Mush [Room]

An exploration on how to cultivate a home

Axel Henriksson / Master's Thesis 2024
Chalmers School of Architecture / Department of Architecture and Civil Engineering
Examiner: Jonas Lundberg / Supervisor: Jonas Lundberg

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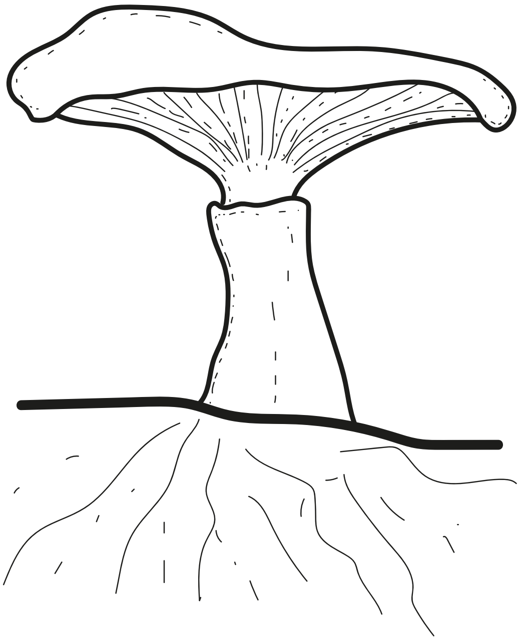

Jag gillar inte höghus
Sten och lätt betong
Jag trivs inte i stan
För den är grå och trång
Jag vill bo i en svamp, annars får jag kramp (svamp)
Det finns hopp för min kropp, i en mullig sopp (svamp)
Kom ikväll och var snäll, till min kantarell (svamp)
Titta in och ta ton, i min champinjon (svamp)

Zvampen - Electric Banana Band (1984)

Abstract

This thesis suggests ways of using biology in architecture, mainly throughout the use of the fungal composite material mycelium, in a single-family house. It will also use biology to develop a building with resilience, metabolism, and flexibility.

Mycelium material has been acknowledged for its energy-cheap manufacture process, its favourable insulative, fire-resistant and high strength- to weight properties. The material, which is based on the bond between fungal roots and a lignocellulosic substrate, can be sourced from agriculture and forestry waste, and has found its use in, among other things, packaging (Ecovative, n.d.-b) and acoustic panels (Mogu, n.d.-b). Several structures in building scale have been built, mainly pavilions, but for load-bearing architectural construction, more research is needed (Dessi-Olive, 2022b).

By experimentation, certain strategies and usage of mycelium construction are evaluated and, if applicable, added to a building design proposal of a single-family home. The house uses the biology of mycelium, plants and decomposing microorganisms to achieve a building that can self-heal, be resilient, metabolize and heat itself. This includes using semi-active mycelium, bio-thermal heating systems and adding plants with various properties. These systems are joined together to form a habitable ecosystem inside a greenhouse, using principals from the Nature house, a type of building first described by Swedish architect Bengt Warne (1993).

The outcome is a building that is energy-cheap to produce and maintain, that leaves the exploited ground healthier than it was before exploitation. The house suggested is built with load bearing mycowelded mycelium columns and cardboard waffle internal scaffolding ceiling slabs, using compression-only geometry. The production methods on the mycelium are varied depending on its function in the building. The greenhouse allows for the mycelium to be the load bearing element as well as the facade material. This is a way of construction mycelium that has not previously been used in large-scale permanent structures. The results add to the discussion about the potential of the mycelium material and the potential of using biology in architecture.

Keywords: Bio-design, Mycelium, Nature house

Fig. 01. Fruiting bodies on waffle cardboard panel (lab. 4)

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Introduction

The Anthropocene

Since the industrialisation, humans have rapidly altered the planet and the conditions we live in. Many agree that we now have entered a new geological era, the Anthropocene, named after ourselves. In this era, humans act as rivers and are the biggest transporters of matter on the planet. In 2018, humans were responsible for moving 24 times more material around the surface of the planet than rivers move sediment to the oceans (Cooper et al., 2018). This enormous transformation on the planet has many complications. The dislocation of material does not only change the geology of the planet but also changes the climate as carbon stored in geological layers is now displaced and emitted to the atmosphere as greenhouse gases.

The extraction and processing of materials have an immense effect on the planet. According to UNEPs report Bend the trend (2024), 55 % of the greenhouse emissions as well as 90 % of land use related biodiversity loss are connected to material extraction and processing. Since mining often penetrates the Earth's surface at ground water level, water contamination is a serious risk. Mining is also the biggest producer of waste in the world, particularly bauxite, copper, nickel, and zinc mining (European Environment Agency, 2021). The waste is hazardous to the local environment as well as its inhabitants due to its toxicity and the mining companies lack of responsibility (le Roux & Hecht, 2020). Extraction and processing are responsible for up to 40 % of particulate matter health related impacts, costing the world 200 million disability-adjusted life years every year (UNEP, 2024).

Extraction of finite natural resources also leads to the potential end of said resources, since they cannot regenerate themselves. In the production of concrete, the aggregates sand and gravel, are forever lost and cannot return to its original form. Sand is the most-consumed natural resource on the planet besides water. It is used in concrete, asphalt, glass, and even in silicon chips inside electronic devises. It is also one of the least regulated resources (UNEP, 2019). As the world is currently facing a shortage of sand, this has led to criminality as gangs illegally mines sand from rivers (Beiser, 2019). Sand extraction can also lead to erosion and create expensive infrastructure failures. In 2000, a bridge in Taiwan collapsed due to extraction of sand in a river (Beiser, 2019). Marine sand extraction also has devastating consequences for ecosystems (Hebel & Heisel, 2017).

The use of materials is also scaling up. According to UNEPs report of global sand resources (2019), China increased its use of concrete by 540% from 1999 until 2019. With the help of high-energy processes, we manufacture long-living materials, but the processes are often irreversible. Materials such as glass cannot be turned back into the sand it originates from. If we use the materials in a higher rate than it naturally regenerates, we will eventually get a shortage on even as abundant materials as sand.

Fig. 02. Construction scaffolding in Göteborg

The short life span of buildings

Even though the materials we create and use, can last for thousands of years, our buildings do not last that long. A report from World Green building council (2019) states that 39% of global greenhouse gas emissions are related to constructions. At the same time, buildings are demolished prematurely. In China, buildings are regularly being razed before their intended life span. Guiwen Liu (Liu et al., 2014) investigated over 1700 razed buildings in seven communities in China from 2008 to 2010 and found that the average lifespan of buildings is only 34 years, way younger than the intended lifespan. The same is true for Japan, as the average lifespan of residential buildings there is only 25 years (Wuyts et al. (2019).

Building from non-renewable waste

To reduce the amount of raw material extracted, we need to reuse and recycle the materials already in use. Wood products, metals, and to some extent plastics can be recycled and re-used, but in modern architectural assemblies the materials are combined using foam, resin, paint, or glue into conglomerates that can be very hard and expensive to separate, if not impossible (Dessi-Olive, 2022b). The materials are then impossible to turn back into their original shape and a full circular system can therefore not be achieved (Dessi-Olive, 2022b), (Hebel & Heisel, 2017). Therefore, new materials need to be extracted, processed, and manufactured into new products, leaving a trail of greenhouse gas emissions and environmental and societal problems.

For certain materials, circularity can also come with complications. Plastics are recyclable but loses some of its integrity in the process, and virgin plastics must enter the loop for the new material to have the same properties.
Moreover, most plastic contains toxic chemical additives that during its lifecycle leaks out, posing a danger to human users as well as nature (Wiesinger et al., 2021). During recycling, these chemicals are carried over to the next product, and the process of recycling can even create new toxins. Brosché, (2021), therefore argues that plastics should be considered as non-circular materials and not be recycled.

Biomaterials

Bio-based materials are renewable within a short time span. The materials are made from organisms that can be cultivated and farmed. The materials can then decompose, and the soil created can nurture new organisms, creating a fully circular system. Basing materials on biological processes can, if done right, bring circularity into the built environment (Ross, 2017).

Timber is the most common biomaterial. It is versatile, strong, and relatively fast-growing, but faces challenges when it comes to global supply, biodiversity, and

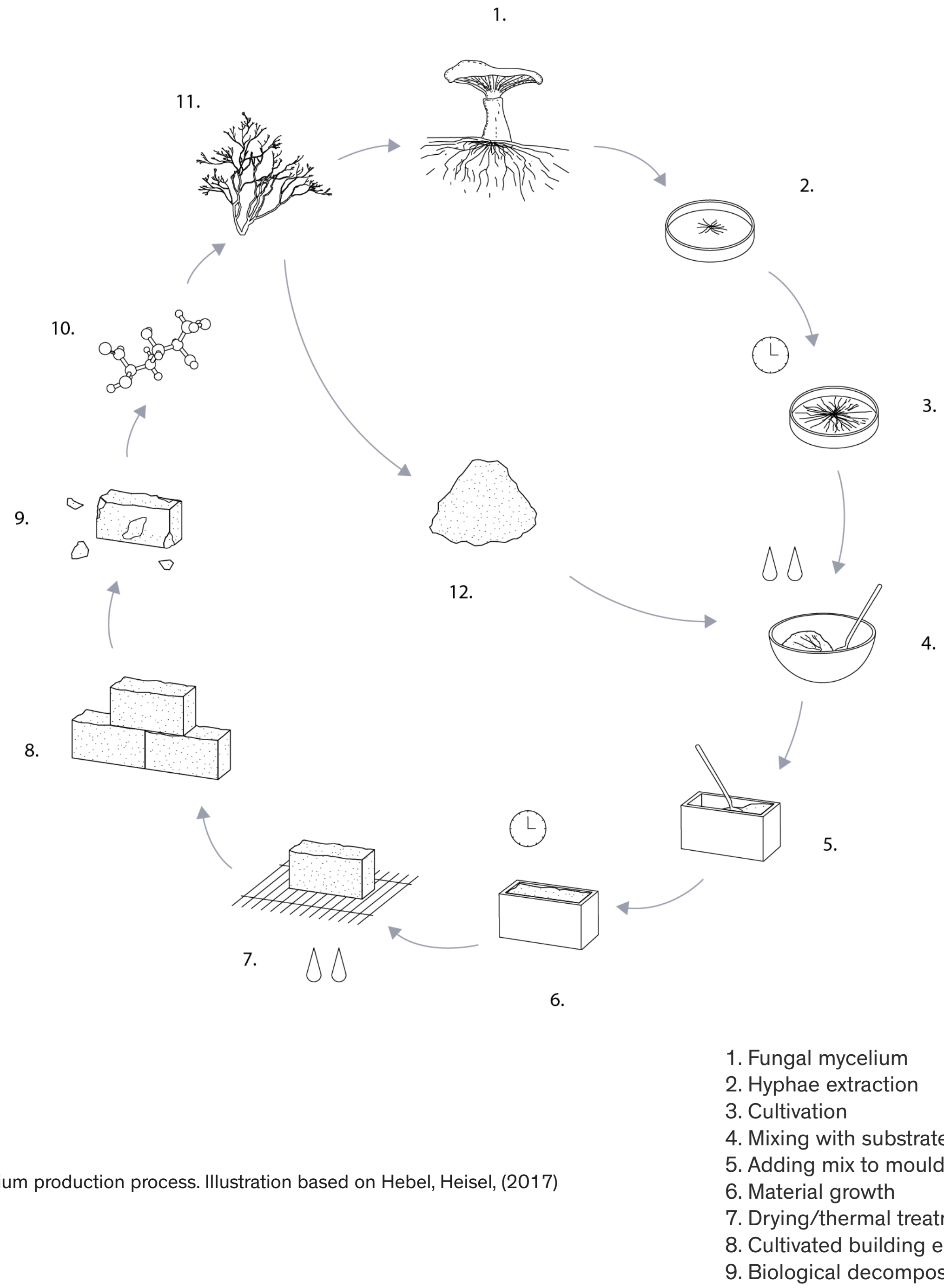


Fig. 03. Mycelium production process. Illustration based on Hebel, Heisel, (2017)

1. Fungal mycelium
2. Hyphae extraction
3. Cultivation
4. Mixing with substrate
5. Adding mix to mould
6. Material growth
7. Drying/thermal treatment
8. Cultivated building element
9. Biological decomposition
10. Biological nutrients
11. Plants
12. Substrate

Fig. 04. Mycelium brick (lab. 3.3)

land use. To meet the demands of an increasing world population, land more than twice the size of India will need to be turned into agriculture. Simultaneously, land the size of the continental United States will be needed to meet the increasing demand for timber (Searchinger et al., 2023). Meeting the demand of food and timber as well as protecting biodiversity, restoring forests, and storing carbon poses a grand challenge. As the world increases its agricultural output, more waste is also created. The waste is abundant, the total residue bio-mass from agriculture in south-east Asia exceeds 500 million ton every year (Tun et al., 2019).

The field of bio-design has gained increased interest in recent years. Besides the possibility of gaining circularity and environmental benefits with the materials, they have also been investigated for their resilience, self-healing or adaptable properties. There are several projects currently investigating different bio-based alternatives to traditional materials using bacteria, fungi, and plants. Examples include bacterial self-healing concrete, engineering bamboo and producing fungal mycelium biomaterials (Hebel & Heisel, 2017). The focus of this project is on fungal materials.

Mycelium

In its most basic form, mycelium is a material made from the bond between the fungal web of hyphae, simplified as the roots of the mushroom, and lignocellulosic substrates. The hyphae of the fungus acts like a glue and binds the material together to a foam-like material.

Mycelium can be cultivated from agricultural or forestry waste and can be grown in labs or *in situ*. Because it can be grown from agricultural waste, land used for agriculture could simultaneously support food production and growth of mycelium material. Mycelium therefore only claims small amounts of land. Agricultural waste is abundant and has little to no economic value (Jones et al., 2018). The production of the material utilizes the fast growth of fungi which is very energy efficient (Dessi-Olive, 2022b).

The material has a lot of embedded air and is therefore a good insulator (Elsacker et al., 2019). Additionally, it has good acoustic properties. It is more fire resistant than many traditional materials and produces less smoke and CO2 when burned (Jones et al., 2020). Mycelium can be shaped to grow in moulds, like a concrete casting process. It can also be left to grow on internal or external scaffolding and form a shape through this. Another possibility is to 3D print mycelium (Shen et al., 2023).

Problem description

The extraction and processing of finite resources used for the building industry leads to environmental problems, health problems and climate change. A circularity system using traditional materials is not always possible, due to material degradation or non-recyclability. This leads to the necessity of examining alternative bio-based materials.

Bio-based materials are renewable in a short time span. Mycelium can be grown on agricultural or forestry waste in an energy-efficient way and is insulative, fire-resistant, lightweight, and sound insulative. This makes fungal materials interesting to examine in architectural applications.

Aim

The aim of this thesis is to suggest ways of working with mycelium composite material in a structural and semi-temporary way by using it in the design of a single-family two-level home. The home follows the principles of the nature house and is built inside a greenhouse which supports the structure by protecting it from weather and temperature extremes. The overall design also supports various systems using, biology which enables the house to self-heal, self-organise and metabolise.

Research questions

How can mycelium and other complementary bio-based building materials be used in a large-scale permanent house?

How can the nature house type contribute to producing and maintaining a house built with cultivated and partly living material?

How can a building use biological attributes such as metabolism, resilience, and self-repair?

Delimitations

The study should be seen as an overview and a test bed to try several mycelium strategies out in a large-scale design. Therefore, the project will not go into depth in a specific strategy. The outcome of the experiments is incident-based reflections on potential usage and not technical data. The results will be compared to literature.

The experiments will mainly use one type of substrate and fungal strand. The substrate was chosen due to its properties described in literature. The fungal strand, *Pleurotus ostreatus*, oyster mushroom, was chosen due to it being one of the most common used in literature (Sydor et al., 2022).

This thesis aims to suggest many different solutions and will therefore not go in depth on the technical details of the systems and the mycelium construction such as the life span, humidity and mycelium strength. The technical solutions described in the design of the buildings are idea-based and should be seen as suggestions that are not fully detailed or engineered.

The focus of application in architecture in the design suggestion has been its construction system, its columns, walls, and ceiling slabs as these are not common in built mycelium structures. Less focus has been put into the design of loose and fixed furniture or flooring.

The design is geographically placed in a southern Swedish context, with its temperate climate taken into considerations. A different approach and design may have to be applied when working with mycelium in other climates.

The projects undertake the construction and usage of the building as a part of the scope. The behaviour of the human inhabitants and the user experience such as odour is reflected upon, but not the main focus of the thesis.

Background

Fig. 05. Chantarelles forms complex symbiotic relationships with neighbouring plants and trees and cannot be cultivated.

Fungi

Fungi is a kingdom of eukaryotes that include moulds, mushrooms, and yeasts. They can be found in every part of the world, even at the poles and in deep oceans (Nationalencyklopedin, n.d.).

The *Ascomycota* and *Basidiomycota* divisions are the types of fungi that get fruiting bodies larger than 1 mm. The fruiting body is what we commonly refer to as the mushroom and is a way for the mushrooms to sexually reproduce. In reality, the fruiting body usually only makes up ca. 1-2% of the mushroom. The largest part of fungi is their hyphae, small thread-like structures between 2–10 µm in diameter that are hidden in the ground or in dead wood etc. Together, they shape complex matrix networks that makes up the mycelium of the fungus (Nationalencyklopedin, n.d.).

Mycorrhizal mushrooms

Mycorrhizal mushrooms are fungi, mostly *Basidiomycota*, that through their hyphae create symbiotic, or sometimes parasitic relationships with plants. They are therefore difficult to cultivate. These mushrooms have huge importance in ecosystems, as ca 80% of all vascular plants on the planet are dependent on the mycorrhizal fungi and their mutualistic relationship (Nationalencyklopedin, n.d.).

Saprobic Mushrooms

Apart from the important symbiotic relationship described above, the biggest importance fungi have on our ecosystems is in their role as decomposers (Nationalencyklopedin, n.d.). The saprobic (decomoposing) mushrooms use enzymes to break down dead organic material into nutrients. These mushrooms are easier to cultivate, as they are not dependent on relationships with other species. Different kinds of Saprobic mushrooms cause so-called white-rot, grey-rot, or brown-rot (Sydor et al., 2022).

Mycelium material

To be able to decompose and live of the dead organic material, the mushroom forms their mycelium matrix around its livestock. Doing so, they bind the material together and act as a sort of glue. Together with the bonded substrate, the mycelium can create a dense but light foam-like material named mycelium composite.

The history of mycelium

Mycelium composite as a material was first described by Phil Ross in the early 1990s and explored in a series of artworks (Ross, 2017). Since then, many more structures have been created and products using mycelium composite have been established on the market. The interest has grown steadily and in 2020 there was 35 patent applications for fungal-based materials (Sydor et al., 2022). Large-scale structures have mainly included temporary pavilions and research prototypes. Architectural assemblies found in literature include mainly wall-structures, columns, and shell structures.

A list of a selection of pavilions, research prototypes, commercial products and other structures follows:

Pavilions

Mycotectural Alpha was an early larger scale mycelium arch construction exhibited By Philip Ross at Kunsthalle Düsseldorf in 2009. The construction is based on bricks grown separately and stacked into an arch (Wolff, 2023).

Hy-Fi Tower Pavilion built in New York 2014 by David Benjamin led studio The Living is one of the first large scale structures. The pavilion consists of mycelium bricks stacked to form three merging cylinders. A steel support system is added as load-bearing support (Stott, 2014).

Carlo Ratti's *Circular Garden* was a temporary pavilion raised in the botanical garden at the Milan Design Week 2019. It consists of a series of arches shaped by catenary curves, with a combined length of over 1 km (Ratti, 2019).

The Growing Pavilion was a pavilion built for the 2019 Dutch Design Week, using mycelium wall panels mounted on a circular wooden construction (Pownall, 2019).

Research prototypes

The *Myco-tree* mycelium structure was one of the first load-bearing large-scale mycelium structures when showcased the 2017 Seoul Biennale of Architecture and Urbanism. Using mycelium and bamboo, the branched column was designed to utilise compression-only form to be able to use the weak material structurally. The column could support a four-by-four meter bamboo grid at three meters height of a weight of 134 kg in total. The construction could also withstand 0.7 kN horizontal point load at a height of 1.27 m (Heisel et al., 2017).

The *HOME* project used veneer strips welded together with ultrasonic welding to create a 3-dimensional lattice scaffold for mycelium to grow around in the creation of mycelium panels. The veneer strips improved the performance of the sample as it created tension and compression in parallel to its grain direction (Rossi et al., 2022).

La Parete Fungina is a wall-section prototype built by students of University of Virginia School of Architecture and researcher Jonathan Dessi-Olive in 2022. It used a total of seventeen slabs, welded together using loose inoculated substrate, a technique called myco-welding (Dessi-Olive, 2022b).

L'Orso Fungino was also built by students at University of Virginia School of Architecture and Dessi-Olive in 2022, as another wall prototype. Instead of welding, it uses post-tensioning systems to stabilise two monolithic *in situ* grown mycelium parts together (Dessi-Olive, 2022b).

The *BioKnitt* prototype was a project connected to the Hub for Biotechnology in the built environment, HBBE in 2023. The structure consists of mycelium filled knitted tubes that intersect and create a dome. The structure was casted and grown hanging from a wooden scaffold and when dried up, turned upside down to create a compression-only dome based on catenary curved tubes (Kaiser et al., 2023).

The Living Room was a mycelium shell structure grown by HBBE in 2023, using knitted wool fabric formwork. The formwork was hanging while growing to create compression-only loads of the mycelium shell when finished growing (Youngs, 2023).

Products

Mycelium leather is a type of pure mycelium that creates flexible textile-like properties that can be grown on liquid livestock (Elsacker et al., 2023). One example of mycelium leather is *Reishi* from the company Mycoworks, made from reishi strands with commercial launch in 2019 (Mycoworks, n.d.).

Airmycelium Foam is a flexible pure mycelium-based foam for "a varitety of applications" (Forager by Ecovative, n.d.), It was developed by Forager, a sister company of Ecovative with commercial launch in 2022

Mushroom® Packaging from Ecovative is packaging made from mycelium composite. According to Ecovative, it is cost- and performance-competitive to and has a shelf life for 30 years if kept in standard dry storage conditions (Mushroom packaging By Ecovative, n.d.).) The first launch of EcoCradle® Packaging was in 2010 (Ecovative, n.d.-a).

