
fig.1

Growing Materiality - Is Mycelium the Material of the Future?

Rebecca Peacock

“This is not a drill.
It’s code red for the Earth.
Millions will suffer as our planet is devastated - a terrifying future that will be created, or avoided, by the decisions you make.
You have the power to decide.”

- Greta Thunberg (The Indian Express, 2022)

Contents

Acknowledgements

I would like to thank my supervisor, Masa for all her help and input throughout the year and Alan from Milkwood Mushrooms, for his knowledge and guidance.

fig.2
Mycelium growing on paper

Why?

This dissertation aims to investigate what Mycelium is, its role within the ecosystem, its current uses within the Creative Industry focusing primarily on how Mycelium can be used to create a material and where it is being used in the industry.

At present, materials used in the construction of buildings consume a large amount of resources which in turn, adversely affects the environment. If there are natural materials readily available that are carbon neutral, why are they not being used?

Cement is a widely used material, especially as a component of concrete, but its carbon footprint is significant as it requires large amounts of heat and energy in the manufacturing process alone. Mycelium flourishes on waste materials and only requires room temperature to grow and although its properties would not allow it to replace cement in the production of concrete elements, Mycelium can be
considered as a material which could help reduce the amount of man-made materials that are accumulating in the environment at the moment and furthermore taking years to breakdown.
(Van der Hoeven, 2020)

This study came about when resourcing materials for a design project. It will spark curiosity, encourages dialogue, allows people to delve further into other related topics. It will outline how nature and humanity can co-exist thus creating a more sustainable future in design. At this stage we cannot just be thinking of ourselves but future generations, wildlife and most importantly this planet. We only have one.

“If life on earth is to survive, we must rethink our relationship with Nature.” (Oxman, 2021)


fig.3
Mycelium growing on a tree stump

Question – **Is Mycelium the material of the future?**

The overall purpose for this topic is to acquire a better understanding of how Mycelium grows. It will also try to investigate what substrates it excels in and once grown, the stages it goes through to create a material that is used in construction and home décor. Next the advantages and disadvantages of the material will also be discussed in comparison to man-made materials that are currently being used.

Objectives:

What is Mycelium?

What is its purpose in nature and how does it grow?

Where does it grow and how to identify Fungi.

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Varieties of fungi species.

Are certain species more suited to creating different end products?

What species grows in certain substrates?

What are the preferred conditions for growing? e.g. soil, heat, moisture.

The properties of Mycelium.

How fast does Fungi grow?

How is it manufactured?

How does it differ from man-made products that are already used within the Design Industry?

What products are made using Mycelium?

What has it been used for in construction and design so far?

This study will include both desktop research and an experiment in growing Mycelium. The desktop research will look at the theoretical resources through a literature review, include case studies as well as analysis of products that have already been launched in the market. The experiment will give a better understanding as to how Mycelium grows and the duration to produce a product.

fig.4
Mycelium and Pinheads on a substrate.

Discovering Mycelium

Through examining existing literature, the research will focus on several important factors about Mycelium: Firstly it will explore what Mycelium is, its purpose in nature, how it grows and talk about two of Lynne Boddy's experiments; discussing its properties as a material and looking at the examples of its application. Next, a breakdown will be given of different species and how they excel on certain substrates with examples of products that are on the market at present.
Two case studies will be briefly discussed in relation to experiments already undertaken by other designers around the world and finally a comparison of Mycelium to materials that are currently being used will be mentioned.

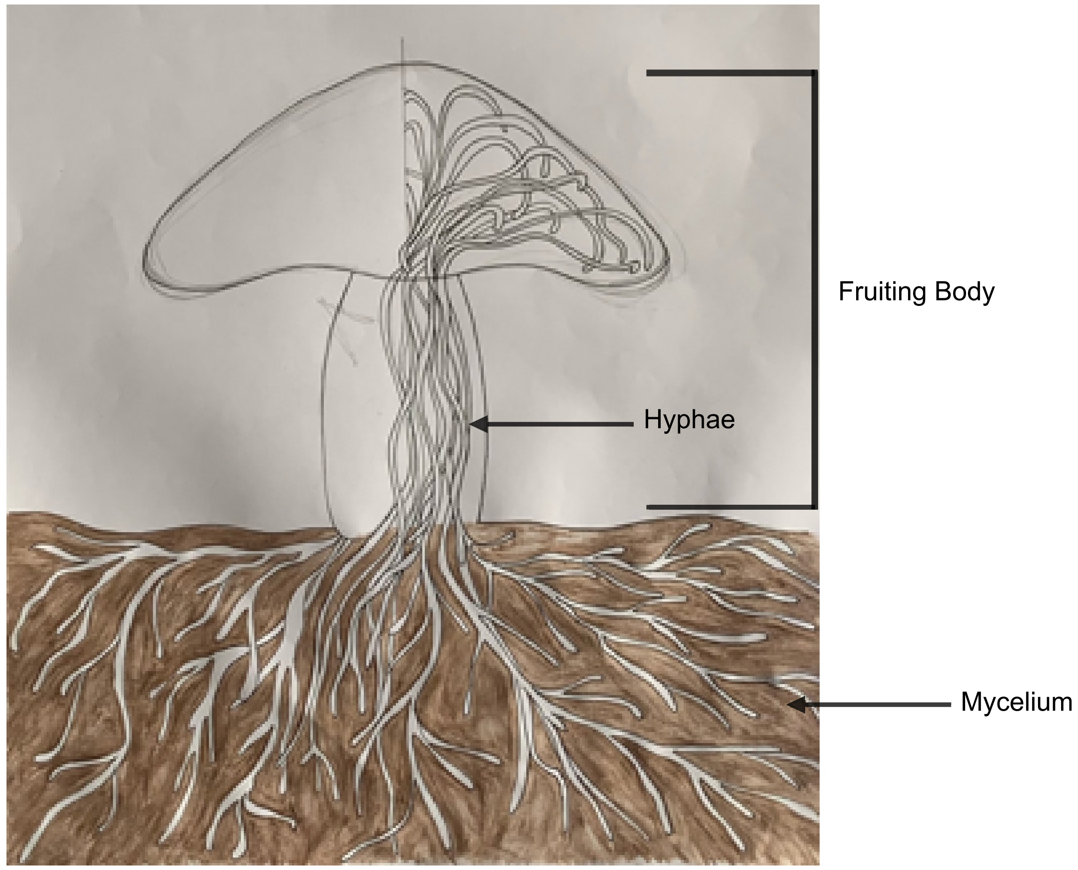


fig.5
Structure of Mycelium

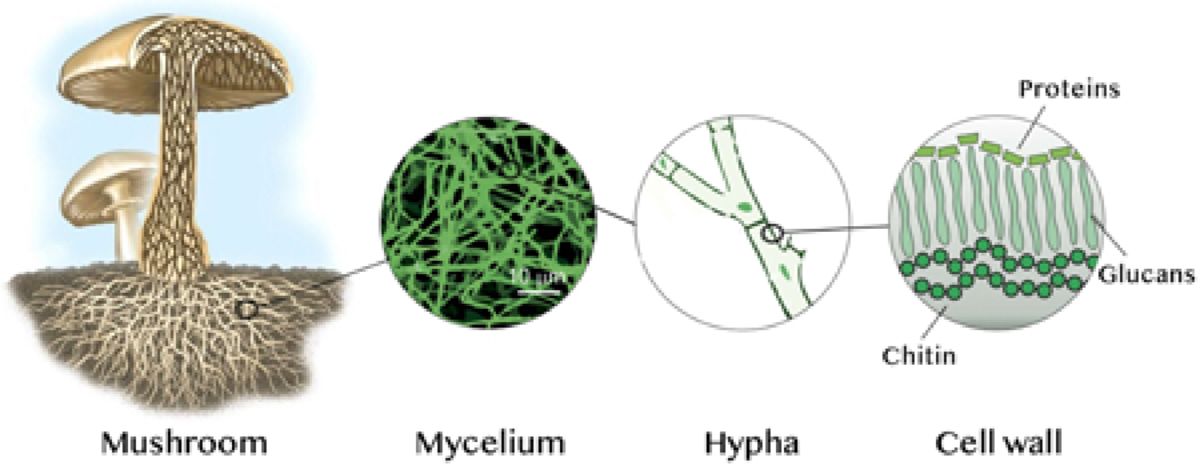


fig.6
Diagram showing Hypha

What is Mycelium?

Paul Stamets (Stamets, 2005) a Mycologist from the United States defines Mycelium and describes the process of its development as, “Mushrooms reproduce through microscopic spores, visible as dust when they collect en masse. When moisture, temperature and nutrients are right, spores freed from a mushroom germinate into threads of cells called hyphae. As each hyphae grows and branches, it forms connections with other hyphae from compatible spores to create mycelial mat, which matures, gathering nutrients and moisture.”

Researchers have calculated that around thirty thousand spores are released from a single mushroom every second. The mushroom part of the fungi only exists for a few days before it decomposes. Mycelium is the vegetative stage of the fungus and consists of a mass of branching, thread-like hyphae. The Mycelium that is produced from Fungi, lives underground. It can survive for a few years and some that have been tested are known to be hundreds of years old. (fig.5)

Mycelium is how fungi feeds. The hyphae stretches to reach its food as they are long and branch out. Merlin Sheldrake (Sheldrake, 2020) gives an example of how small the hyphae are, “They are only a single cell thick, five times thinner than an average human hair”. Hyphae is the equivalent of stems, roots and leaves in a plant. (fig.6) The more the hyphae can touch, the more they ingest. It immerses itself in its food by using pressure. If they are trying to penetrate through certain materials such as plastics. E.g. Mylar and Kevlar, they develop special hyphae that can reach pressures of fifty to eighty atmospheres. The hyphae create an adhesive to attach onto the plant, preventing them being pushed away from the surface. (Sheldrake, 2020)

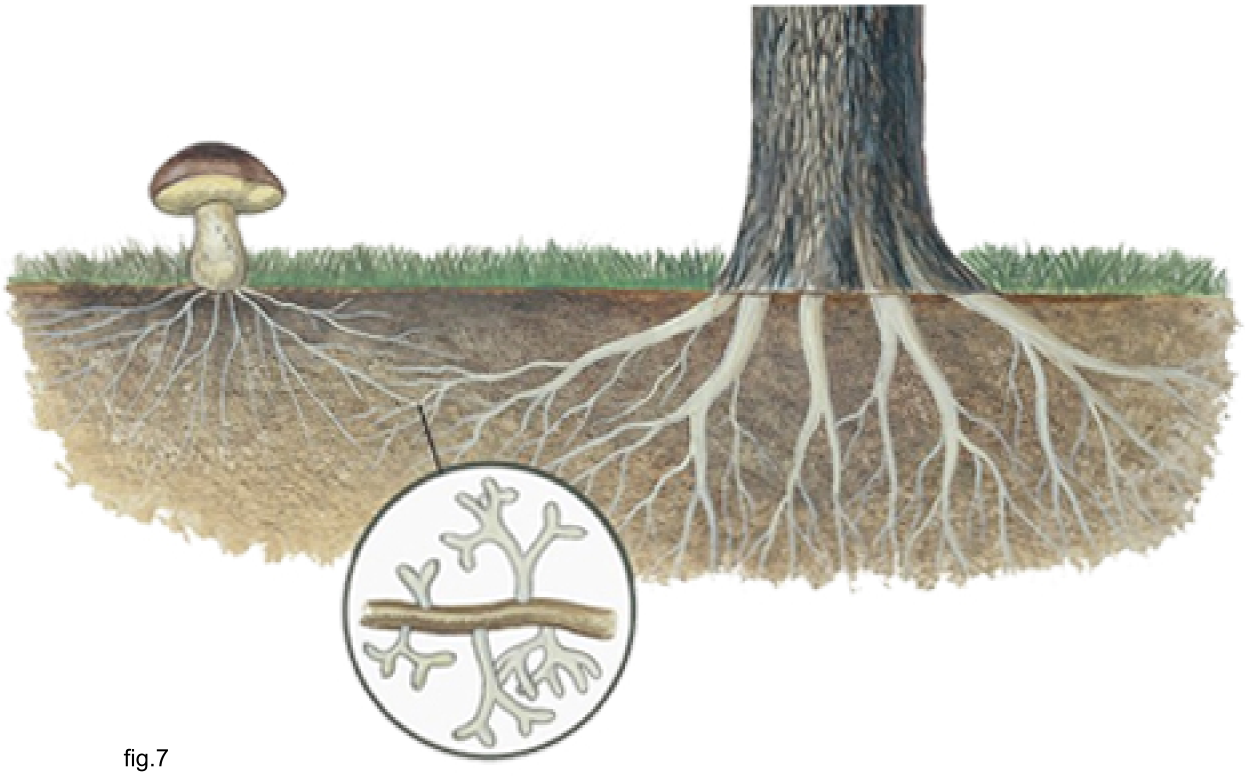


fig.7
Two inter connected nodes in the Wood Wide Web

fig.8
Piedmont White Truffle

Mycelium’s purpose in nature and how it grow’s

Suzanne Simard (Simard, 2019) in ‘Fantastic Fungi’ discusses a Mycorrhizal fungus which forms an underground community, linking older trees to other trees around them. The Mycorrhizal forms a unique organism which creates a symbolic relationship with the tree by wrapping its fungal body around the soil particles, extracting nutrients and water and then brings it to the roots of the tree. (fig.7) In return, the tree provides the fungus with nutrients such as sugar to survive. The sugars are full of carbon that the tree has stored during photosynthesis.

