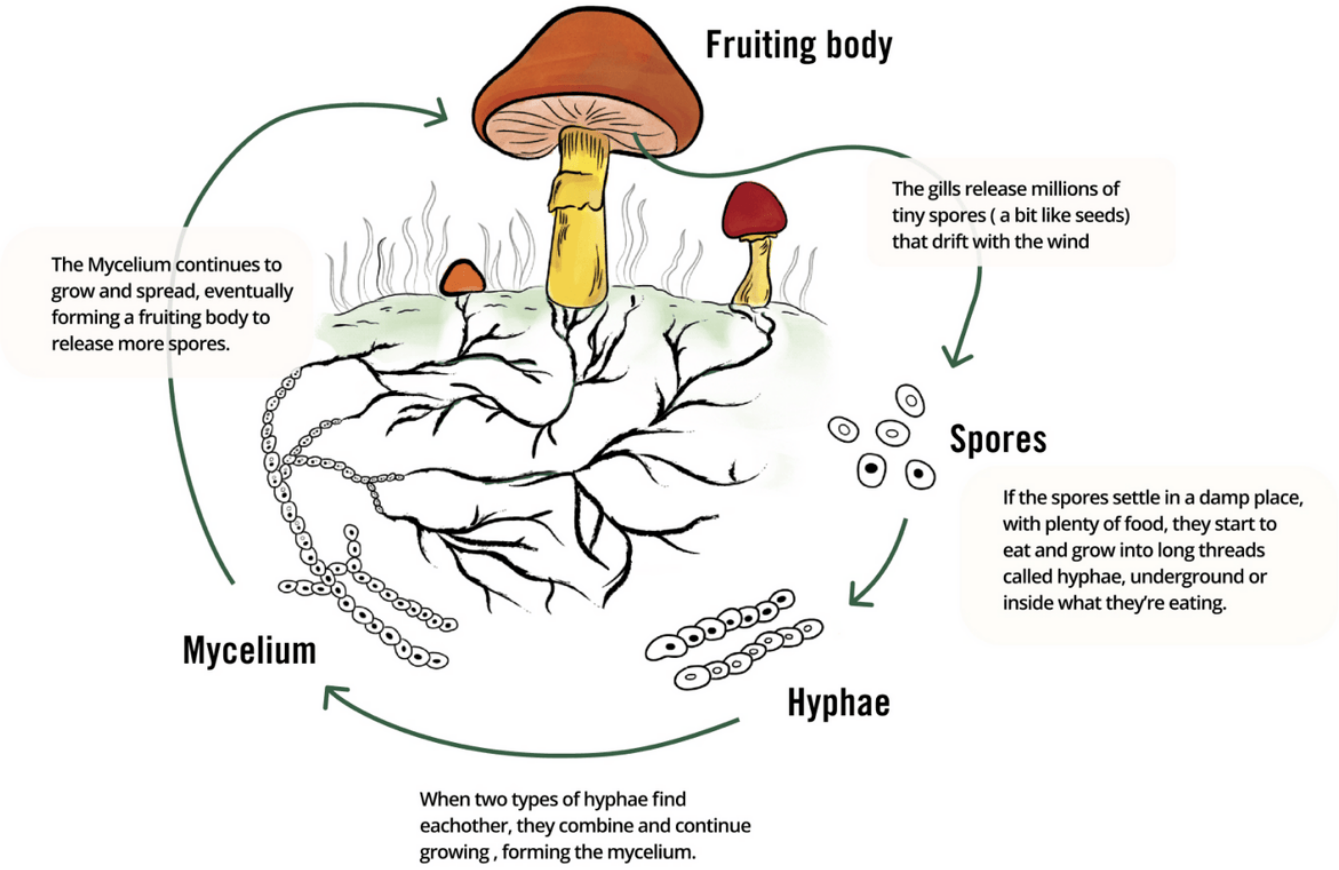
Digital fabrication

SET-UP


Theoretical Framework
Experiment 1:Mycelium Growth
Experiment 2: Extrudability
Experiment 3: 3D printing with caulking gun
Experiment 4: 3D printing with paste extruder
Experiment 5: Acoustic properties
Experiment 6: Influences acoustic properties
Panel design
Data
Product

Theoretical Framework

MYCELIUM



https://www.eversiowellness.com/pages/our-mushrooms

Types of fungi

Dutch name	Latin name	Growing speed	Growing medium	Growth temperature
Shiitake	Lentinula edodes	35-80	Hardwood	21-27
Grijze Oesterzwam	Pleurotus ostreatus	12-21	Variety	24
Roze Oesterzwam	Pleurotus Djamor	7-10	Variety	24-30
Blauwe Oesterzwam	Pleurotus ostreatus var. columbi	12-21	Variety	24
Gele Oesterzwam	Pleurotus cornucopiae var. Citrin	10-14	Variety	21-29
Nebrodensis Oesterzwam	Pleurotus Nebrodensis	10-15	Hardwood	12-15
Bleke Oesterzwam	Pleurotus pulmonarius	8-14	Variety	24-29
Iepoesterzwam	Hypsizygus ulmarius	14-21	Hardwood	21-27
Konings Oesterzwam	Pleurotus Eryngii	12-16	Variety	24
Tarragon Oesterzwam	Pleurotus euosmus	7-14	Variety	21-27
Loin's Mane	Hericium erinaceus	10-14	Hardwood	21-24
Stammetjesstekelzwam	Bankeraceae	10-14	Hardwood	21-24
Reishi Rood	Ganoderma lingzhi	10-20	Hardwood	21-27
Reishi Zwart	Ganoderma neo-japonicum	10-20	Hardwood	21-27
Cordyceps	Cordyceps	10-14	Rye, Brown Rice, Flour	21-24
Chaga	Inonotus obliquus			
Fluweelpootje	Flammulina velutipes	14-18	Variety	21-24
Beukenzwam	Hypsizygus marmoreus	30-45	Hardwood and softwood	21-24
Bundelzwam	Pholiota nameko	14	Hardwood	24-29
Melkwitte paddenstoel	Calocybe Indica	10-14	Variety with vermiculite and coco coir	24-30
Eikzwam	Buna Shimeji	14-30	Hardwood and softwood	21-24
Gewoon Elfenbankje	Trametes versicolor	14-21	Variety	24-29
Zwavelzwam	Laetiporus sulphureus	25-35	Hardwood	24-27
Witte zwavelzwam	Laetiporus cincinnatus	25-35	hardwood	24-27
Cantharel	Cantharellus cibarius	-	-	-

Pleurotus – Oyster Mushroom

https://www.thecricket.com/expert_help/mushroom-of-the-week-the-oyster-mushroom/article_0f93bc0c-3c65-11ec-b889-2fa3cf7ce2f3.html

Urban waste

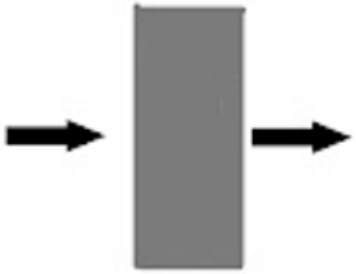
Orange peel

Grinded Coffee

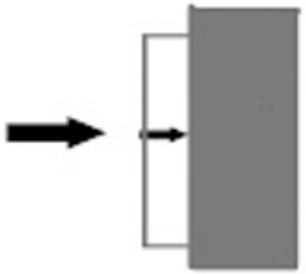
Cardboard

Brewery’s Grain

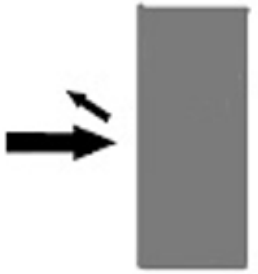
ACOUSTIC PERFORMANCES



Transmission



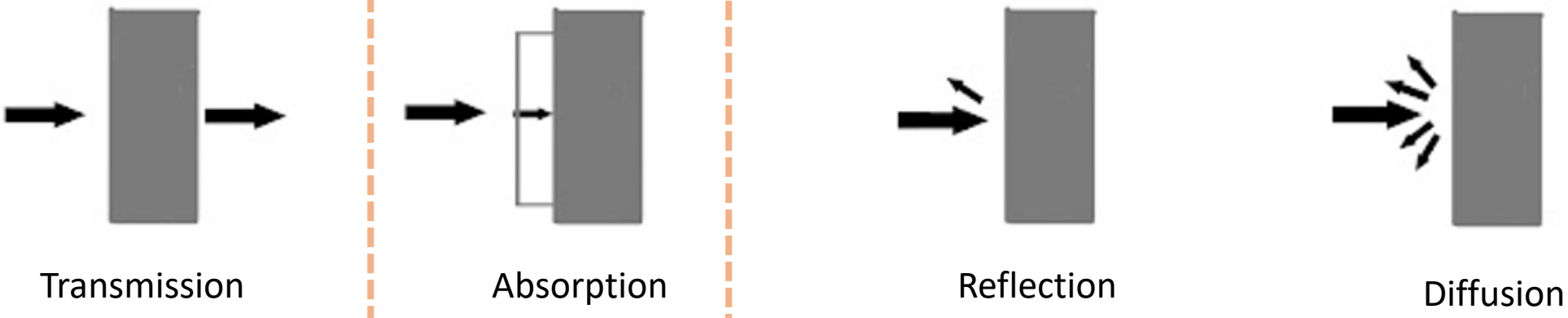
Absorption



Reflection

Diffusion

ACOUSTIC PERFORMANCES



Influences sound absorption

- fiber size
- the thickness
- the density
- the porosity
- the tortuosity
- the resistance of air flow
- the thermal characteristic length
- and the viscous characteristic length

Influences sound absorption

- fiber size
- the thickness
- the density
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- the tortuosity
- the resistance of air flow
- the thermal characteristic length
- and the viscous characteristic length

Reference project

Wave acoustic panel MOGU (https://mogu.bio/mycelium-acoustic-panels)

Digital fabrication

Lovely Trash Column
Blast Studio
(Tree Column, n.d.)

Pulp Faction
Lund University
(Goidea et al., 2020)

Mycelium Chair
Studio Klarenbeek & Dros
(Fairs, 2013)