Mogu is a company that creates acoustic panels made from mycelium composite. The panels also have exceptional fire rating (B-s2-d0) and are moisture-resistant to RH > 80% (Mogu, n.d.-a). The acoustic panels were commercially launched in 2019 (Mogu, 2019).

Furniture/Other

MyCanoe was a 240 cm long canoe made of monolithic mycelium composite in built by Katy Ayers and Ash Gordon in 2020, showcasing the material's buoyant and waterproof properties (Kuta, 2020).

Zvampen by Swedish designer Olle Sahlqvist, designed in 2023 is a chair made from monolithic mycelium composite with a wooden core (Sahlqvist, n.d.).

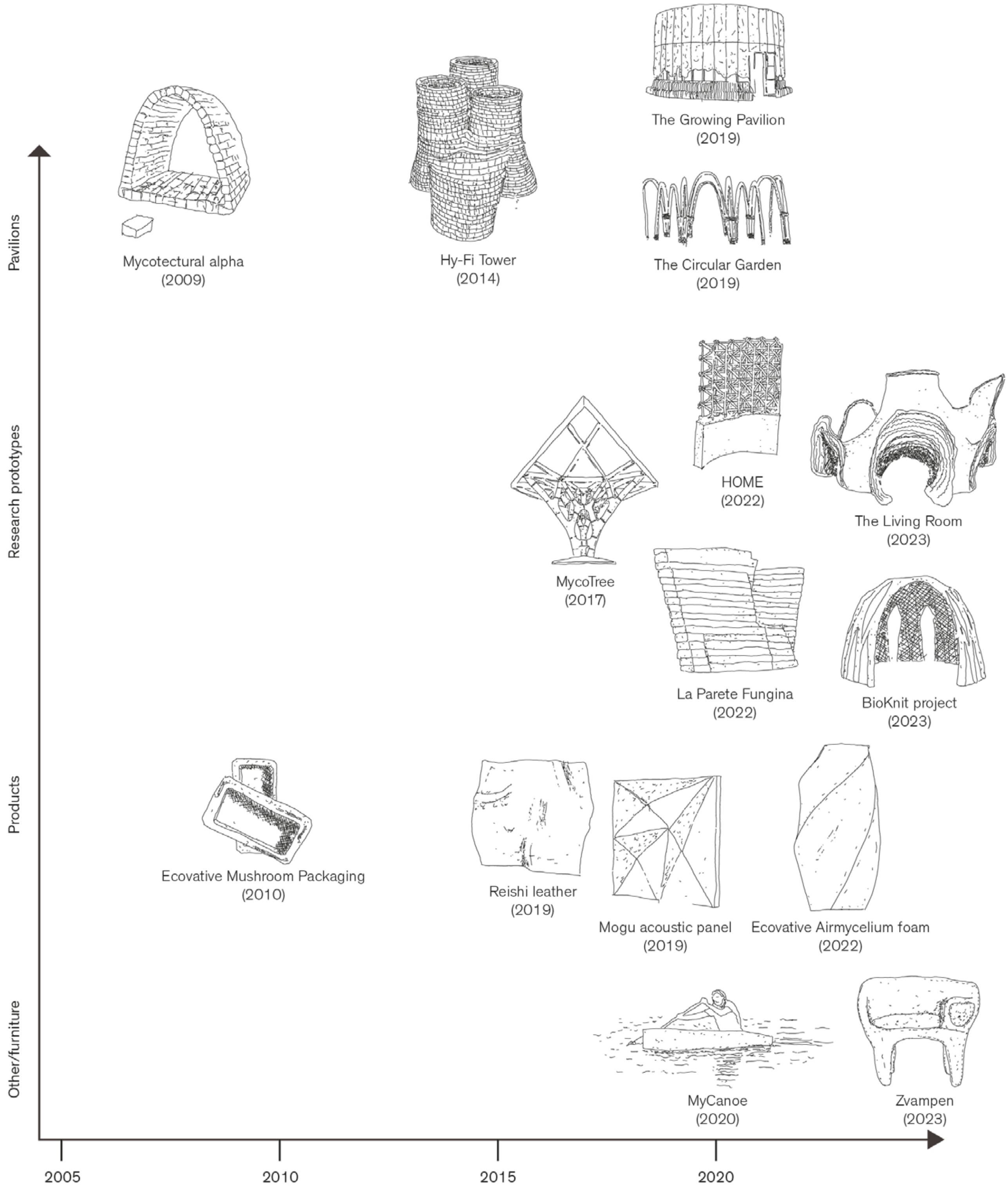


Fig. 06. Mycelium pavilions, prototypes and products sorted by time.

Theory

Nature house

The nature house was first described by Swedish architect Bengt Warne. The nature house as a type was created as an answer to living in a more sustainable home, using the local resources, as well as drawing inspiration from and using the biological processes that surrounds us (Granmar, 2021). Bengt Warne formulated four rules for what a nature house should contain and do:

> Rule #1: Ensure the actual needs, not the artificial ones. Technology should be subordinate to the principles of biology. In lifestyle, construction, and housing, we must learn from nature.
>
> Rule #2: Let our homes collaborate with nature. Organisms rely on natural flows such as sun, wind, rain, soil, and plants. We can shape our houses according to the same principles.
>
> Rule #3: Provide residents of houses with the means to control flows and cycles. Let us have the ability to light a fire, ventilate, water, cultivate, and modify according to our own needs and preferences.
>
> Rule #4: Use sophisticated yet environmentally friendly technology when nature's energies are insufficient. (Warne, 1993, p. 13, own translation)

From the builder's perspective the nature house is a house within a greenhouse with off-grid systems and ecological building materials (Granmar, 2021).

Climate as a design factor

The nature house is also a good way to save energy. Encasing the living spaces with a glazed shell is an energy-saving method that enables heat-catching to the south and a buffer zone to the north. Hönger and Brunner names the strategy 'encasement' in the book Climate as a design factor (Hönger & Brunner, 2013), and references to The growing house in Berlin, 1932, by architect Martin Wagner. The house has many similarities to Bengt Warnes nature houses (Hönger & Brunner, 2013).

Another strategy described up by Hönger and Brunner to make a house more energy efficient is called 'Embedding'. Embedding simply means digging into the terrain and using the ground as heat regulation. The ground heats the building in the winter and cools it in the summer. This strategy has been used to successfully grow bananas and avocados in greenhouses without any external heating as far north as in Skåne in southern Sweden, in a greenhouse buried ca 2,5 m into the ground on three sides. The 500 square meter large greenhouse could remain 2-3 °C inside even as the outside temperature dropped to -16 °C in wintertime, simply through ground heat (Olsson, 2023).

Fig. 07. Opuntia cactus grows wood-like around the joints of its modules.

The living building

Today, our buildings need maintenance, and various support systems such as electricity, plumbing and waste removal with the need of human labour. The project GrAB (Growing as Building) was a research group active between 2013 and 2016 connected to the University of Applied Arts in Vienna. The aim of the project was to develop architectural concepts from growing structures. One of the visions from the projects imagines "*[...] buildings that behave like living organisms, developing and sustaining themselves independently, and being part of a natural system*." (Hoheneder & Gruber, 2016)

Bayer (2017) has similar ideas and argues that a well-functioning living system in many cases can reduce the need for human labour as it would be self-healing and responsive to its environment.

In an ecosystem, different species co-exist, collaborate, or take advantage of each other. A relationship between species that has evolved from a collaboration with other species beneficial for both is called a mutualistic relationship. When one species lives of the other without benefiting, or even harming the other species, it is called a parasitic relationship.

Hoheneder & Gruber (2016) argues that as a species, one could say our current relationship with the ecosystems that we are exploiting is parasitic because the extraction of resources, for example, harms them. We do not see the need of retaining these systems if they are not vital to our current way of living. Using biology in the building is a way of creating symbiotic relationships with ecosystems instead of parasitic.

Growth

In architecture, growth almost always comes with additional extractions and the claim for more land. Most building techniques are based on the principle of addition, combining prefabricated elements, transported from afar, on site.

In biology, growth can take place within the organism itself, by generating modules with materials sourced from the organism itself. While the strategy of taking advantage of the local material and energy has been used in buildings for a long time (e.g. rainwater collection or solar power), it has only been used in the operating part of the building, and not in the building phase (Hoheneder & Gruber, 2016).

The growth can also lead to differentiation, as a cell with one particular use can divide and create cells with another use. The Opuntia cactus grows in modules of soft materials but as the plant becomes bigger, the layer around the joints of the modules becomes wood-like. This shows the adaptability of biological growth.

Another lesson to learn from the cactus is that joints are the weakest point and therefore need extra support.


Fig. 08. Mycelium can repair itself (Lab 7.)

Resilience

Ecosystems are usually resilient. They have been developing for millions of years and have survived big environmental changes. In technology, resilience is connected to safety with regards to damage due to unforeseen events. In architecture, resilience could include a higher degree of flexibility within structural systems as well as more resilient material systems (Hoheneder & Gruber, 2016). Living mycelium has an adaptability that could contribute to a higher degree of resilience in a building. When grown in moulds, it migrates to the borders of the mould and creates a ca. 2 mm thick skin due to more oxygen being available (Elsacker et al. 2019). The relocation of biomass in this example could be a process that can contribute to the flexibility in a system. Non-load-bearing walls can be situationally adapted by cutting holes or letting holes heal up. As a hole is cut in a wall of hibernated mycelium, the material can be reactivated, and create a skin around the newly cut wound. When the hole is not needed anymore, active mycelium could simply be added so that the hole grows together. This process could for example be used to create furniture, shelves built into the walls and to add and remove windows.

Another type of resilience found in biology is the protection against hostile organisms and viruses. Essential oils in certain plants have been found to reduce the growth of mould. Fincheira et al. (2023) found that the essential oils of thyme (*thymus vulgaris*) and oregano (*origanum vulgare*) were effective in stopping growth of two species of mould. As a building out of mycelium might be vulnerable to mould, cultivating these plants might help to mitigate infections, functioning as a sort of immune system of the building. The mycelium in itself could also help against mould, as semi-active mycelium can discourage mould growth (Bayer, 2017). As a third protection, natural enemies to different pests and harmful organisms can be planted out.

Self-repair

In biology, many ways of coping with wounds have evolved at all levels of an organism, from the macromolecule and single cell to the entire organism. Self-repair could even be considered a prerequisite of life itself (Hoheneder & Gruber, 2016). In technical materials, self-repair has very few human-made examples and present a huge challenge. The use of biology in building materials could make this more feasible. Mycelium material is self-repairing at two different scales.

Due to the need of oxygen, mycelium migrates to the borders of the material it grows on (Elsacker et al., 2019). Failures in the material that would aerate previously anaerobe parts of the material, could therefore be self-repaired since the damage would be over-grown with mycelium.

Additionally, as with most organisms, the fungal mycelium has a way of reacting and preventing damage. In potential local damage, the hyphae can regrow and feinforce by connecting to neighbouring hyphae, making the mycelium network more robust around certain vulnerable points (Elsacker et al., 2021).

If parts of the walls of the building could be kept alive, it could be turned into a protective layer, repairing potential damages. Today, we protect sensitive materials like wood with plastic based paints and coats. If the outer shell could be kept alive, we could avoid the use of non-renewable and sometimes toxic and irreversible materials, as well as achieving a higher degree of independence in the building.

Fig. 09. Carnivourus plants have a complex metabolism

Metabolism

In the essay *Plan Not to Plan Anymore,* Hoheneder and Gruber (2016) envision the benefits of a building that could metabolise in the same way as living organisms:

"Buildings that are able to metabolise like living organisms would free us from the huge responsibility we have acquired by letting more artificial systems which are completely dependant on our care" (Hoheneder & Gruber, 2016)

Metabolism is crucial for all life. It consists of catabolic reactions, gaining energy from the bonds when breaking down larger molecules into smaller ones, as well as anabolic that uses energy to build larger molecules from smaller. We use the energy from the catabolic reactions to fuel the anabolic, while plants can use biosynthesis and use the energy from the sun as source (Betts et al., 2022).

A house that involves human life, plants and fungal structures could potentially create a metabolism within the structure and site. The local climate conditions with sun and rain could fuel a system where technology and biology work together. Nutrients from black and grey water created by the human inhabitants could be used for planting food. Waste created by the plants could partially be used as a substrate for the fungus as a building material or even as food for the inhabitants. In addition, hydroponic cultivation systems could be added to provide better conditions for cultivation and more food for inhabitants. This idea also corresponds to the idea of closed loop system that is marked as one of the desired factors of the nature house.

One existing system that could answer to the metabolism vision is the biothermal water heater described by Brown in the book *The Compost Water Heater* (Brown, 2014). As the decomposition of organic matter is carried out by micro-organisms such as bacteria and fungi, heat is released. By slowly pumping water through a compost pile, the heat can be transported into and used throughout the building.

Even though using compost for heating is not a new invention–more than 2000 years ago farmers used a layer of manure to heat growing beds and prolong the growing season–it is a kind of heating few people have used in an efficient way (Brown, 2014).

In projects described by Brown, water from compost systems have reached 50-60°C throughout long winters of Vermont, USA. The systems could also last 16 months before rebuilding is necessary (Brown, 2014). This system can heat the building but is also a way of creating a loop for nutrients as the compost can be used to cultivate new plants.

Intelligence

Intelligent technical systems in buildings are already able to control, for example, the intake of sunshine by automatisation and the press of a button on a mobile phone or even through voice control systems (Luxaflex, n.d.).
Even refrigerators are now connected to internet to be controlled through phones. Smart refrigerators can have touch screens, be able to read their content and suggest recipes as well as being able to communicate with ovens and stoves (Samsung, n.d.).

On a larger scale, temperatures are regulated from thermostats in buildings and can connect with heating and cooling systems. When the building can react on its own impulses it removes a lot of the responsibility from the inhabitant, as systems can run themselves (Hoheneder & Gruber, 2016). An automated building could react on regulating temperature, but also air moisture and ventilation.

Death

When a building is torn down, a lot of the materials become waste. In 2018, 600 million tons of construction and demolition material waste was created in the USA alone. 455 million tons of them was used again, mostly as aggregates, and 145 million tons ended up as landfill (U.S. Environmental Protection Agency, 2024). While the death of a conventional building would lead to pollution, the end of a building of solely bio-based material can be decomposed back into nutrients and support new organisms.

Working with mycelium

Challenges

Mycelium is an interesting material due to its energy-efficient production, the abundant source of cheap substrates, and the property of being compostable.

Fig. 10. Contamination and mould is one of the challenges when working with mycelium

The biggest challenge with mycelium in load-bearing architectural applications is that it is a weak material, averaging 0,1-0,2 MPa in compression strength tests. However, as the material is also very light-weight, the strength- to weight ratio is favourable in comparison to concrete (Shen et al., 2023), (Dessi-Olive, 2022b). Another challenge is the risk of contamination which is one of the main issues when working with mycelium. Typically, the substrate needs to be sterile for the mushroom to be able to outgrow contaminators such as moulds (Dessi-Olive, 2022b). The substrate is typically sterilized or pasteurised which can be an expensive process due to the equipment and energy needed. The inoculated substrate is vulnerable to contamination, especially before widespread mycelium colonisation (Dessi-Olive, 2022b).

Another limitation is the possible thickness of the grown material. At a certain thickness, approximately 150 mm, the mycelium doesn’t get enough oxygen to grow sufficiently, which again presents a risk of contamination. (Elsacker et al., 2021), (Dessi-Olive, 2022b) Mycelium is stronger in compression than tension which is something that must be taken into consideration when designing with the material (Dessi-Olive, 2022b).

Grown in labs or *in situ*

Much of the scientific literature uses expensive technology, such as autoclaving, for substrate sterilisation and are incubating at the optimal growing conditions in sterile lab environments (Sydor et al., 2022). As these require advanced and often expensive tools, it is also interesting to review the growing process *in situ* in non-sterile environments and with low-tech sterilisation. The two mycelium walls La Parete Fungina and L’Orso Fungino were both grown in a non-sterile out of the lab environment but with active already inoculated sterile substrate delivered from Ecovative (Dessi-Olive, 2022b).

Sterilisation/pasteurisation

Sterilisation is a way of terminating all microbiological competitors in a substrate, leaving the substate empty for the mushroom to grow. It can be done by achieving temperatures warmer than 100 °C for a sustained amount of time (GARF, 2020). This can be done in an autoclave or a pressure cooker.

Pasteurisation can be done by submerging the substrate in water between 65 and 75 degrees for ca two hours. This will reduce the amount of micro-organisms in the substrate and reduce the competition for the mushroom. It will leave some heat-resistant bacteria alive that can help protect the substrate from competition for the mushroom (Sayner, n.d.). As a more modest temperature can be used, pasteurisation can be done using an ordinary stove.

Fig. 11 Mycelium composite brick (Lab 3.)

CMB (composite mycelium)

The most common and implemented type of mycelium material is mycelium composite. The composite is created by propagating fungal hyphae in a substrate. Under the right environmental conditions, the fungal hyphae can grow and bind together the substrate to form a mass. The substrate can be either a forestry or agricultural waste product and is therefore, if sourced locally, cheap and sustainable.

The mycelium acts as a binder or glue and creates a composite material together with the substrate. The result is a foam-like, light material that can grow into almost any shape (Dessi-Olive, 2022b) The composite lignocellulosic products are more rigid and are therefore useful for applications such as hard packaging, insulation, and furniture. Physical treatment through heat and/or compression are used to create rigidity and prevent further growth. Heat pressing increases the density of the material and promotes cross-linking of molecular bonds (Vandelook et al., 2021)

Mycelium composites are currently used in packaging with several manufacturers in North America and Europe, such as Ecovative (Ecovative, n.d.-b). Mogu is a company that specializes on acoustic and wall panels made from mycelium composite (Mogu, n.d.-b).

Fig. 12. Mycelium leather growing in liquid livestock (Lab 5.)

PMM (pure mycelium)

Another mycelium material that has gained notice in recent years is pure mycelium material. Pure mycelium is, as the name suggests, a material only consisting of the bonds between the fungi and does not contain a substrate within the material itself. Pure mycelium material can be created by separating the mushroom from the livestock, either through liquid fermentation or on solid livestock (Vandelook et al., 2021). The material could be used when flexibility is preferred over rigidity for, example in fabrics, fake leather, and flexible foams. Different chemical treatments can be applied to the fungal tissue to create different properties such as pliability, durability, or protective coating (Vandelook et al., 2021). Some products on the market are AirMycelium™ from Ecovative (Ecovative, n.d.-b) a resilient foam-like material, and Reishi, a mycelium-based leather alternative from the company Mycoworks (Mycoworks, n.d.).

Fungal strands

Sydor et al. (2022) recommends the usage of fungi that creates white rot in applications of mycelium-based materials, as they can create better physical properties. This is due to their ability of degrading lignin in the cell walls of woody plants to a higher degree.

The three most common species of fungus species found in scientific literature about mycelium-based composites are oyster mushroom (*Pleurotus ostreatus*), reishi (*Ganoderma lucidum*) and turkey tail (*Trametes versicolor*) (Sydor et al., 2022). For this thesis, Oyster mushroom and Reishi is used, the first for the composite material investigations, and the latter to create mycelium leather since it has been done commercially for this purpose (Mycoworks, n.d.).

Substrates

Mycelium can be grown on a large variety of substrates to receive different properties. This is cost-efficient since it can grow on agriculture and forestry waste with little to no commercial value (Jones et al., 2020). This waste is abundant and exists everywhere where people cultivate food, which gives potential of up-scaling mycelium production.

The properties of mycelium composite can vary depending on which substrate it binds and can therefore be tailored depending on desired properties of the application. Mycelium composite grown on substrates with more lignin content such as sawdust performs better in compressive tests, while those grown on less dense substrate, such as straw, has more embedded air and is therefore better insulators (Ghazvinian & Gürsoy, 2022).

Post-growing states

Another way of tailoring the properties of mycelium is using different methods of deactivation. Different states and post-growth treatment gives a variety of properties.

Fully active

Fully active mycelium is the state it is in when it grows. As it grows, it is actively decomposing its substrate. The mycelium needs airflow and sufficient moisture levels to be able to continue being in the active state (Shen et al., 2023).

Hibernated/semi-active

If the moisture is removed, the growth will stop, and the mycelium will enter a hibernated or semi-active state where it is still alive but not active. Eben Bayer (2017) argues for the potential of mycelium in this hibernated state, claiming that mycelium insulation works better semi-active than if heat-treated, due to its ability to reactivate and fight off mould, should it get wet.

Heat-treated

Heating the material will kill the fungus. This is a faster process than letting it dry in room temperature.

Fig. 13. Fully active mycelium develops a white fungal skin

Cold pressed

Cold pressing increases the density of mycelium composites. However, cold pressed mycelium performs worse in tensile strength and stiffness than heat pressed mycelium.

Heat pressed

Heat-pressing mycelium composite after growing increases homogeneity, strength, and stiffness to the material. The process softens the lignin, which forms new cross-links and strengthens the material (Bitting et al., 2022). The compressive strength after pressing is comparable to wood products such as OSB or MDF. Heat-pressing is also a way of reducing variations of density and thickness of the samples (Appels et al., 2019).

Time

Mycelium performs differently in compression tests depending on the growth period. Ghazvinian & Gürsoy (2022) show that the compression strength of mycelium composites is reduced after five weeks of growth. As the time goes on, the fungi will consume and degrade more of its fibrous substrate, resulting in reduced strength of the substrate and more fungal hyphae structures. Elsacker et al. (2021) show that full surface colonisation usually happens in just over a week. For a full colonisation all through the material, some more time is probably needed.

Production methods

Casting

The most common way to create mycelium materials or products is to grow the mycelium in a mould. The mycelium can grow into almost any shape (Dessi-Olive, 2022b) Using a reusable mould for casting is an efficient way for mass-producing mycelium products (Goidea et al., 2022). However, when cast in solid volume, the mycelium migrates to the borders, making it cover a smaller percentage of the total volume, and thereby limiting the potential strength of the composite. (Elsacker et al., 2019). Casting also makes complementary materials needed even though it should be done in reusable moulds. Many of the existing projects involving mycelium casting, used plastic moulds, making them semi-dependent on petroleum-based products (Dessi-Olive, 2022b).