The climate change related research shows that CO2 is one of the highest greenhouse gases in the atmosphere and it is also what plants photosynthesize. Plants store carbon in different places such as leaves, or stems but its known that approx. seventy percent of the carbon ends up below ground. Its stored in cell wall of the plants until it exchanged for nutrients via the root exchanges with the Mycorrhizal Fungi. After the carbon has been absorbed by the fungi, its then stored underground for thousands of years. When Mycelium dies it also locks in the carbon for extended periods of time, building a carbon reserve for the future. (Simard, 2019)

Through the Mycorrhizal network ‘Mother Trees’ are able to recognise their offspring and communicate with each other through carbon. “Carbon is their universal language.” They are able to support weaker trees by regulating the flow of carbon between them. If the ‘Mother Trees’ knows there are pests around she will increase the competitive environment to protect her seedlings. This wouldn’t happen without fungi. (Sheldrake, 2020) *Tuber Magnatum* (Piedmont White Truffles) are an example of Mycorrhizal fungi. (fig.8)

The ‘Wood Wide Web’ is a common phrase used in Mycology and also when discussing mushrooms, indicating as to how they are linked. Merlin Sheldrake studied a type of plant called Mycoheterotrophs, *Voyria Tenella* in a rainforest in Panama. (fig.9) They do not contain chlorophyll which is uncommon in plants but they somehow link in with the fungal network obtaining nutrients and sugars from other plants through the fungi. Other examples of Mycoheterotrophs are *Monotropa Uniflora* (Ghost Pipe) (fig.10), *Sarcodes Sanguinea* (Snow Plant) (fig.11) and *Allotropa Virgata* (Candycane or Sugarstick).(fig.12&13) (Sheldrake, 2020)

Jay Harman (Harman, 2019) goes as far as claiming that life on earth would not be possible, if the Mycelium did not exist, as it plays a crucial role within the ecosystem.


fig 9
Voyria Tenella


fig 10
Monotropa Uniflora


fig.11
Sarcodes Sanguinea


fig.12
Allotropa Virgata

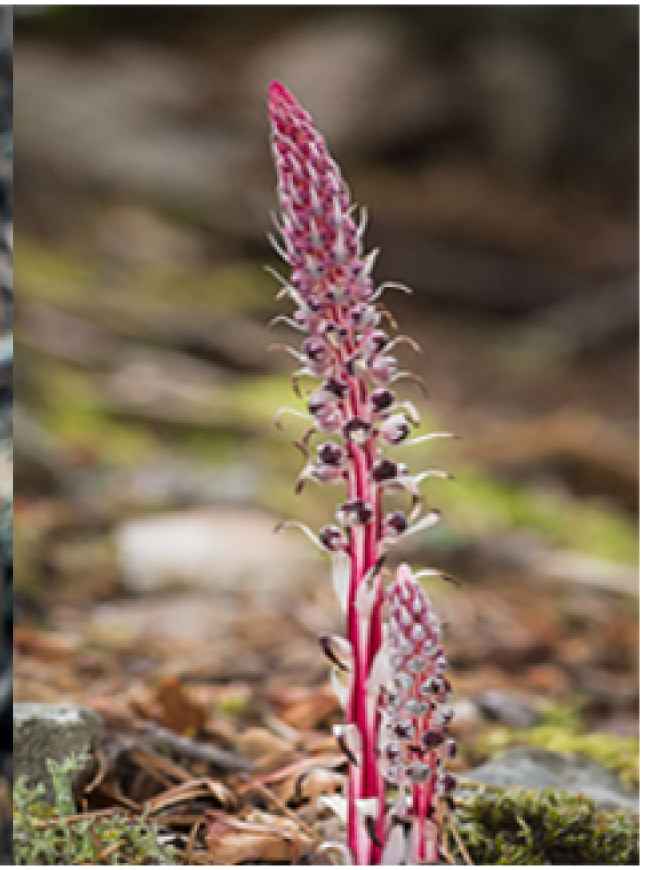


fig.13
Allotropa Virgata

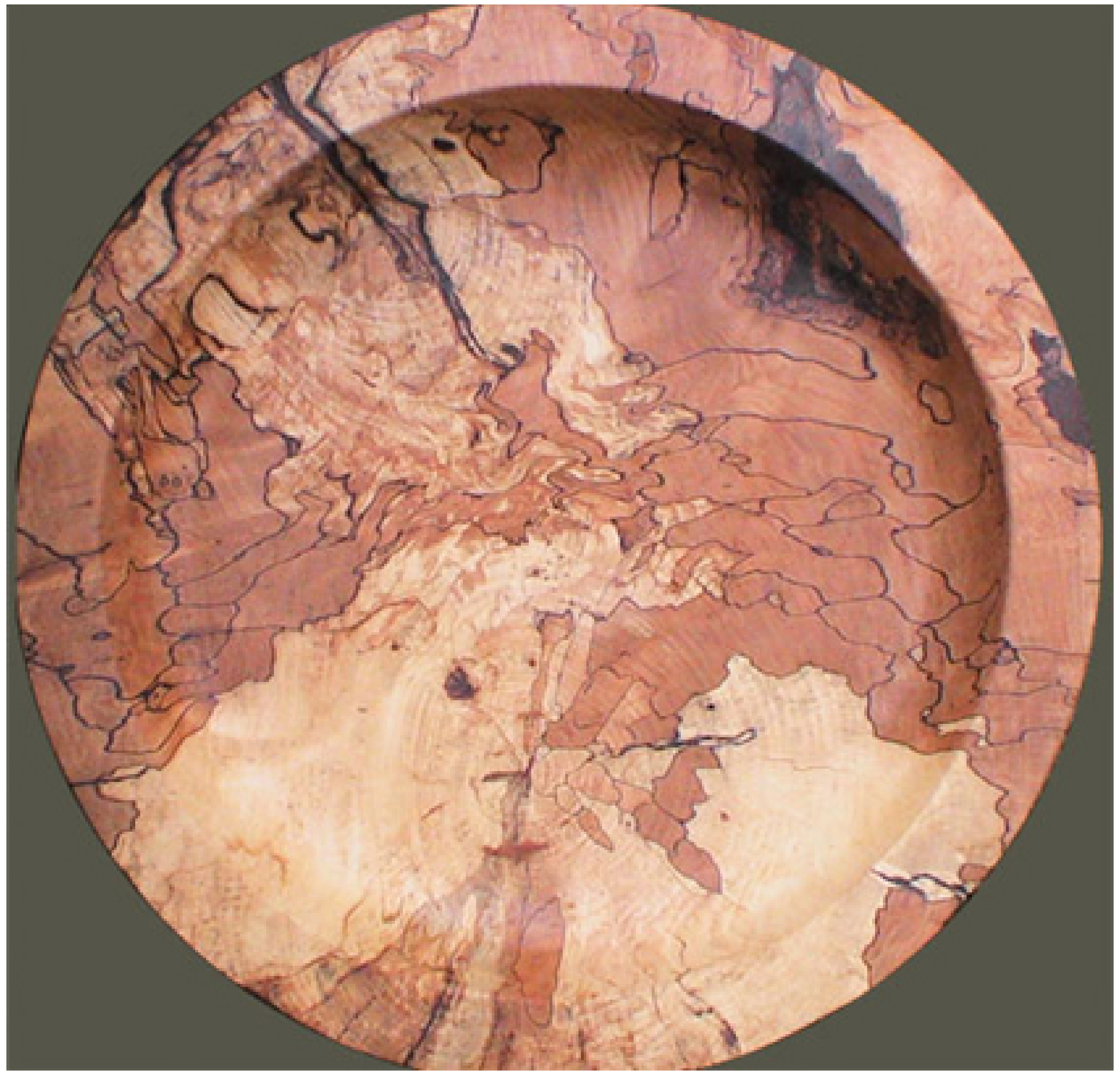


fig.14
Fungal Zone Lines in Wood.

Mycelium, meet Mycelium

Fungi seldom lives on its own and occasionally comes into contact with other fungi or bacteria. When two different Mycelium meet, a chemical recognition indicates whether it is a different species, another individual of the same species or itself. This can be observed by cutting a piece of a log, which will more often than not show line differentiating areas of decay.(fig.14) They are called zone lines and vary in colour. Majority of them are dark in colour but occasionally some can be orange depending on the type that has established themselves.

When Mycelium meets another species, they fight by "*producing inhibitory chemicals that pass through the air, like the gas warfare of the World War One trenches, or that diffuse through the water in the resource in which the fungus is growing.*" (Boddy, 2019)
With this, comes deadlock. Deadlock is where neither species are better off or one takes control over the other. Sometimes an agreement is made by both fungi to share the territory.

Stereum hirsutum also known as, Hairy Curtain Crust is a fungi that cannot take over territory from other species but its excels in keeping other fungi out. Many factors can alter the outcome of 'the war' such as location, temperature, water, nutrients available and the quality of them as well as any other organism interfering with the battle.

"Who would ever have thought that so much was going on in a piece of rotten wood!"
(Boddy, 2019)

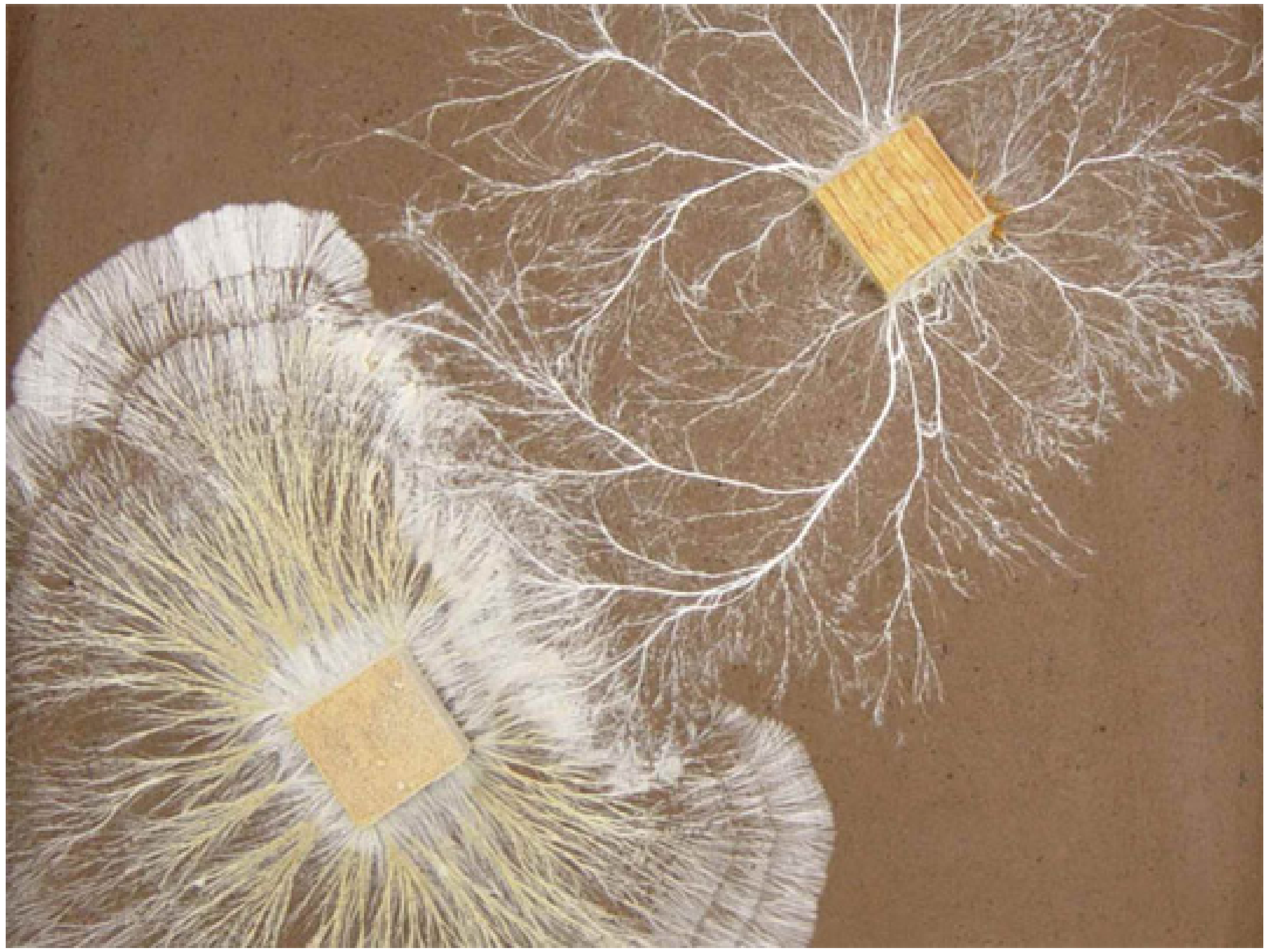


fig.15
Mycelium Growing from Wood Block.
Lynne Boddy Experiment

Lynne Boddy - Experiments

Lynne Boddy is a Professor of Fungal Ecology at Cardiff University, who has been studying Mycelium's foraging behaviour for over ten years. Lynne's experiments are mentioned in the book, Entangled Life, highlighting how her "studies illustrate the problems that Mycelial networks are able to solve." (Sheldrake,2020)

In order for fungi to survive, it requires another source of food before nutrient supplies are no longer available. This research lead to an experiment carried out by Lynne and her colleagues. Starting off, they used a small wooden block and let the "wood rotting" fungus grow within that block. The Mycelium started to spread outwards, in all directions, creating a white circle of some sort. Through the growing process, the Mycelium came into contact with another wooden block. A small amount of the Mycelium connected with the block but the whole dynamic of the Mycelial network changed. Within a few days, the Mycelium had completely changed and was unrecognisable. It has stopped growing in different directions, withdrew some of it branches and thickened the link to the new block of wood.(fig.15) (Sheldrake, 2020)

With these results, Lynne repeated the experiment by allowing the 'wood rotting' fungus to grow out from the first block and come across the second block again. Before allowing the Mycelial network to 'remodel' itself, she has taken away the first block and all the hyphae that was growing from it. The Mycelium grew from the first block in the same direction as the second block. "The Mycelium appeared to possess a directional memory, although the basis of this memory remains unclear." (Sheldrake, 2020)

Mycelium's actions are similar to slime mould but instead of trying to recreate Tokyo's underground network, Lynne Boddy decided to remodel Great Britain's land masses using soil, in hope of encouraging Mycelium to work out the most efficient routes between the cities of Britain. Cities were distinguished using wood filled with *Hypholoma fasciculare* which is known as sulphur tuft. The size of the blocks were in proportion to the population of the cities. The Mycelium grew out from the blocks aka the cities and created the same network as to where the motorways in England are currently located. Lynne said, " You could see the M5, M4, M1, M6. I thought it was quite fun." (Sheldrake, 2020)

"Mycelial Fungi are maze-dwellers, and solving spatial and geometrical problems is what they have evolved to do." (Sheldrake, 2020)

fig.16
Fairy Ring

fig.17
Beechwood Sickener

Where Fungi grows

In England and Ireland many species of fungi grow amongst cut or grazed grass, feeding off dead matter found in the soil. Grazing land that hasn't had any chemical fertilisers or been ploughed are usually much richer in fungi then land that has been reseeded and having lime and fertiliser introduced. (Harding, 2022)

Grazing land, attracts different species of fungi like Dung Roundhead and Egghead Mottlegill as they feed off the horse and cow dung that is present on the land. Woodland or grassy areas often have 'Fairy Rings' present. (fig.16) 'Fairy rings' can also be known as 'elf rings' or 'pixie rings'. They can be seen during late summer to early autumn. (Trust, 2022)

Patrick Harding (Harding, 2022) describes 'Fairy Rings' as "A result of fruitbodies produced at the growing edge of the buried Mycelium which under uniform soils grows a circular disc." In English and Celtic folklore, 'Fairy rings' are said that if humans were to join in with the elves and pixies dancing, they would be punished by the fairies and made dance in the ring until they were tired.