Experiments

EXPERIMENTS

1. Mycelium Growth

2. Extrudability

3. 3D printing with Caulking Gun

4. 3D printing with Paste Extruder

5. Acoustics

6. Influences Acoustics

Material Development

Mycelium Growth

Extrudability

1. Mycelium growth

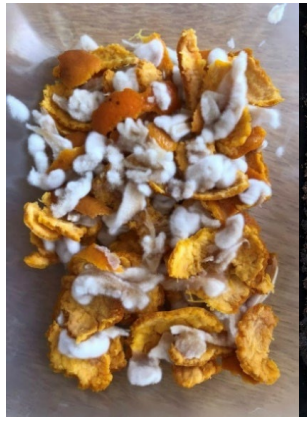
Tested Materials

Orange peel

Grinded Coffee

Cardboard

Brewery's Grain



Oyster Mushroom

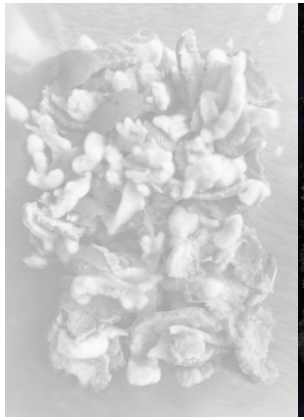
Tested Materials

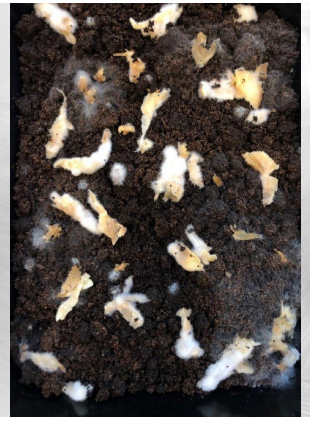
Orange peel

Grinded Coffee

Cardboard

Brewery's Grain





Oyster Mushroom

2. EXTRUDABILITY

Tested Materials

Results

Syringe

All-purposes flour

Wheat flour

Whole Buckwheat flour

Self- rising flour

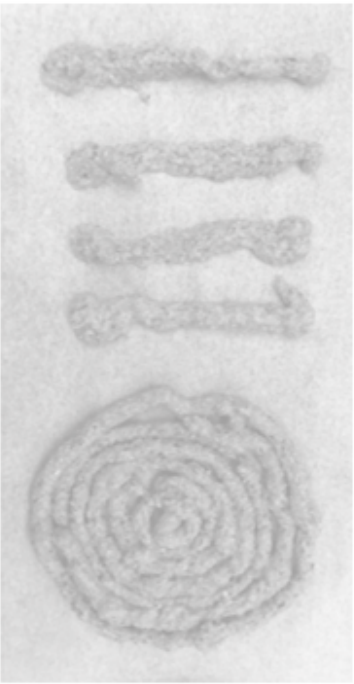
Results

Syringe

All-purposes flour

Wheat flour

Whole Buckwheat flour



Self- rising flour

Printability

3D printing with caulking gun

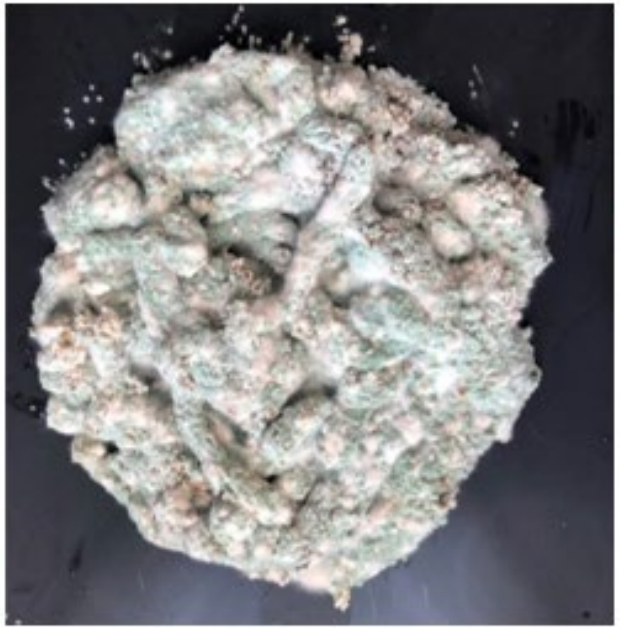
3D printing with paste extruder

3. 3D PRINTING WITH CAULKING GUN

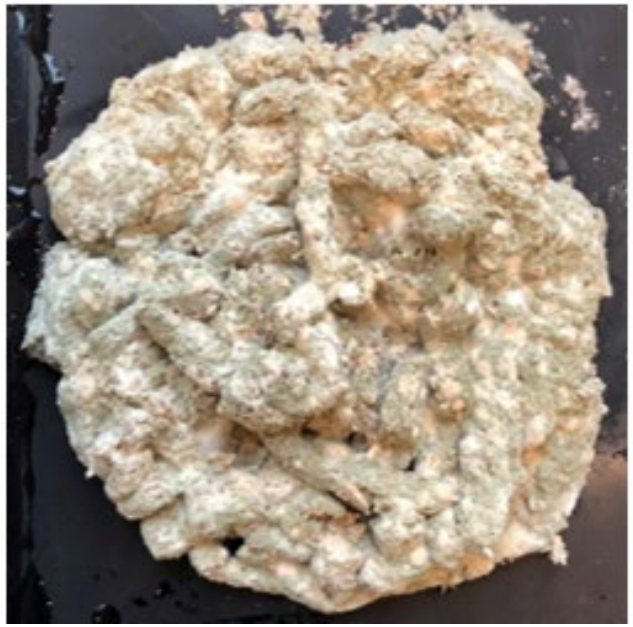
Equipment

Result Brewery's Grain

Day 1



Day 5



Day 14

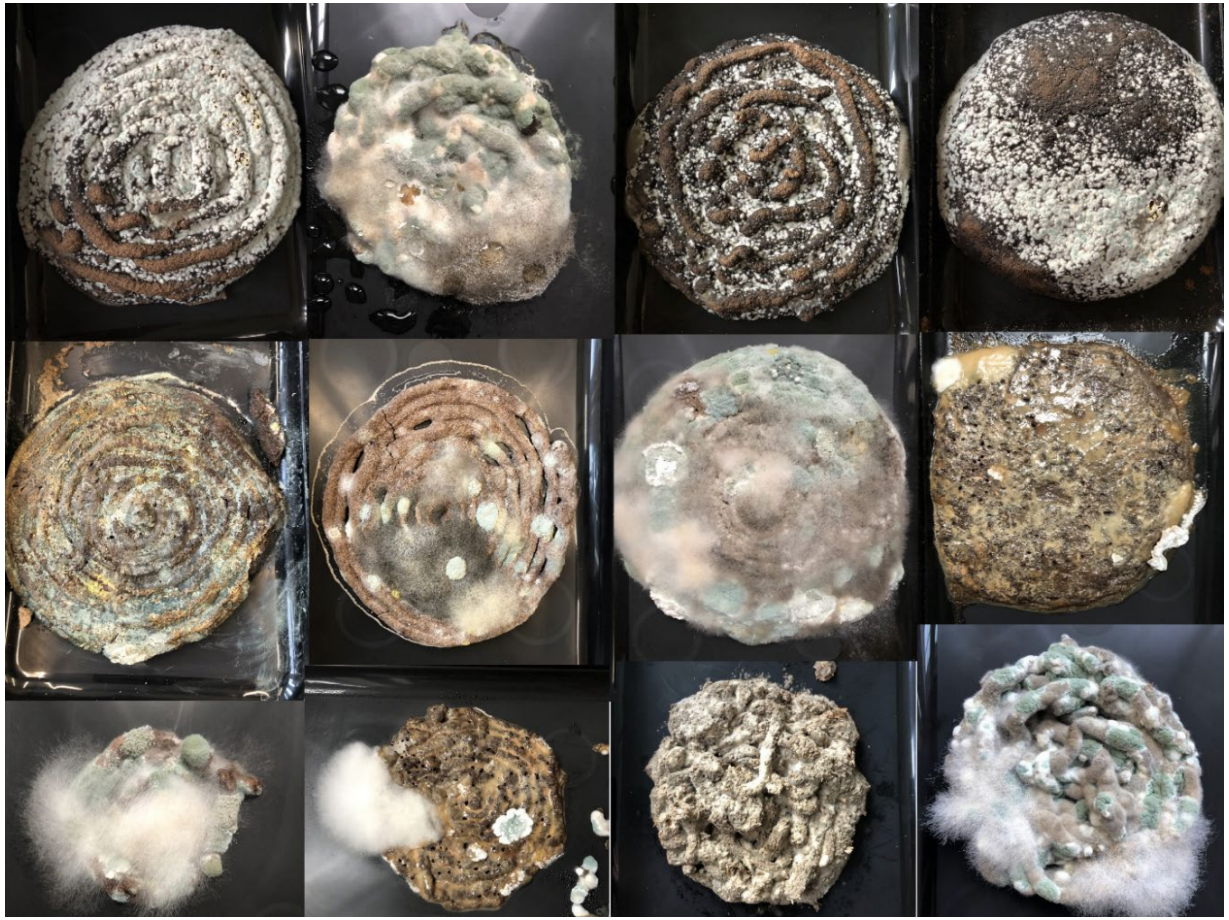
Result Grinded Coffee

Day 1

Day 5

Day 14

Other experiments



Conclusion

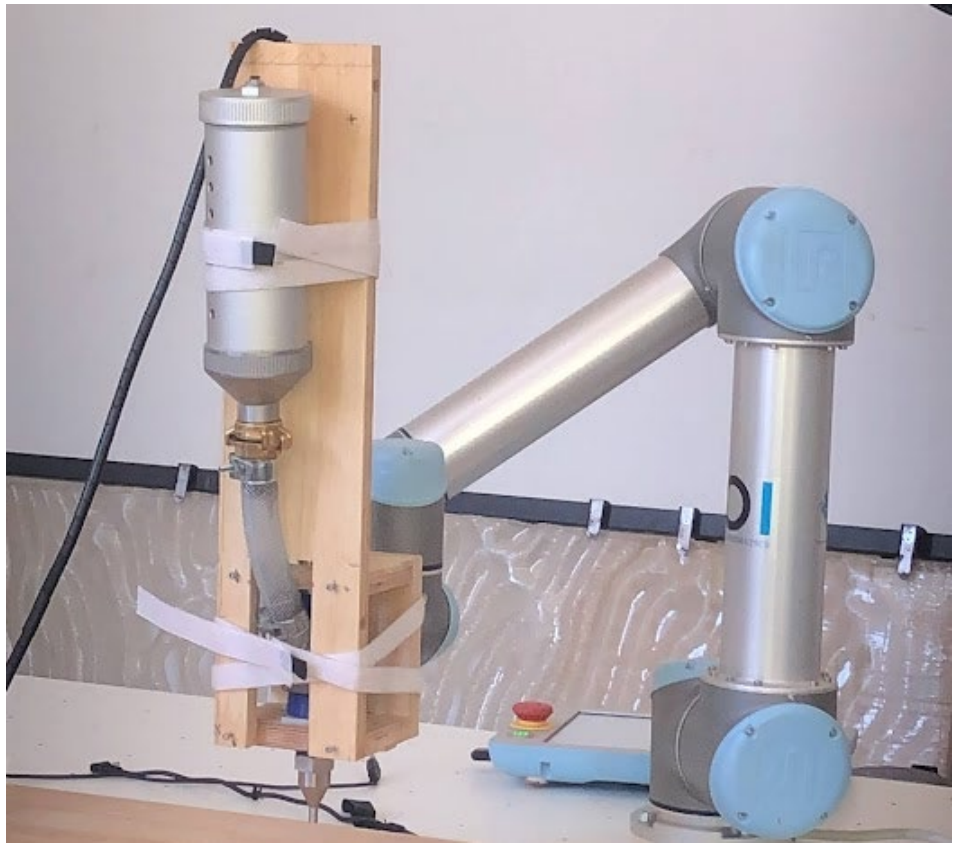
- Coffee generates molds
- Brewery’s Grain for next steps

Remaining variable:

- Type of flour

4. 3D PRINTING WITH PASTE EXTRUDER

Equipment



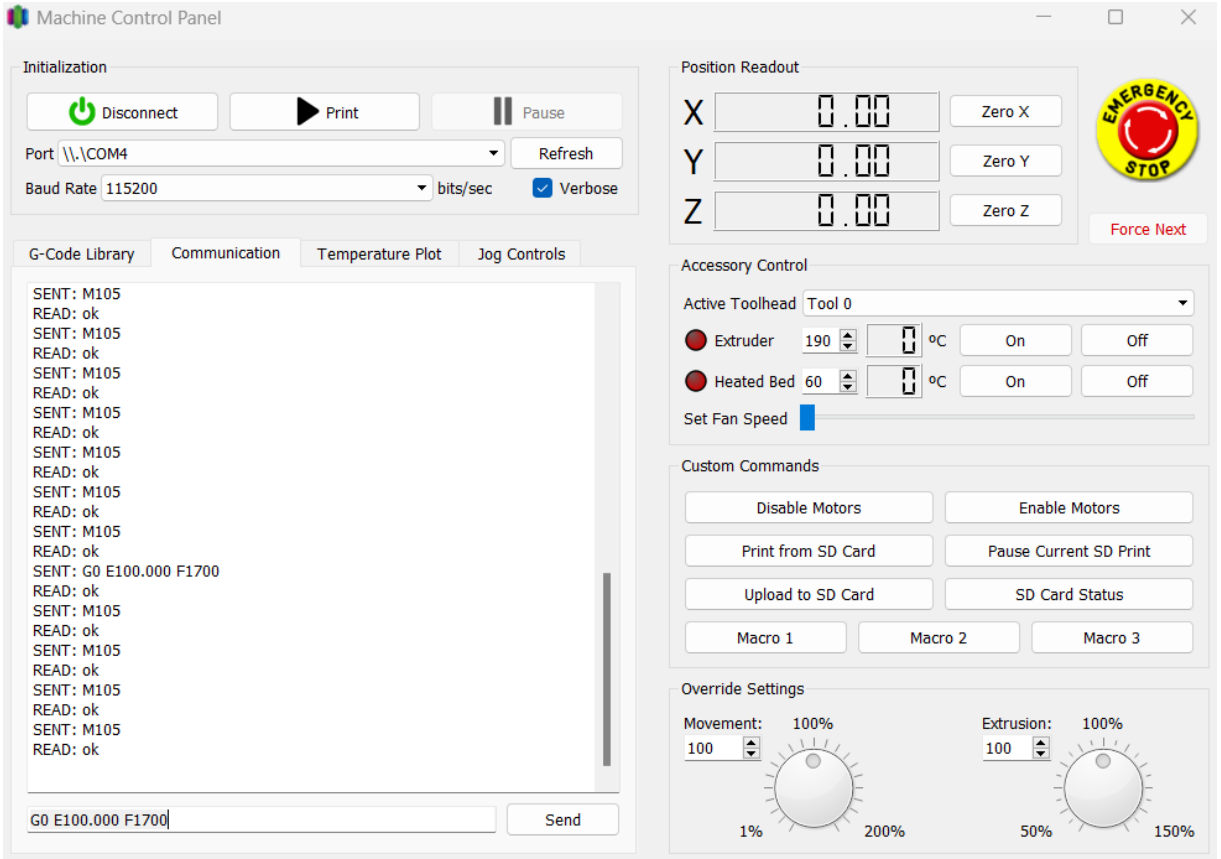
UR5 Robot + LDM WASP Extruder XL 3.0

Extruder

G0 = Start motor

E = Amount of rotations

F = Speed of rotations

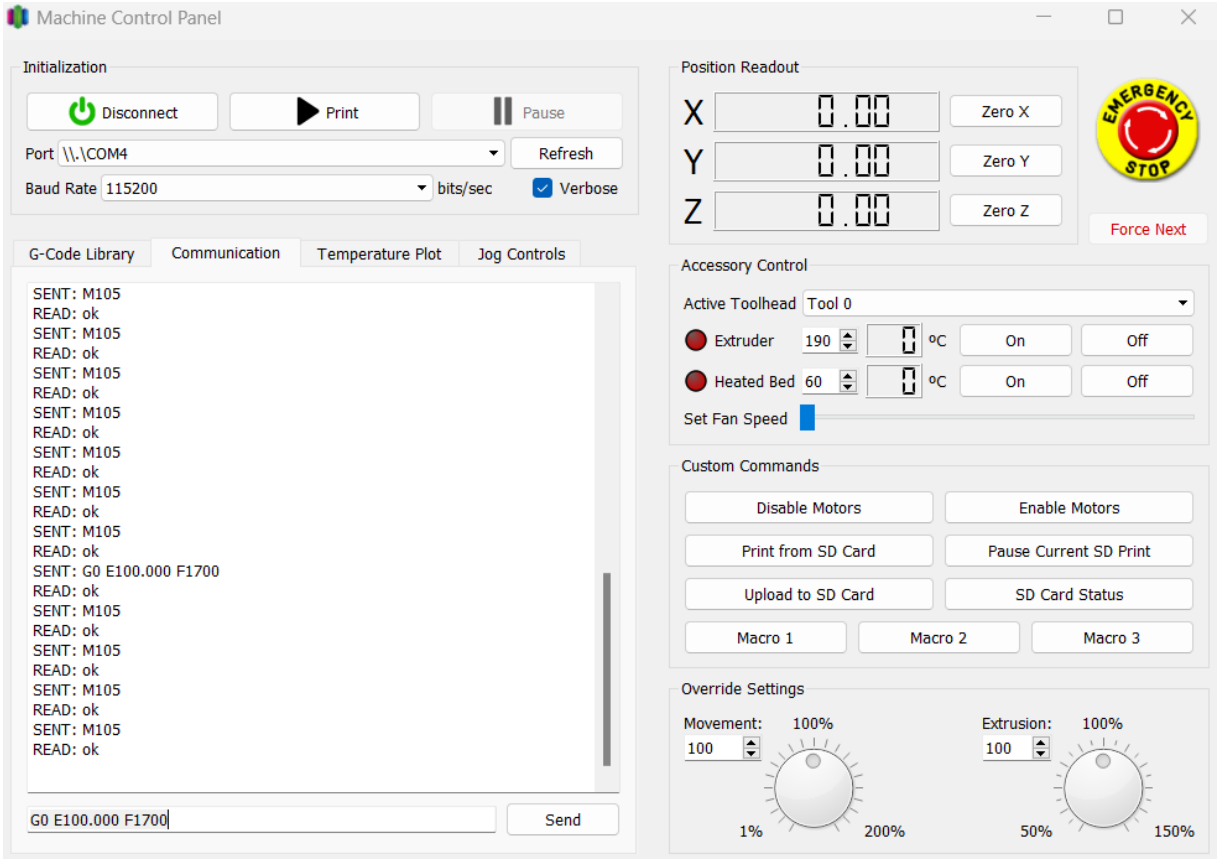


Extruder

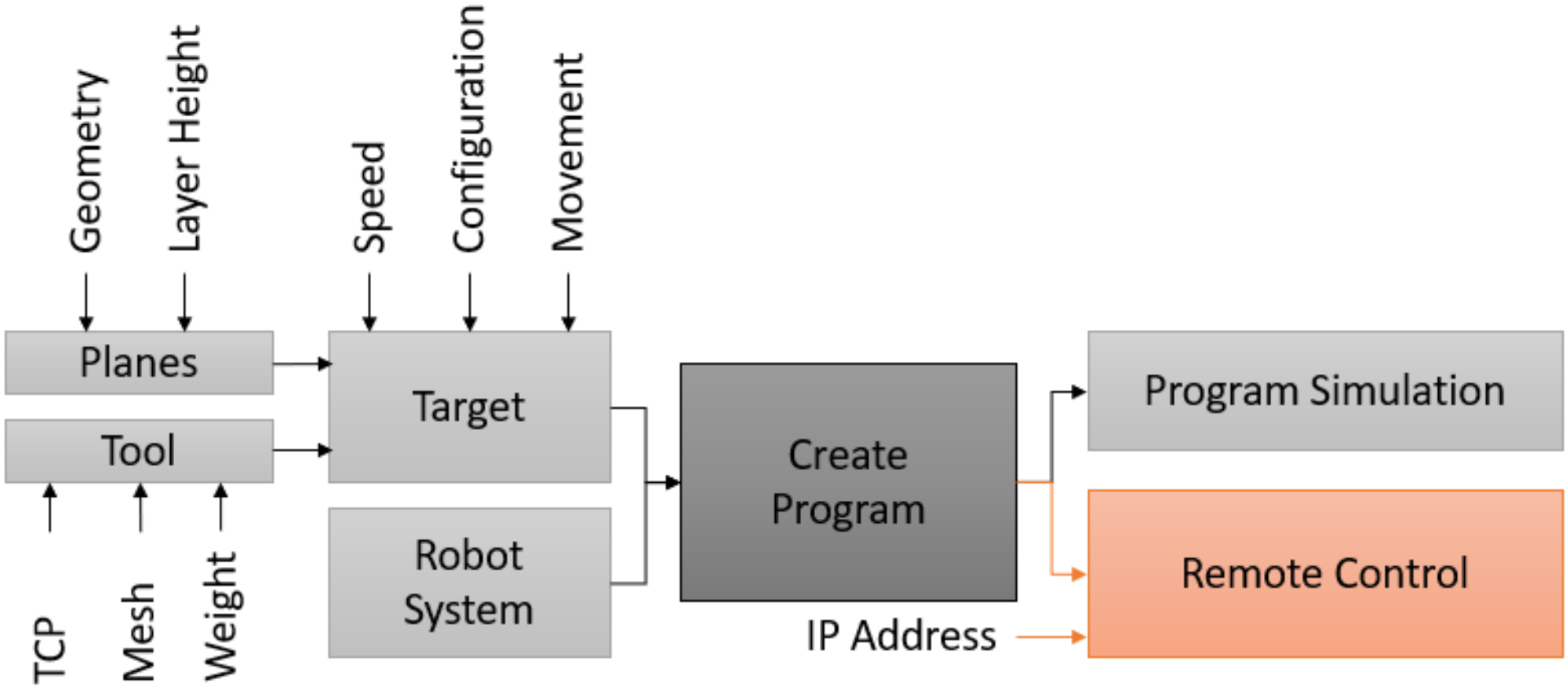
G0 = Start motor

E = Amount of rotations

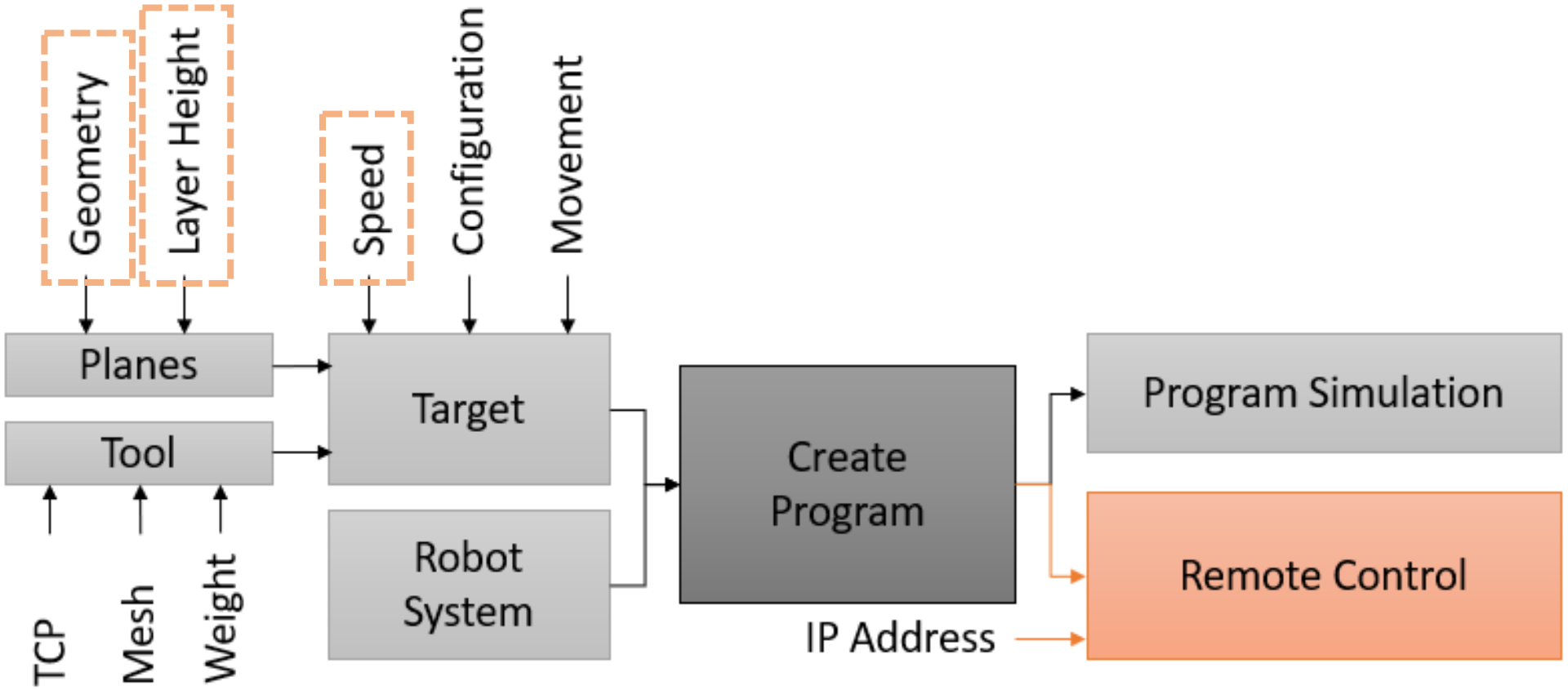
F = Speed of rotations



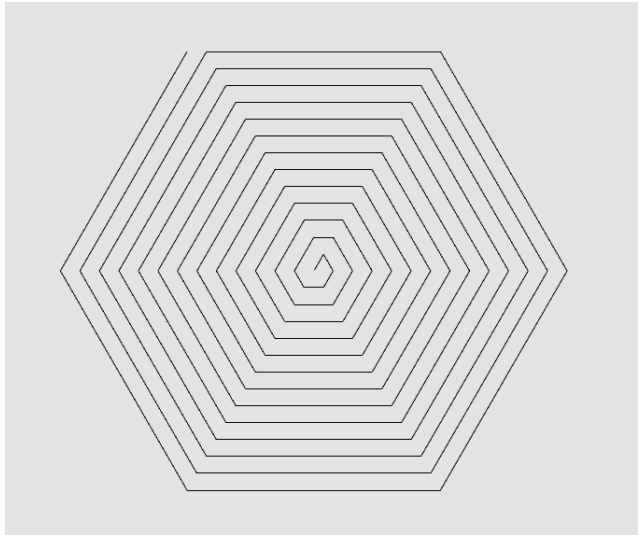
Robot

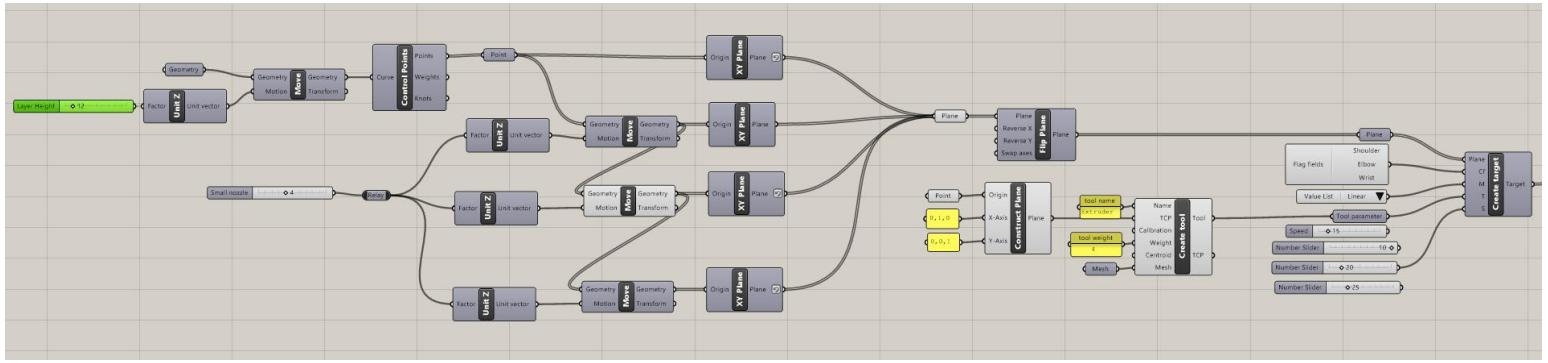

Geometry
Layer Height
Speed
Configuration
Movement
Planes
Tool
Target
Robot System
Create Program
Program Simulation
Remote Control
IP Address
TCP
Mesh
Weight

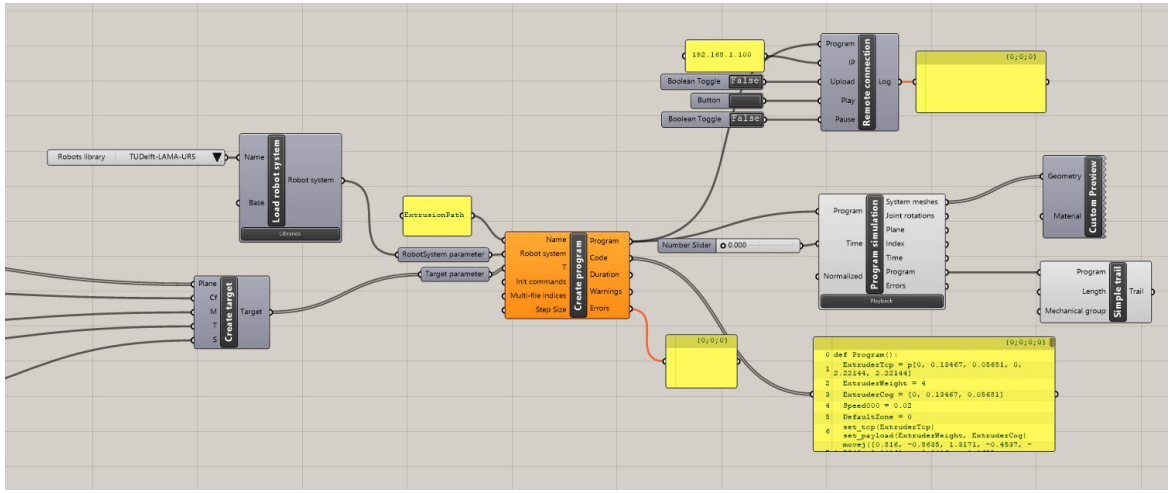
Robot


Geometry
Layer Height
Speed
Configuration
Movement
Planes
Tool
Target
Robot System
Create Program
Program Simulation
Remote Control
IP Address
TCP
Mesh
Weight