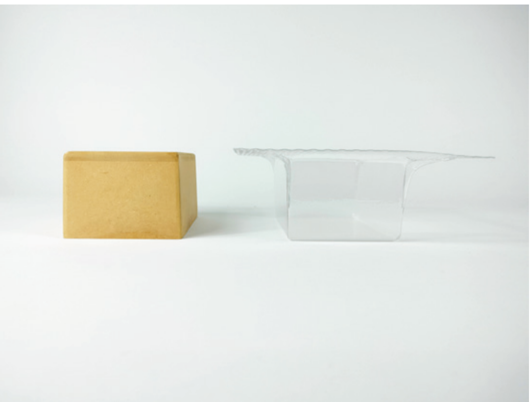


Fig. 14. Plastic brick casting mould (Lab 3.)

Fig. 15. Fruiting bodies developing on an
active mycelium brick (Lab 7.)

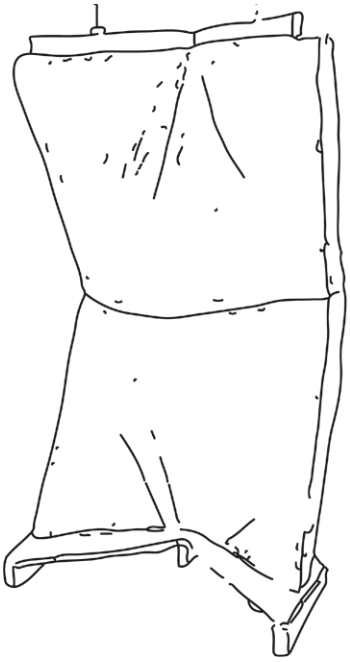


Fig. 16. L'Orso Fungino wall prototype used post-tensioning as a way of stabilising

Myco-welding

Through myco-welding, several monolithic blocks of mycelium composite material can grow together to become a larger structure. Since mycelium can't grow in moulds thicker than ca. 150 mm without additional oxygen intake (Elsacker et al., 2021), myco-welding can be a strategy to make larger and thicker elements. An example for myco-welding being used in research is the prototype of a wall structure called La Parete Fungina, where several large blocks of mycelium composite grew together by the addition of active inoculated substrate in between the layers, similar to mortar in a brick wall (Dessi-Olive, 2022b).

Sandwiching

Jiang et al., (2017) researched bio-composite sandwich structures in which all materials are biodegradable. Three different natural fibre skins where tested (jute, hemp and cellulose), with mycelium-bond agricultural waste as a core and bio-resin as matrix. Due to the fungus preferring the biological properties of hemp skin, hemp performed best when testing for strength, while the stiffness was more dependent on the core (Jiang et al., 2017).

Post-tensioning

In the project 'L'Orso Fungino' Dessi-Olive (2022b), structure together with students at the University of Virginia School of Architecture, showed the process of binding mycelium together using post-tensioning in a V-shaped wall. The mycelium was packed into monolithic forms with cardboard tubes running through. The tubes created a void in the mycelium blocks to allow for steel wires to run through the material. The steel wires were fastened to plywood plates on both sides of the wall structure, with a tensionable winch on one side. The result was successful in stabilising the wall structure but requires further research to be used as an actual vault, beam, or wall (Dessi-Olive, 2022b).

Dessi-Olive used steel wires to bind monolithic mycelium blocks into a wall structure with post-tension. To make the post-tension system fully bio-degradable, a bio-based rope, for example hemp, must be used instead. This could make the tensioning system weaker and will change the mechanism of tensioning the structure.

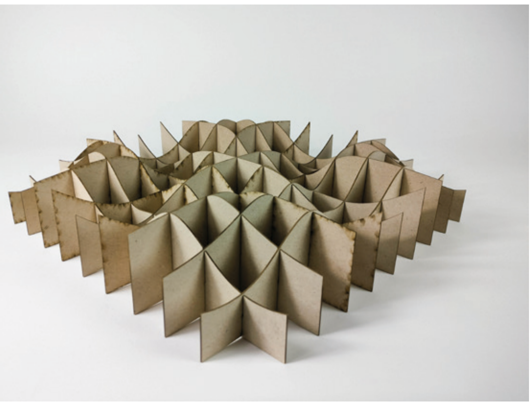


Fig. 17. Complicated scaffolds could be digitally produced and laser-cut to add support for the living mycelium (Lab 4.)

Internal scaffolding

Internal scaffolding could be a way to shape the mycelium as well as making it stronger or stiffer. By making a waffle structure in cardboard, it is possible to create complex shapes for the mycelium to grow on. This method was utilised by Dessi-Olive in 2018 in the creation of the Thick and Thin Arch (Dessi-Olive, 2022b). The arch of mycelium was moulded in an internal cardboard waffle structure and a plastic wrapping cover, and was ultimately able to support a person of 75 kg with a span of ca. 1 m.

Another type of internal scaffolding is described in the HOME project (Rossi et al., 2022). Wooden veneer strips machine-weaved into a 3-dimensional lattice scaffolding. Mycelium was allowed to grow on top and the results showed that the lattice was reinforcing the mycelium block.

Digital fabrication

Digital fabrication could be a way to circumvent issues caused by casting, such as limited oxygen towards the centre and the need for complementary materials in moulds. Digital fabrication could produce more efficient geometries without the need for complicated moulds. This allows for reduction of complementary materials as well as a possible higher inflow of air to the centre of the material, potentially making it stronger.

Elsacker et al (2021) used robotic wire-cutting to cut a large block of active mycelium materials into intricate shapes. The “wound” of the cut was thereafter self-healed by the live mycelium. The method shows promising use of subtractive form-finding, something that is not common in mycelium-related literature.
The ‘Tilted Arch’ project investigated 3D printing of mycelium bio-composites and the bio-welding of the fabricated components (Modanloo et al., 2021). So did the ‘Pulp Faction’ project, with the production of a 2m tall 3D-printed fungal composite column (Goidea et al., 2020).

Another study showed that a stronger and more stable composite could be achieved by strengthening the pure substrate with chitin from crustaceans.
The substrate was printed first and later grown over with mycelium, an indirect inoculation. The study, however, concluded that it could be difficult to use indirect inoculation for larger components due to the biological limitation of the lengths the mycelium could spread to (Shen et al., 2023).

Issues with 3D-printing mycelium include a high risk of contamination and a need for advanced tools, making it questionable if this could be efficiently done *in situ* (Mohseni et al., 2023).

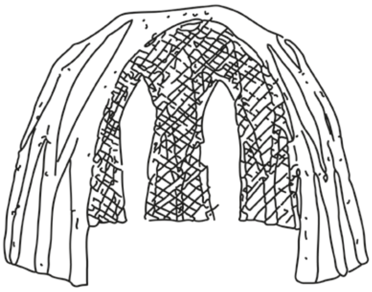


Fig. 18. The Bio-knit pavilion was a gravity shaped dome made out of mycelium filled knitted tubes.

Hang-drying technique

The active and living state of mycelium composite can create a flexible material that can be bent at will. When dried out or heat-treated, the mycelium will become more rigid. This has been utilized in a series of experiments conducted by Jonathan Dessi-Olive together with students (Dessi-Olive, 2022a). Slabs of mycelium are grown in rectangular casts and after a few days of growing, jute or hemp ropes are fastened in anchor points, and left to grow fixed over an

Fig. 19. Mycelium grown in a knitted tube
is hang-drying (Lab 9.)

additional couple of days. The rectangular mycelium slab is then hung up at the rope anchor points and allowed to hang-dry at different levels, creating gravity shaped complex ribbon-shaped bends.

Mycoknitted structures

Mycelium needs airflow and a sterile environment to be able to grow. At the same time, geometry is important to be able to grow efficient constructions that work compression-only. By using fabric from natural fibres, gravity based, air permeable moulds can be made for casting efficient structures. In the BioKnit prototype, a dome was created by casting mycelium in hanging knitted tubes, grown *in situ* (Kaiser et al., 2023). The Living Room prototype, on the other hand, was created by smearing a so-called myco-crete paste on a hanging knitted surface, also grown *in situ* (Youngs, 2023).

Parametric design

The Myco-tree (Heisel et al., 2017) as well as the Cardboard Waffle Arch (Dessi-Olive, 2022b) both show the importance of geometry in load-bearing mycelium constructions. Due to the poor tensile properties of mycelium, load-bearing structures should be modelled to work in a compression-only manner. Digital tools and parametric are an important part of being able to create these structures. The Myco-Tree was computed through the 3D graphic statics plugin for Rhino while Dessi-Olive used RhinoVAULT programme (Heisel et al., 2017), (Bitting et al., 2022).

Humidity

Commercial greenhouses usually have a high air humidity due to the very high number of plants and constant watering and spraying. In the book Bo & leva lycklig i växthus, the author Leif Hultman himself lives in a house within a greenhouse (Hultman, 2022). He claims that the habitable greenhouse does not get very high humidity levels due to less plants compared to a commercial greenhouse. His greenhouse also has an automatic ventilation system that can be alternated by preference of the inhabitants. In the author's greenhouse, the air moisture is between 40 and 60 % relative humidity (RH) (Hultman, 2022). Mycelium is sensitive to moisture as it can absorb moisture and enable mould to grow in the material. When subjected to 40 % RH in 40 °C, mycelium samples gained only 3,15 % - 8.22 % weight depending on substrate and post-growing method (Appels et al., 2019). However, the Mogu acoustic panels can survive humidity up to 80 %, (Mogu, n.d.-a) showing that it is possible to produce mycelium materials able to withstand humid environments.

Methods and tools

The thesis method consists of three parts:

- A series of material experiments are conducted. The goal is to try out several different geometry-finding strategies, test different properties of mycelium and discover how to cultivate mycelium *in situ* in a non-sterile environment.
- A comparison between biological systems and architectural systems that, with literature studies, leads to different ways of using biology in architectural systems.
- A design based on the nature house principals, biological systems and mycelium construction.

Experiments

The objective of the experiments is to gain knowledge on the process of making mycelium building components. By trying it out in real life, the challenges become apparent, and difficulties or advantages that are not mentioned in different scientific papers can be noted. By experimenting with the material, ideas for the design will also be generated.

The findings from the experiments are only evaluated from a single or a few samples. For the experiments to be scientifically trustworthy, at least ten samples plus reference samples should be evaluated at all experiments. Instead, the findings are incident-based and will be compared to scientific papers of correspondent themes.

This strategy was chosen because the purpose of this thesis is not to add material data to the mycelium discourse, which many studies gave already done, but rather to add a design suggestion and a way of working with mycelium to construct it. The knowledge outcomes from the experiments are mainly practical.

The experiments are carried out in a non-sterile environment using simple tools. The inoculation of the substrate has not been done beforehand. More detailed descriptions of the experiments are found in the appendix.

Lab 1.

The aim of experiment 1 is to gain knowledge about the process of growing mycelium. The materials used are left over saw dust from the wood workshop at Chalmers, wheat flour and inoculated saw dust from the online mushroom farming shop Svamphuset.se. Three different amounts of water were used in a total of four samples, to learn more about the amounts of ingredients needed.

Lab 2.

The target for lab 2. is to create a geometry shaped by gravitation by hang-drying. After growing a square panel of mycelium composite, hemp rope is fastened in the corners and the sample is hung from the corners while drying, gaining a spherical surface that, when turned upside down, will be loaded compression-only. This time, another substrate is used: straw pellets from Svamphuset.se. The pellets are heat treated at production, so no further sterilisation is said to be needed (Svamphuset, n.d.). These were mixed with hay from a pet shop that was sterilised by boiling for 10 minutes.

Fig. 20. Mycelium bricks growing in moulds (Lab 3.)

Lab 3.

By casting, this experiment is set to construct bricks of mycelium. These bricks could later be used for other experiments. This experiment can showcase the possibilities and disadvantages of additive assembly with generic shapes. Another kind of substrate is used for this experiment: oak pellets from Svamphuset.se.

Lab 4.

While lab 3 is about generic shapes, this experiment aims to investigate how a complex mycelium panel can be created in a non-wasteful way. By using parametric design and CNC tools to create a waffle structure as an internal scaffolding that guides the growth of mycelium into complex shapes, the panel can be produced in an efficient way. Since the mould is made from cardboard and is consumed by the mycelium, no fossil-based mould is needed. While in the beginning of the growth process, the mycelium is divided into cells by the cardboard before it fuses with the cardboard and becomes a monolithic panel. This enables single cells to be exchanged in the sensitive first part of the growing process.

Fig. 21. Sample of mycelium leather (Lab 5.)

Lab 5.

The goal of this experiment is to make a small sample of pure mycelium leather and examine if it could be made low-tech from household tools and materials. Mycelium leather could be used in the design.

Lab 6.

This lab aims to create a simple but useful lampshade out of mycelium composite. By growing a piece of furniture, it is possible to showcase the versatility and usefulness of the material. It is also a trial to see how thin mycelium elements can be and to discover how the mycelium can be shaped after a more complex mould.

Lab 7.

As described by Elsacker et al. (2022), active mycelium can bridge gaps of at least 5 mm and fuse two blocks together. The goal with this lab is to show how mycelium can be self-healing and grow over wounds and cracks in the material. By documenting the growth multiple times every day, we can follow the process of self-healing.

Lab 8.

Appels et al. (2019) describes how mycelium enters a hibernated state when dried. The material can thereafter be re-activated and start growing when moisture conditions are once again favourable. The goal with this experiment is to examine what these favourable conditions can be and how to achieve them. Is it enough to simply spray water on the material or is something else necessary?

Lab 9.

The aim of this experiment is to examine firsthand the possibilities and difficulties of knitted textile casting, as well as to examine the possibilities of using gravity as a way of shaping catenary arches. The BioKnit self-supporting structure described by Kaiser et al. (2023), shows a promising way of making a large-scale single piece prototype with knitted tubes grown *in situ*. The dome shape is formed by gravity which makes it work in a compression-only manner when turned upside down, utilising the hang-drying technique also described by Dessi-Olive (Dessi-Olive, 2022a).

Prototype (lab 10)

The aim is to continue the cardboard internal scaffolding method used in lab 4., by using it in an arched flooring architectural element. The complexity is increased from the previous experiment as the sample is curved from both sides. Therefore, fabric is fastened on the bottom of the arch to form cells for the mycelium to grow in. This experiment will show test a method for a potential flooring in the design.

The results from the experiments are found in the next chapter.

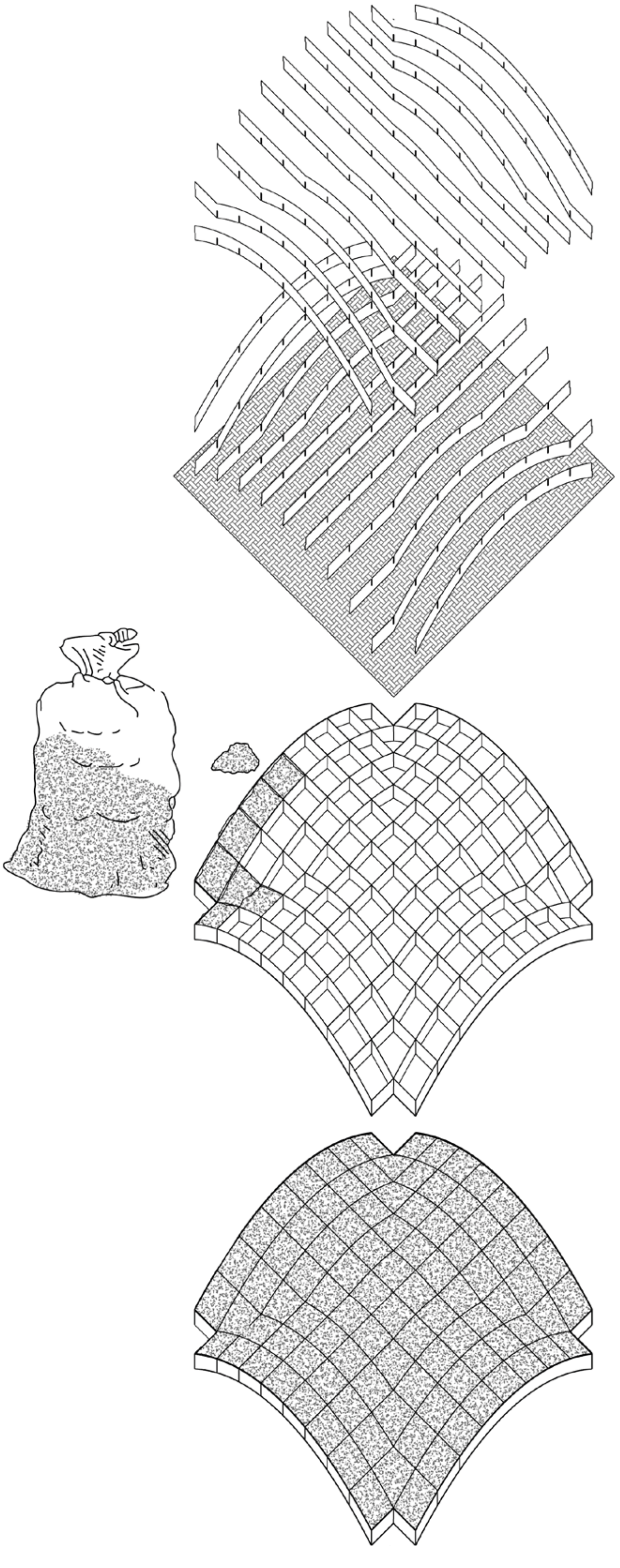


Fig. 22. Production diagram of ceiling slab prototype (Lab 10.)

Design

The outcome of the experiments is summarised in the next chapter. The information is compared with literature to form a plan on how to construct the building in a feasible way. The findings from the experiments are used to decide on mycelium strategies for the design. The design also uses the theory of the nature house (Warne, 1993) and Climate as a Design Factor (Hönger & Brunner, 2013).

Parametric design

As geometry is important in mycelium structures, parametric tools are used in the design of the ceiling slabs. The structure is modelled through parabolic catenary arches computed with Kangaroo in Grasshopper. This allows for the structure to be modelled with gravity as a factor, and work in a compression-only manner. The arches of the ceiling slabs are also inspired from classic masonry architecture as these are also compression-based.

The building as a living organism

In the essay Plan to not Plan Anymore, Hoheneder & Gruber (2016) suggests different ways we can benefit from using biology in architecture. These characteristics includes self-healing, self-organisation, metabolism, and intelligence and are typical for biology and desirable in architecture. This thesis aims to show how to practically implement them in the design of a building. This is done by a comparison between biological and architectural systems and a literature review. One characteristic, self-healing, is also tried out in an experiment.

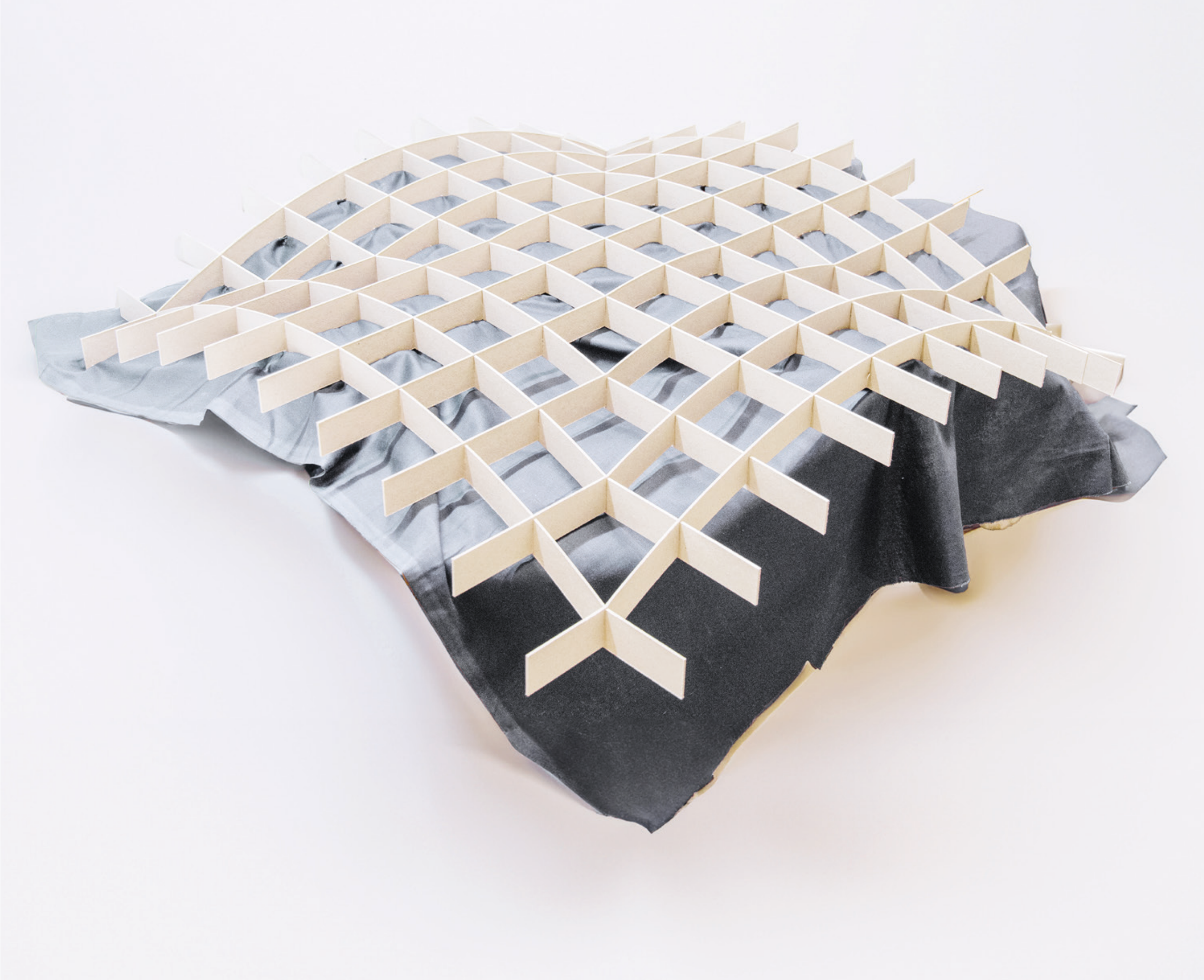


Fig. 23. CNC-cut cardboard waffle mould
with fastened textile (Lab 10.)

Results

Reading instructions
The results from experiments are presented in a table. The most important results are identified and highlighted. A complete description of the experiments can be found in Appendix. The experiments are then translated in the design of the building, together with the knowledge from the literature review. The design is presented chronologically as a living organism, in the stages of birth, life and death.