In woodlands, fungi is present amongst the soil but it can also be found on rotting tree leaves, old stumps, fallen trees and living trees. Some fungi develop through a weak spot in the substrate, the Mycelium spreads and then creates a bracket like mushroom on the tree. Others access the roots of a tree by creating a web or a fungus root.
e.g. Mycorrhizal fungus. Mycorrhizal species are host specific. *Russula nobilis* also known as Beechwood Sickener is an example of this. (fig.17) Other fungi are limited to a small number of tree species. Oak, Beech, Birch and Scots Pine are trees that have a large number of associated species of fungi.Other habitats where fungi is present include gardens, parks, particularly bonfires, manure heaps and wood stacks. (Harding, 2022)

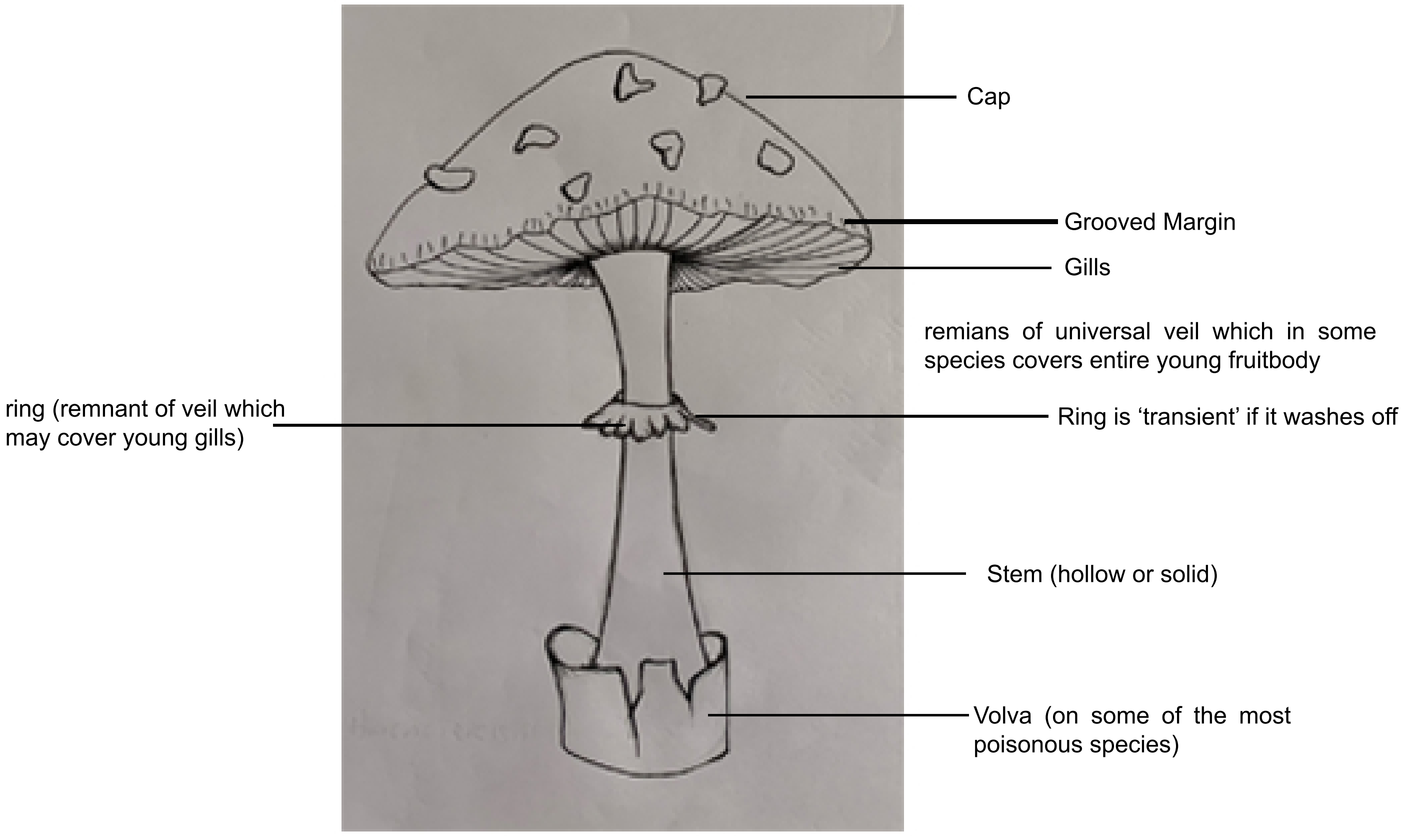


fig.18
Mushroom Characteristics

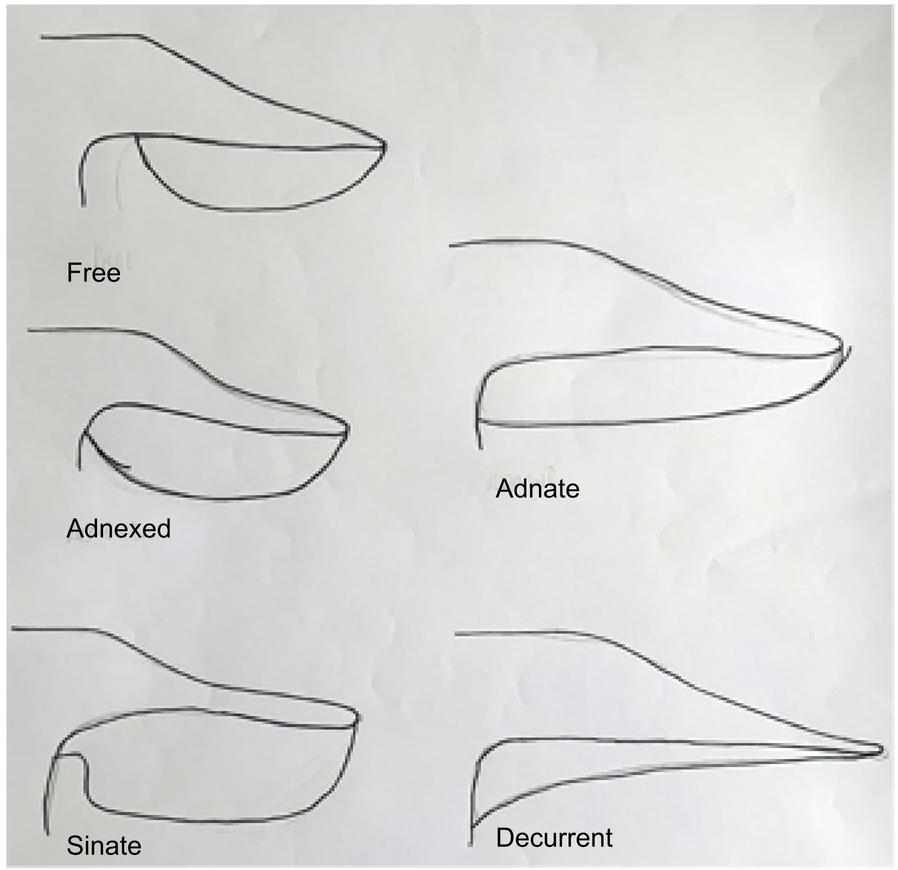


fig.19
Gill Characteristics

Identifying Fungi (characteristics)

When identifying Fungi, there are an number of characteristics to look for although some species cannot be identified without a microscope. Colour which can be variable, shape which changes as the mushroom matures and also the smell and texture the fungi. Notes should be taken of the substrates it was found on or in and the time of year as well as any particular smells or texture. See figure eighteen, highlighting different parts of the mushrooms to note when try to extinguish the species. (Harding, 2022)

The gill characteristics are also very important when identifying a fungi. (fig.19) To get a better understanding of the way gills are attached to the stem on the mushroom they would need to cut in half. A spore print helps with the accuracy. When collecting a spore print, the stem would need to be removed and place the gills down on a piece of glass. Cover to keep moist and leave for approx. four hours. A white or coloured deposit should be left. (fig.20) (Harding, 2022)

There are over three million species of fungi worldwide and some researchers believe there are still more to be discovered. A number of fungi species releases spores without producing mushrooms at all.

fig.20
Spore Print

Examples of species identifed in East Clare

fig 21
Shaggy Inkcap Mushroom (*Coprinus Comatus*) is part of the Agaricacese family. They are usually located in woodland, vegetation or grass areas.
Season - Spring to early Winter.
Size - Cap 5-15cm, Stem 8-30cm x 10-15cm.

fig.23
Turkeytail *(Trametes (Coriolus) Versicolor)* is part of the Coriolacese family. They are usually located on stumps, logs, standing dead wood and on living wood. They can also be found on majority of broad-leaved trees and are groups overlapping.
Season – Throughout the year.
Size – 2-7cm, 2-5cm broad x 1-5mm thick.

fig 22
Tinder/ Hoof Fungus (*Fomes Formentarius*) is part of the Coriolaceae family. They are usually located on dead or dying birch but can also found on beech, oak and sycamore.
Season – anytime as their fruiting bodies can live for many years.
Size – 7-40cm across, 5-20cm broad 7-20cm deep.

fig.24
Fly Agaric *(Amanita Muscaria)* is part of the Amanitaceae family. They are usually located around Birch, Pine and Spruce
Season – Late summer to early Winter.
Size – Cap 10-20cm, stem 15-20cm x 15-20cm

Examples of species identifed in East Clare

fig.25

Birch Polpore/Birch Bracket (*Piptoporus Betulinus*) is part of the Coriolaceae family. They are located on Birch trunks or branches living or dead

Season – Throughout the year. Fruitbodies persist.

Size – 8-30cm across, 5-20cm broad. 2-6cm thick.

fig.26

Small Staghorn (Calocera Cornea) is part of the Dacrymycetaceae family. They are usually located on dead wood of beech or Sycamore trees. They can also be found on Conifers

Season: Throughout the year.

Size 2-10mm high x 1-2mm wide.

fig 27

Amethyst Deceiver (*Laccaria Amethystina*) is part of the Tricholomataceae family. They are located on soil under broad-leaved trees and can also be found mixed up with Beech litter

Season: Autumn or late summer to early winter.

Size: Cap 1-4cm, Stem 4-8cm x 3-6mm wide.

fig 28

Scarlett Elf Cup (*Sarcoscypha Austriaca*) is part of the Sarcoscyphaceae family. They are usually located on dead wood on the woodland floors

Season – Early winter to early spring.

Size - Cups are approx. 4cm wide, Stem is 3 5cm.

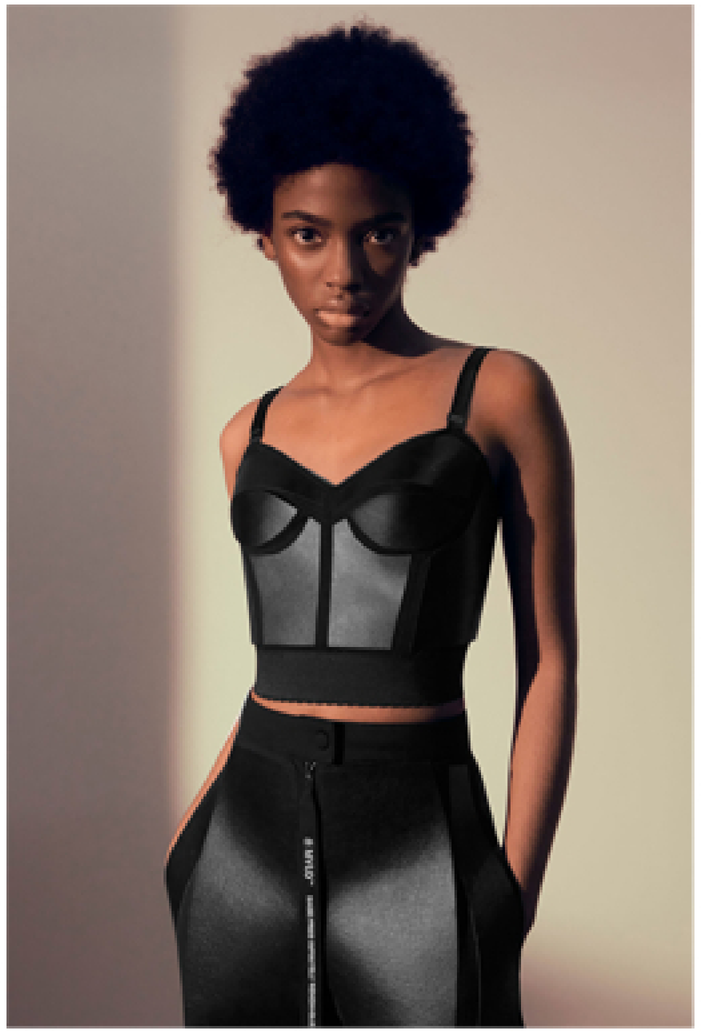


fig.29
Stella Mc Cartney Clothing

fig.30
Adidas, Stan Smith Footwear

fig.31
MyCoTex garment

Properties and examples used in commercial settings

Mycelium has been used in Architecture, Art, Design, Fashion, Medicine and Engineering due to its many properties, flexibility, ease of growing and health benefits.

Fungi Perfecti is owned by Mycologist, Paul Stamets and is a prime example of a company that cultivate mushrooms for food and medical purposes. This is another area where
mushrooms benefit our health and well being.

When dried, the materials properties are fire resistance, anti-bacterial, buoyancy, durable, water resistant, it has acoustic qualities as well as being thermal.

Ecovative was the first company to use Mycelium back in 2007 for insulation of gloves and foam for footwear. They have won numerous awards.

Mycelium has been explored in material form creating an alternative to leather. (fig.20) Fabric and textiles used for production of clothing use Mycelium due to its woven-like texture, flexibility, strength and water resistance properties. MycoWorks, MyCoTex and Bolt Threads are some companies that have created sustainable clothing using Mycelium. Bolt Threads collaborated with brands such as Stella McCartney and Adidas to produce bags, clothing and shoes using Mylo. (fig.29&30) Mylo is a bio-based alternative to leather. “The material that sparked a ”mushroom leather” movement.” (Mylo,2022)

From sustainable clothing to bio-manufacturing materials for construction, Mycelium is used throughout the different industries. Biohm is an example of that. As a company, they use waste products from other industries, mixed with Mycelium to create sustainable items such as insulation panels.