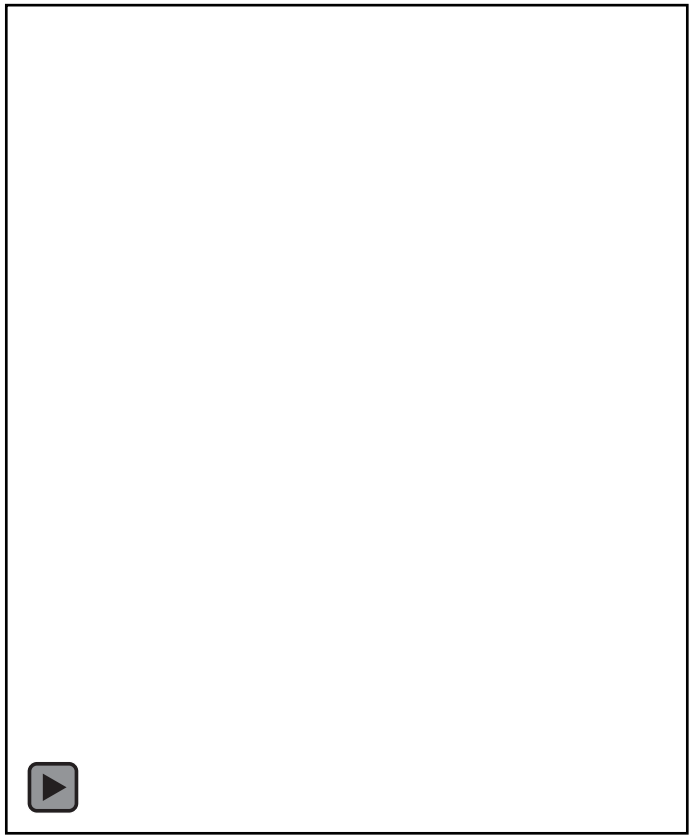
Create program

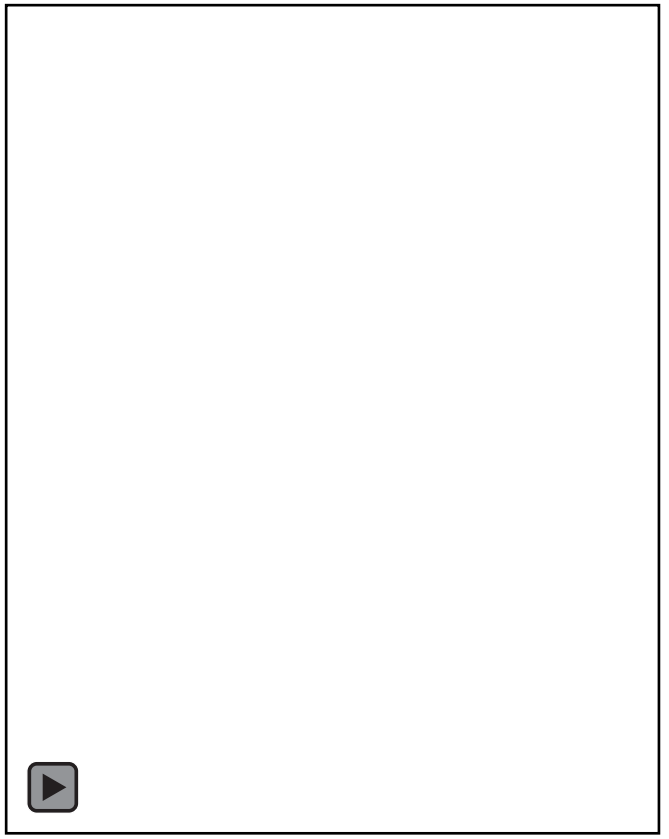




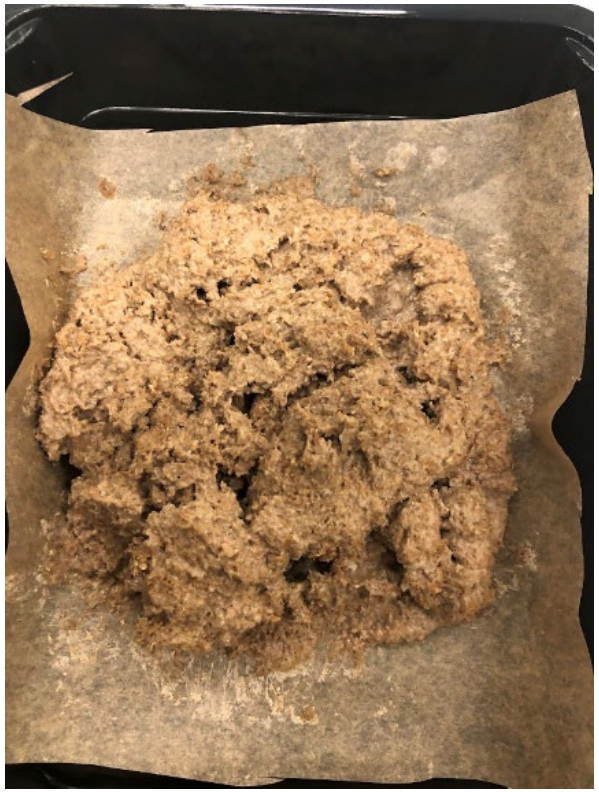


Results





Results



Conclusion

Print settings:

G-code	G0 E1000.000 F1700-2000
Layer 1	12mm
Layer 1+	4mm
Speed	20mm/s

Mixture ratio: Brewery’s Grain : Flour : Mycelium : Water

6:6:1:8

Conclusion

Remaining variables:

- Line distance
- Nozzle size

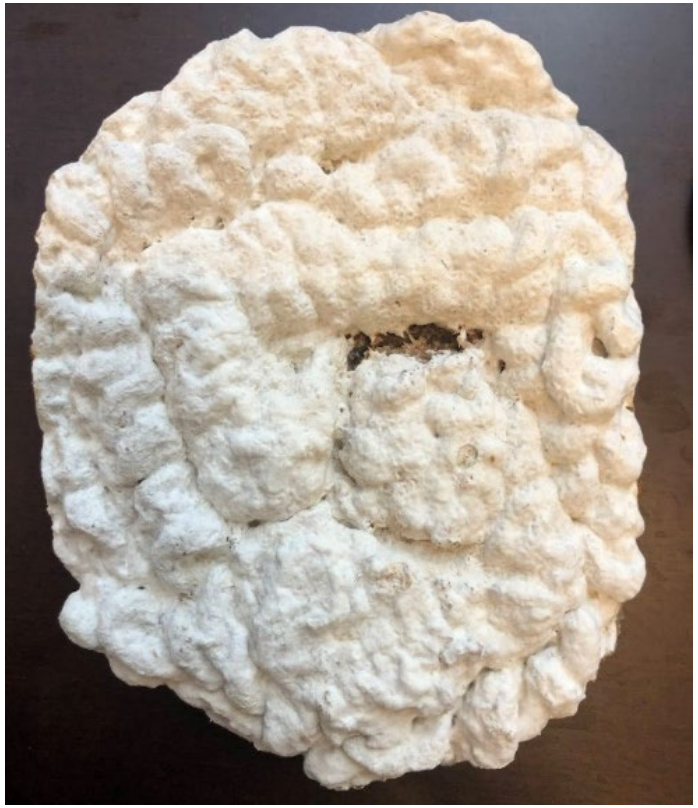
Acoustic Performances

Acoustics

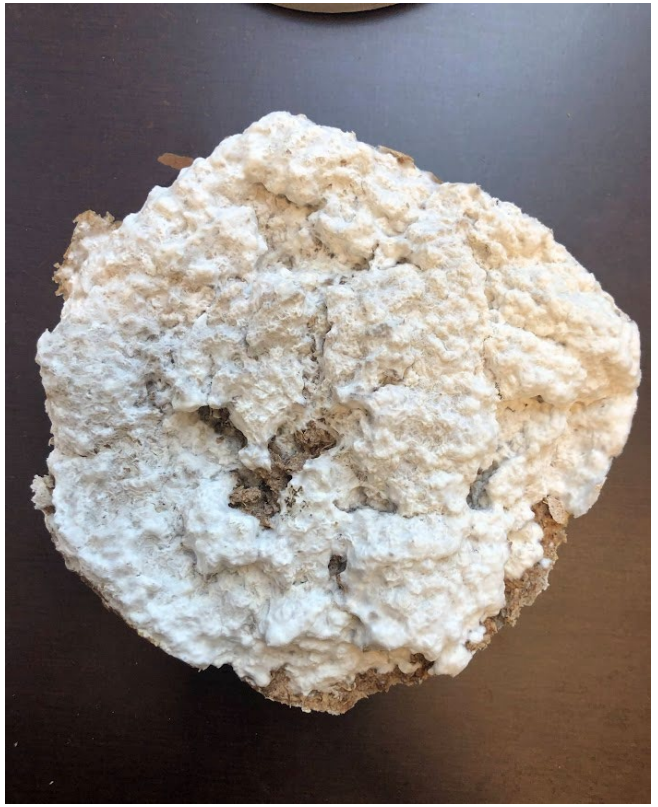
Influences Acoustic properties

5. ACOUSTIC PROPERTIES

Tested Materials



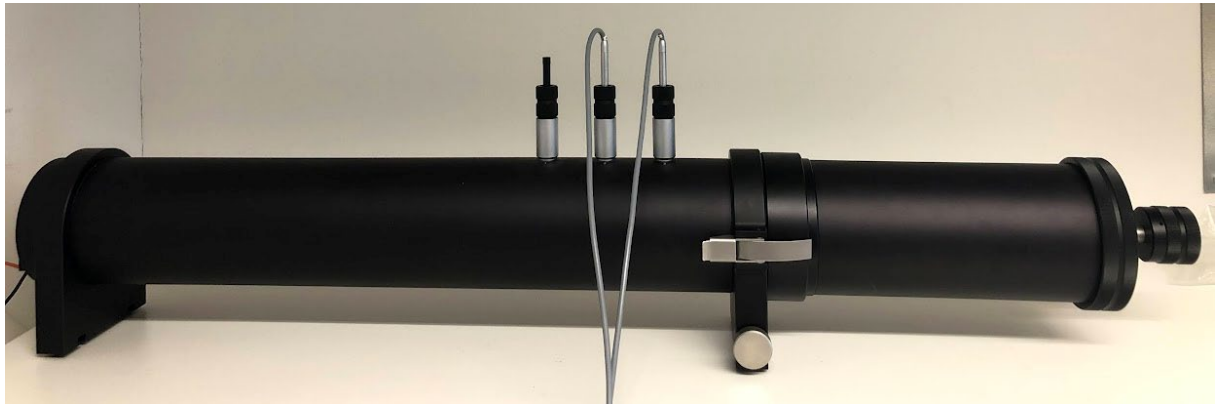
Sample 1



Sample 2

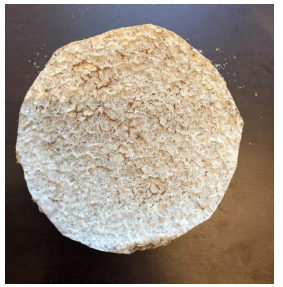
Sample 3

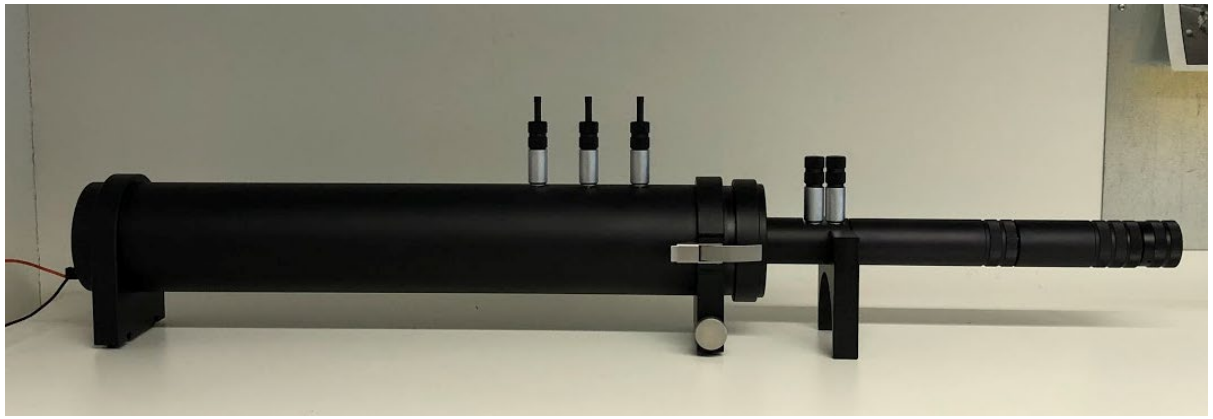
Equipment



Low frequencies 50-800Hz

Sample diameter 10cm



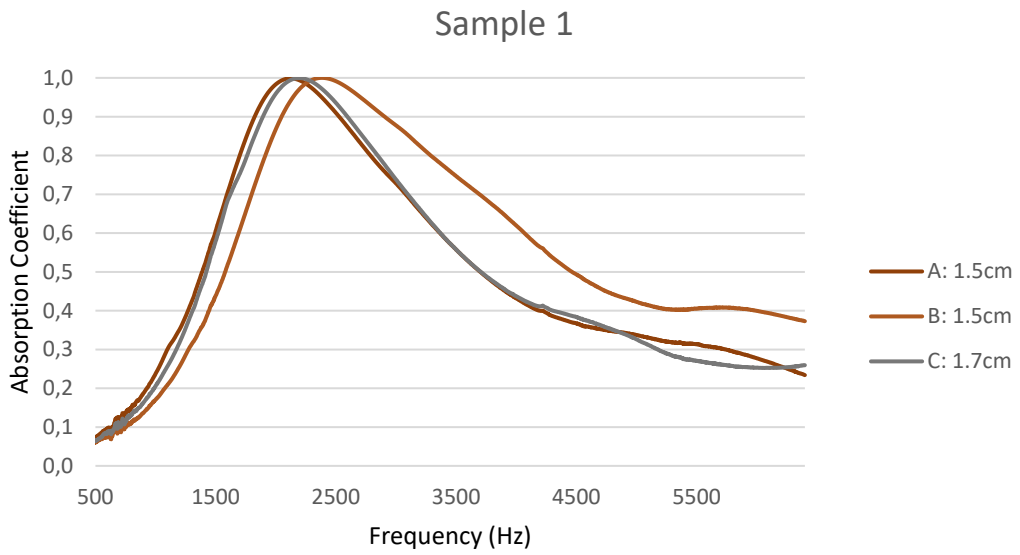


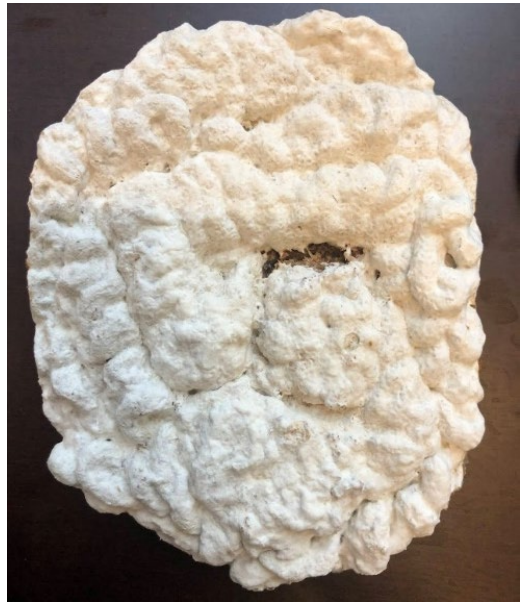
High frequencies 500-6400Hz

Sample diameter 2.9cm

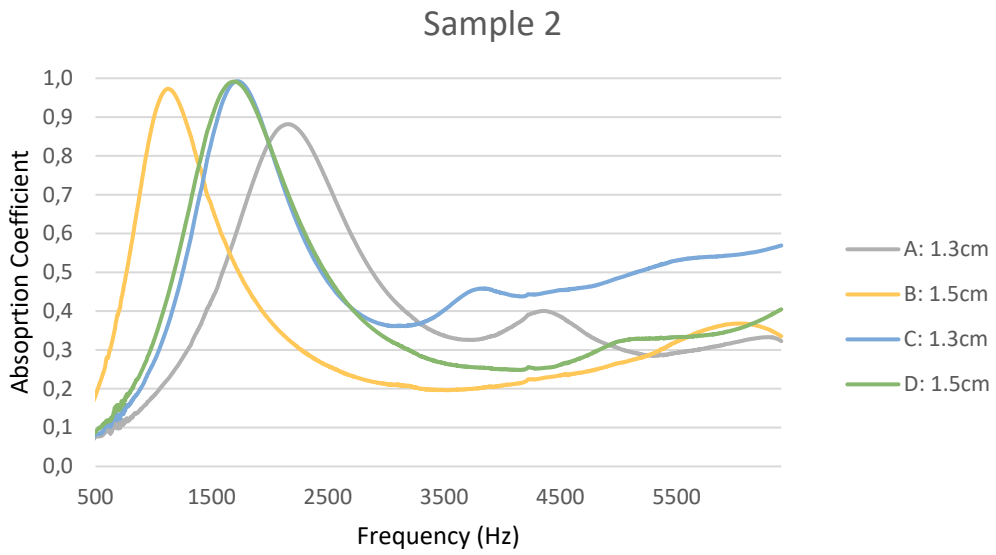
Impedance tube B&K 4206

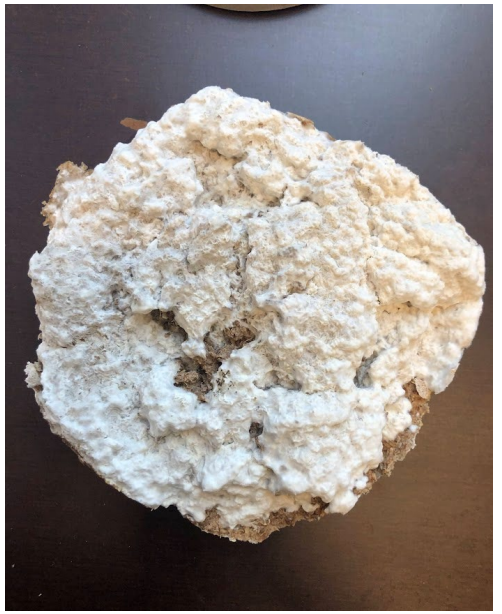
Sample 1


Sample 1
Absorption Coefficient
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
500
1500
2500
3500
4500
5500
Frequency (Hz)
A: 1.5cm
B: 1.5cm
C: 1.7cm