Birth starts with a guide on how the building is built. It describes the steps and strategies used. It also shows detail drawings, giving information about the mycelium construction.

Life is focusing on the systems of the building, comparing them with the biological processes of an animal. This chapter also shows the plans, facades, and section drawings of the building.

Death is presenting how the ending of the building's lifecycle might be carried out. It shows how the site is turned back to an original state.

Fig. 24. Mycelium growth on cardboard waffle (Lab 4.)

Results material experiments

Table 01. List of experiments carried out for this thesis, showing the target, different substrates, moulds, method of sterilisation, time for incubation, drying method, results and learning outcomes.

Experiment	Fungi	Product/Target	Substrate	Mould
1	*Plerurotus ostrateus*	Reproduction/test	Sawdust and wood chips from unspecified wood, wheat flour 60% of the sawdust, different water amounts: 230 %, 330% and 430 % of substrate	None (growing bags only)
2	*Plerurotus ostrateus*	Hang-dried panel	Straw pellets, hay, 200% water	Cardboard box taped on the inside
3.1	*Plerurotus ostrateus*	3 brick samples	Oak pellets, wheat flour 10% amount of the oak pellet, 200 % water	PET Plastic vacuum shaped mould
3.2	*Plerurotus ostrateus*	3 brick samples	Oak pellets, wheat flour 60% amount of the oak pellet, 200% water	PET Plastic vacuum shaped mould
3.3	*Plerurotus ostrateus*	3 brick samples	Oak pellets, wheat flour 10% amount of the oak pellet	PET Plastic vacuum shaped mould
4	*Plerurotus ostrateus*	Cardboard waffle shaped panel	Oak pellets, wheat flour 10% amount of the oak pellet	Laser cut cardboard waffle structure, soaked in hydrogen peroxide
5	*Ganoderma lucidum*	Mycelium leather	6 g honey in 300 ml water	Glass jar and tupperware
6.1	*Plerurotus ostrateus*	Lampshade	Oak pellets, wheat flour 10% amount of the oak pellet	Metal lampshade
6.2	*Plerurotus ostrateus*	Lampshade	Oak pellets, wheat flour 10% amount of the oak pellet	Metal lampshade
6.3	*Plerurotus ostrateus*	Lampshade	Sawdust and wood shavings from unspecified wood, wheat flour 10% of the sawdust	Metal lampshade
7	*Plerurotus ostrateus*	Self-healing test sample with brick	Brick from 3.3	_
8.1	*Plerurotus ostrateus*	Re-activation test sample with brick	Brick from 3.3	_
8.2	*Plerurotus ostrateus*	Re-activation test sample with brick	Brick from 3.3	_
9	*Plerurotus ostrateus*	Parabola mycoknitted tube	Oak pellets, wheat flour 10% amount of the oak pellet, 200 % water	Machine knitted tube, 100% cotton
10	*Plerurotus ostrateus*	Cardboard waffle shaped flooring scale 1:5	Sawdust and wood shavings from unspecified wood, wheat flour 10% of the sawdust	CNC Knife cut cardboard waffle structure and 100 % cotton fabric soaked in water and 75% alcohol

Substatrate sterilisation	Incubation and growing	Denaturing and drying	Results	learning outcomes
100° oven for 2 h	20 days	100° oven for 2 h	Mix 1 most successful, mix 2 most mould, mix 3 too much water	**Too much water in two samples stops sufficient growth**. The mix with least amount of water has the biggest growth, the middle mix has the biggest contamination. **Probably too big percentage of wheat flour.**
Pellets already sterilised, hay boiled for 10 min	Abolished due to low growth rate and contamination	_	Mould, destroyed	**Wheat flour should be used to make initial growth rate higher. Boiling the hay for 10 min is perhaps not enough to sterilise it.**
Pellets already sterilised, wheat flour pasteurised in water bottle standing in 65° to 75° water for 2 h	Contamination in all samples	_	Mould, destroyed	Two samples got contaminated quickly, one did better even though it also had signs of mould. The one that did better was transfered into a growing box with water on the botton. Instead of growing a skin, it grew long threads on the surface and down to the water. **Pasteruisation method was not good enough. I should use more wheat flour.**
Pellets already sterilised, wheat flour pasteurised in textile juice filter in 65° to 75° water for 2 h	Abolished due to contamination after 5 days	_	Mould, destroyed	All three samples got heavily contaminated quickly. Perhaps too much wheat flour is not beneficial after all. **Oak pellets should be sterilised together with the wheat flour.**
Pellets and wheat flour pasteurised in a pillowcase in 65° to 75° water for 2 h	14 days in mould, 5 days in growing box	Air drying	Three strong bricks	The pasteurisation method seems working. Growth is even throughout the mould. **The samples were small enough to be airdried.**
Pellets already sterilised, wheat flour pasteurised in water bottle standing in 65° to 75° water for 2 h	27 days	Air drying	Successful panel, sprouting fruiting bodies when air-dried	Even though the sample was grown wth the same mix as 3.1, it was more successful. **Perhaps because of better growing conditions in a larger growing box, gaining more air-flow**. Still slow growth and some black dotted mould when growing. **The finished sample is very loosely filled and crumbles on the bottom**. When air-dried, the sample sprouted fruiting bodies, likely due to a slow drying process and more air-flow.
Pasteurisation of jars with substrate in 65° to 75° water for 2 h	4 months	Heat pressing with iron	Small and thin sample of mycelium leather	Pasteurisation of jars was difficult, the round jar leaked an let in water, making imbalance in the substrate. Growth is very slow without incubation chambre. **Honey might not be the best substrate**, instead malt and yest extract can be used. **A pressure cooker is better for sterilisation.**
Pellets already sterilised, wheat boiled in a juice filter in water for 2 h	Abolished due to contamination after 5 days	_	Mould, destroyed	**Pasteurisation should include the oak pellets.**
Pellets and wheat flour pasteurised in a pillowcase in 65° to 75° water for 2 h	Abolished after 30 days due to low growth	_	Limited growth, destroyed	It is hard to tell why the growth was so slow. The growing precondidtions are the same as the successful 3.3. It could perhaps be **bacteria contamination,** or lack of airflow.
Sawdust and wheat flour pasteurised in a pillowcase in 65° to 75° water for 2 h	21 days in growing bag, 26 days in mould	Air-drying	Result The lampshade holds together but is very brittle.	The brittleness of the lampshade is likely due to the low density of the substrate used. The saw dust mostly contained wood shavings, creating a low density substrate. **If more dense saw dust would have been used, the lamp would have probably turned out stronger.**
_	_	_	Grew together partly. Mould started growing, experiment discontinued	The distance of the crack between the two parts was probably too large. The growing box had to be opened to be photographed and this likely caused **contamination** that forced the experiment to stop. **However, it was clear that the mycelium were able to self-heal**
_	_	_	Nothing happened	**Dried hibernated mycelium cannot be reactivated by only water spray**
_	_	_	Mould started growing, experiment discontinued	The sample got mould on the surface, but not inside the brick. The water was probably not entering the middle of the sample. Even though my experiments **didnt show reactivation**, litterature shows that it is possible (Appels 2019)
Pellets and wheat flour pasteurised in a pillowcase in 65° to 75° water for 2 h	25 days i growing box	Air-drying while hanging	Uneven filling of tube, uneven growth, lumps when dried	The sample grew while curled up in a box and was hung in the parabola shape when dried. **The angle change was too big** and this broke up the mycelium material that dried into lumps. The uneven spread and growth is due to the **dificulty filling the tube by hand**. Some sort of filling tool would be beneficial to use.
Sawdust and wheat flour pasteurised in a pillowcase in 65° to 75° water for 2 h	_	_	Very limited growth	The growing box was sprayed with very much alcohol to sanitise it. This alcohol was not aloowed to air out before the sample was placed. **This overly use of sanitiser could lead to a hostile environment for the fungus, and cause the limited growth.**

Birth

The site is a non-specified south-facing sloping hill area in southern Sweden. The building is designed to be dug into the ground, using the embedding strategy described by Hönger & Brunner (2013). This will make use of ground temperature regulation, creating warming effects in winter and cooling in summer.

The flooring on the first floor will be stomped clay, which is prepared before the house is in place. The next step is to rise the greenhouse, which will shelter the building during its growth and life.

The result from the experiments shows promising results for cardboard waffle design for designing and casting complex shapes. The CNC-knife fabrication method enables the structure to be designed parametrically. As the mould becomes a part of the structure, external moulds can be minimised. Cardboard waffle internal scaffolding has also been tried in literature, where an arch constructed could support the weight of a person (Dessi-Olive, 2022b).

The thesis suggests a two-level building. The waffle cardboard waffle strategy is utilised in the ceiling slabs. They are using catenary arches to make the load-bearing mycelium ceiling slab work in a compression-only way. The way of using cardboard waffle as an internal scaffold is a way of making sure the mycelium will grow in its designed shape. After some time, the organic scaffold will be consumed by the fungi and fuse with the shape, effectively turning the slab into a monolithic element. However, due to the cellular division during the initial sensitive growing phase, single cells can be exchanged if showing signs of contamination. To reduce the thickness of the ceiling slab between levels, the arches must be rather flat. This leads to the forces at the column pointing outwards. To combat this, external buttresses or internal tension band must be installed. To simplify the construction, tension bands are chosen. They consist of hemp rope fastened with a winch system on wooden corner pieces.

To hold the substrate in place, natural fibre textile is fastened to the cardboard waffle structure. As the mycelium fills up the cells, the textile will be gravitationally shaped, creating a pillow-like appearance in every square. The mycelium will grow through the textile creating a white layer.

Another strategy that is implemented in the design is myco-welding which is used for columns and walls. As there is a biological limit of the thickness of mycelium elements due to lack of oxygen, myco-welding is a way of constructing larger elements. The columns and walls are made with myco-welding together large mycelium blocks, grown in reusable moulds. They are angled, to be able to support outward forces not eliminated by the tension bands. The walls are thick and able to insulate the building well.
The walls in between the columns are constructed in a similar way as the columns, through mycowelding. Windows are placed in the non-load-bearing walls in between columns. The holes for windows can be planned before growing the walls, but holes can also be cut out

of the wall, using subtractive form-finding. The wound of the cut can be self-healed through the migrating mycelium biomass that creates a skin on the cut.

The structural system, the ceiling slabs and the columns, are using saw-dust substrate to yield the strongest load-bearing properties. The walls in between the columns are taking less weight and can use other types of substrates to get more embedded air. This will make them a better insulator.

Fig. 25. Mycelium growth on cardboard waffle (Lab 4.)

Site

1. Dig a hole in a south sloping hill

2. Prepare the floor of the building by removing organic matter

3. Raise the greenhouse on top, covering the hole.

4. Add gravel and clay in layers to create a rammed earth floor where the house inside the greenhouse is supposed to be. Prepare tubes for floor heating in the clay floor.

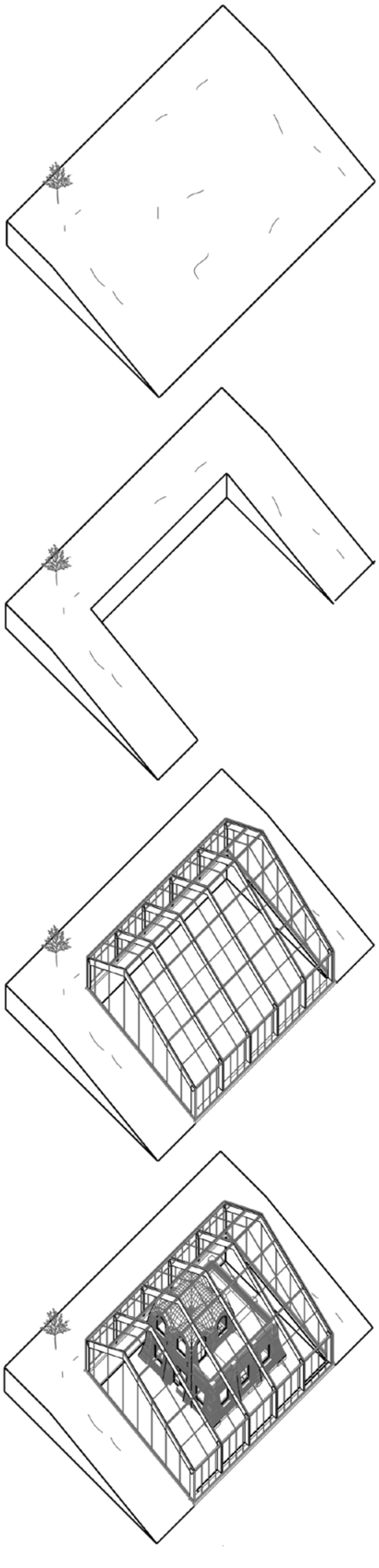


Fig. 26. Process of preparing the site and constructing the building

Flooring/ceiling

1. Use left-over cardboard for waffle mould. CNC knife cut the cardboard into shapes calculated from cumputational tools.

2. Add pieces of cardoard together using bio-based adhesive to form 3,8 m long carboard pieces.

3. Add the pieces together to a waffle structure.

4. Fasten fabric on the bottom side of the waffle by sewing.

5. Add the cornerpieces made of wood and tension the hemp rope in between them with the winch.

6. Fill each cell with active mycelium composite, grown on sawdust substrate. Pack as densely as possible.

7. Place in a plastic growing chamber/growing tent equiped with air filtered ventilation and humidifier.

8. Let grow for ca 30 days.

9. Take out from the incubator and let dry using a construction fan.

10. Mount on the columns. Add flooring on top.

Columns

11. Build reusable 170 mm deep moulds with a non-organic inside cover.

12. Add sawdust substrate mycelium composite up to 150 mm and cover with plastic film with air-holes. Calculate for the loss of volume of the mycelium when dried.

13. Dry the mycelium using a construction fan.

14. Use mycowelding to grow the slabs together. When fused, use a construction fan to dry the columns out.

15. Place columns on flat natural stones.

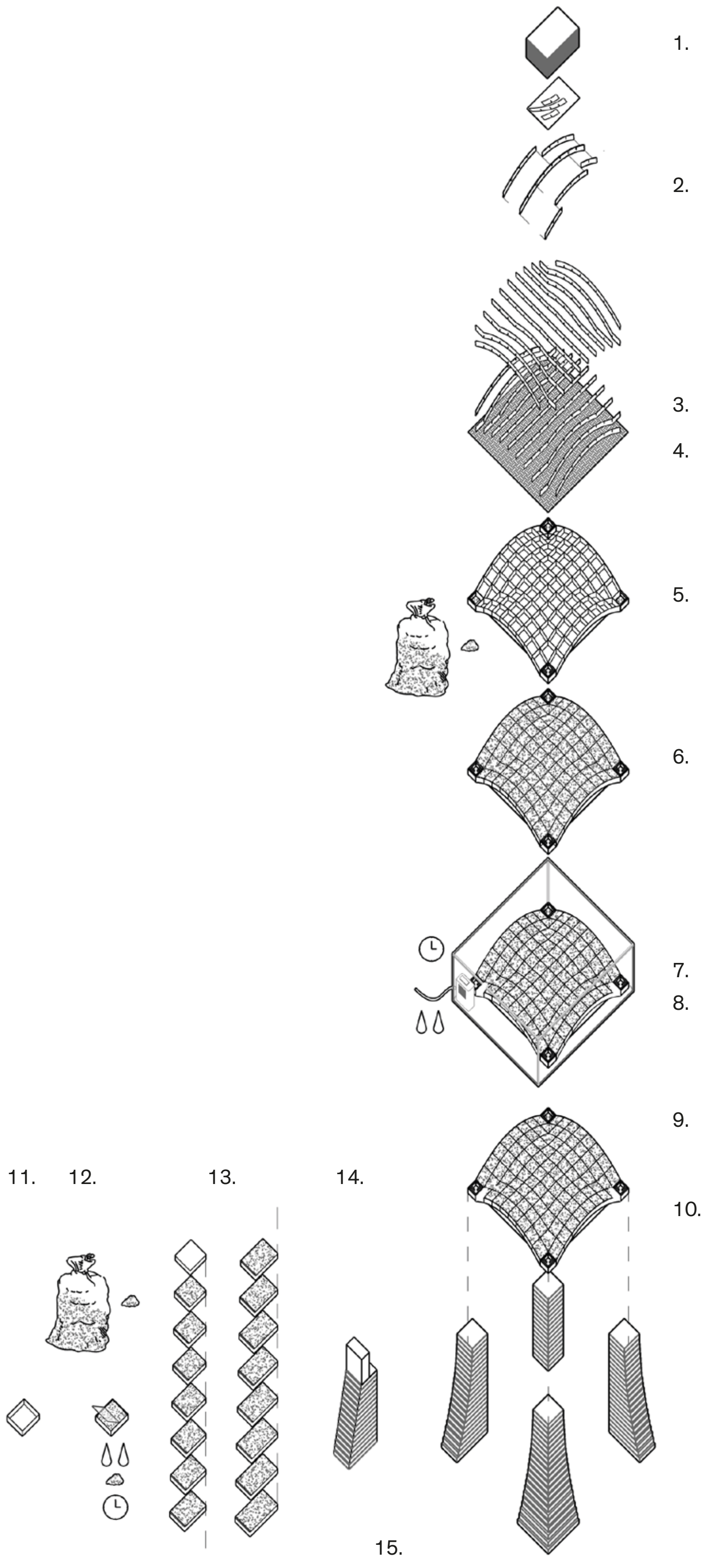


Fig. 27. Process of cultivating the constructive system: ceiling slabs and columns

Walls

1. Build reusable 170 mm deep moulds with a non-organic inside cover.

2. Add mycelium composite with straw substrate up to 150 mm and cover with plastic film with air-holes. Calculate for the loss of volume of the mycelium when dried.

3. Dry the mycelium using a construction fan

4. Use mycowelding to grow the slabs together. Shape to desired shape by saw. When fused, use a construction fan to dry the columns out.

5. Use active mycelium to fasten the window in place.

6. Dry the wall with construction fan.

Fixed furniture / composite boards

7. Build reusable 100 mm deep moulds with a non-organic inside cover.

8. Add mycelium composite with saw dust substrate. Cover with plastic film with air-holes

9. Heat-press the mycelium into ca 30 mm thick boards.

10. Build kitchen/shelves with the boards

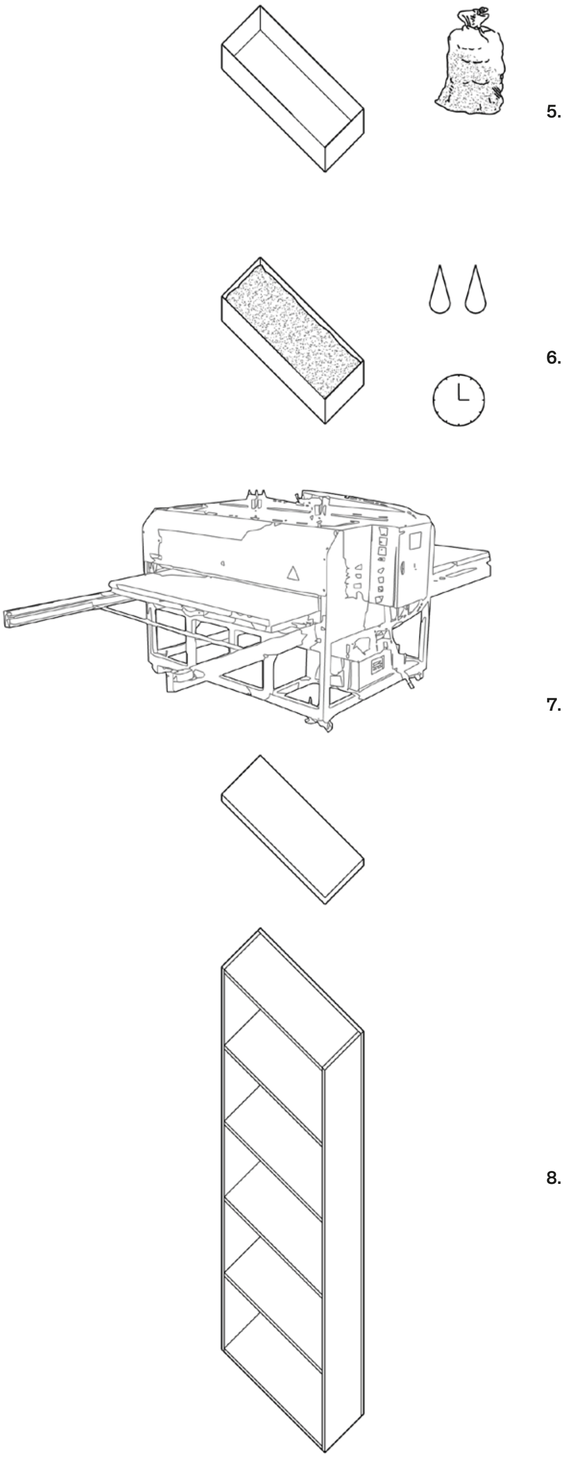


Fig. 28. Process of cultivating and heat-pressing mycelium for furniture

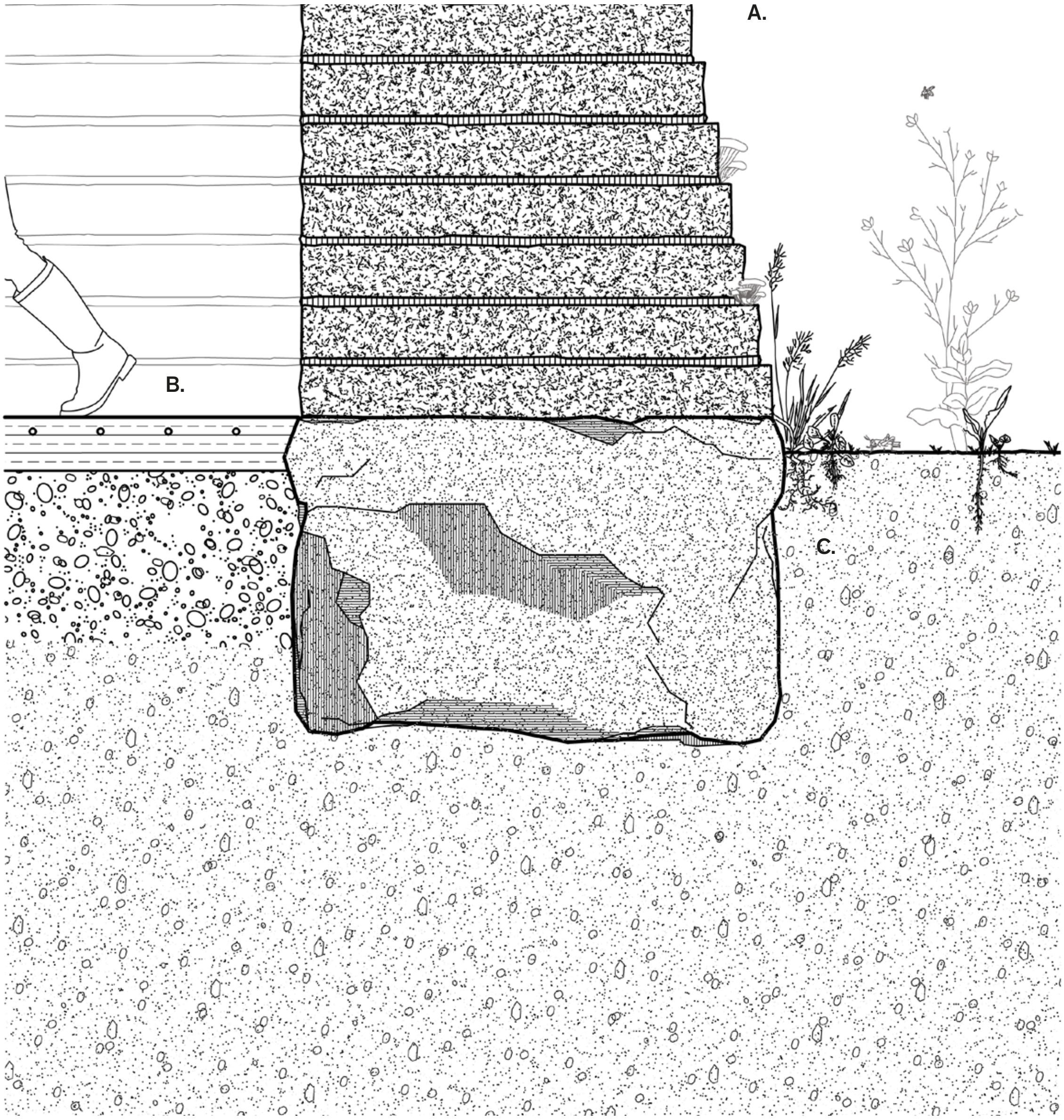


Fig. 29. Detail of meeting with ground
1:20

A.	700-1300 mycowelded mycelium column on sawdust substrate
B.	500-300 gravel 3 × 50 rammed earth floor Water pipe floor heating Wax
C.	Stone