Biohm compares Mycelium properties to materials that are currently being used;
“Mycelium not only outperforms petrochemical/plastic based construction materials in thermal and acoustic insulation but, as a natural material, it is also safer and healthier. Mycelium does not contain the synthetic, resin-based compounds that can cause harmful toxic smoke and the quick spread of flames during a fire.” (Biohm,2022)


fig.32
Insulation Panels

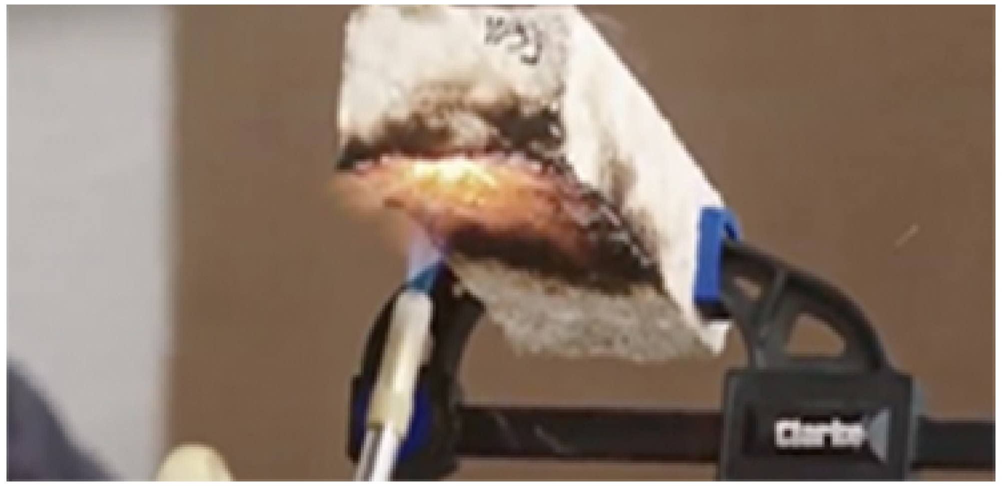


fig.33
Example of testing

Furnishings made using Mycelium

Biohm - Biotechnology company focusing on insulation panels.

“Nothing is ever-lasting. Everything is ever-changing. We do not design. We refine what nature has given us.” (Biohm,2022)

Biohm have created an insulation panel using Mycelium and by-products from the agricultural and commercial sectors that would otherwise end up in land fill. (fig.32) From using these materials, their manufacturing process is said to be carbon-negative and it illuminates at least sixteen tonnes of carbon per month.The benefits of Biohm using Mycelium for their insulation panels is that its breathable, wicks moisture and holds little VOCs giving it an A+ rating. They have tested their panels alongside the majority of synthetic ones that are on the market currently and the results are outstanding. The Mycelium panels have achieved thermal conductivity as low as 0.024W/m.K. As insulation panels, fire resistance is a major factor, from initial testing, they have found out that they release less heat and smoke when burning compared to synthetic panels. (fig.33) They also provide acoustic insulation and tests show an acoustic absorption of at least 75% at 1000Hz. (the typical frequency of road traffic noise) Other benefits include health and wellbeing, sustainability and can be made to order. They can be built to any size and space required.

Biohm are currently working on developing new products and other application for Mycelium.


fig.34
Growing Mycelium


fig.35
Accoustic Panels


fig.36
Hanging Pendants

Mogu - Biotechnology company focusing on acoustic panels

Mogu is a company based in Italy that provide acoustic panels made using Mycelium along with upcycled textile residue. (fig.35) Over the years, they have worked with different strains of Mycelium to now supply commercial companies with sustainable products on pre-engineered substrates made of excess agro-industrial waste.The acoustic panels are available in a variety of different shapes due to the flexibility of Mycelium and its substrate. Again due to Mycelium's acoustic and fire resistant properties, the acoustic panels meet the EU legislations and sold worldwide.

"Mogu was founded on the belief that it is possible to employ Nature's intelligence to radically disrupt the design of everyday products, seeking a finer balance between the man-made and the rhythms of the natural ecosystem." (Mogu, 2022)

Sebestian Cox and Ninela Ivanova - Biotechnology partnership focusing on light fixtures and stools

Cox and Ivanova worked together on creating statement furniture such as lighting fixtures and stools using Mycelium and wood. (fig.36) They showcased their work at the Design Frontiers 2017. Through extensive research and experiments, they identified the best fungi species that created Mycelium for their furniture. They used *Fomes Fomentarius* (Hoof Fungus) due to its many qualities and how it grows, binding to the coppiced hazel and goat willow wood. Both wood species are considered waste. They combined both wood and Mycelium to create something truly amazing.

"Mycelium offers us the opportunity to create products that not only continue but advance our ethos of sustainability and test our ability as a studio to design for new methods of manufacture." (Cox, 2017)

fig.37
Living Material

fig.38
Production Process

Jonas Edvard Nielsen - MYX Lamp

Jonas Edvard Nielsen is an Industrial Designer who created a unique and evolving lampshade for Maison et Objet back in 2014.

The lampshade used a combination of hemp fibres, left over from the textile industry and Oyster Mushrooms. (fig.40) The process took approximately three weeks for the Mycelium to grow and create the lampshade shape and from them produced edible mushrooms that were harvested and dried. Once the shape was covered with Mycelium, it was placed in a custom made kiln to dry out the Mycelium until it was inactive. Once dried, the object is then created. When the lampshade is no longer required, It can then be composted leaving no trace.

The MXY lampshade is now part of the Danish Crafts Collection. (Chin, 2014)

fig.39
Close-up of mushroom growth

fig.40
Lampshade with fruiting bodies

fig.41
The Hy-Fi

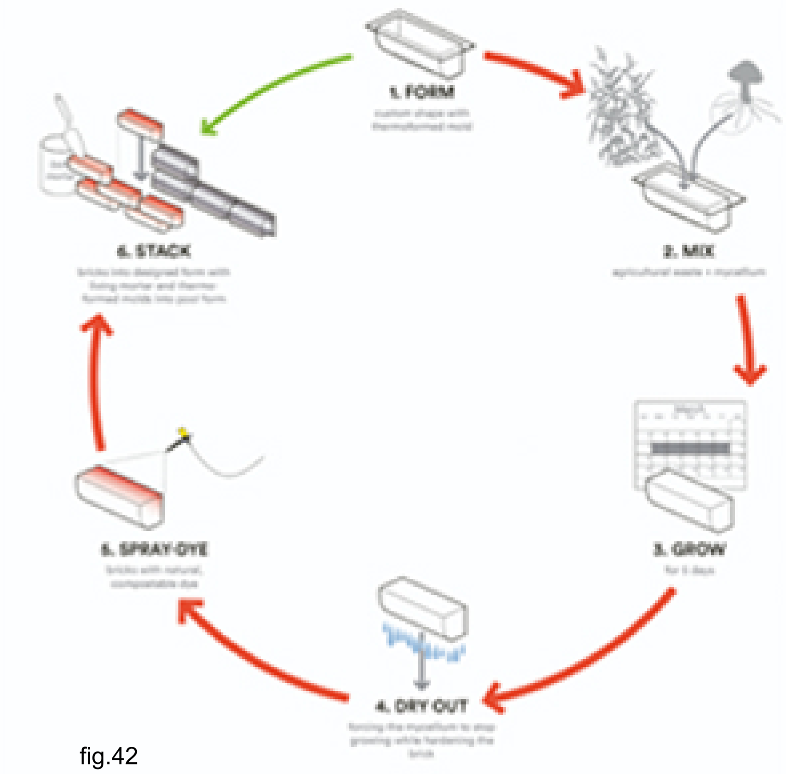


fig.42
Organic brick process

Case Study One - The HY-FI

Location: Queens, New York.

Designers: The Living

Year: 2014

The Hy-Fi was designed by David Benjamin of New York Architects (The Living), consisting of three circular towers made of compostable bricks. It was commissioned and designed for MOMA PS1 Young Architect Program. (fig.41)

This building reached twelve metres in height creating a solid base with not one chimney but three interconnected. (fig.46) When surveying the area and taking note of weather conditions in New York, they had to ensure the building would withstand the elements. The final structure could resists gusts of up to 65mph.The Hy-Fi was made up of approximately ten thousand organic bricks using low-value crop waste e.g. corn husks and Mycelium. (fig.42) Once placed in the moulds, the mixture took five days to grow using zero energy. They were 18" x 9" x 4" in size, weigh one pound, sustainable and affordable to make, highlighting the advantages of using
Mycelium as a material. (fig.43) When the building was deconstructed nearly three months later, the bricks were given to local community gardens returning them back to the carbon cycle and the mould structure was returned for further research. (Maloney, 2014)

“After three years of accelerated aging, the material performed exactly the same way as it did originally.” (Benjamin, 2022)

fig.43
Organic bricks

The Hy-Fi

fig.44
Interior view

fig.45
Exterior view

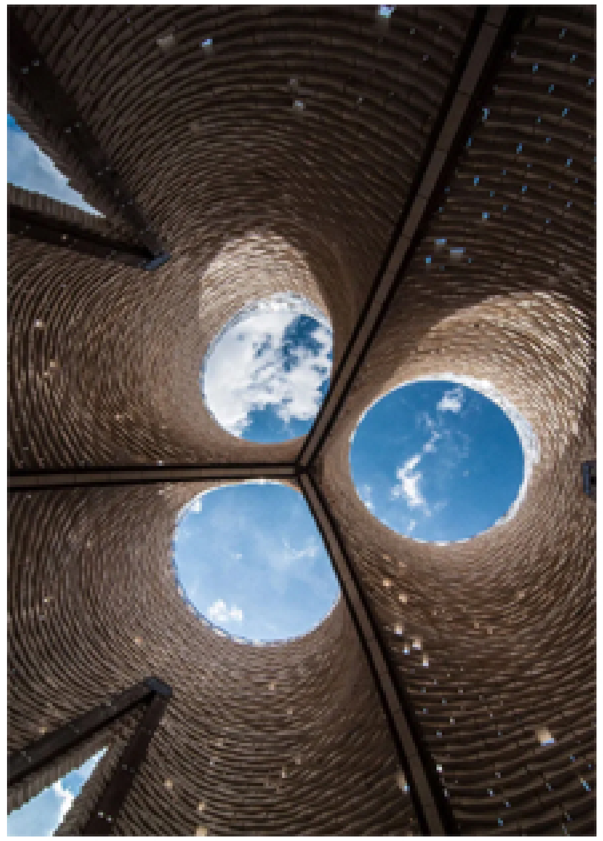


fig.46
Interior view

fig.47
Location in MoMA

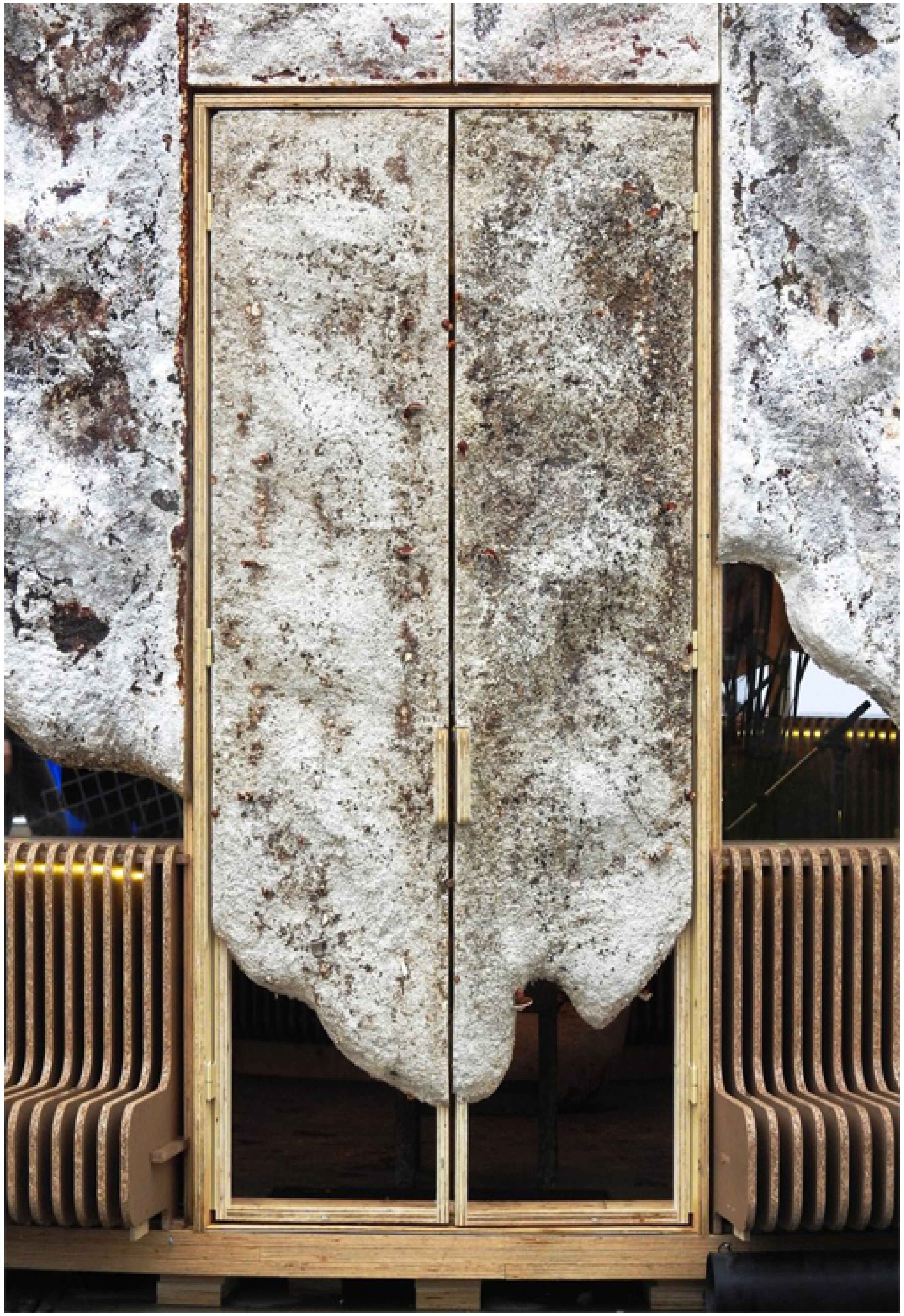


fig.48
Entrance

Case Study Two - The Growing Pavilion

Location: Dutch Design Week

Designer: Pascal Leboucq, who collaborated with Krown Design

Year: 2019

The Growing Pavilion was designed by Pascal Leboucq who is a well-known set designer and artist. On this project he collaborated with Erik Klarenbeek's studio Krown Design at Amsterdam studio Biobased Creations.

This temporary building was made up of five raw materials such as Mycelium, wood, cotton, bulrush and waste from the agricultural sector. The wooden frame was built first and then eighty eight Mycelium panels were attached onto the frame. Due to Mycelium's properties the panels can be easily removed as they are lightweight.