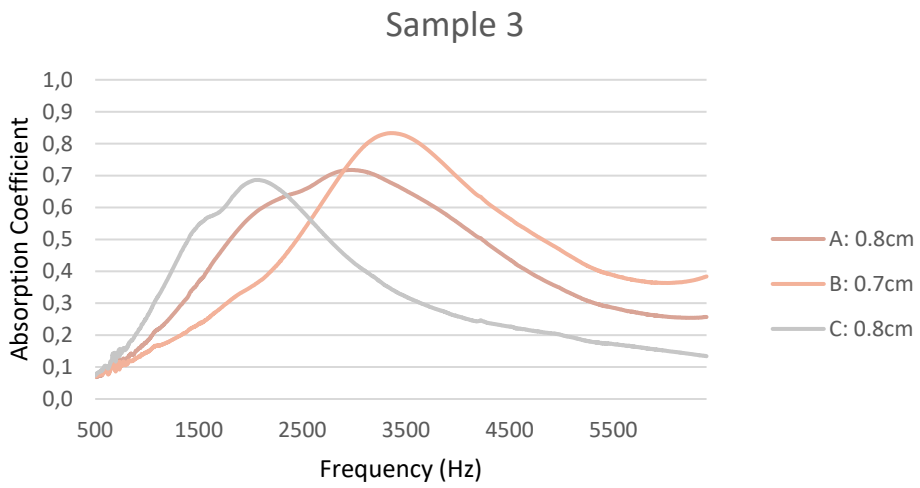


Sample 2


Sample 2
Absoprtion Coefficient
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
500
1500
2500
3500
4500
5500
Frequency (Hz)
A: 1.3cm
B: 1.5cm
C: 1.3cm
D: 1.5cm



Sample 3


Sample 3
Absorption Coefficient
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
500
1500
2500
3500
4500
5500
Frequency (Hz)
A: 0.8cm
B: 0.7cm
C: 0.8cm

Conclusions

Low frequencies no influence

Added variables:

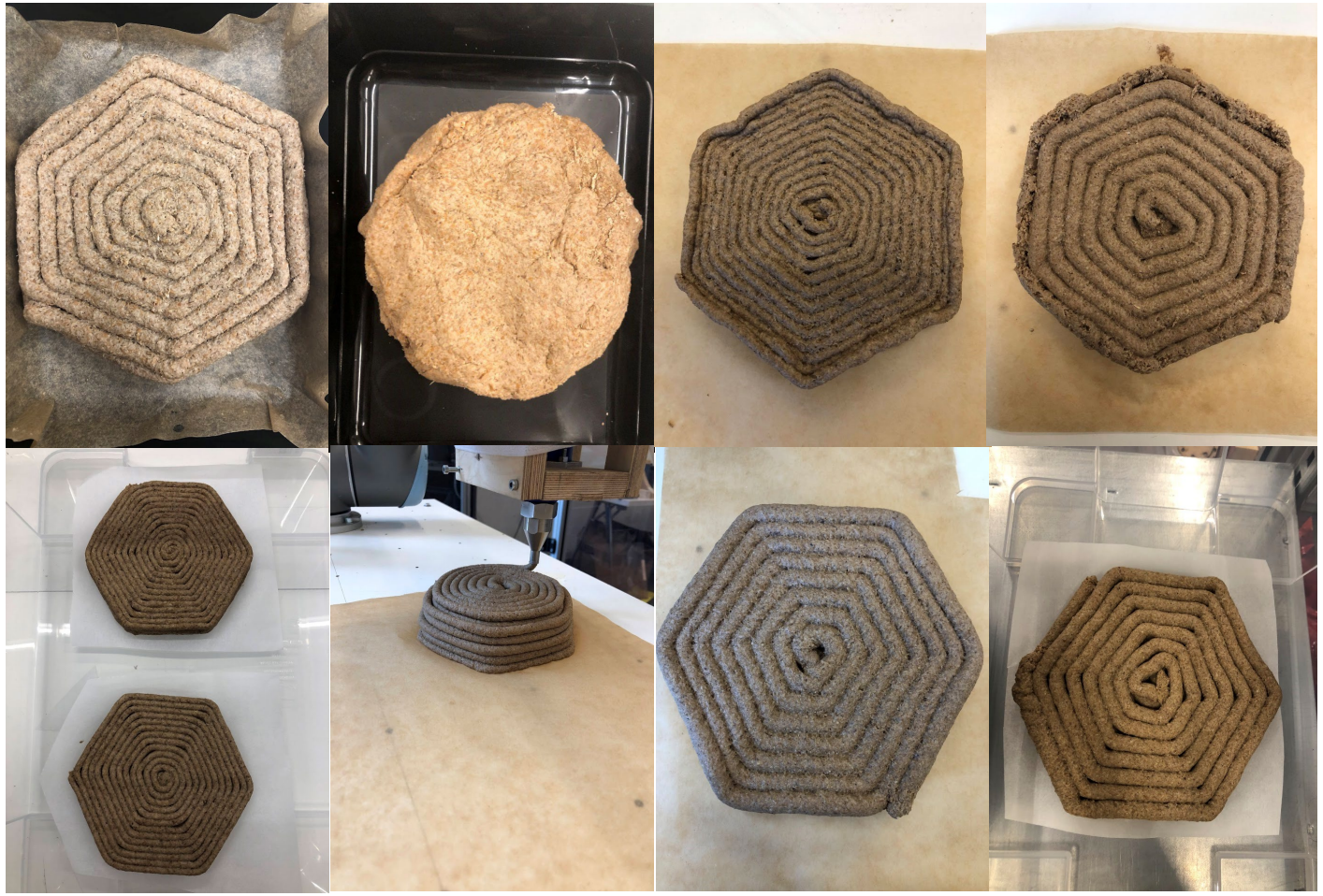
- Thickness
- Mycelium Growth Time
- Printed vs not Printed

6. INFLUENCES ACOUSTIC PROPERTIES

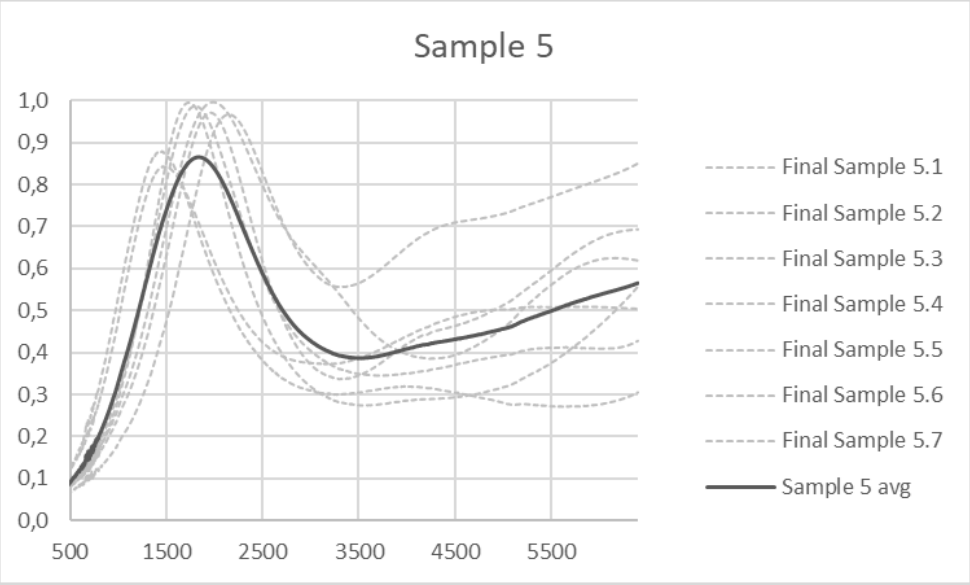
Tested Variables

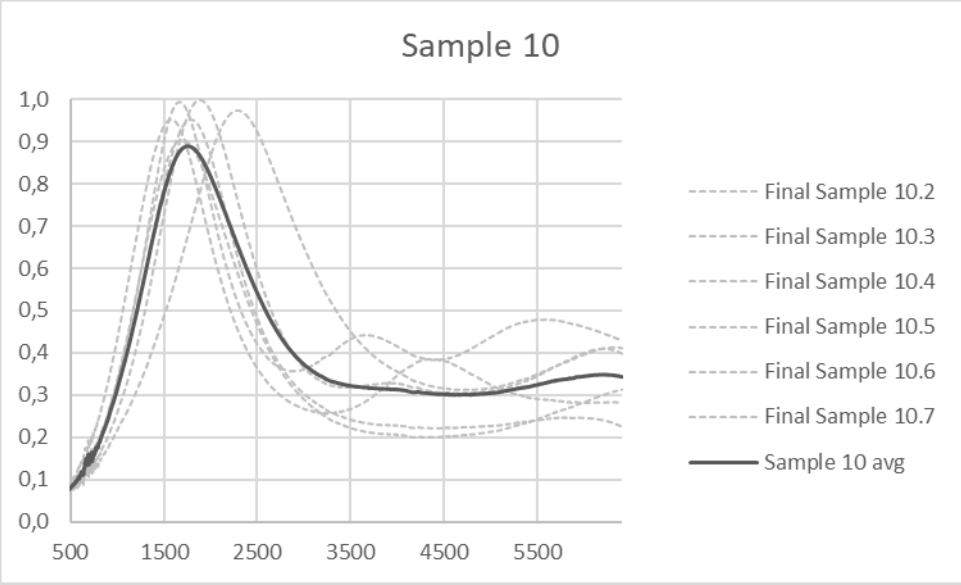
- Printed vs not printed
- Nozzle size
- Type of flour
- Line distance
- Thickness
- Growth time