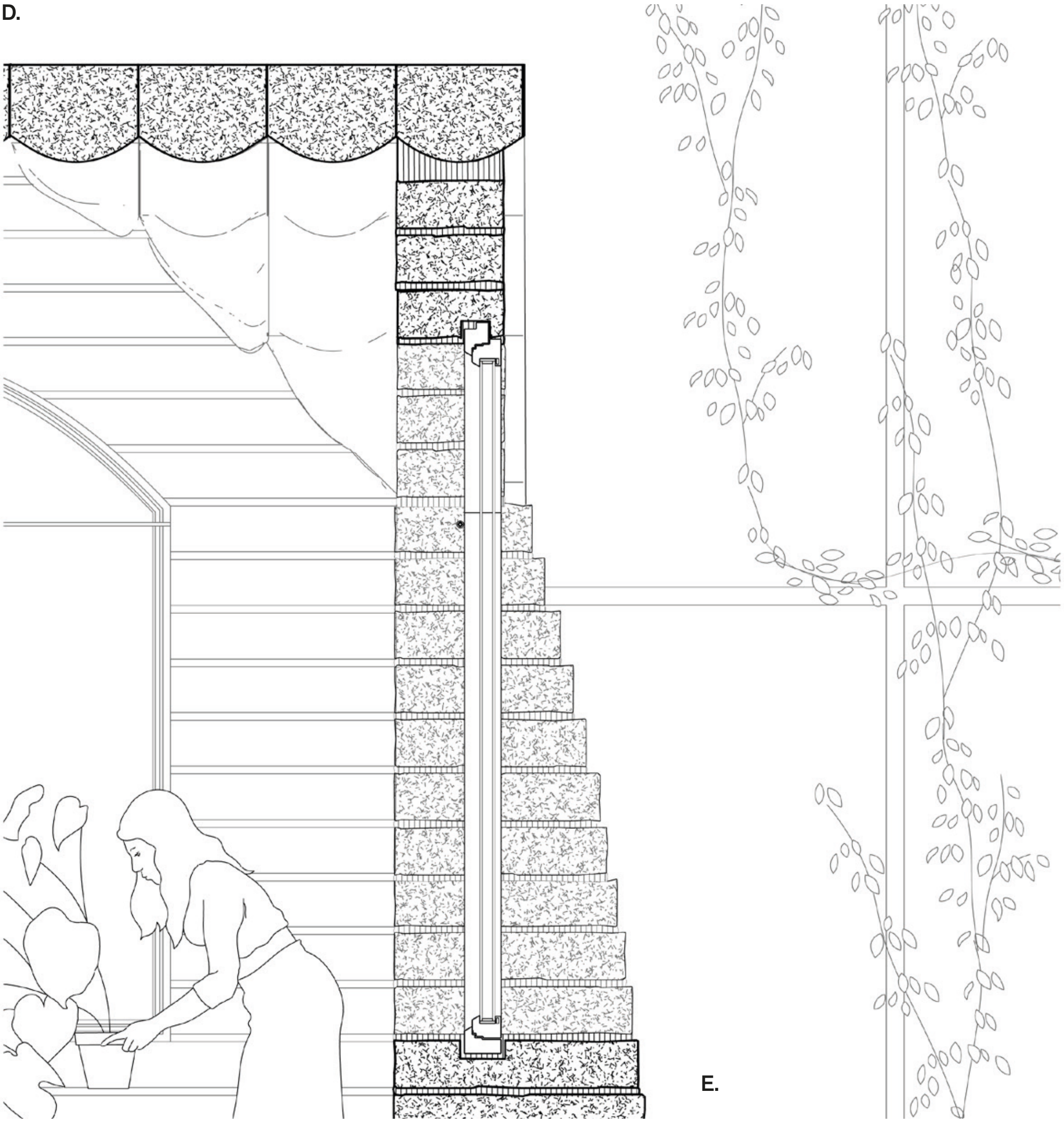


Fig. 30. Detail of wall section and meeting with roof, second floor
1:20

D. 150 cardboard waffle mycelium ceiling slab on sawdust substrate
E. 700-300 mycowelded mycelium wall on straw substrate

Life

The base of the design comes from the prototype (lab. 10). The mycelium building is a 9 square building based on modules of 3,6 × 3,6 m. There is also a second floor, consisting of four modules. Here, another bedroom is found as well as a large terrace facing the south with connections to the garden. These measurements allow for flexible rooms adapted for accessibility. The design is divided into a private part with two bedrooms and the toilet to the north and a more public part to the south, facing the garden. The shower is placed on the outside of the mycelium building inside the greenhouse, to help protect the mycelium construction from water.

If needed, the building can grow, adding more modules to the structure. These can be grown *in situ* on the initial building.

The life of the building uses and borrows from biological systems. These systems have been developing and working for millions of years, shaped by the slow course of evolution. Using the same logics for a building will ensure energy and material efficiency and can reduce the need human maintenance. These systems will in many ways be self-supported and not connected to the grid. The off the loop-systems and the sheltering greenhouse is parts of the nature house concept. In the life of the building, the human inhabitants are reduced to a part of the system. The life of the building should put as much respect and care for the other organisms it hosts.

The greenhouse garden supports the cultivation of various fruits and vegetables. The ground heat as well as the surplus heat from the bio-thermal heating system will warm the greenhouse in winters, making sure it rarely drops beneath 3 degrees. At the same time, the ground temperature regulation will cool the building on hot summer days. The even temperature ensures the well-being of the mycelium walls and mycelium growth but also supports the cultivation of many fruits and vegetables in the greenhouse.

The human inhabitants can grow their own food and the residues can be turned into mycelium material that can become furniture or provide mushrooms. If the house needs to grow or shrink, more modules can be added to the construction. These can also be cultivated from the organic residues. The residues can also together with black and grey water support the biothermal heating plant. This compost-based system will in the next step support the plantings with nutrients, creating a metabolic closed loop within the building. A pond is added to the garden, providing a hydroponic system. This uses the nutrient exchange between plants and the fish, potentially increasing the yield

A more detailed description and a comparison between different biological systems and the systems in the building follows.

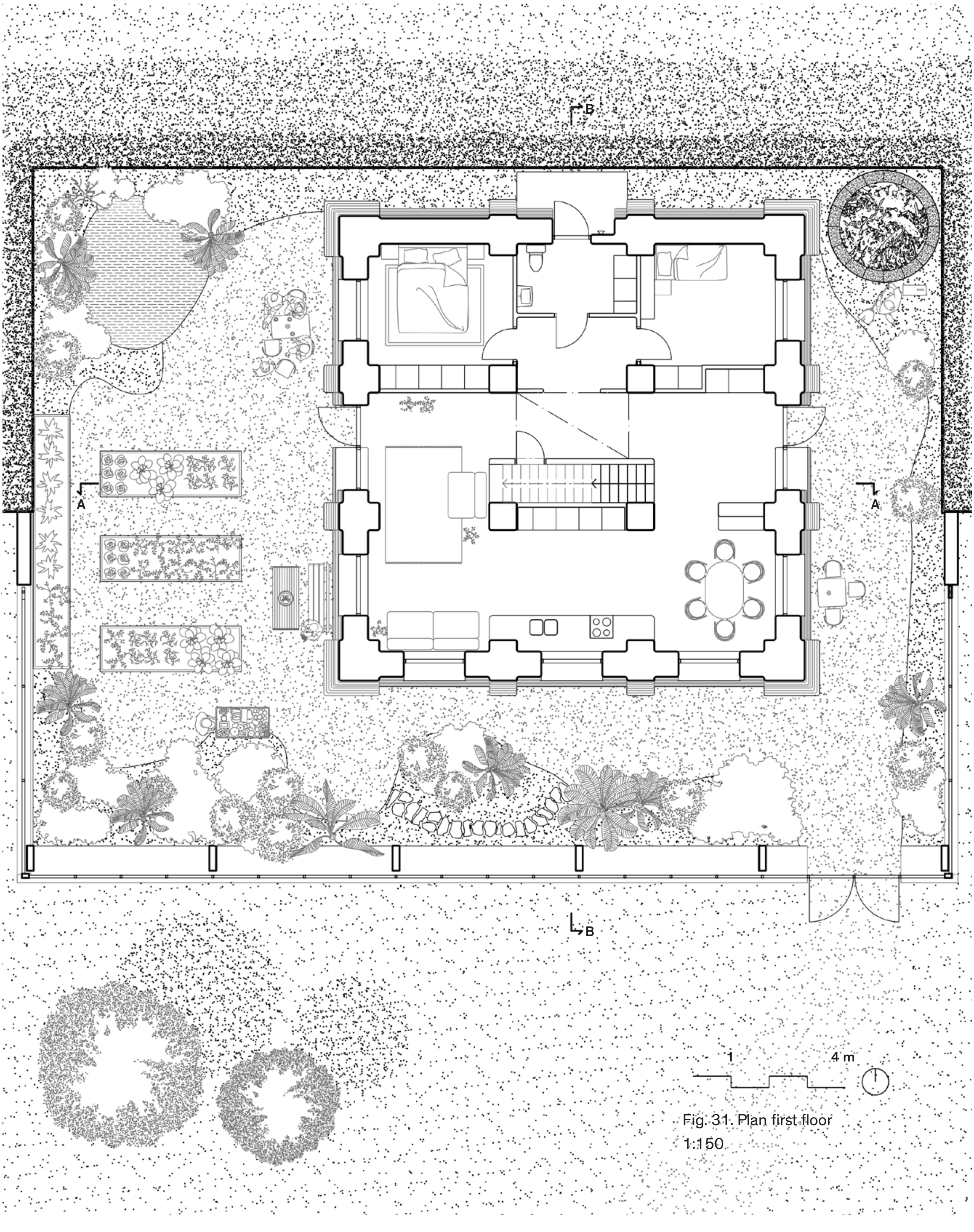


Fig. 31. Plan first floor
1:150

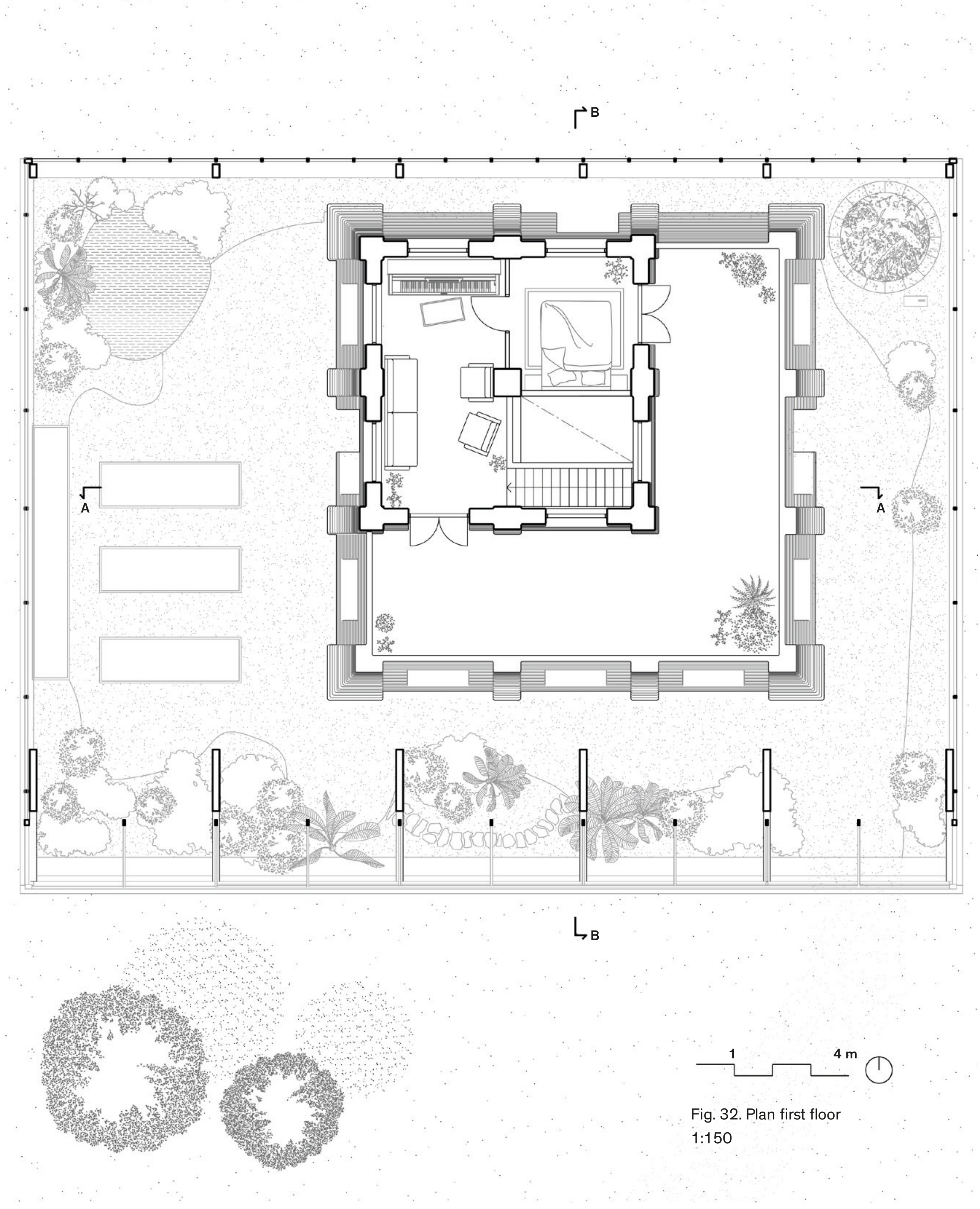
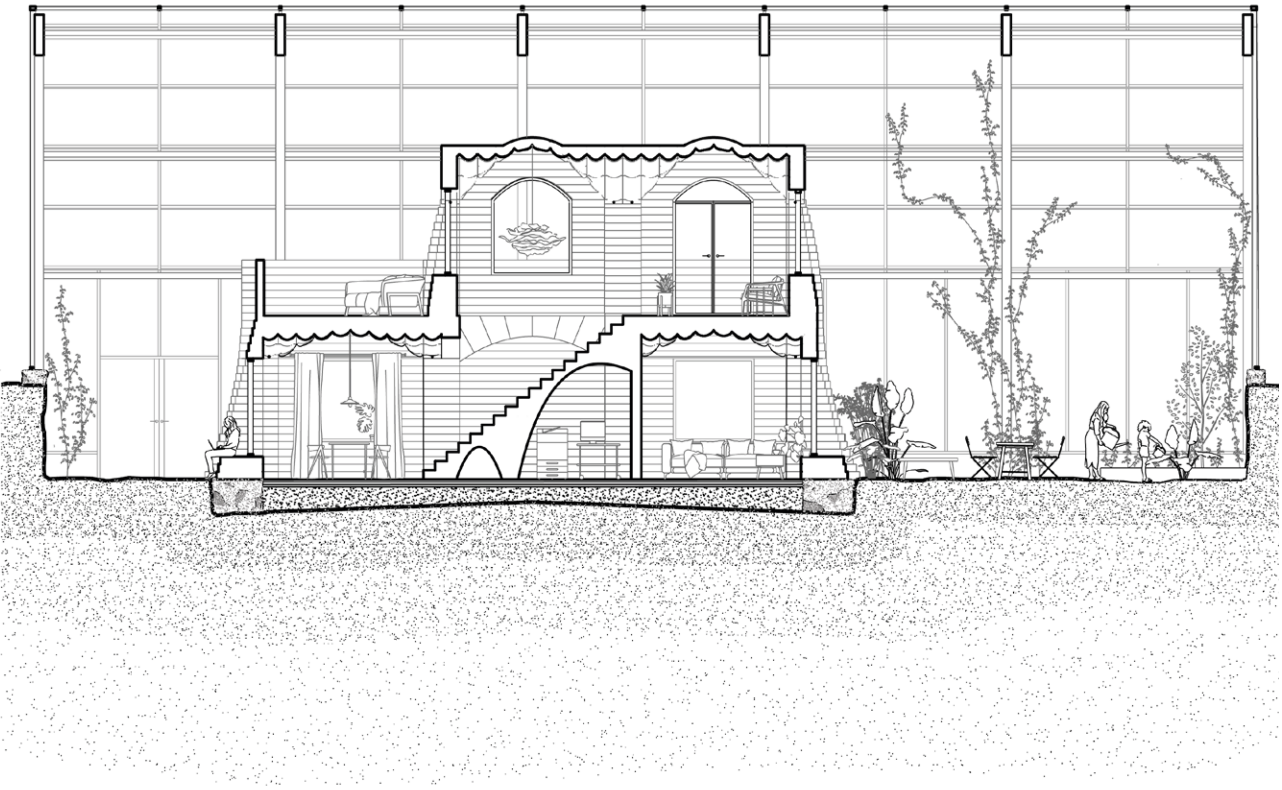


Fig. 32. Plan first floor
1:150



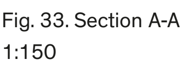
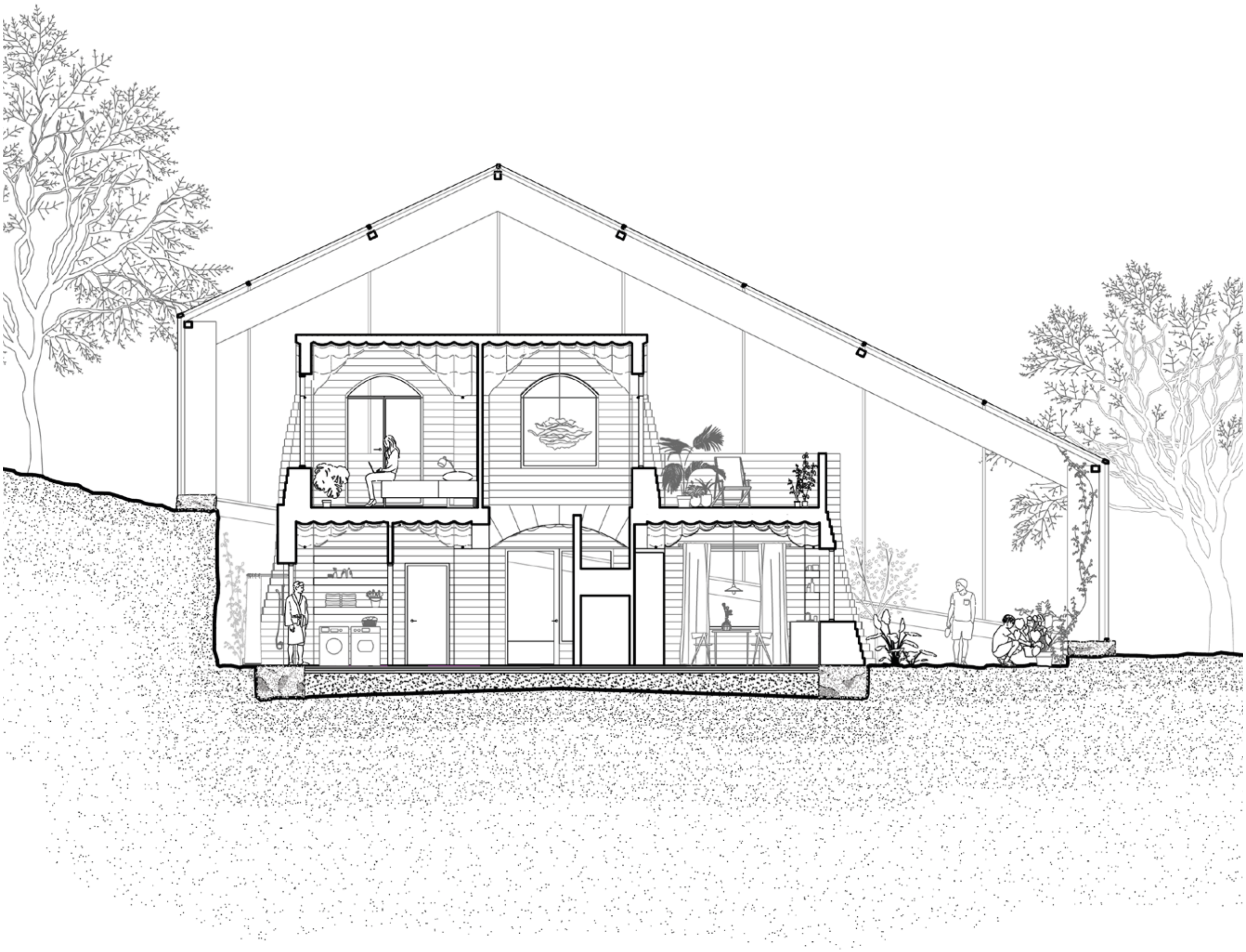