During the ten days of the DDW, to reinforce the story behind The Growing Pavilion, Oyster mushrooms were harvested for consumers to eat from Mycelium that was separate to the building. (fig.53)

Due to the success of the DDW, the Growing Pavilion was rebuilt at Floriade Expo 2022. (Pavilion,2022)

fig.49
The Growing Pavilion

The Growing Pavilion

fig.50
Interior view

fig.52
Interior view

fig.51
Interior view and clothing display

fig.53
Mushroom harvesting

fig.54
Marine Wildlife

fig.55
Mycelium packaging

Mycelium versus Plastic

Plastic was invented in 1907 by Leo Baekeland and changed manufacturing forever. A variety of different plastics are still being made today including polyethylene, polystyrene and Nylon. Approximately 90% of plastic is not recycled and ends up in landfill, incinerated, buried or in the ocean. Toxins are released when its burnt harming both wildlife and ourselves. We as consumers eat on average five grams of micro and nano plastic through our food every week. Five grams is the equivalent of a plastic bottle cap or a credit card.

Two reports released in 2021 from the European Protection Agency, one in September indicating that 69% of plastic waste in Ireland is incinerated instead of being recycled. The second report that came out in December, showed that recycling in Ireland is dropping while general waste is rising. This indicate that Ireland are too reliant on burning their rubbish. “*In 2019, almost half (46%) our rubbish was burned - up from just 4% in 2009.*” (Corr,2022)

Every bit of plastic that has ever been made is still around today and eight millions tonnes end up in the oceans each year.(fig.54) (Till & Franklin, 2019)

Plastic has been used in every industry including Interior Design, Architecture and Furniture Design.

Mycelium on the other hand has been around since time begun and can live on for hundreds of years. Products made from Mycelium can decompose back into the soil in about forty days if needed and all it requires for growth is a controlled temperature, humidity, air flow and CO2. Its properties such as strength, flexibility and durability, coupled with its structure, makes Mycelium an easy material alternative for a range of products.

There are many companies that have been using Mycelium such as Biohm, Mogu, Sebastian Cox to create products that are being used in the Design Industry. Other companies such as Magical Mushroom Company, Paradise Packaging, Grown.Bio and Bio Fab are all producing packaging using Mycelium as its water resistant and can be broken down. (fig.55) Philip Ross, co-founder and chief technology officer of MycoWorks, mentions that when producing Mycelium based materials, we will never run out of the resources needed.

It is clear that plastic is a harmful substance to wildlife, the human race and is still very much present on this planet compared to Mycelium taking around forty days to decompose. Producing Mycelium uses about 12% of enery in comparison to plastic production and generates 90% less CO2.

Mycelium has caught the attention of humanity, opening up endless possibilities for the future.

fig.56
Mycelium product

Conclusion

To conclude, Mycelium has been around longer than any of us and will still be here long after we are gone. It is the glue that holds the entire ecosystem together.

Ecovative was the first company to introduce Mycelium products back in 2007, creating insulation for gloves and foams for footwear. Sixteen years later, we have packaging, clothing, insulation panels, lampshades, bags and shoes. They are all made from a group of hyphae that are,"only a single cell thick, five times thinner than an average human hair" (Sheldrake, 2020) and waste material.

Identifying fungi requires time and understanding of the different species. Mushrooms are the fruiting body of the fungi which is equivalent to a flower from a plant. They come and go in the blink of an eye so one must be observant.

Mycelium's properties are evident throughout the review and products that are leading the market at present are proof of that. Whilst Mycelium is a strong material, the Mycelium bricks produced currently can only withstand 30psi compared to concrete, which can hold between 4000 psi to 10,000 psi. However, 'The Hy-Fi' has proved a building made of Mycelium bricks can withstand harsh weather conditions for three months and then filter back into the soil as if it was non-existent. (fig.41)

Although Mycelium does not offer itself as a straightforward replacement for concrete or other structural components in the building industry, its potential as an insulator and its application in a variety of finishes and furnishings must be explored and pushed further. Application of Mycelium in wider field of product design creates a meaningful impact in terms of sustainability.

Designers, Architects and Material Innovators are now understanding how nature works and using that to their advantage in production of biodegradable materials from the likes of Mycelium. (Till & Franklin, 2019)

fig.57
Underside of a Mushroom

Understanding Mycelium

Initial research such as visiting woodlands, observing nature, sketching, and photographing different mushrooms inspired this experiment. Desktop research gave first-hand observation to see exactly how it works. Anecdotal evidence is based on personal research growing fungi myself.

For the topic, the specific approach will be undertaking an experiment to grow fungi in different substrates and note how they digest particular materials. Observing the process from spores to fully grown. Data will be recorded on how long it takes to grow and how much is made in this experiment for production purposes.

Plan of work:

Stage one of the investigatory process would be researching individual fungi/spores that work well with specific substrates and collecting or purchasing them.

Stage two would be gathering the different substrates. e.g. coffee, sawdust.

Stage three will be creating an adequate environment for the spores to grow in. From initial research, specific bags are available for growing mushrooms allowing the right ventilation and are transparent allowing the process to be recorded.

Stage four would be capturing the growth of the fungi with a camera and observing the results, from its initial spore stage to fully grown fungi. Any data will be recorded at this stage.

Stage five is presenting the results from my findings through photographic evidence.

This chosen method along with desktop research will help answer the question of how easy it can grow in the right conditions and at what pace.

Understanding Mycelium - Oyster Mushroom

To observe the growth and development of Mycelium, an Oyster Mushroom ‘grow your own’ was purchased. The live observation of the growing process is the most suitable way to observe and record the growth while focusing on the speed and stages of the development.

The material and substate was supplied in a cardboard box within a plastic bag that had a small area for ventilation. A small area at the front was opened in the box and in the plastic bag an X was cut to allow access to air.

Misted twice daily on the area with the X

31/01/22

06/02/22

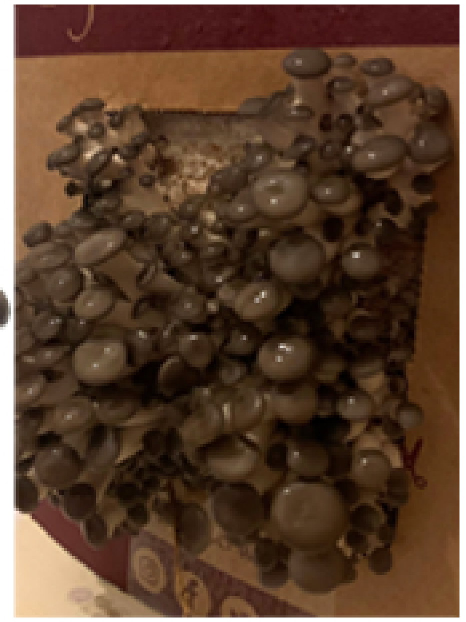
Pinheads starting to show through the mixture

07/02/22

Small pinhead popping through

08/02/22

Pinheads double in size, daily



09/02/22

Ready to harvest

15/02/22

**All images in this experiment are author own.

fig.58 & 59
Mycelium mixed with straw

Experimenting with Mycelium

The visit to the supplier of the Oyster Mushroom kit premises was invaluable for gaining an insight into learning about the conditions required for and their impact on the growth of mushrooms.

From this, various experiments will be carried out. One area will be looking at growing Mycelium using Oyster Mushrooms in different substrates and conditions. Another, will be using existing substate that had already been inoculated with Oyster mushroom spores and introducing a new food source to create a shape using Mycelium.


fig.60
Sporing Mushroom

Experiments One - Five

Oyster Mushroom were the specific spores/mushroom chosen for these experiments as from initial research, they had already been used by companies, creating products for consumers. Straw, Coffee, Bran, Cardboard and Sawdust were the substrates, as they can either be locally sourced or are readily available materials that are cost effective.

When growing mushrooms they require controlled temperatures, air flow, humidity as well as ensuring the substrate is sterilised. "*Sterilization of the substrate is one of the critical steps when it comes to mushroom cultivation*." (Rouvan, 2022) Why? Mycelium would not be able to grow if the contamination in the substrate is too high leading to little if any production.

Temperature is another important factor. Research suggests 22C degrees, which is room temperature for cultivating mushrooms. All experiments were misted daily except experiment three. It wasn't misted until ten days after and kept in a dry area. The rest were kept at room temperature throughout the whole process.

Taking all the research into consideration, different areas were focused on in each experiment.

Experiment One - Bran and Spores. The bran was soaked overnight with water (60:40) but was not sterilised. any excess water was drained and the spores were mixed in and placed in the jar. Three holes were drilled into the lid and microporous tape was placed over each hole.

Experiment Two - Coffee and Spores. The coffee granules were made fresh. (using boiling hot water), soaked for about five minutes and then drained the excess water. Left to cool for fifteen minutes. Mixed in the spores and placed into the jar. Three holes were drilled into the lid and microporous tape was placed over each hole.

Experiment Three - Cardboard and Grown Mushrooms. The corrugated cardboard was cut into six circles to fit into the jar, heated in water for two minutes using a microwave. The grown mushrooms, was cut into small pieces and then placed on each layer of cardboard. Tissue paper was cut and placed over the top of the jar and held on with a rubber band.

Experiment Four - Straw and Spores. The straw was soaked in water and lime over night to create a PH of around 13 to sterilise the substrate. The mixture was tested using a PH meter. Drained and then spores were mixed in with the straw and placed into a jar. Three holes were drilled into the lid and microporous tape was placed over each hole.

Experiment Five - Sawdust, spores and Grown Mushroom. The sawdust was used to soak up car oil. Grown Mushrooms were cut into small pieces and mixed in with spores to the substrate and placed into a jar. Three holes were drilled into the lid and microporous tape was placed over each hole.

Experiment One - Bran Substrate
06/03/22 - 04/05/22
Jar Size 0.5L

06/03/22

Apparatus required for Experiment
Bran not sterlised,

11/03/22

Slow but Mycelium
is starting to show.

17/03/22

Starting to see Mycelium growing.

03/04/22

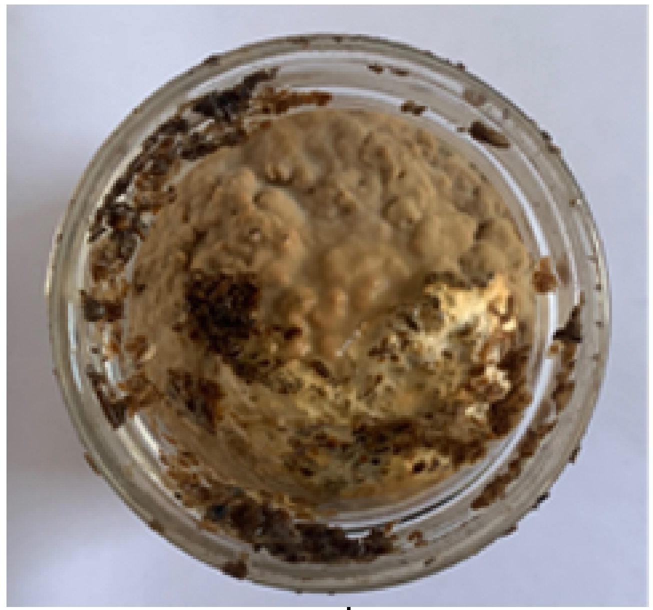
Looking like another bacteria is
starting to grow in the jar.

15/04/22

Alot of liquid gathering at the
bottom of the jar.

Bacteria is starting to take over.
A bad smell starting to occur.
Still looks like some Mycelium is still present.

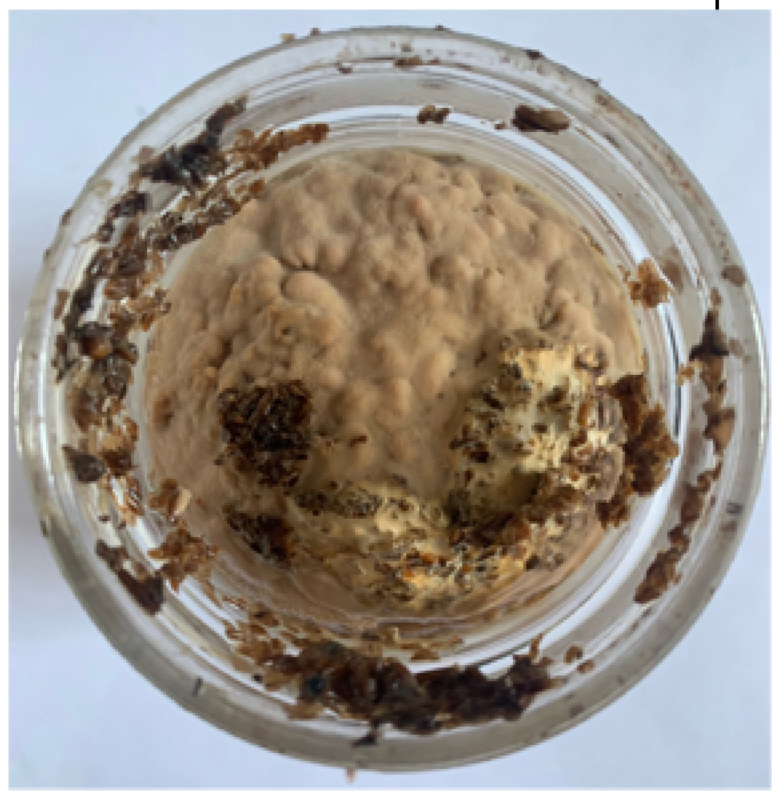
21/04/22



Bacteria has taken over.
Very lumpy.

04/05/22

Alot of excess liquid.



New bacteria taken over.
Putrid smell even with lid on.

**All images in this experiment are author own.

Experiment Four - Coffee Substrate
04/03/22 - 06/05/22
Jar Size 0.5L

04/03/22

Apparatus required for Experiment

Mycelium is starting to grow

11/03/22

17/03/22

Zoomed in view of the Mycelium expanding

Mycelium is spreading around the jar.

The Mycelium looks fresh and soft to touch.