Samples

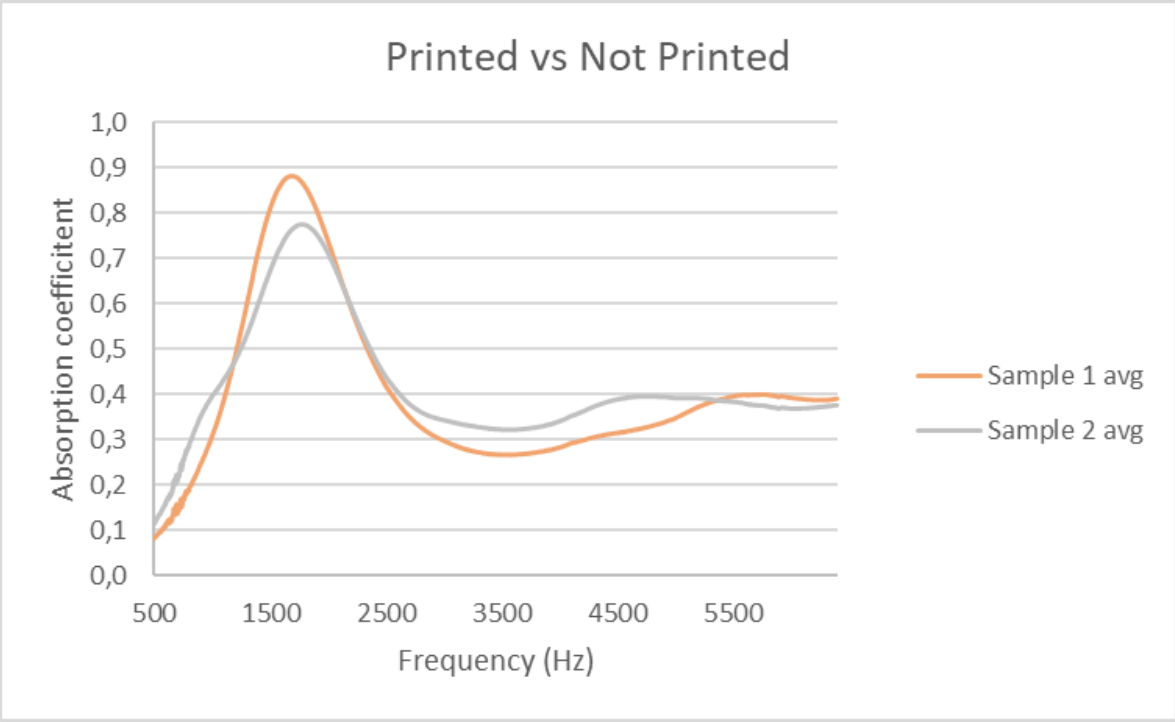


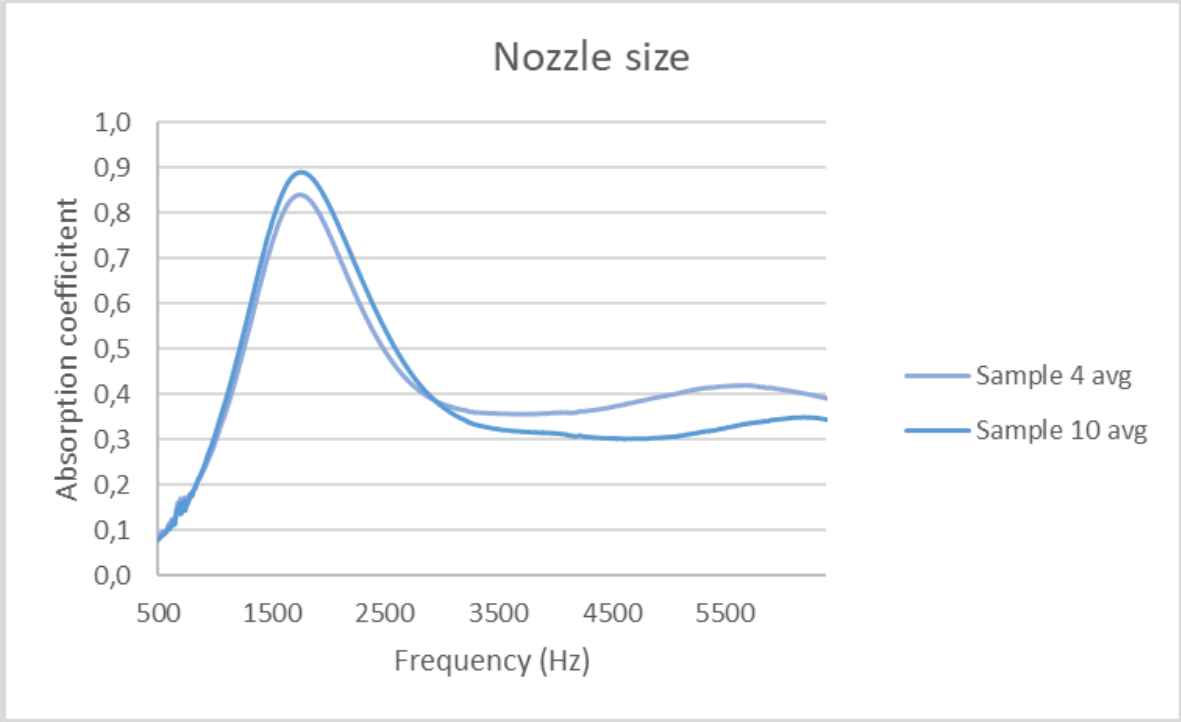
Absorption Coefficient



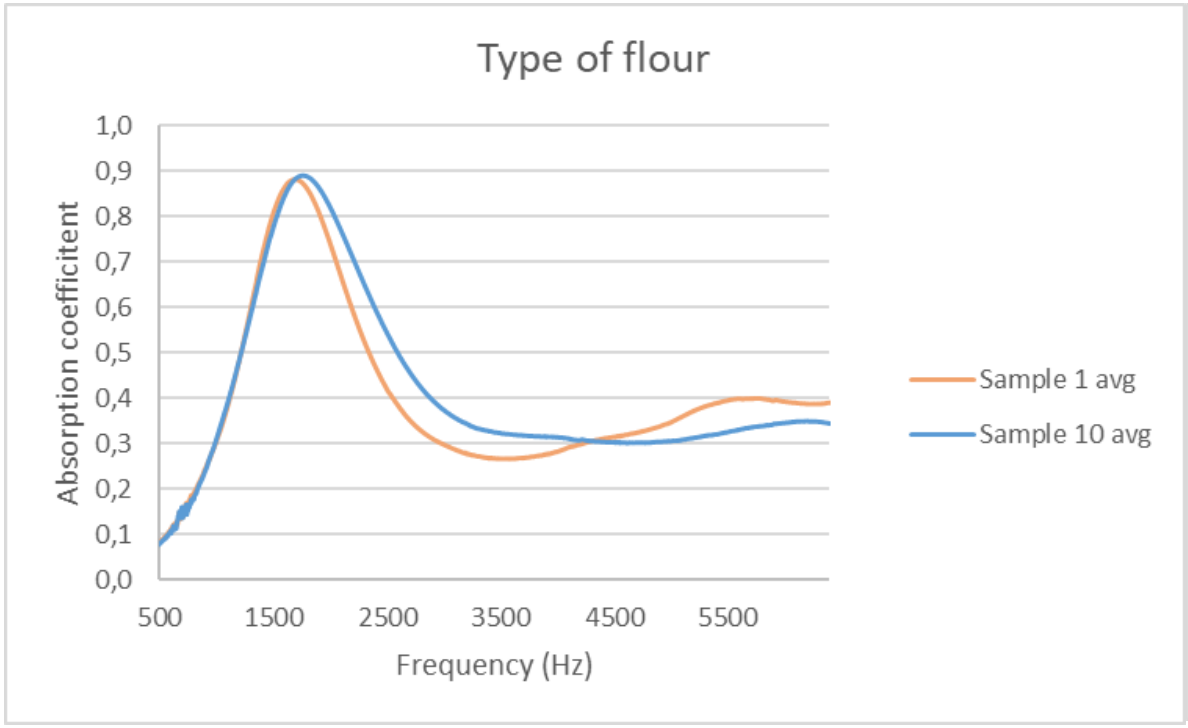


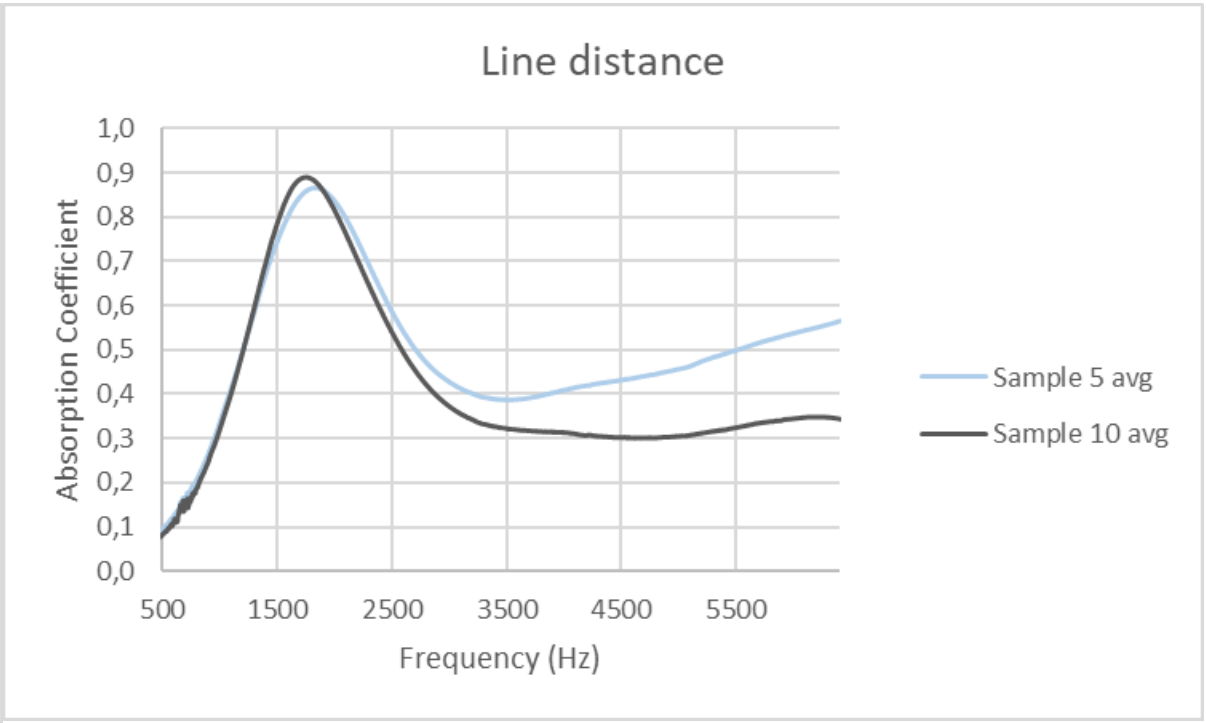
Results


Printed vs Not Printed
Absorption coefficitent
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
500
1500
2500
3500
4500
5500
Frequency (Hz)
Sample 1 avg
Sample 2 avg

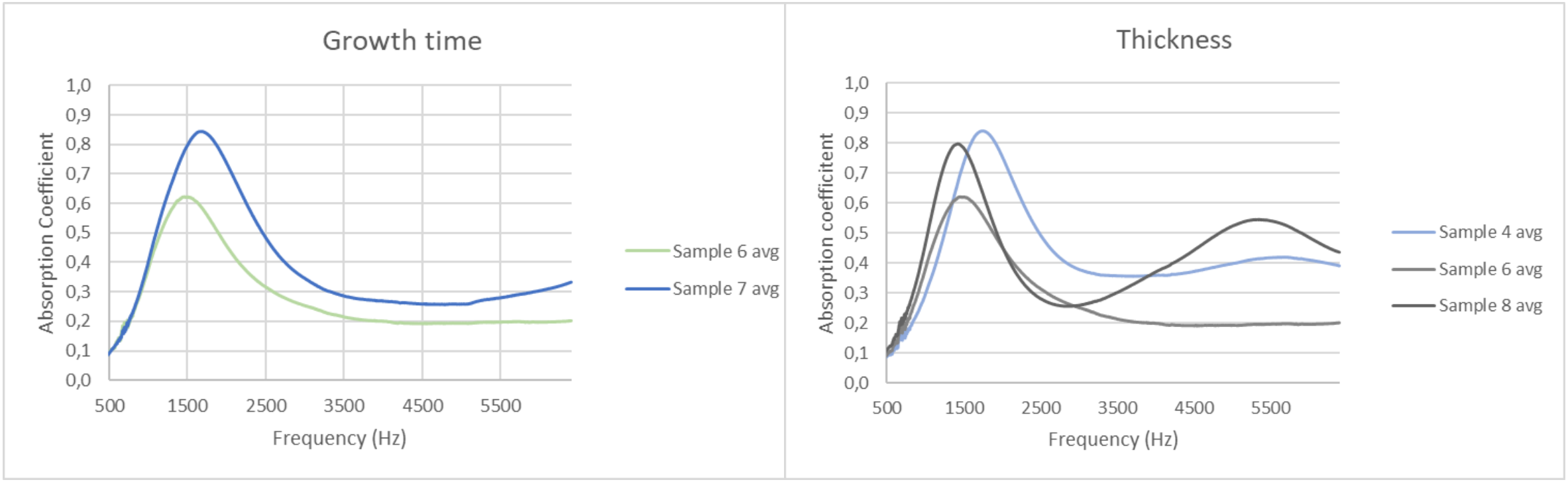

Nozzle size
Absorption coefficitent
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
500
1500
2500
3500
4500
5500
Frequency (Hz)
Sample 4 avg
Sample 10 avg

Results


Type of flour
Absorption coefficitent
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
500
1500
2500
3500
4500
5500
Frequency (Hz)
Sample 1 avg
Sample 10 avg

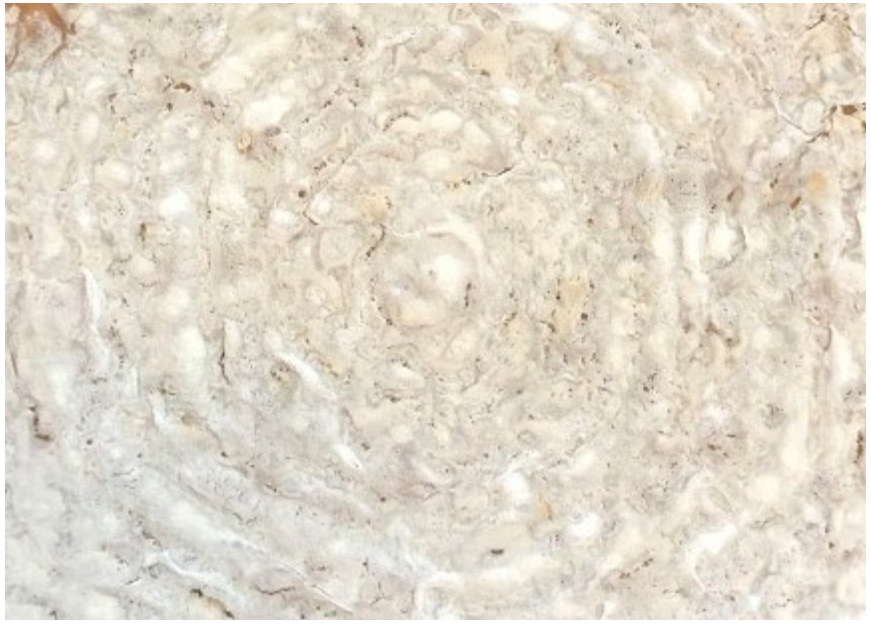

Line distance
Absorption Coefficient
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
500
1500
2500
3500
4500
5500
Frequency (Hz)
Sample 5 avg
Sample 10 avg

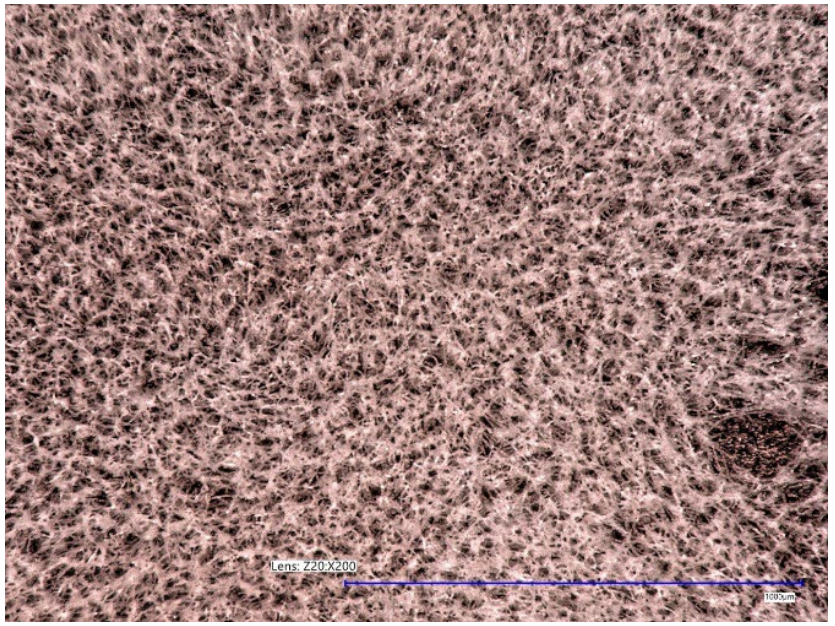
Results


Growth time
Absorption Coefficient
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
500
1500
2500
3500
4500
5500
Frequency (Hz)
Sample 6 avg
Sample 7 avg
Thickness
Absorption coefficitent
Frequency (Hz)
Sample 4 avg
Sample 6 avg
Sample 8 avg