Fig. 33. Section A-A
1:150



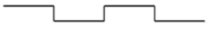


Fig. 34. Section B-B
1:150

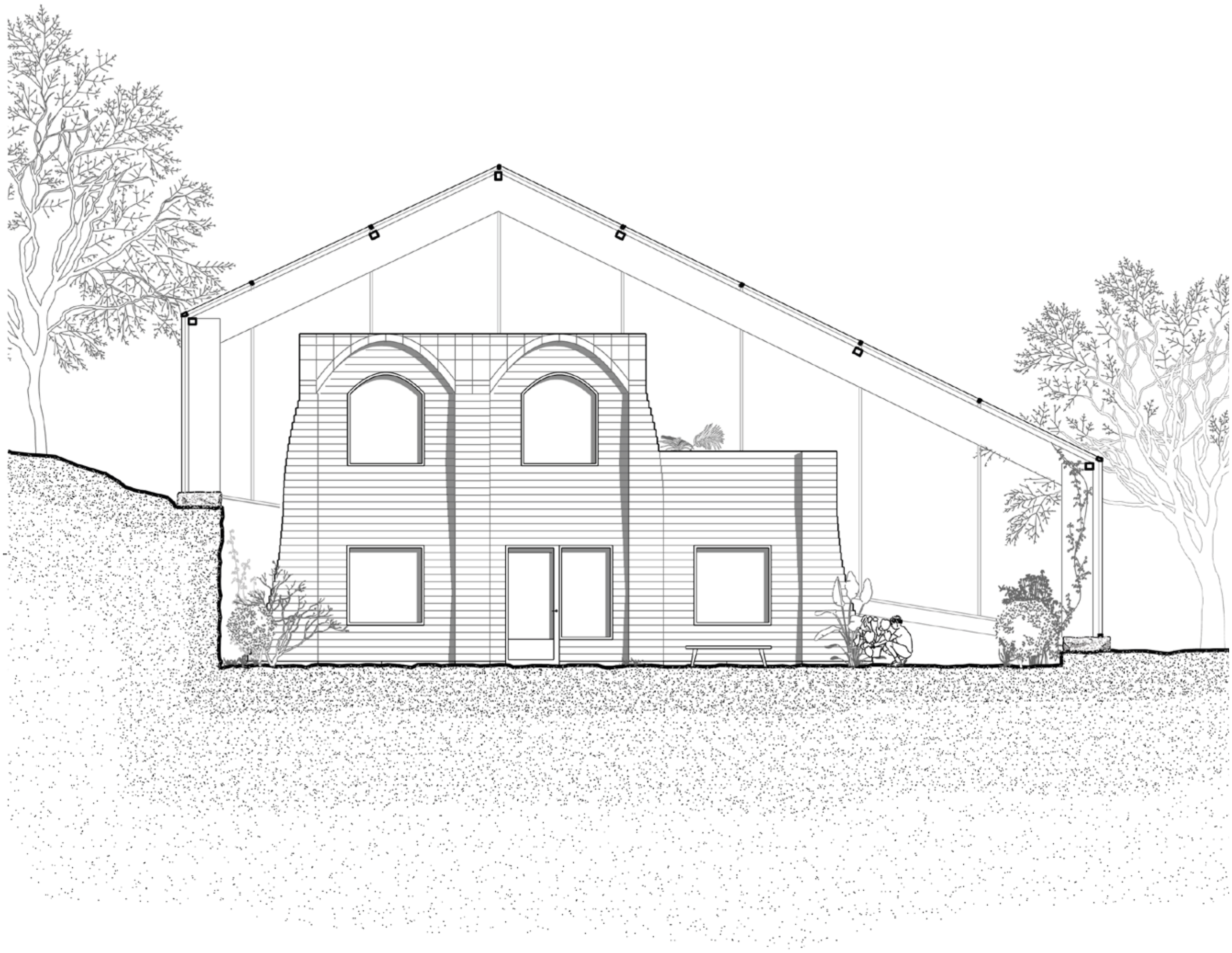
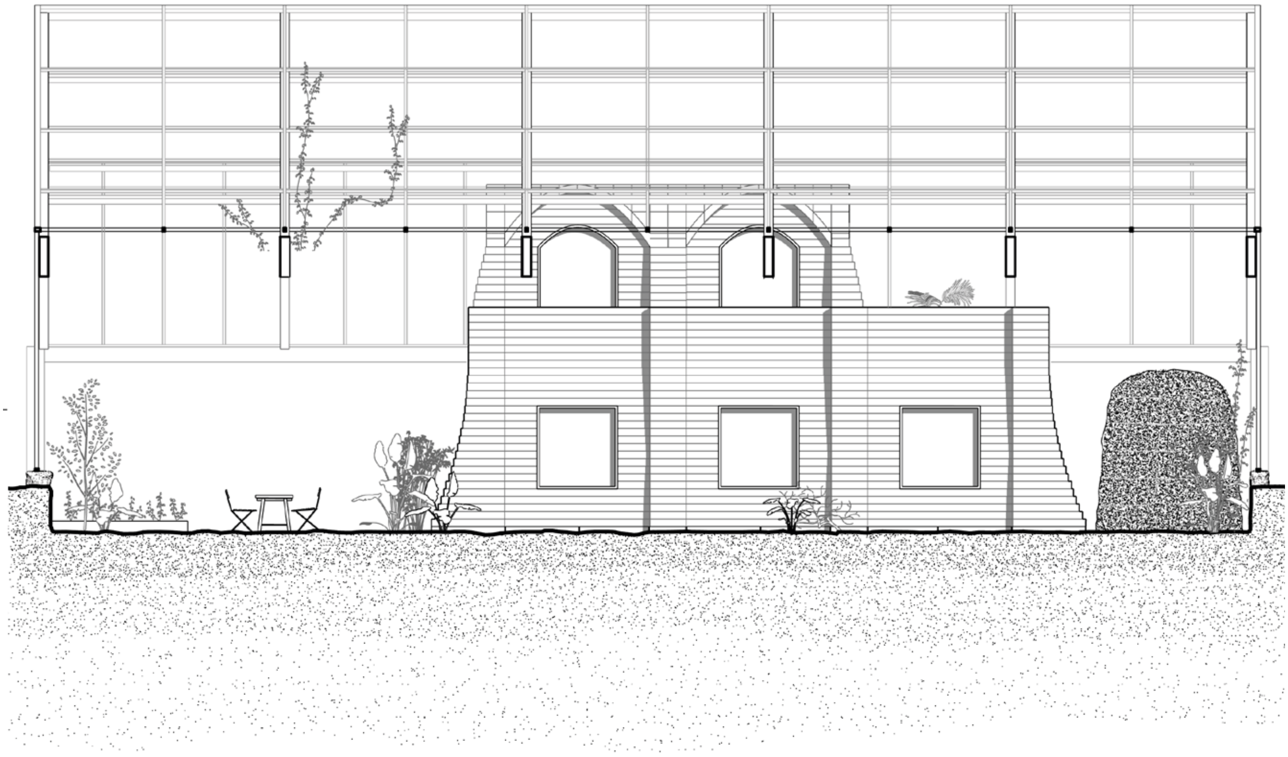


Fig. 35. Façade to the west
1:150



1 4 m

Fig. 36. Façade to the south
1:150

Fig. 37. View from living room towards the kitchen, first floor

A.	Cardboard and textile mycelium ceiling slabs
B.	Mycowelded mycelium columns
C.	Heat-pressed and waxed kitchen worktop

Skeleton

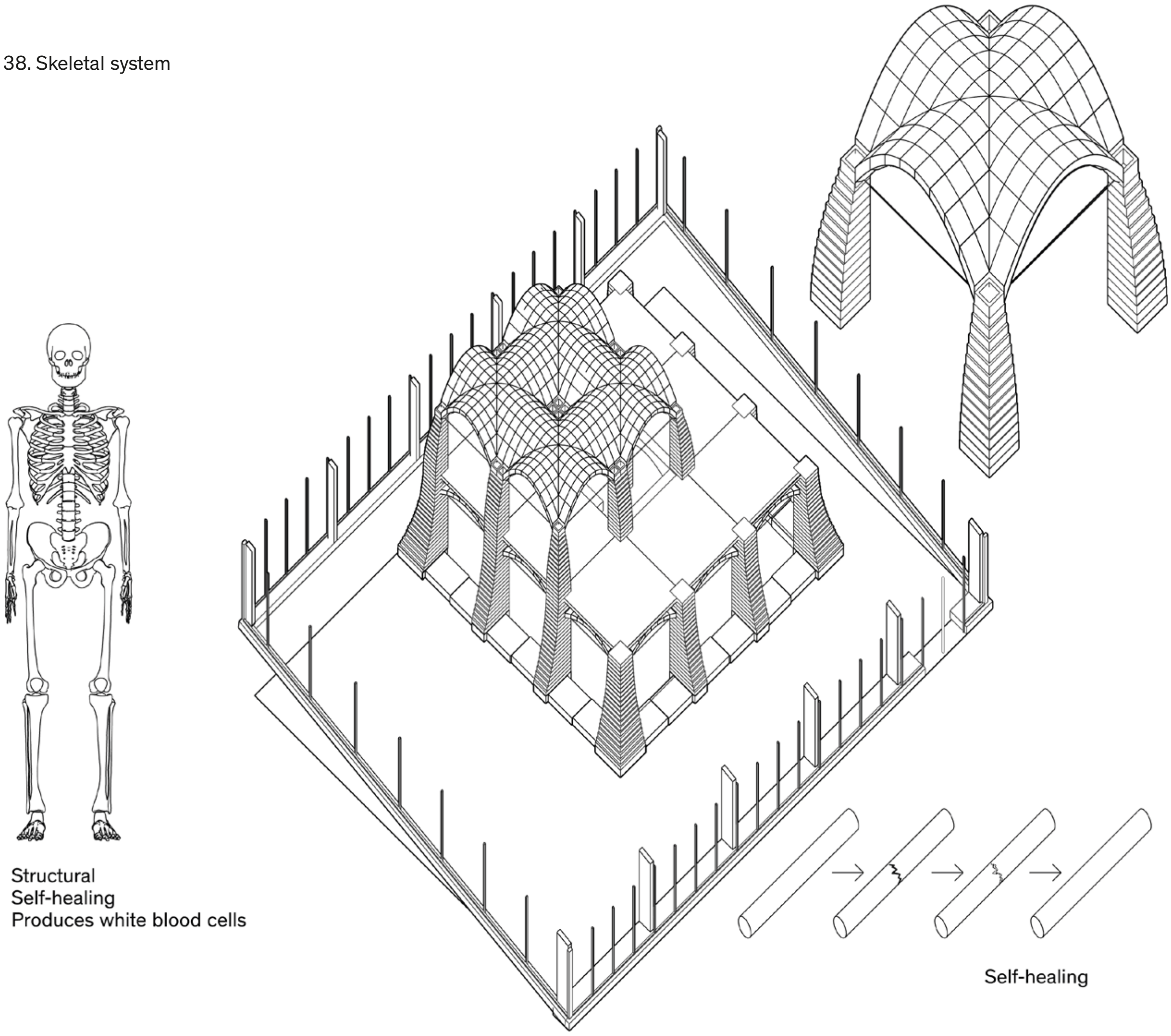
In biology:

In vertebrates, the internal skeleton supports the body and carries the load. It also enables movement and protects internal organs. If wounded, the skeleton can self-heal and grow back together (Betts et al., 2022).

In the building:

The fungal skeleton of the house carries the loads of the building. The mycelium will be air-dried at low temperatures to make the mycelium enter hibernation and become semi-active. This makes it possible for the material to self-heal.

Fig. 38. Skeletal system



Skin

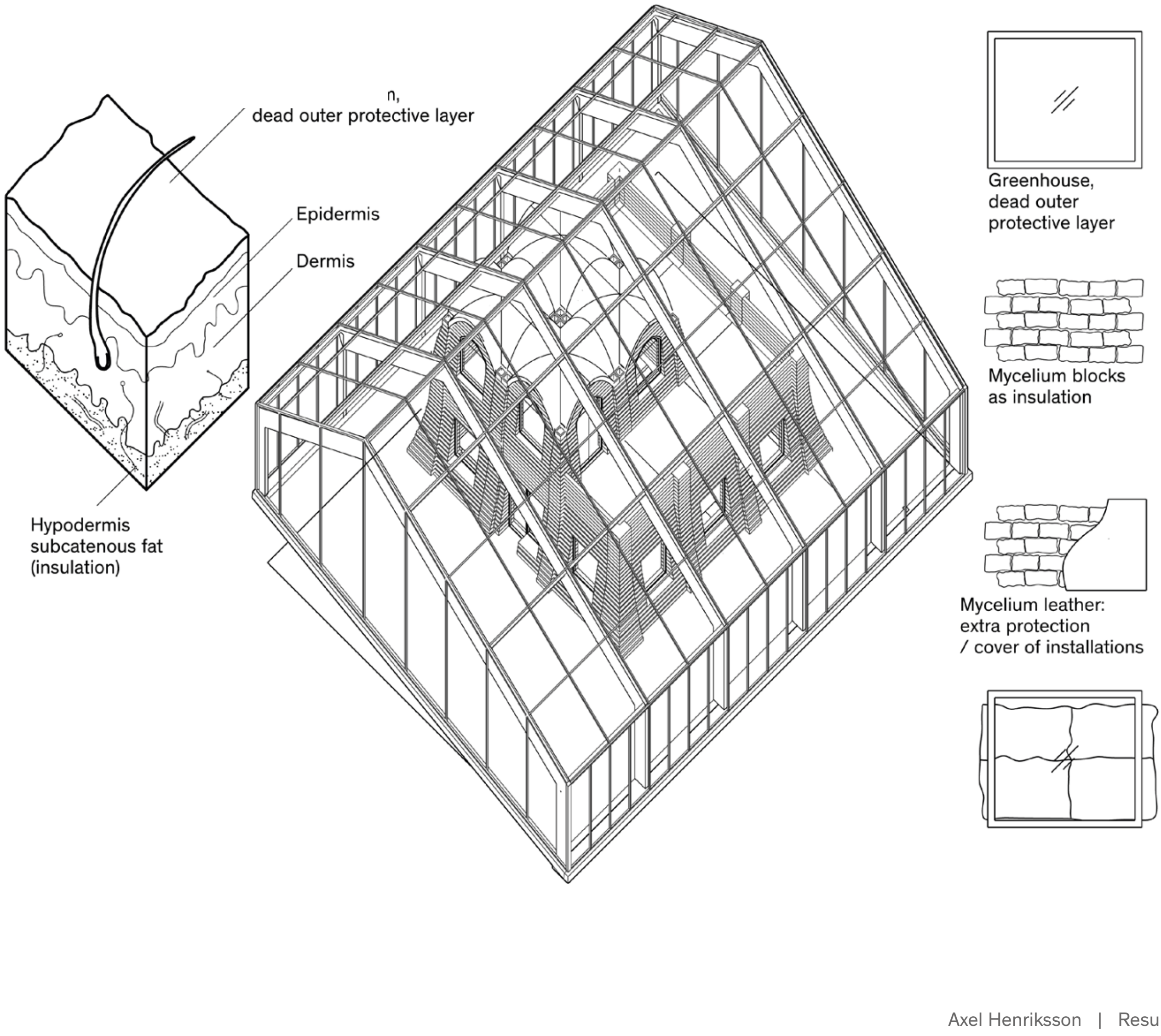
In biology:

The *stratum corneum* is the outermost layer in the epidermis of the skin and consists of dead cells that regularly slough away. It is a protective layer exposed to the outside environment. The dermis adds more protection. Part of it is the papillary layer that contains cells that help fight bacterial infections. The hypodermis further in stores fat that provides cushioning and insulation (Betts et al., 2022).

In the building:

The greenhouse glass functions like the *stratum corneum,* an outer dead and protective layer. Inside, a layer of semi-active mycelium functions like the dermis and hypodermis. The semi-active mycelium helps mitigate mould infections, and the thick mycelium walls insulate the building efficiently.

Fig. 39. Growth



Metabolism

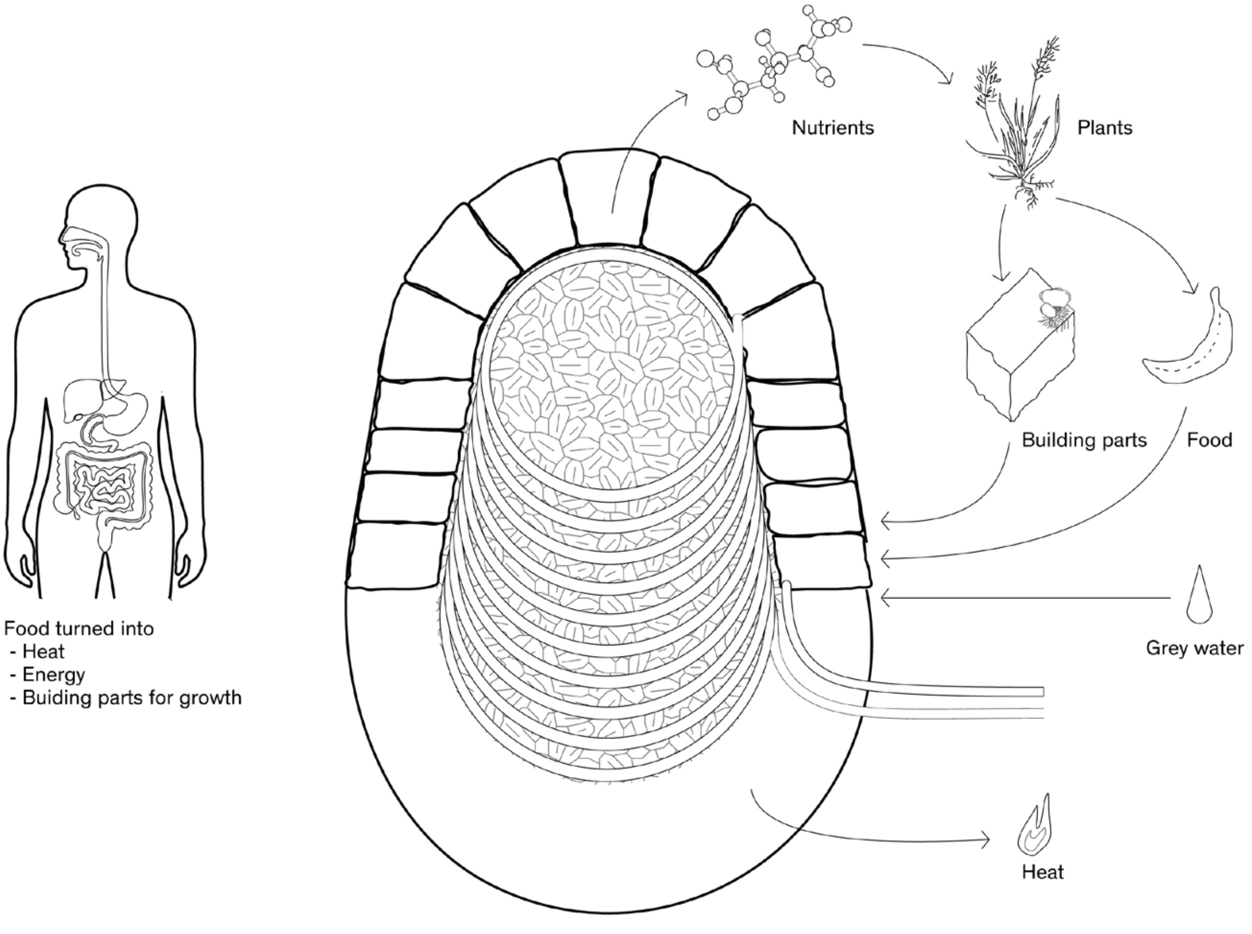
In biology:

Metabolism includes the breakdown of food into smaller molecules, collecting the energy released from molecular bonds. This energy is used by the organisms for heat and processes. The molecules are used to build up the organism. Plants use anabolic (biosynthesis) reactions, combining smaller molecules into larger, with the energy of the sun. This enables circularity within the ecosystems (Betts et al., 2022).

Fig. 40. Metabolic system

In the building:

This system is mimicked in the building. Waste and residues from plants grown in the greenhouse as well as from human inhabitants are allowed to decompose by microorganisms in a bio-thermal heating plant, emitting heat in the process. Water pipes carry the heat to the inside of the internal mycelium building, while the surplus heat regulates the heat in the greenhouse. The outcome of the process is also compost with good nutritional value. This is used to plant new plants that can support inhabitants with new food. The residues from the plants can also be cultivated with mycelium and enable the building to grow new parts.