19/03/22

03/04/22

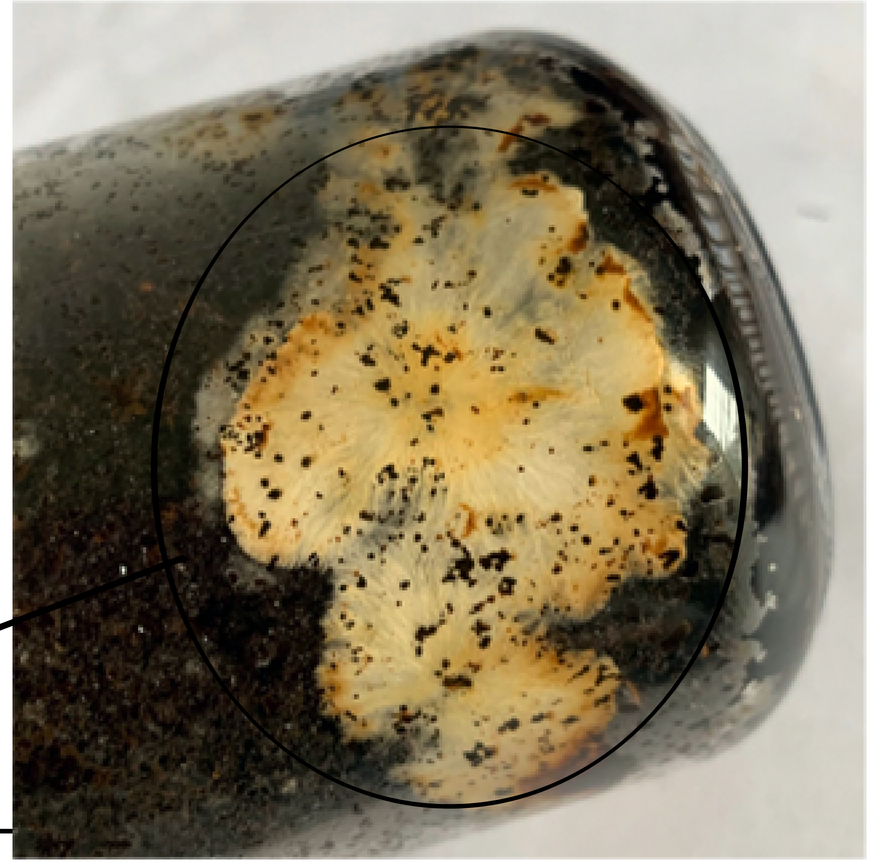
Mycelium is starting to absorb the Coffee colour

Small pockets of Mycelium are starting to show through.

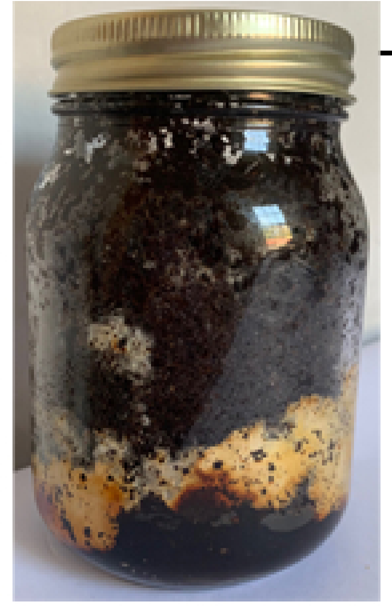
04/04/22

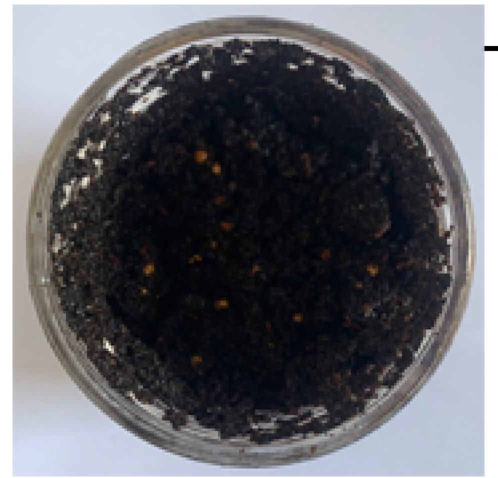
08/04/22

15/04/22

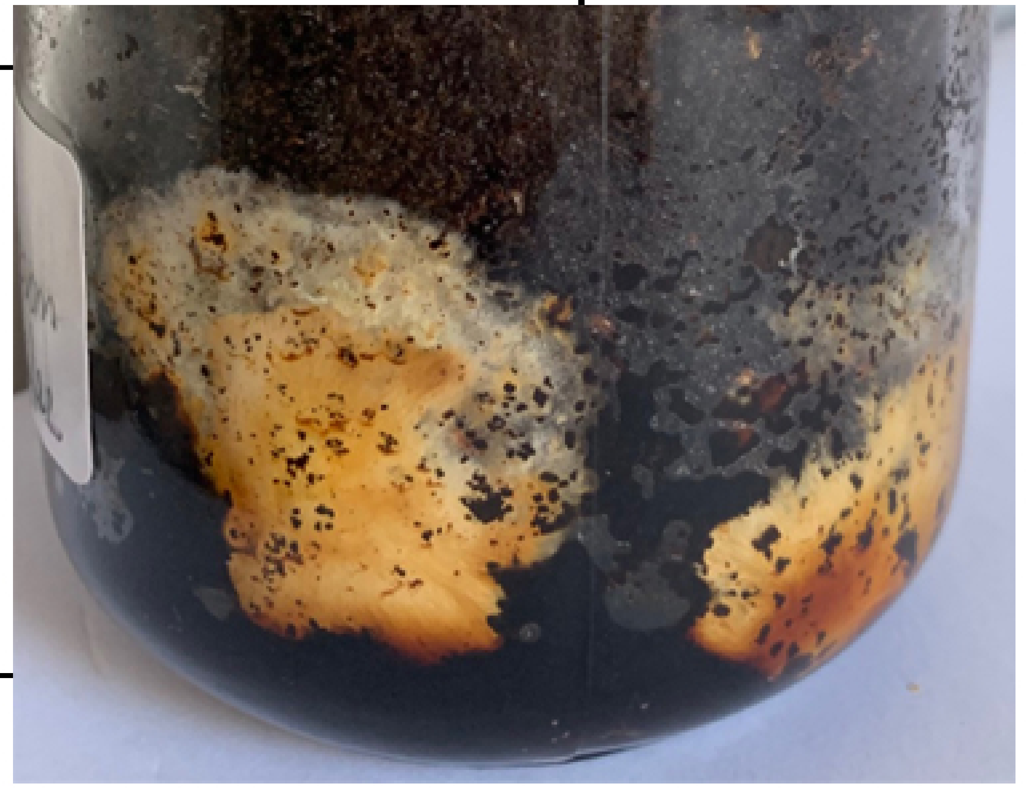


The Individual Mycelium have reached to connect with each other.
The Hyphae are very prominent in these pictures.





Some of the spores on the top of the jar have not grown any Mycelium



Water started to gather at the bottom of the jar. The Mycelium is now a strong coffee colour.

21/04/22

The Mycelium now, looks more like a solid material, whereas before it looked soft and elegant.

06/05/22

From this image, the spores and coffee have created clusters, showing small amounts of Mycelium.

**All images in this experiment are author own.

Experiment Four - Cardboard Substrate
11/04/22 - 05/05/22
Jar Size 0.5L

11/04/22

Apparatus required for Experiment

12/04/22

15/04/22

Condensation showing in this image due to the heat and moisture in the jar.

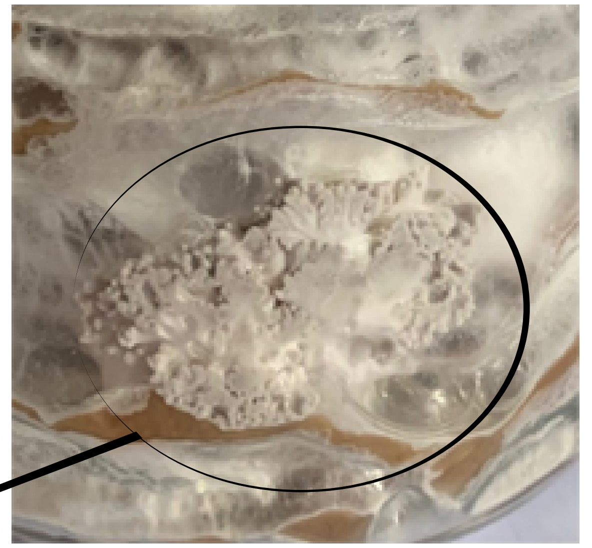
21/04/22

Mycelium growing and expanding through the layers.

24/04/22

Mycelium eating through the cardboard.

26/04/22



Pinheads starting to appear at the side fo the jar.

27/04/22

Pinheads noted to be growing on existing Oyster mushroom.

Tissue paper removed.

28/04/22

Pinheads showing and expanding.

30/04/22 Morning

Pinheads growing in all different directions.
The larger mushrooms are from lower down in the jar.

Photographs taken in the morning and eveing of the same day.

30/04/22 Evening

02/05/22

View showing mushroom growth.

05/05/22

Mushrooms are not ready to harvest but close to it.
Mycelium has eaten through a large amount of the cardboard.
More pinheads are starting to appear.

**All images in this experiment are author own.

Experiment Five - Straw Substrate
07/03/22 - 07/05/22
Jar Size 0.5L

07/03/22

Apparatus required for Experiment

11/03/22

Mycelium starting to show

17/03/22

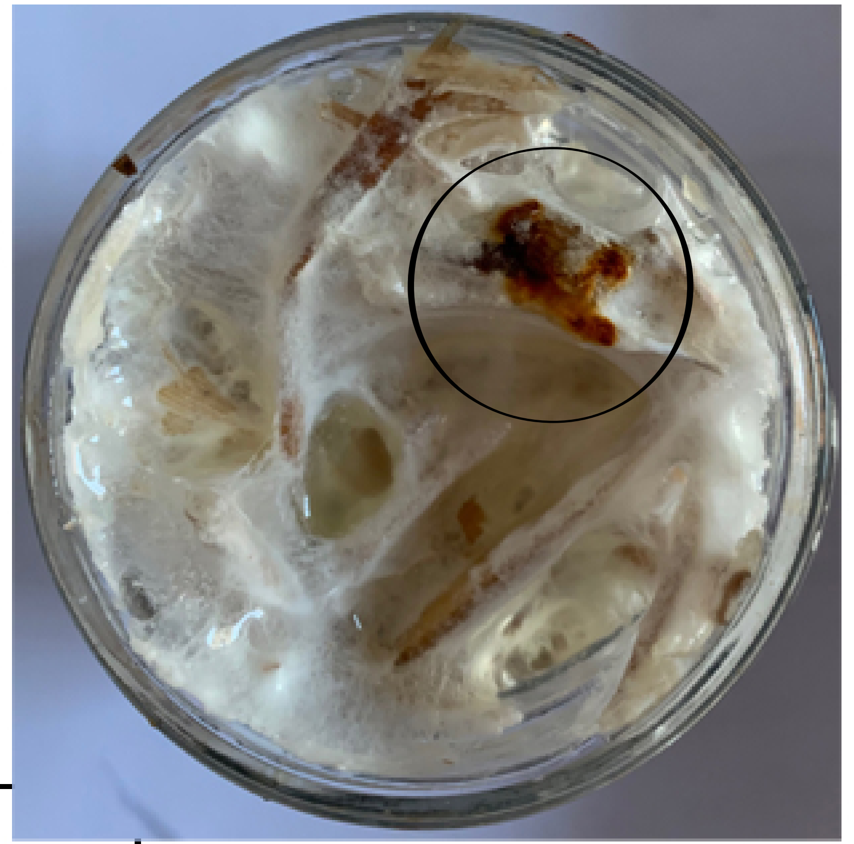
19/03/22

Taken with the lid off. Hyphae are noticeable and water droplets are sitting on the Mycelium

03/04/22

Progression of the speed and amount is noted.

08/04/22

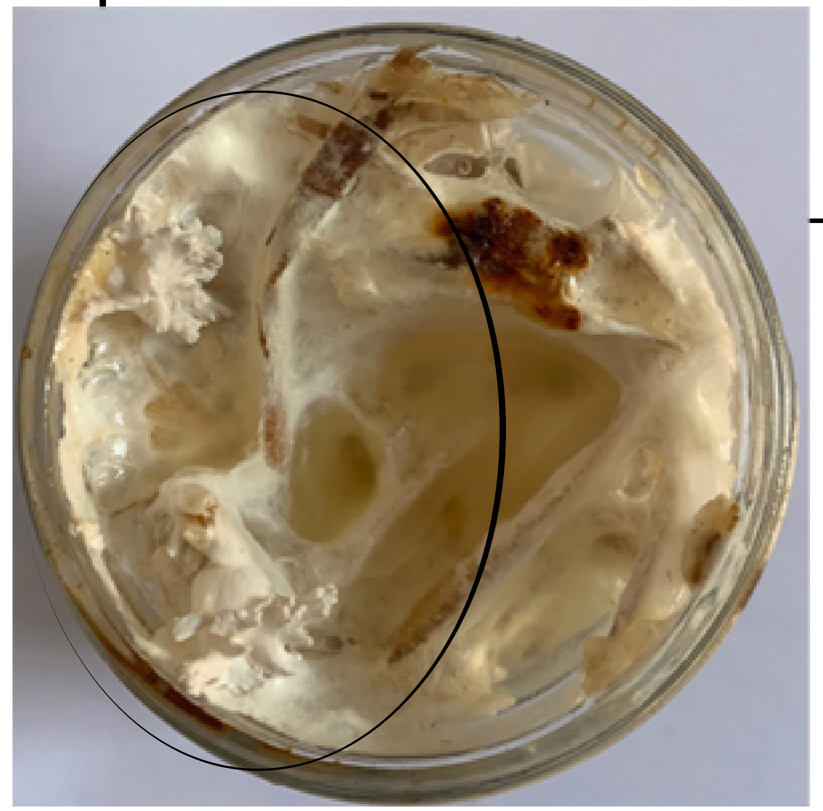


Orange mark is the Mylceium reaching the hole drilled into the lid.

15/04/22

Mycelium is starting to thicken.

21/04/22



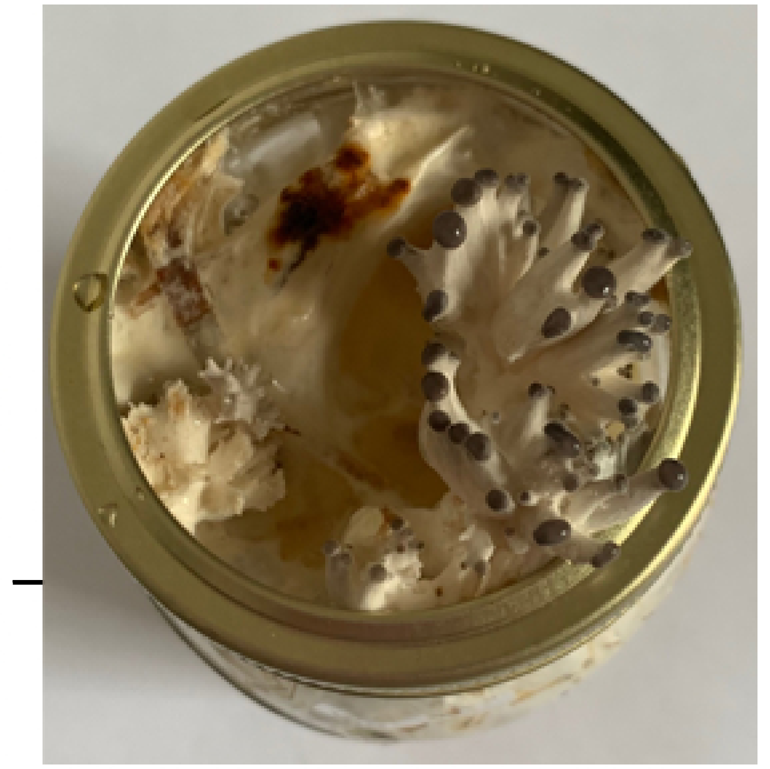
Pinheads starting to grow on the top of the Mycelium. The lid was taken off at this stage to allow the mushrooms to grow.