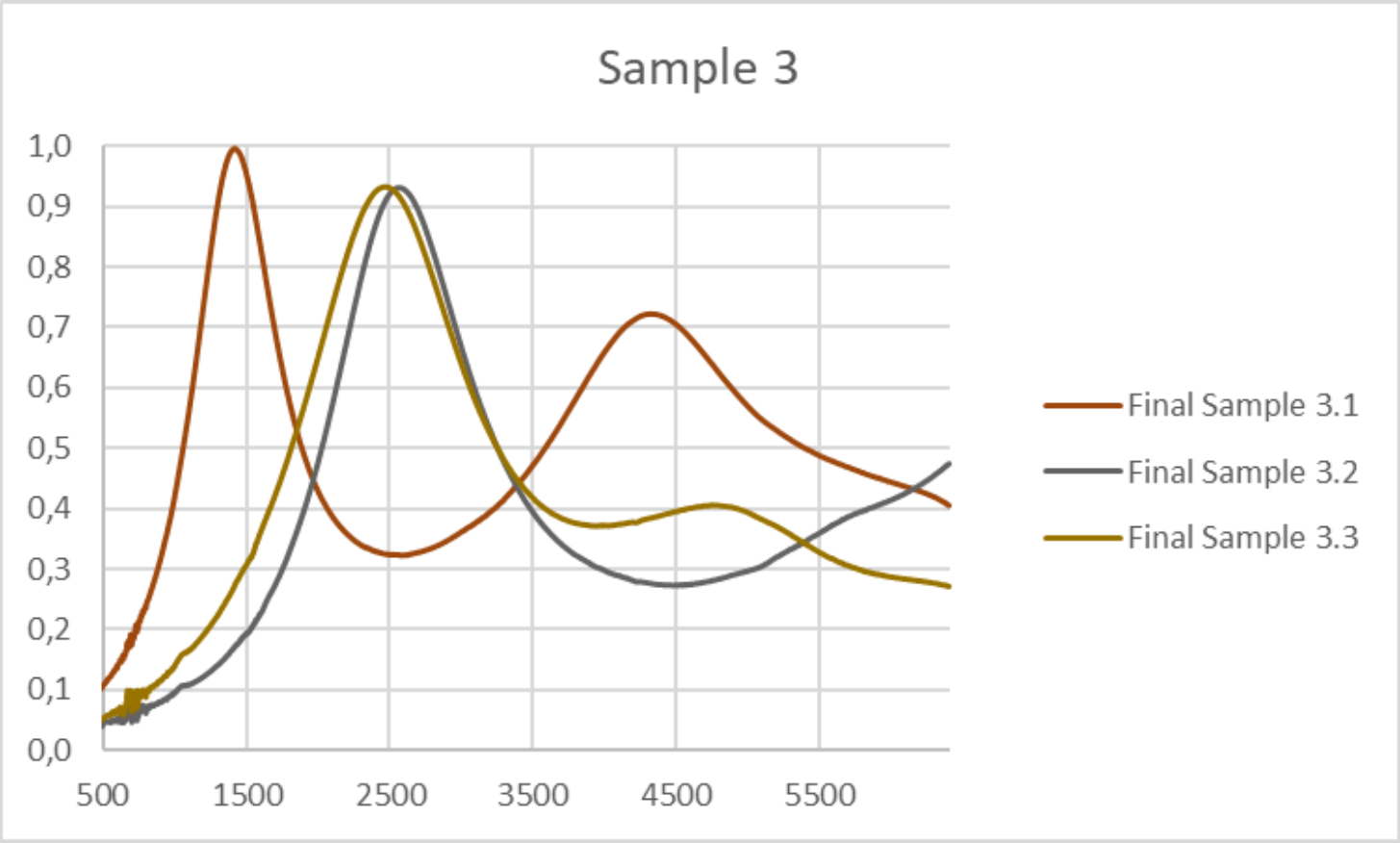
Possible explanations

Micro Perforated panel





Without mycelium



- 3.1 = 4.5cm
- 3.2 = 2cm layer on top
- 3.3 = 2cm no layer on top

Possible explanations

2 Porous absorbers on top op each other

Design

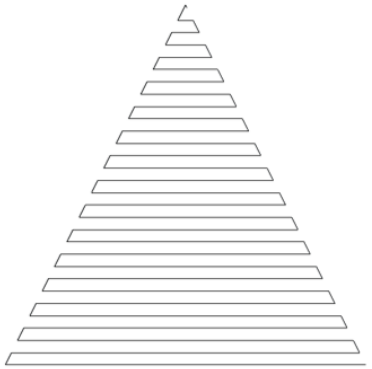
Design options

Customizable Design

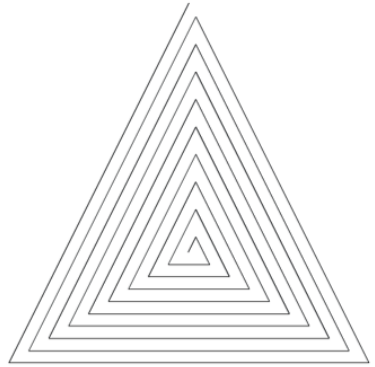
Parametric Design

Object Design

Customizable Desing

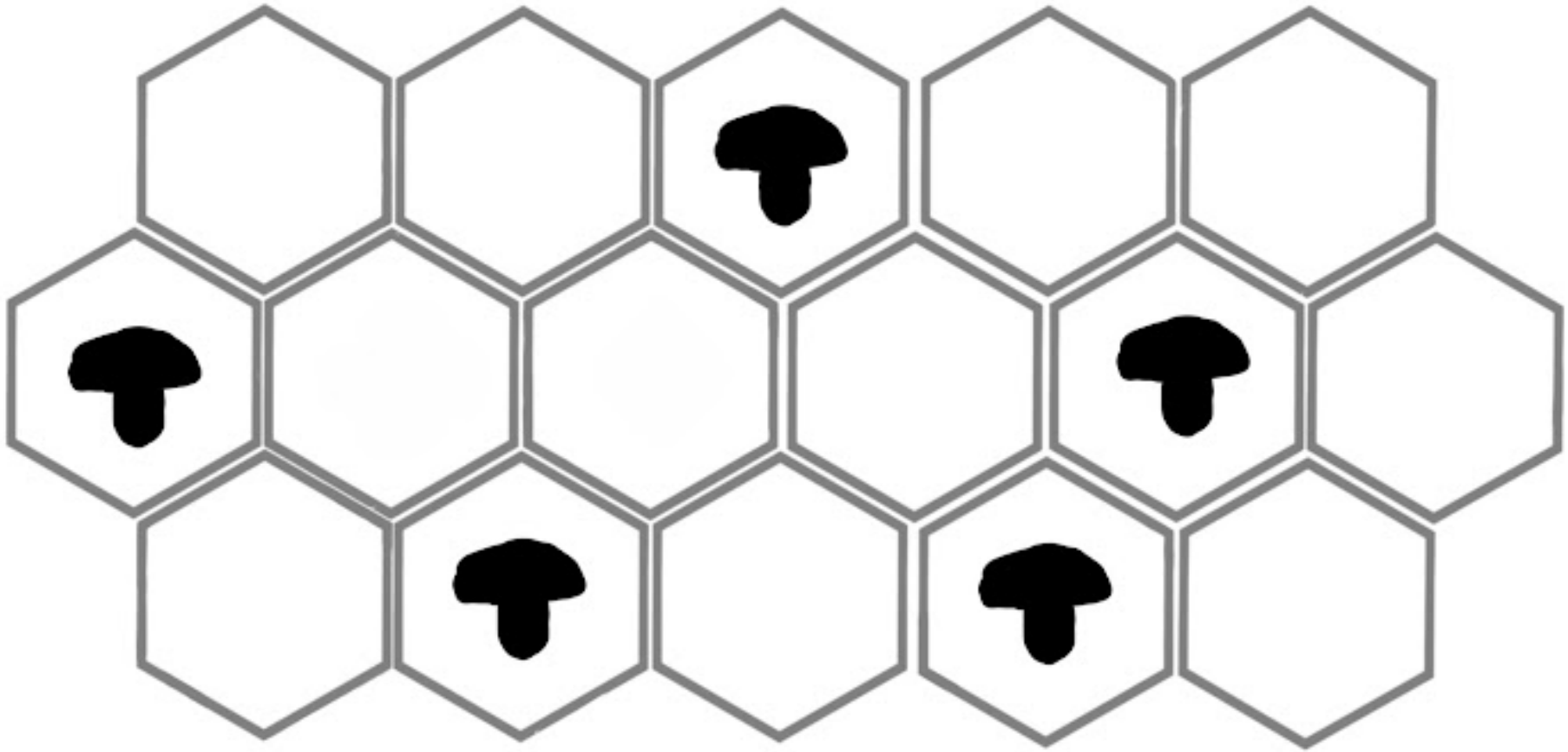


Zigzag pattern

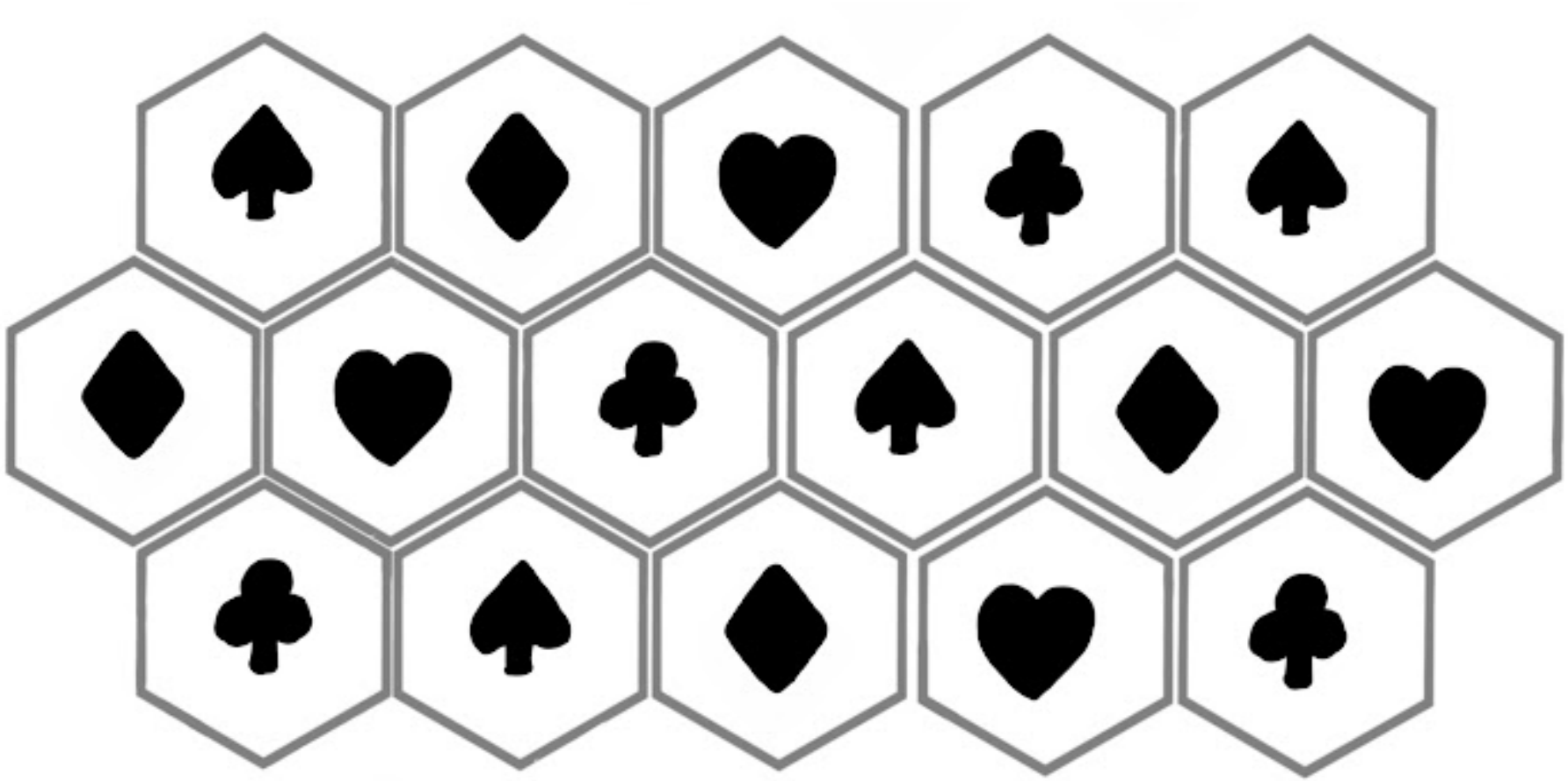


Spiral pattern

Customizable Desing

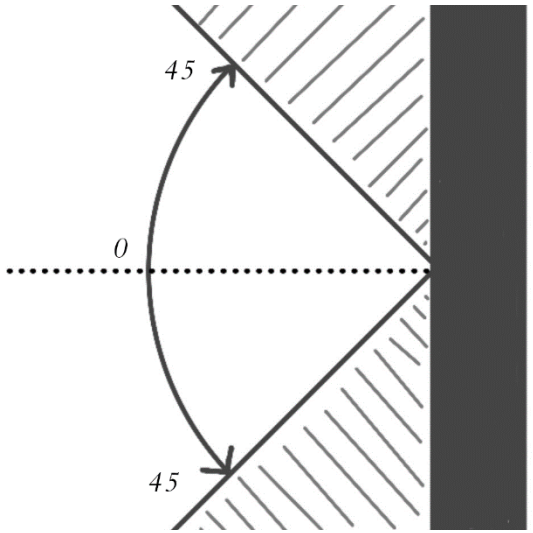


Customizable Desing



Customizable Desing

Parametric Design



Object Design

Colored lamps (Blast Studio, 2022) (top left)

Candle holders by Blast Studio (Beall, 2020) (middle)

Suede-like lamps (Krejci, 2017) (bottom left)

Hypnerotomachia Naturae by Stefan Maier and Giacomo Pala (Jamie D, 2021) (right)