Growth

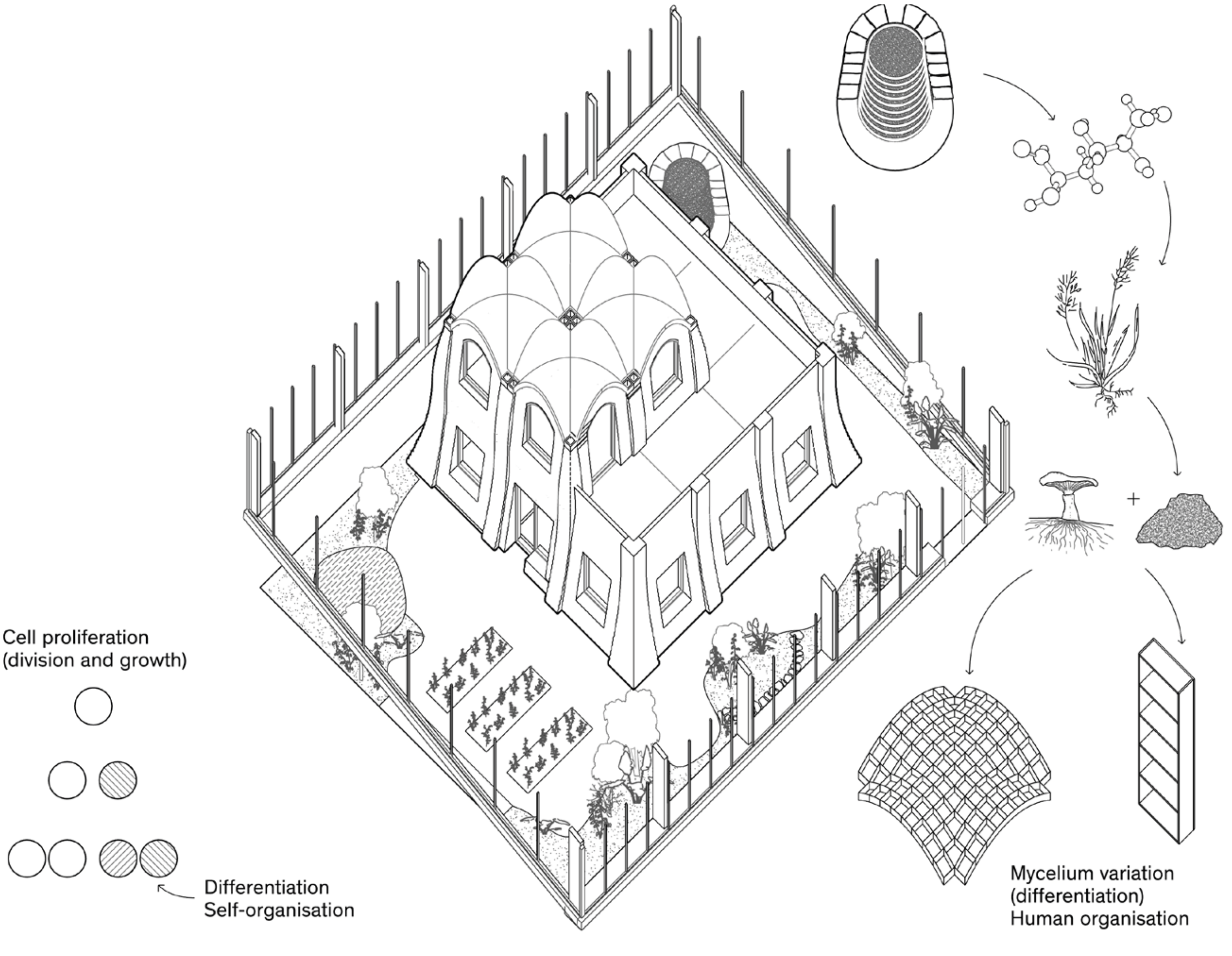
In biology:

Growth in multicellular organisms happen through cell division and the different stages of mitosis. As we all start from one single cell, cellular differentiation is a key in multicellular organisms. Stem cells are unspecialised cells that can turn into any specialised cells, changing its function, size, and shape in the process. Growth in biology happens automatically and is sourced from metabolic processes from within the organism (Betts et al., 2022).

In the building:

In the building, the fungi mirror the stem cells and their cellular differentiation. As mycelium can be very varied, dependant on which substrate, geometry and post-growing process is used, it can be grown to do many different things. Both a big ceiling slab and a mycelium leather curtain can be grown from the same fungal strand.

Fig. 41. Growth



Immune system

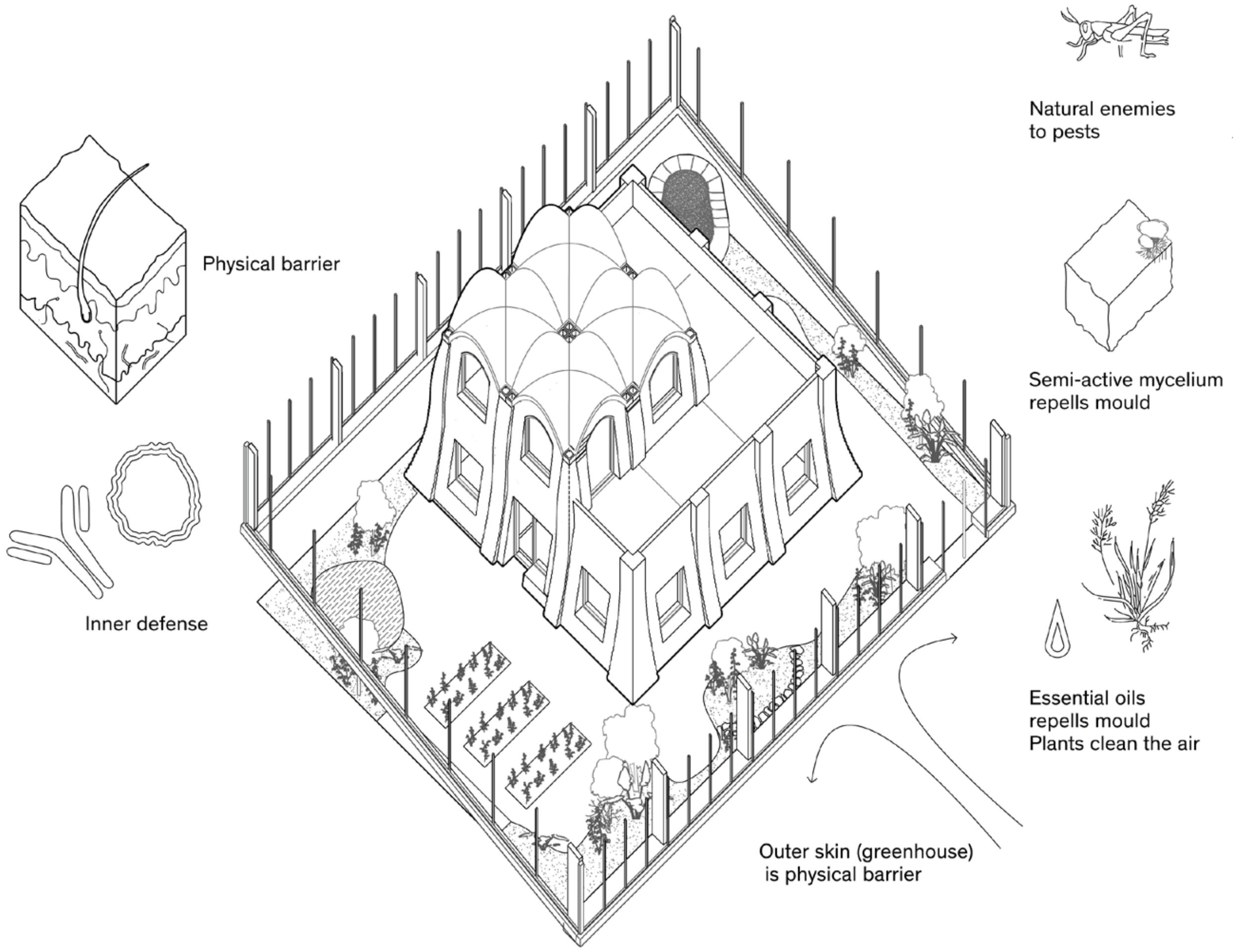
In biology:

Our immune system consists of both cells and organs that protects us from infections and pathogens. A part of the system is the barrier defences such as our skin, that provides a physical hindrance for pathogens. If the pathogens would enter anyway, cells and some proteins provide an internal defence (Betts et al., 2022).

In the building:

The outer greenhouse skin of the building provides a barrier for macroorganisms that could damage a mycelium building. Inside, plants can provide essential oils that could be a way of mitigating mould on the building. The semi-active mycelium could also stop mould. Natural enemies to harmful organisms can also be introduced as an inner defence. One example is green lacewings that hunt different types of lice.

Fig. 42. Immune system



Blood

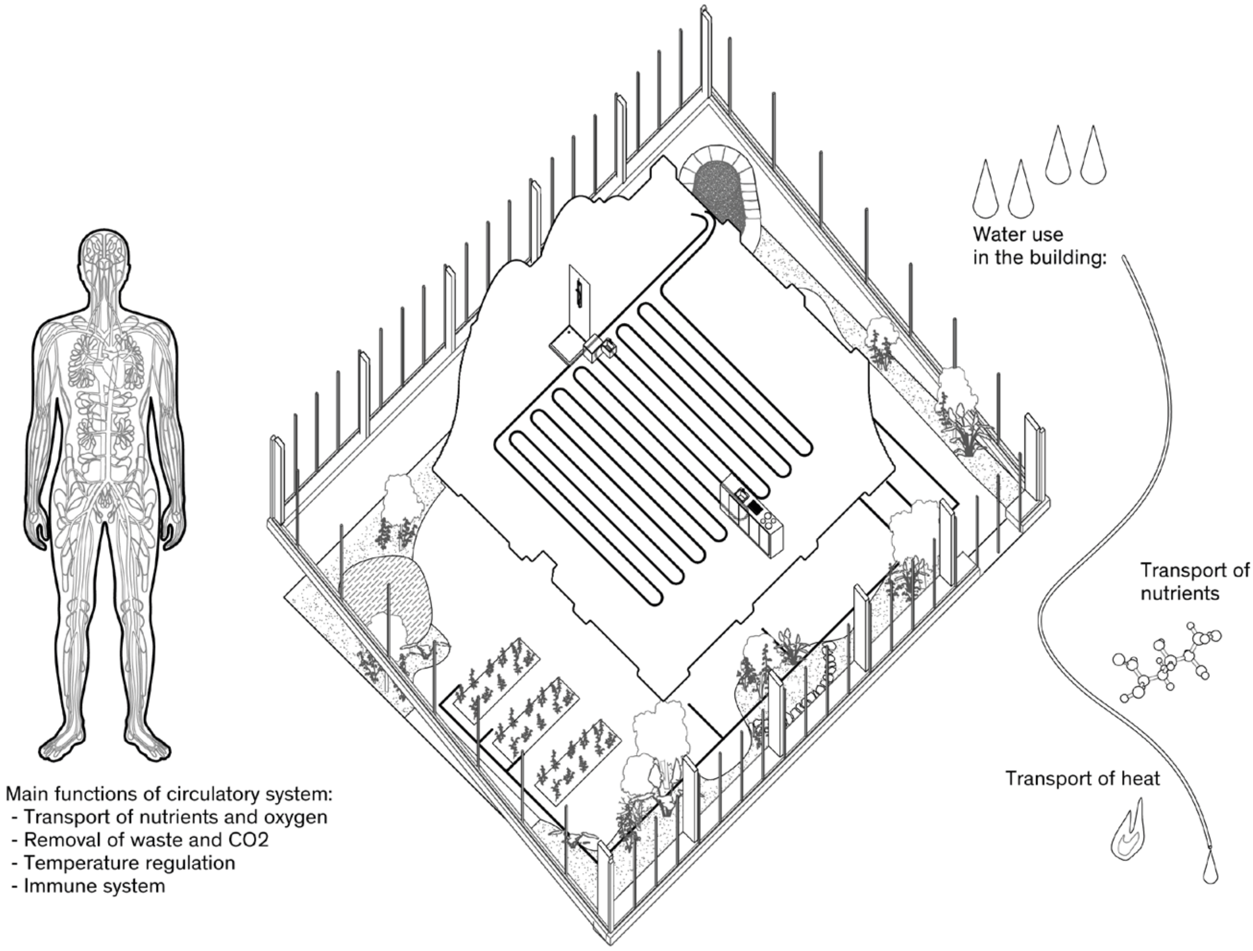
In biology:

The main functions of the blood are transportation, defence, and distribution of heat. The blood transports oxygen and nutrients to the cells and waste products away from them (Betts et al., 2022).

In the building:

In the building, water acts as the blood. It redistributes the heat from biothermal heater to the inside of the building through pipes underground. This system heats the mycelium internal building to be warmer than the outside. The water can also carry nutrients from the compost to the plantings.

Fig. 43. Blood system



Brain/nervous system

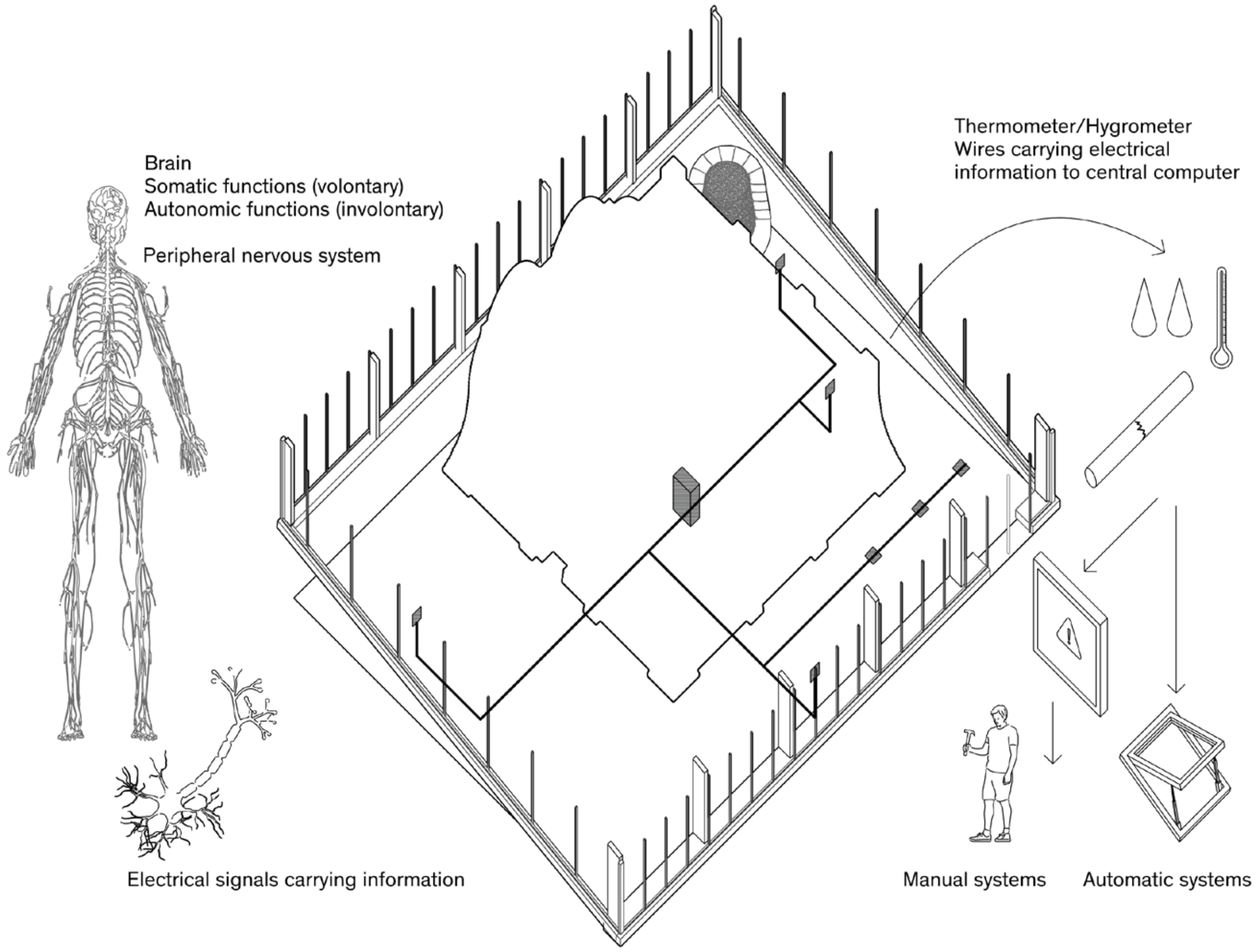
In biology:

The brain and the nervous system controls most of the processes inside of us. The system consists of somatic (voluntary) and autonomic (involuntary) functions. The somatic system has the responsibility of our muscular movement and how we perceive our environment. The autonomic system includes automatic processes such as controlling the heart and smooth muscle of our digestive systems.

In the building:

In the building, some processes will be automated. Hygrometers and thermometers can read of air moisture and temperature, send information through electrical impulses to a central computer and automated processes can take actions. For example, if the sun shines too bright, curtains can be automatically be pulled down. Other processes might need to be mechanically solved. The sensors can detect that the plantation needs watering, and then send a notification to human inhabitants that can carry out the mechanical work.

Fig. 44. Nervous system



Lungs

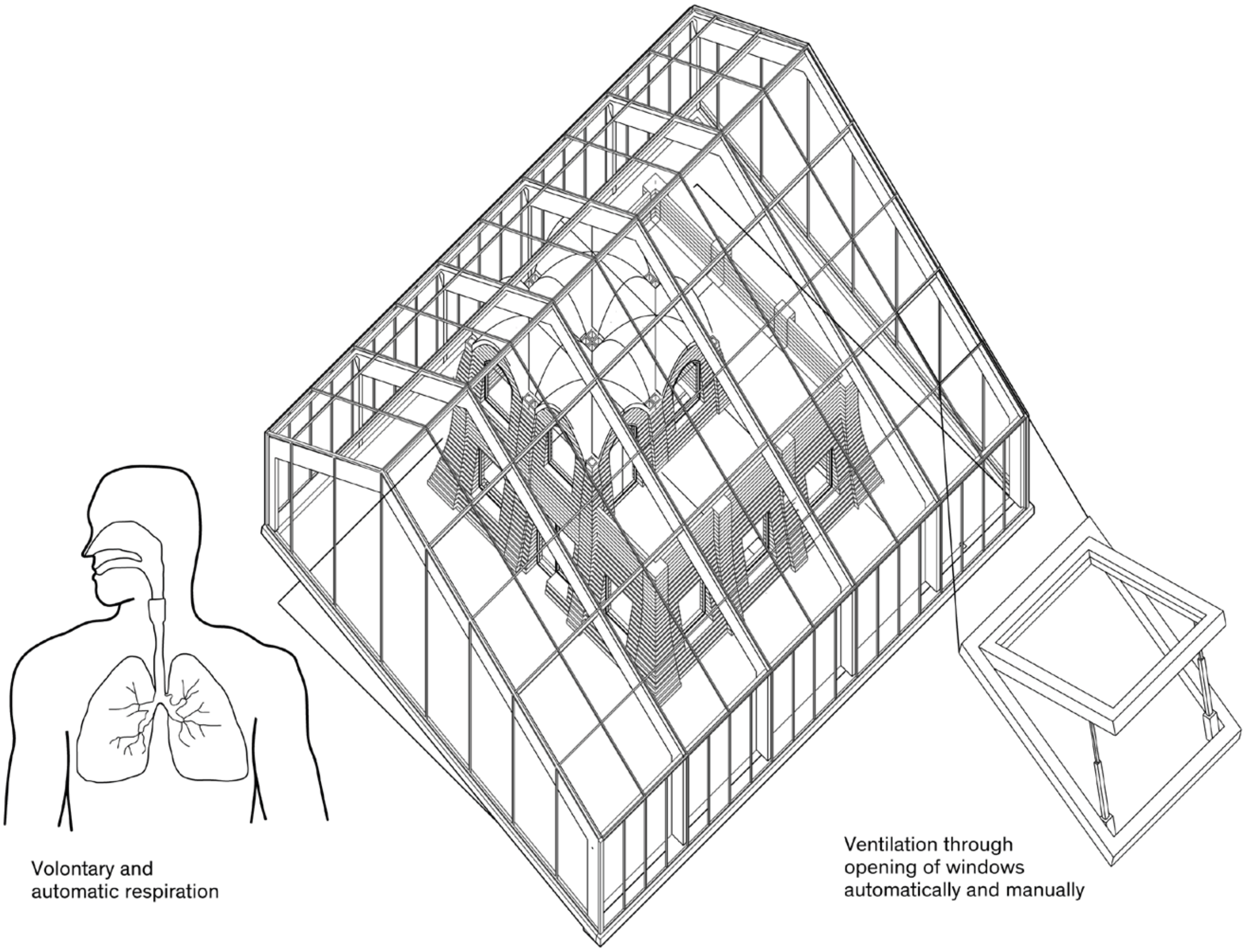
In biology:

Our respiratory system provides our cells with oxygen and releases carbon dioxide. The oxygen is needed to run cellular respiration. We can control our breathing, but it happens also without us thinking about it (Betts et al., 2022).

In the building:

Ventilation is the lungs of the building. The ventilation can happen automatically, controlled by the sensors and the central computer system, but it can also be carried out by the human inhabitants if they want. That type of ventilation can be opening doors or windows.

Fig. 45. Respiratory system



Muscles

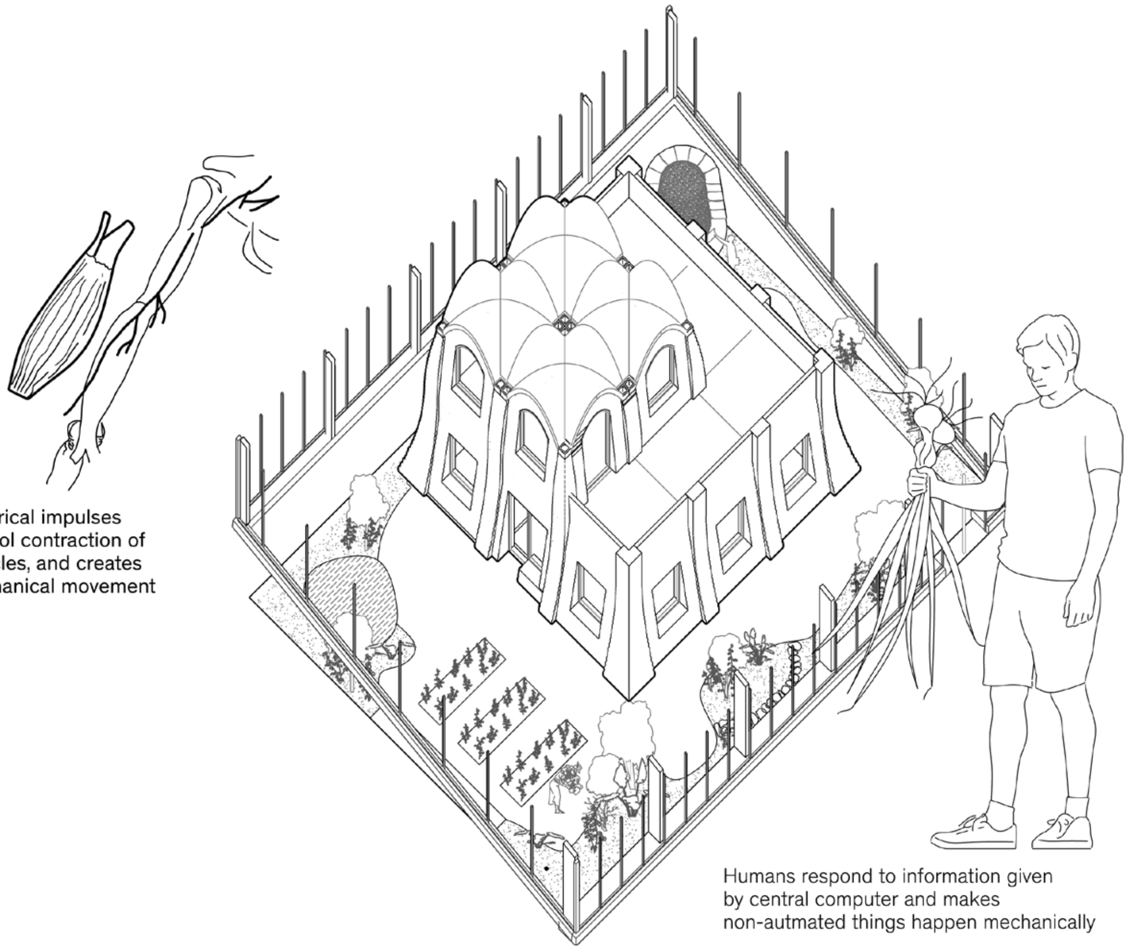
In biology:

The muscles are controlled by the somatic nervous system. Muscles enable us to sit, stand, breathe, talk and move, by contracting and relaxing.