Jar full of Mycelium

24/04/22

Pinheads growing.

25/04/22



26/04/22

Pinheads expanding by the day.

27/04/22 Morning

Images taken in the morning and the evening to give a better understanding how the mushrooms appear so quickly. Out in woodlands, mushrooms appear over night.

27/04/22 Afternoon

28/04/22

30/04/22

Mushrooms are ready to harvest.

**All images in this experiment are author own.

Experiment Five - Car Oil
(12/04/22 - On Going...)
Jar Size 0.5L

12/04/22

Apparatus required for Experiment

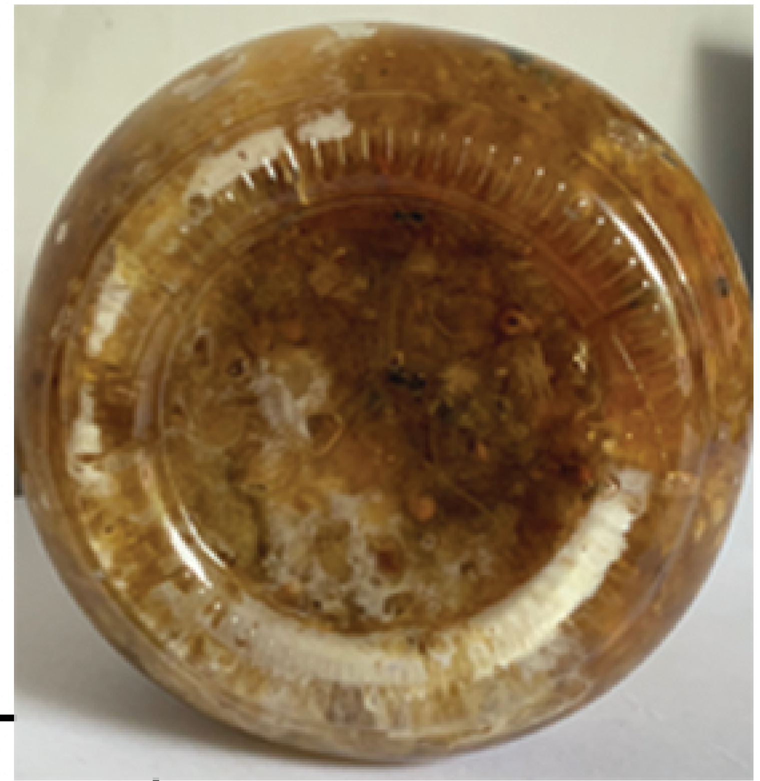
15/04/22

Condensation buidling up inside the jar.

21/04/22

White solution forming at the bottom of the jar.

White solution is looking thicker.



06/05/22

Small amounts of Mycelium evident on the spores when the lid is off.

On going....

**All images in this experiment are author own.

Experiment One
Bran

Experiment Two
Coffee

Experiment Thrree
Corrugated Cardboard

Experiment Four
Sawdust

Experiment Five
Sawdust and Car Oil

Jar Size 0.5L
**All images from experiments are authors own.

Results of Experiments 1 - 5

Experiment One - As the Bran was not sterilised, there was a high possibility that it would not grow as well or at all. After a week in, Mycelium started to show through, giving hope. But as time went on, bacteria showed it presence and continued to take over the bran substrate. A putrid smell started to occur and got stronger through the process of the experiment.

Experiment Two - Mycelium grew straight away in patches where they continued to grow and link up. the Mycelium did not take over the coffee was present. As the experiment went on, water started to build up at the bottom on the jar. The Mycelium turned a brown coffee colour. Towards the end, the Mycelium hardened and created lumps within the coffee substrate. On the top of the jar, clusters have been made by the spores with a tiny amount of Mycelium present. Not all the spores grew in this experiment.

Experiment Three - In this experiment the Mycelium invaded the corrugated cardboard. From the timeline, its noted that the Mycelium excelled and continued to eat through the cardboard and started joining together instantly. From the outside of the jar, the Mycelium looks fluffy and soft. Mushrooms started growing within weeks. Some would die off and then the newer ones would push through. As the actual mushroom was used for this experiment, it was interesting to observe the growth and speed.

Experiment Four - This experiment worked out the best by far. With regards to Oyster Mushrooms, research shows that straw is the best substrate for them. It was incredible to watch the spores feed through the straw and create mushrooms that appeared overnight, while also producing a material that sits below.

Experiment Five - This is an on-going experiment as it started later than the rest. The idea came about from further research. There is movement within the jar, it looks like Mycelium is forming but at a slower rate. The oil that was absorbed by the sawdust has sank to the bottom of the jar.

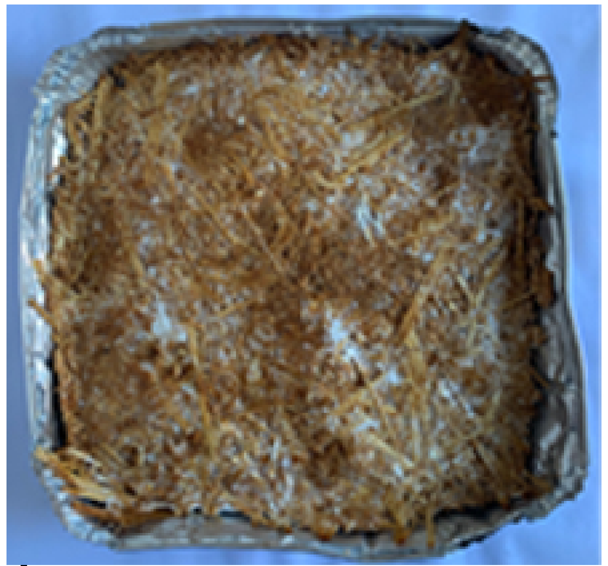
fig.61
Mycelium packaging

Growing Shapes

Through research packaging, shapes and bricks are available to purchase using Mycelium as a main material. From this, different tests were attempted to create shapes. The mixture from the ‘grow your own’ kit had dried up and was not producing mushrooms anymore, so with that, it was broken down. Some of the mixture was placed into a metal biscuit tin and a plastic circular container with lids on both and left in a room that was at room temperature, sometimes colder. They were misted every few weeks.

With the remaining mixture, a wood pellet mixture (60:40 ratio soaked overnight) were incorporated and placed in aluminium foil trays. One was a square and another was a pudding shape and both were covered and placed in an area with an average temperature of 22C. They were misted every second day. Air holes were placed in various spaces on the top.

Growing Shapes
(03/04/22 - 09/05/22)



This shape, made no obvious changes for nearly a month. Underneath small areas showed Mycelium growing. Mushrooms started coming through five weeks later.

03/04/22

Spores, Mycelium present and straw, mixed with hydrated wood pellets in both shapes.

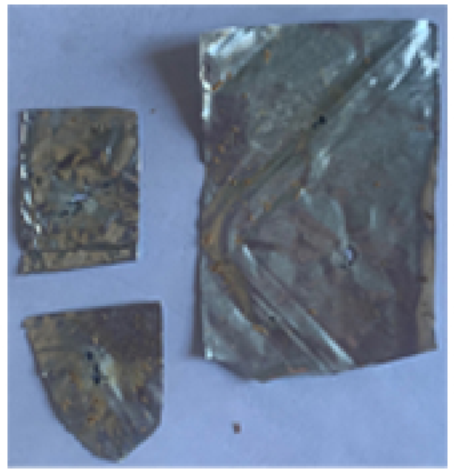
08/04/22

28/04/22

Small amount of pinheads popped through, but nothing more until 20 days later.

06/05/22

09/05/22



*To note, small areas on the bottom of the metal trays in each shape, looked like they had been eaten away.

**All images in this experiment are author own.

Growing Shapes

15/04/22 - Mycelium Excelling, Before drying out Mycelium in container.

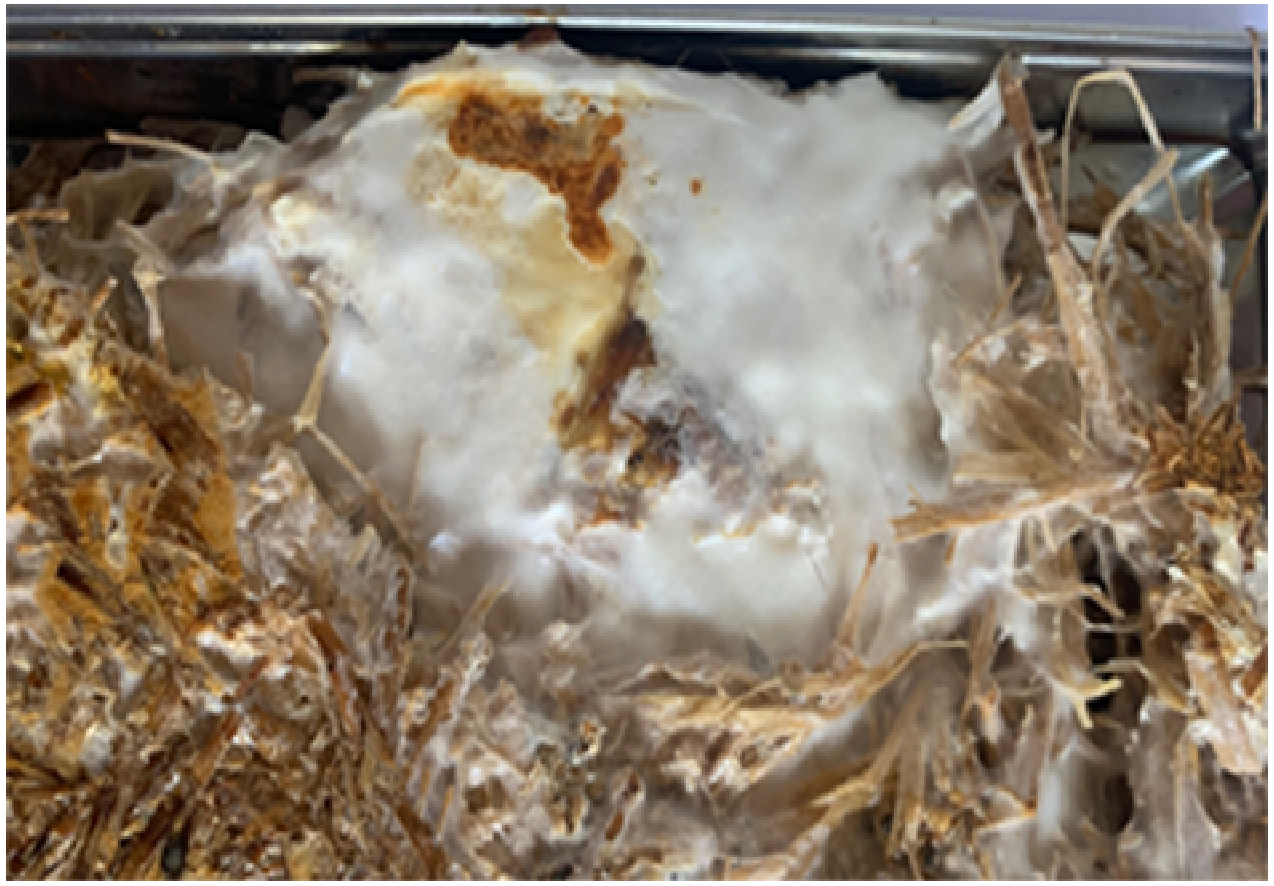
10/05/22 - Mycelium dried out and shaped created.

**All images in this experiment are author own.

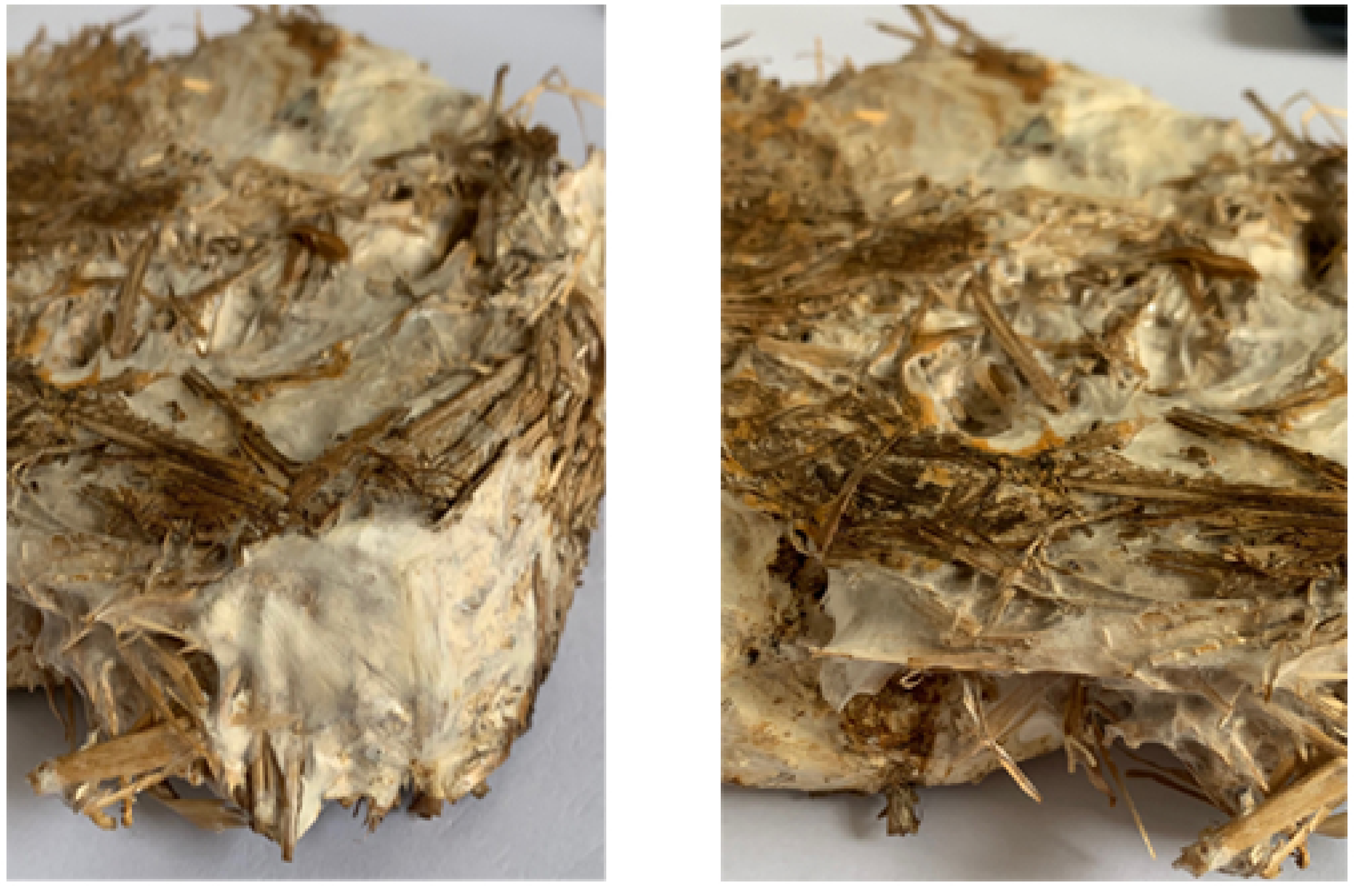
Growing Shapes

15/04/22 - Showing progression of Mycelium growth with straw substrate.