Ingredients

Oyster Mushroom

https://www.indiamart.com/proddetail/fresh-oyster-mushrooms-25685530755.html

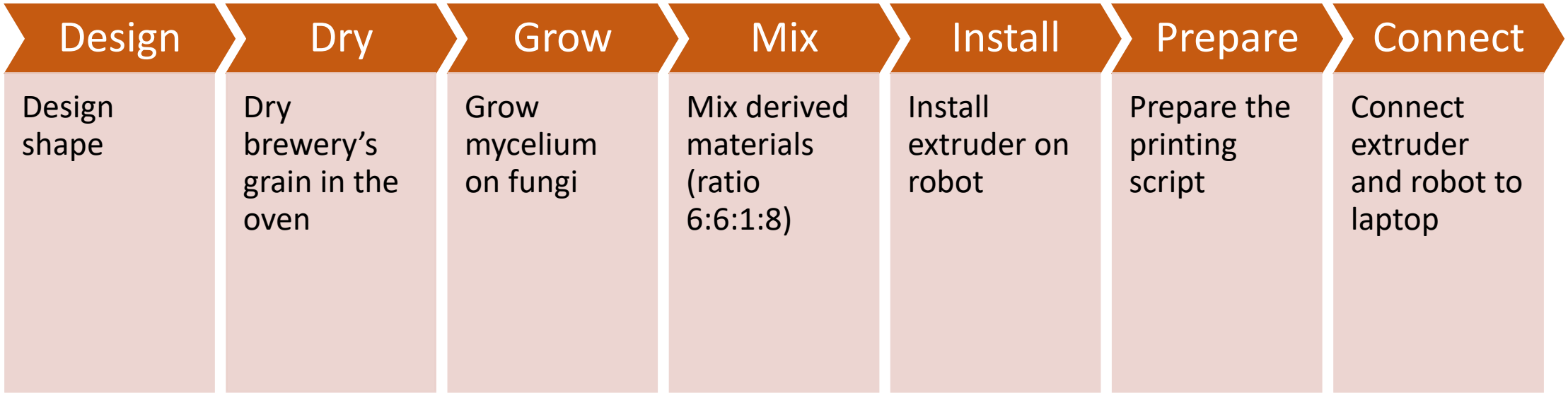
Brewery's Grain

https://www.forbes.com/sites/robindschatz/2020/05/19/how-upcycled-ingredients-can-help-reduce-the-940-billion-global-food-waste-problem/

Flour

https://boerentrots.be/blog/bloem-hetzelfde-als-meel

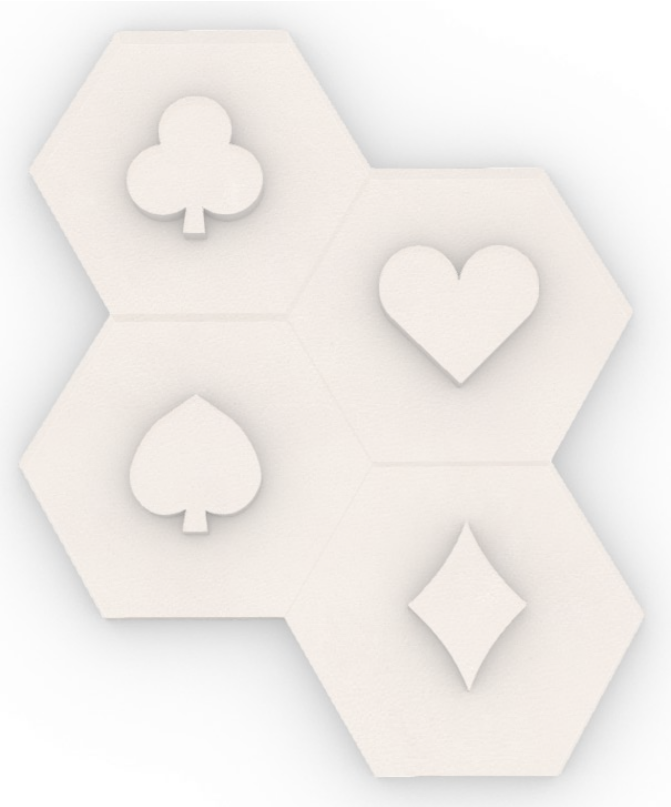
Production process



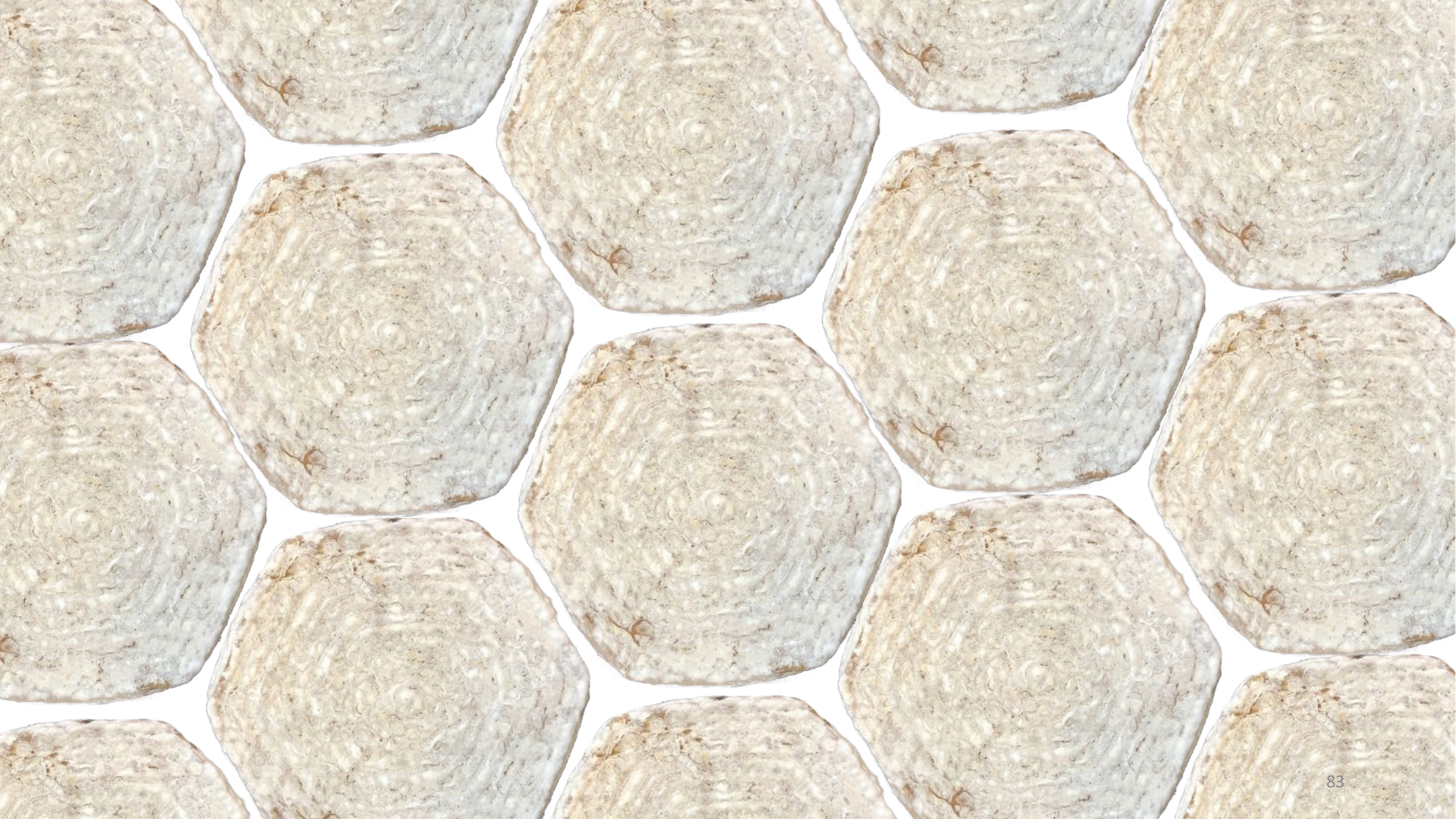
Production process

Insert	Connect	Print	Store	Grow	Dry
Insert cartridge to the extruder	Connect air pressure to the extruder (+/- 2 bar)	Print the desired shape	Store the print in a closed box	Let the mycelium grow (+/- 2 weeks)	Dry the print in the oven to stop the mycelium growth

Design possibilities



Hypnerotomachia Naturae by Stefan Maier and Giacomo Pala (Jamie D, 2021)

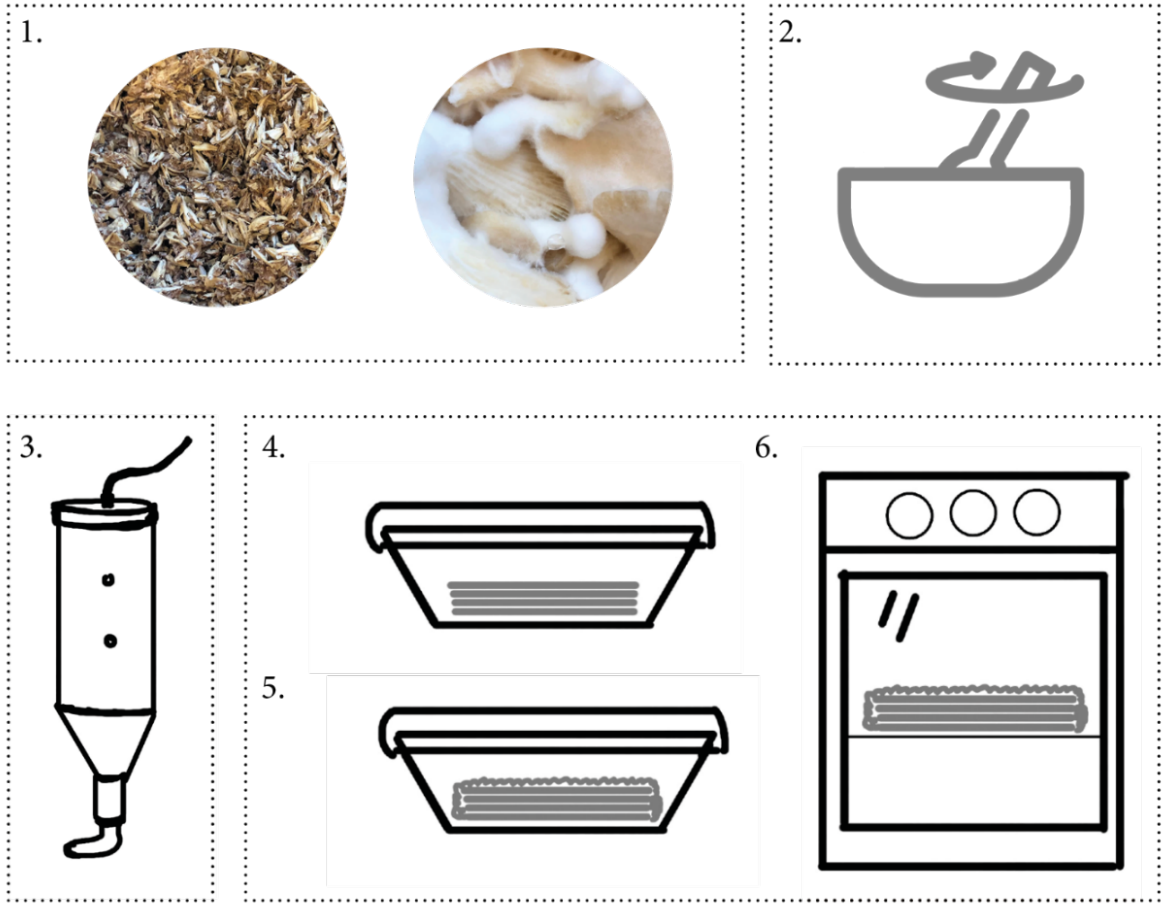


Conclusion

CONCLUSION

How can a sound absorbing panel for indoor use be 3D printed with a mycelium bound biomaterial which finds its origin in urban waste?

Production process



1. Prepare the matrials
2. Mix the materials
3. Extrude the paste into a shape
4. Store the sample in a closed box
5. Let the mycelium grow
6. Dry the mycelium

Experiment	Outcome
1. Mycelium Growth	Material: Grinded Coffee & Brewery's Grain
2. Extrudability	Additives: **All-Purposes Flour & Wheat Flour**
3. 3D Printing with Caulking Gun	Material: **Brewery's Grain** Variable: Type of Flour
4. 3D Printing Paste Extruder	Print Settings: **Layer 1 12mm, Layer 1+ 4mm, Speed 20mm/s** Extruder Settings: **Speed 1700-2000** Variables: Line Distance, Nozzle Size Mixture Ratio: **Brewery's Grain-Flour- Mycelium-Water 6:6:1:8**
5. Acoustics	First Values Elimination Low Frequency Measures Variables: Thickness, Mycelium Growth Time, Printed vs not Printed
6. Influences Acoustics	Influencing Variables: **Thickness** **Mycelium Growth Time** Possible Acoustic Explanation: **Micro Perforated Panel** **2 Porous Absorbers on top of each other**

Category	Conclusion
Waste Material	Brewery's Grain
Additives	All-Purposes Flour & Wheat Flour
Ratio Brewery's Grain:Flour:Mycelium:Water	6:6:1:8
Print settings	Layer 1 12mm Layer 1+ 4mm Speed 20mm/s
Extruder settings	G0 E15000.000 F1700-F2000
Influencing Variables	Thickness Mycelium Growth Time
Possible Acoustic Explanation	Micro Perforated Panel 2 Porous Absorbers on top of each other

Reflection

REFLECTION

Strengths	Printable material Variables which influence the properties Use a robot, create a printing script and print useful samples
Weaknesses	No perfectly grown panel No specific result on behavior of the mycelium Too long with coffee
Opportunities	Future research on the estimation of the mycelium behavior Use the produced material for other products Research mycelium with a microscope for a better understanding
Treats	End of life scenario, when will it dissolve The mycelium growth time is influenced by a variety of environmental conditions A possible leak of supply of the brewery's grain

LIMITATIONS OF THE RESEARCH

- Growth conditions
- Store bought oyster mushrooms
- Brewery’s grain mixtures
- Only food binders

FUTURE RESEARCH

- Finding waste products which can create an extrudable paste to replace the flour
- Determine the best growth conditions for the developed material
- Research the behavior of the mycelium film formed on the surface of the panels

SOCIETAL IMPACT

- Fully bio-based building product which can generate life after its lifespan
- 3D printed, so customizable which makes it interesting for a broader public
- Gives guidelines for creating a printable biobased/living material

“There’s a brilliant chemistry to mushrooms, and endless possibilities. We’re just at the beginning of understanding them.”
– Michael Pollan