17/04/22 - Just out of the oven and cooling



15/04/22 Zoomed in photograph of Mycelium growing. The orange mark is rust from the tin.



26/04/22 - a few weeks after. The slab of materials is quite solid.

**All images in this experiment are author own.

fig.62
Mycelium

Learning from Mycelium

Fungi requires sterilisation of the substrate, it is inoculated with, to ensure no other bacteria gets in. Mushrooms have been growing for millions of years without any human involvement or interaction. They grow in woodlands and grazed land as either individuals or groups without being sterilised, so why do they need humans to step in and kill other bacteria that it has been fighting off for years? With experiment one, the substrate was not sterilised and other bacteria invaded the bran, wiping out the Mycelium. That poses the question as to why has fungi not become extinct already.

From the perspective of the tests undertaken for this project, when analysing results from the various experiments carried out at home, around fifty percent did not give good results, thus demonstrating Mycelium as an application, cannot be grown everywhere, only in particular substrates. It requires further research into specific species of fungi and the substrates they could excel in. Different companies spent time researching and experimenting with Mycelium and various substrates before finding the right combination suitable for their product. However, it certainly appears to be a good green solution for the future.

One wonders, how much time, energy used and material waste was created before arriving at the finished product, and, how long would it take to counteract the energy used. The experiments that have taken place from research such as Jonas Edvard's lampshade use plastic to store the living material. How much plastic over the years has been made to assist in experimenting a natural material for research? Companies spend so much time growing a natural material, to be more sustainable but end up using a plastic bag. Understandably, Mycelium would eat its way through majority of storage options like cardboard. Nevertheless, can an alternative material with less carbon footprint be made to withstand Mycelium and its substrates in the growing process. Perhaps plastic alternatives from cellulose could be used to make the process more sustainable.

fig.63
Mycelium

Learning from Mycelium

From plastic to oil, fungi feed on the organic compounds, breaking down petroleum-based materials known as Mycoremediation, hence the car oil experiment. The fungi would not survive on the oil alone. A woody substrate would need be to be incorporated such as sawdust. To date, oil and fungi have not been used in any material applications but that does not mean they won't. Oil spills in oceans are happening too often and Paul Stamets discusses this problem in a blogpost on his website, 'fungi perfecti'. He indicates that researchers have identified a strain of Oyster mushroom that has a salt tolerance as well as results showing that straw inoculated with Oyster mushrooms can float. With that in mind, over twenty five million tonnes of plastic end up in the ocean each year, does that mean not only can fungi reduce major oil spills but can also breakdown plastic that floods the oceans at present. Only time will tell. (Stamets,2010)

With nature in mind, humans are guided by the seasons. Companies create offers to generate sales and as consumers, we buy 'stuff' not really considering the environmental impact it has made to get onto the shop floor . With summer only around the corner, the beach is a busy place especially when the sun shines. What do people buy for the beach? Chairs, umbrellas, buckets and spades made majority of the time from plastic. Once the sun starts to sets, the chairs are too heavy or might have broken throughout the day, with people leaving them on the beach or up beside a rubbish bin that is already over flowing. Imagine if deck chairs or umbrellas once finished with, breakdown and filter back into the ecosystem as if only a memory. Another example where this could potentially be very valuable, is festivals. Once the party is over and the last person standing has left, all that remains in the once green fields are plastic tents and sleeping bags. Waste could be halved if even tents were made from Mycelium and well as the cost of the ticket could drop, as someone has to pick up the rubbish and dispose of it. Landfills are reduced, the carbon footprint is down and overall the planet is a better place for it.

When considering products in design, lighting and furniture are great as one-off pieces like art but what about different applications used on a daily basis. Construction happens every day and uses materials for walls, plasterboard, insulation, roofing etc. From the research review it has been established that insulation panels were the only Mycelium product found that could be used in construction on a daily basis. Lighting made using Mycelium was also included but the light fixtures designed would not work in every project. Mycelium made, Acoustic panels could be used for sound insulation but again not in every design. More products that have meaning and substance need to be created.

Mycelium is a resource that will never run out , giving humanity the opportunity to expand it uses.

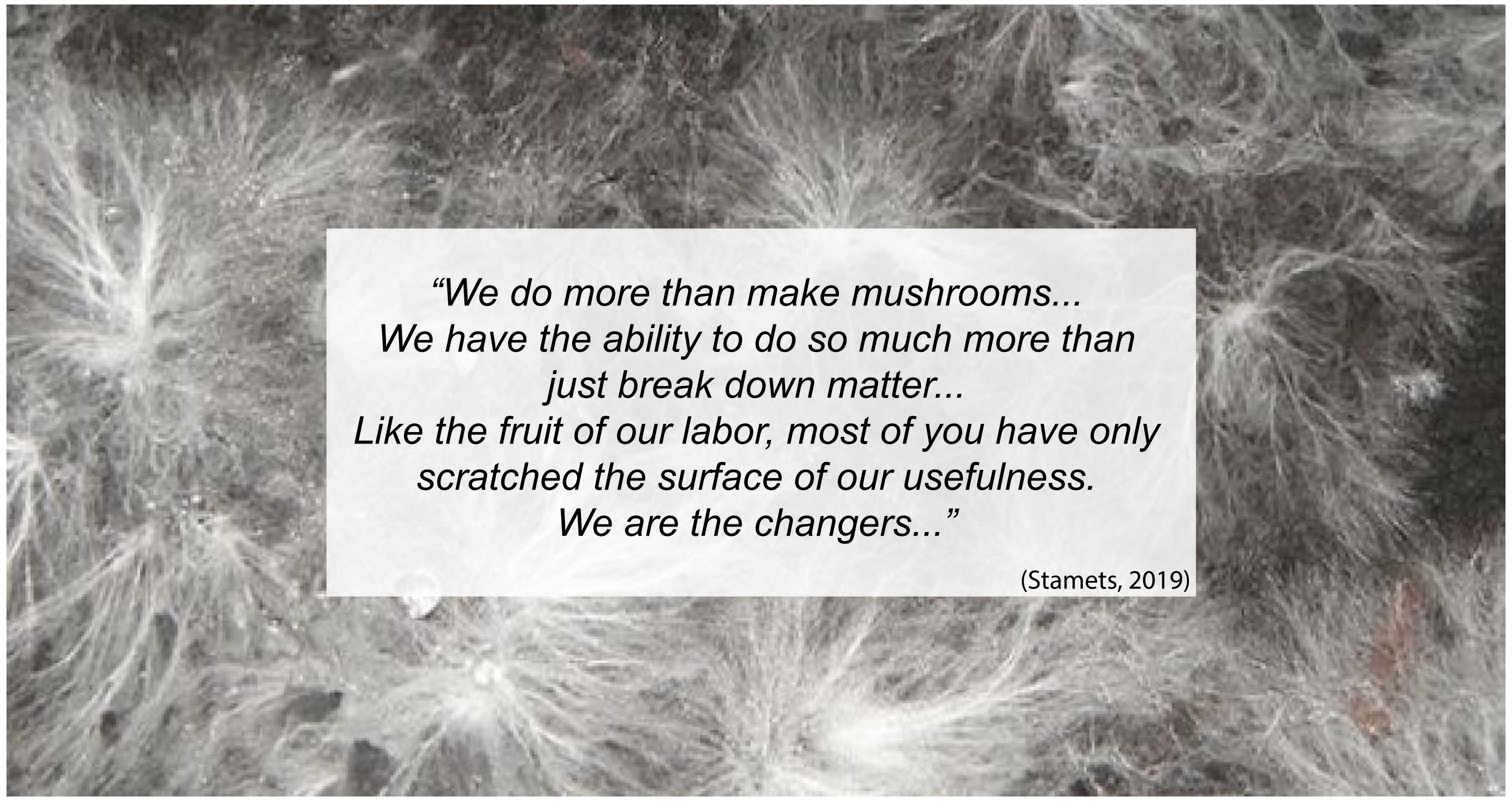


fig.64
Mycelium

Is Mycelium the future? Yes!

To summarise this research topic, Mycelium is natural material that thrives in the right conditions, creating a variety of different products that are readily available on the market. Findings from this dissertation have given a better understanding of how nature and humanity can co-exist in creating a more sustainable future in design.

The research gathered from the literature review, explains Mycelium’s function within the ecosystem in great detail, it focuses on the many benefits of the end products as well as highlighting ways to identify specific fungi.

From the various experiments, results show how well Fungi/Mycelium can grow in a substrate that it excels in, giving further insight into the quantity and pace for production. It is evident that Mycelium has little impact on the environment in comparation to other man-made products that are currently being used such as plastic. Petroleum, plastic and cement are all man-made materials that have a negative impact on the environment and being able to cut back on them in the Design Industry would be beneficial to the planet.

In 2019, the irish government declared a climate and biodiversity crisis in Ireland. Cop26 took place last year, bringing together over two hundred countries in need of accelerating action on the Paris Agreement and the UN Framework Convention on Climate Change. If Architects and Designers could make the small change to using more sustainable products, we would be helping not just ourselves but the planet, wildlife and future generations.

“The greatest threat to our planet is the belief someone else will save it”
(Swan, 2022)

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fig.19 Sketch by author based off image from book, Harding, P. Mushrooms. Pg.6

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fig.25 - fig.28 Author's own photographs.

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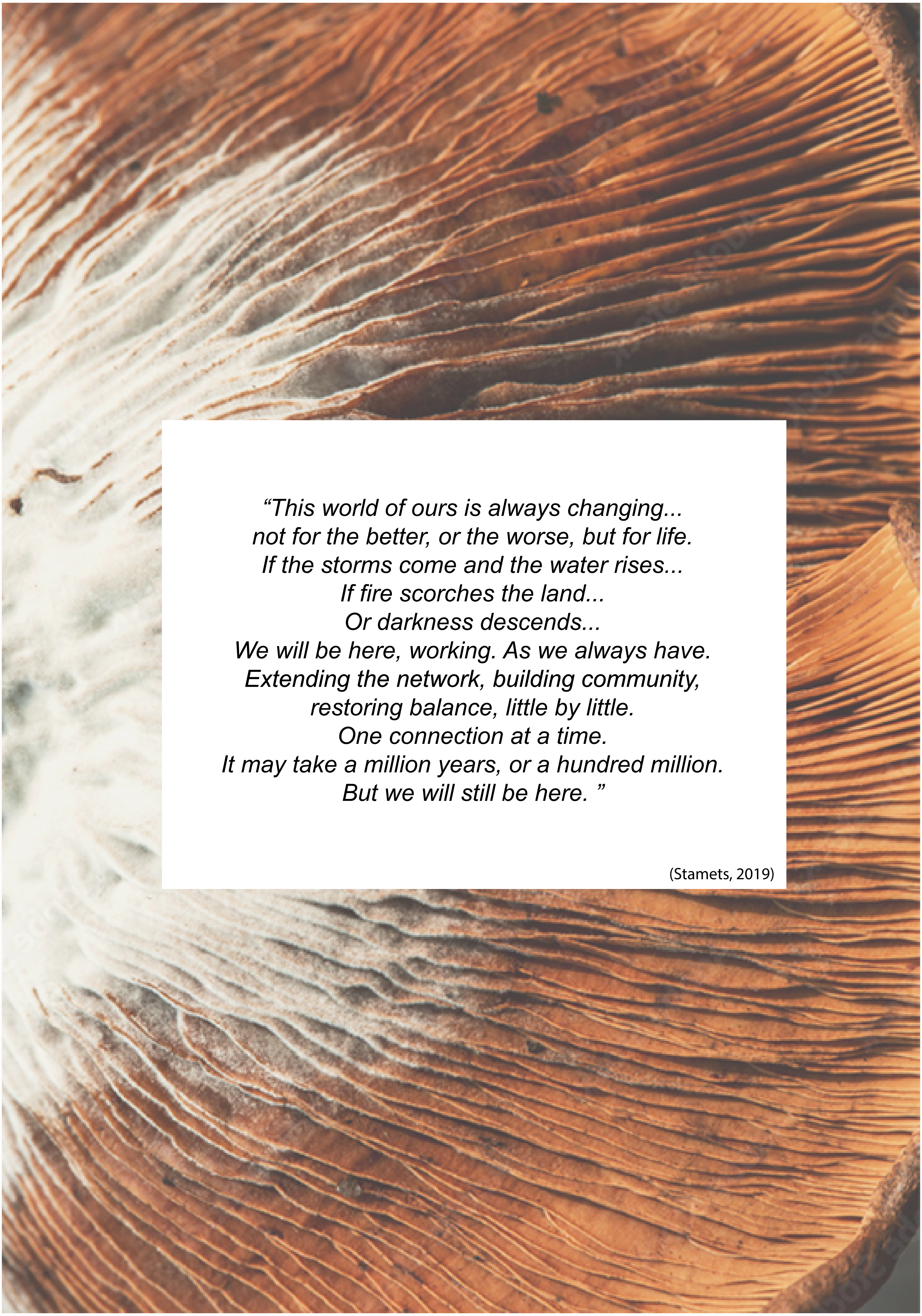

"This world of ours is always changing...
not for the better, or the worse, but for life.
If the storms come and the water rises...
If fire scorches the land...
Or darkness descends...
We will be here, working. As we always have.
Extending the network, building community,
restoring balance, little by little.
One connection at a time.
It may take a million years, or a hundred million.
But we will still be here. "

(Stamets, 2019)

fig.65