In the building:

The human inhabitants functions like the muscles of the building. They will carry out the notifications that the central computer system notifies of and do the mechanical work. They will take care of plants, handle the growth of the building etc. They are a part of the system.

Fig. 46. Muscular system



Electrical impulses control contraction of muscles, and creates mechanical movement

Humans respond to information given by central computer and makes non-autmated things happen mechanically

Death

The death of the building happens when the human inhabitants want to move, or the mycelium reaches the end of its life, and they are not regenerated. The inhabitants will start to strip the building of everything that is inorganic. Wires, windows, refrigerators, and plumbing pipes are taken out and packed into a container. When everything non-organic in the internal building is gone and the inhabitants are ready to move, the greenhouse is demounted and moved into a new site. There it can get a new life.

The rest of the internal building is left. As weather and temperature will create cracks in the mycelium walls, the structure will start to decompose. In the end, it will fall into the hole where it stands and fill it up. The degradation process is fast and after a couple of years it has all turned into soil. The soil is extra nutritious now and the remains of the building will feed new organisms. The only sign of the building left is natural stones laid in a grid under a layer of soil.

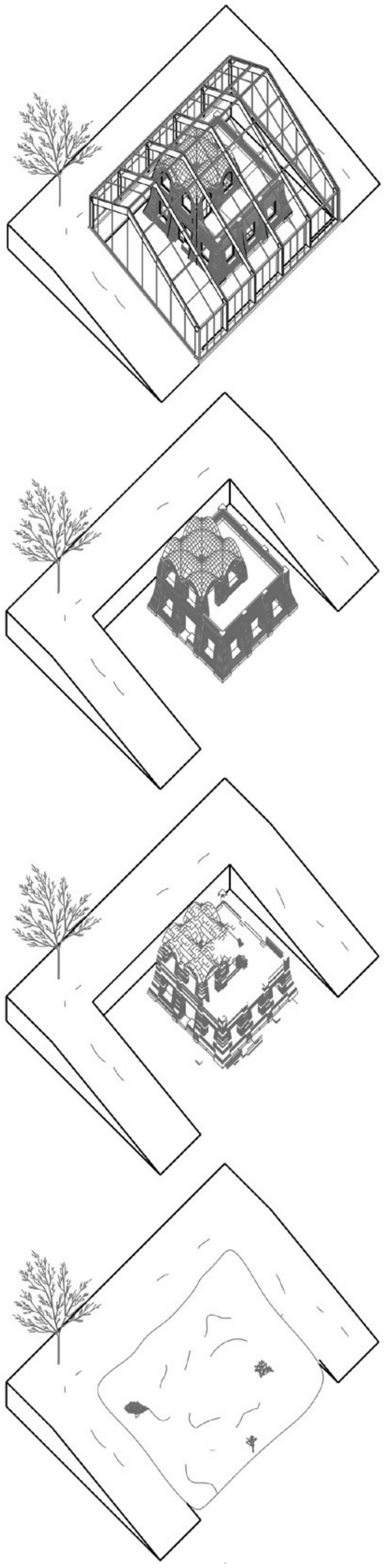


Fig. 47. Process of leaving the building to decompose

Discussion

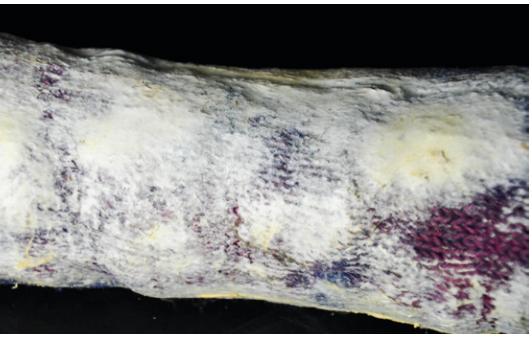


Fig. 48. Mycoknitted tube (Lab 9.)

Fig. 49. Mycelium brick (Lab 3.3.)

Fig. 50. Mycelium leather (Lab 5.)

Mycelium in a large-scale permanent house

Growing *in situ*

The experiments done for this thesis are done with simple equipment in a non-sanitary environment. This has led to many challenges of contamination, but the successful attempts also show that growing building parts *in situ* can be feasible. Growing the house *in situ* could add a higher risk of contamination compared to growing elements in sterile lab environments. However, as labs can have limited amounts of space for large assemblies and can add costs and energy, it is interesting to examine an in-situ scenario. *In situ* cultivation also brings flexibility, as additions and subtractions of the structure can be carried out throughout the whole lifetime of the building. To combat the difficulties regarding contamination, growing chambers or growing tents is suggested. This method is tried in small scale in lab 4 and in bigger scale for the prototype. The temperature, airflow, and humidity in the experiments for this thesis has not been regulated more than making sure they exist. In a larger scale *in situ* scenario, equipment such as an air-filtered fan and a humidifier should be installed in the in the growing chamber, to secure favourable growing conditions. The construction of the growing chambers should be light and movable. It should be openable so that it can be mounted on existing walls to grow structures attached to the wall.

Low tech

This work shows that it is possible to grow mycelium material with very primitive tools. The pasteurisation of substrate was caried out in a pillowcase sitting inside a pot of water on a movable cooker hob. However, the simple tools make the process unpredictable. Many of the experiments failed due to mould, likely due to insufficient sterilisation of the substrate. Sterilisation in an autoclave is preferable but this is a sophisticated and expensive lab equipment. Something in between the two would be a large pressure cooker, able to heat the substrate above 120 degrees.

Structure

Flooring in between the levels is one of the least researched architectural elements for mycelium in literature. The Thick and thin arch used cardboard internal scaffolding described by Dessi-Olive was able to support 75 kg with a span of ca. 1 m (Dessi-Olive, 2022b). Even though the dimensions of the construction system are generous and designed to work in compression, more research is needed to be able to conclude the structure will hold.

The ceiling slab should be tested by compression tests, preferably in full scale. One reinforcing method could be to add internal bamboo fibres for the mycelium to grow on. Another method could be to add ballast weight on the flooring on the second level, to reduce the effect of point loads.

The construction of the columns could also be taken one step further and tried out. Potential enhancements to the system are post-tensioning the mycelium blocks together.

Flexibility

As mycelium can be vary varied, many different products and furniture can be cultivated for the home. Shelves can be added to a wall by growing in place. Holes can be cut in walls, and the wounds can be self-healed, gaining the same mycelium skin as the rest of the wall. The house can be in constant flux, changing with the needs of the inhabitants.

Mycelium variations

The mycelium can vary depending on its use in the building. The structural systems should use mycelium grown on sawdust since these form a denser and stronger material. The non-load bearing walls could instead be grown with an airier substrate such as straw to gain more inbound air and be a better insulant. Mycelium leather could be used to clad the walls for a cleaner finish than the rough mycelium composite.

Life span

The life span of mycelium packaging by Ecovative is 30 years in dry conditions (Mushroom packaging By Ecovative, n.d.). It is difficult to know what the life span of a much bigger structure, but it can be assumed this can represent the upper limit of the life span of a mycelium building. Further research and trials are needed to specify the possible life span of a mycelium architectural size construction but for now, this means that using the mycelium material forces, but also allows for the building’s life expectancy to be short.

Today, a lot of buildings get prematurely torn down. In Japan, the average life span of buildings are as short as 25 years (Wuyts et al., 2019). While you can argue that buildings life should always be maximised, there are applications where this is not reasonable for various reasons.

As mycelium is a bio-based material with minimal embodied energy, we can allow ourselves to build building with short life spans. This can allow for flexibility. If the user of the suggested building design in this work can pack the greenhouse, windows, and technical systems up, move them to a new location and let the rest of the house naturally decompose. As the building can leave the exploited land better (more nutritious) than it was before exploitation, the problem of exploited land is reduced.

The nature house

Untreated mycelium is sensitive to temperature swings and rainfall and is therefore unfit for an outdoor environment (Dessi-Olive, 2022b). A greenhouse outside the structure acts like an outer skin, providing shelter from rain and snow. As the structure is sunken into the ground, the ground heat will help levelling out the temperature swings. The compost heating system is placed inside the greenhouse to further level the temperature and heat the greenhouse during the winter. The even temperature and protection against weather will make the mycelium structure within more durable. Additionally, this will prolong the growing season inside the greenhouse and make it possible to produce food early in spring.

The greenhouse also reduces the stress on the mycelium construction. Since the building is inside a greenhouse, wind loads are negligible, which makes it easier to achieve a compression-only structure.

Warne (1993) suggests that the nature house should learn from biology and use off-the-grid systems. The design shows how this could be done in a very direct way using mycelium and a bio-thermal heater. The first uses biology to produce the building and obtain biological attributes in the process. The latter uses the biological process of metabolism to heat the building and get fertile soil for cultivation. Additionally, plants and insects, sheltered by the greenhouse offers protection.

The processes described in the thesis that are using biological processes are all rather slow. More research could be done on making faster systems using biology. An example could be using plants to get flexible sun shading. Another could be using inflatable geometries of plants to create flexibility in interchangeable walls.

Biological attributes

Metabolism

The plantings in the greenhouse do not only have a recreational and food-providing purpose but is also a vital part of the systems of the building. As part of the metabolic system of the building, the plants bind energy from the sun by combining smaller molecules into bigger. This energy is then used to heat the building by decomposing microorganisms. Our traditional way of gaining heat is burning this energy as well as fossil energy to receive heat. Burning displaces most of the molecules into the atmosphere. The biothermal heating system is a way of using the potential energy bound in these molecules without burning, and the molecules can instead be stored in nutritious soil and nurture new life.

Self-healing

Lab 7 showed that active mycelium could self-heal. It was more difficult to reactivate hibernated mycelium, as lab 8 was not successful. However, literature support the claim that hibernated mycelium can be self-healing through reactivation (Appels et al., 2019). By using hibernated mycelium as the main material for the construction of the building, large parts can be self-healing. If a traditional building would have a crack in the façade, an expensive and labour-intensive maintenance needs to start. If a crack would appear in the mycelium building, the fungal material can be reactivated by placing a growing chamber on top of the wounded area. The mycelium will then fuse the crack together. Fixing faults can also be done by manually adding active mycelium substrate inside the damaged area. This will then fuse with the original wall, leaving it healed.

Resilience

By having a diversity of species inside the building, a sort of controlled ecosystem can be achieved. Certain plants have essential oils that can help mitigate mould growth. The semi-active mycelium also adds another defence. Certain species of insect can be used as a natural defence against harmful microorganisms.

The user

By achieving these systems, the building can be more self-governing. Labour-intensive maintenance and fossil-based heating can be replaced by using biological systems. The human inhabitants that are using the building are receiving information about the systems from a central computer. With current technology however, it is difficult to include all systems in this computational system. The user should therefore know a lot about the systems, and preferable be interested in cultivating plants and fungi.

Conclusion

From literature reviews and experimentations, certain strategies have been selected for the construction of a single-family building within a greenhouse. The strategies and substrates are varied throughout the building to work optimally with their use. These strategies include waffle cardboard internal scaffolding that enables cellular but at the same time monolithic mycelium cultivation for ceiling slabs. It can also control the geometry of the mycelium so that the slab works in a compression-only manner. Another implemented strategy is mycowelding, enabling large assemblies to be constructed using smaller mycelium building blocks.

The mycelium is one of the things that enables the building to work more like a living organism than regular buildings, as it allows the house to self-heal, offers resilience and can metabolise. The metabolism is also achievable due to the bio-thermal heater that uses living organisms to produce heat and nutritious soil for plants. The plants are another addition to the building that improves resilience, contribute to the metabolism of the building as well as produces food to the inhabitants. A greenhouse is enveloping the building and these systems, giving them shelter from weather, levelling temperature and protects them.

Fig. 51. Fruiting bodies (Lab 4.)

Bibliography

Appels, F. V. W., Camere, S., Montalti, M., Karana, E., Jansen, K. M. B., Dijksterhuis, J., Krijgsheld, P., & Wösten, H. A. B. (2019b). Fabrication factors influencing mechanical, moisture- and water-related properties of mycelium-based composites. Materials and Design, 161, 64–71. https://doi.org/10.1016/j.matdes.2018.11.027

Bayer, E. (2017). The future will be biofabricated. In D. Benjamin (Ed.), Embodied energy and design (pp. 152–161). Lars Müller publishers.

Beiser, V. (2019). Why the world is running out of sand. BBC Future. https://www.bbc.com/future/article/20191108-why-the-world-is-running-out-of-sand

Betts, J. G., Desaix, P., Johnson, E., Johnson, J. E., Korol, O., Kruse, D., Poe, B., Wise, J. A., Womble, M., & Young, K. A. (2022). Anatomy and Physiology 2e. OpenStax, Rice University. https://openstax.org/details/books/anatomy-and-physiology-2e

Bitting, S., Derme, T., Lee, J., Van Mele, T., Dillenburger, B., & Block, P. (2022). Challenges and Opportunities in Scaling up Architectural Applications of Mycelium-Based Materials with Digital Fabrication. Biomimetics, 7(2). https://doi.org/10.3390/biomimetics7020044

Brosché, S., Strakova, J., Bell, L., & Karlsson, T. (2021). Widespread Chemical Contamination of Recycled Plastic Pellets Globally. Ipen, December.

Brown, G. (2014). The compost-powered water heater (1st ed.). The countryman press.

Cooper, A. H., Brown, T. J., Price, S. J., Ford, J. R., & Waters, C. N. (2018). Humans are the most significant global geomorphological driving force of the 21st century. Anthropocene Review, 5(3), 222–229. https://doi.org/10.1177/2053019618800234

Dessi-Olive, J. (2022a). Craft and structural innovation of mycelium structures in architectural education. In M. F. Hvejsel & P. J. S. Cruz (Eds.), Structures and architecture (pp. 43–50). CRC Press/Balkema. https://doi.org/10.1201/9781003023555

Dessi-Olive, J. (2022b). Strategies for Growing Large-Scale Mycelium Structures. Biomimetics, 7(3). https://doi.org/10.3390/biomimetics7030129

Ecovative. (n.d.-a). History. https://web.archive.org/web/20120505025210/http://www.ecovativedesign.com/about-ecovative/history/

Ecovative. (n.d.-b). Home page. Retrieved February 22, 2024, from https://www.ecovative.com/

Elsacker, E., Peeters, E., & De Laet, L. (2022). Large-scale robotic extrusion-based additive manufacturing with living mycelium materials. Sustainable Futures, 4(May), 100085. https://doi.org/10.1016/j.sftr.2022.100085

Elsacker, E., Søndergaard, A., Van Wylick, A., Peeters, E., & De Laet, L. (2021). Growing living and multifunctional mycelium composites for large-scale formwork applications using robotic abrasive wire-cutting. Construction and Building Materials, 283, 122732. https://doi.org/10.1016/j.conbuildmat.2021.122732

Elsacker, E., Vandelook, S., Brancart, J., Peeters, E., & De Laet, L. (2019). Mechanical, physical and chemical characterisation of mycelium-based composites with different types of lignocellulosic substrates. PLoS ONE, 14(7), 1–20. https://doi.org/10.1371/journal.pone.0213954

European Environment Agency. (2021). Improving the climate impact of raw material sourcing. (Issue 08). https://www.eea.europa.eu/publications/improving-the-climate-impact-of

Fincheira, P., Jofré, I., Espinoza, J., Levío-Raimán, M., Tortella, G., Oliveira, H. C., Diez, M. C., Quiroz, A., & Rubilar, O. (2023). The efficient activity of plant essential oils for inhibiting Botrytis cinerea and Penicillium expansum: Mechanistic insights into antifungal activity. Microbiological Research, 277(September). https://doi.org/10.1016/j.micres.2023.127486

Forager by Ecovative. (n.d.). Innovation. Retrieved April 23, 2024, from https://forager.bio/pages/innovation

GARF. (2020). Pasteurising vs Sterilising When Mushroom Growing. Archers Mushrooms. https://archersmushrooms.co.uk/pasteurising-vs-sterilising-when-mushroom-growing/

Ghazvinian, A., & Gürsoy, B. (2022). Mycelium-Based Composite Graded Materials: Assessing the Effects of Time and Substrate Mixture on Mechanical Properties. Biomimetics, 7(2). https://doi.org/10.3390/biomimetics7020048

Goidea, A., Floudas, D., & Andréen, D. (2020). Fabricate 2020 Making Resilient. In J. BURRY, M. SKAVARA, J. SABIN, & B. SHEIL (Eds.), Fabricate.

Goidea, A., Floudas, D., & Andréen, D. (2022). Transcalar Design: An Approach to Biodesign in the Built Environment. Infrastructures, 7(4). https://doi.org/10.3390/infrastructures7040050

Granmar, M. (2021). Naturhus. Natur & Kultur.

Hebel, D. E., & Heisel, F. (2017). Cultivated Building Materials. In D. E. Hebel & F. Heisel (Eds.), Cultivated Building Materials. Birkhäuser. https://doi.org/10.1515/9783035608922

Heisel, F., Schlesier, K., Lee, J., Rippmann, M., Saeidi, N., Javadian, A., Nugroho, A. R., Hebel, D., & Block, P. (2017). Design of a load-bearing mycelium structure through informed structural engineering: The MycoTree at the 2017 Seoul Biennale of Architecture and Urbanism. Proceedings of the World Conference on Sustainable Technologies, 1–5. https://www.researchgate.net/publication/320443920

Hoheneder, W., & Gruber, P. (2016). Plan to not plan anymore - on growing and building. In B. Imhof & P. Gruber (Eds.), Built to grow (pp. 29–39). Birkhäuser.

Hönger, C., & Brunner, R. (2013). Strategy. In T. Unruh (Ed.), Climate as a design factor (2nd ed., pp. 34–55). Quart Verlag GmbH.

Hultman, L. G. (2022). Bo & leva lycklig i växthus. Lassbo Förlag.

Jiang, L., Walczyk, D., McIntyre, G., Bucinell, R., & Tudryn, G. (2017). Manufacturing of biocomposite sandwich structures using mycelium-bound cores and preforms. Journal of Manufacturing Processes, 28, 50–59. https://doi.org/10.1016/j.jmapro.2017.04.029

Jones, M., Bhat, T., Huynh, T., Kandare, E., Yuen, R., Wang, C. H., & John, S. (2018). Waste-derived low-cost mycelium composite construction materials with improved fire safety. Fire and Materials, 42(7), 816–825. https://doi.org/10.1002/fam.2637

Jones, M., Mautner, A., Luenco, S., Bismarck, A., & John, S. (2020). Engineered mycelium composite construction materials from fungal biorefineries: A critical review. Materials and Design, 187, 108397. https://doi.org/10.1016/j.matdes.2019.108397

Kaiser, R., Bridgens, B., Elsacker, E., & Scott, J. (2023). BioKnit: development of mycelium paste for use with permanent textile formwork. Frontiers in Bioengineering and Biotechnology, 11(July), 1–12. https://doi.org/10.3389/fbioe.2023.1229693

Kuta, S. (2020). Is fungus the answer to climate change? Student who grew a mushroom canoe says yes. NBC News. https://www.nbcnews.com/news/us-news/fungus-answer-climate-change-student-who-grew-mushroom-canoe-says-n1185401

le Roux, H., & Hecht, G. (2020). Bad Earth. E-Flux Architecture. https://www.e-flux.com/architecture/accumulation/345106/bad-earth/

Liu, G., Xu, K., Zhang, X., & Zhang, G. (2014). Factors influencing the service lifespan of buildings: An improved hedonic model. Habitat International, 43, 274–282. https://doi.org/10.1016/j.habitatint.2014.04.009

Luxaflex. (n.d.). PowerView® automation. Retrieved May 1, 2024, from https://www.luxaflex.se/powerview-automation/?gadsource=1&gclid=Cj0KCQjw0MexBhD3ARIsAEI3WHKhc7DwsGslRBXBfh9GZYjDCDgBbQalig4dhs0R3vpfrP03kOOfJB4aAqcWEALw_wcB

Modanloo, B., Ghazvinian, A., Matini, M., & Andaroodi, E. (2021). Tilted arch; implementation of additive manufacturing and bio-welding of mycelium-based composites. Biomimetics, 6(4). https://doi.org/10.3390/biomimetics6040068

Mogu. (n.d.-a). Material Data Sheet. https://mogu.bio/wp-content/uploads/2023/09/Acoustic_Technical-Datasheet_2023.pdf

Mogu. (n.d.-b). Radical by Nature. Retrieved February 22, 2024, from https://mogu.bio/

Mogu. (2019). SAVE THE DATE – Mogu Acoustic is coming – Official Launch on June 19th. Retrieved April 29, 2024, from https://mogu.bio/save-the-date-mogu-acoustic-is-coming-official-launch-on-june-19th/

Mohseni, A., Vieira, F. R., Pecchia, J. A., & Gürsoy, B. (2023). Three-Dimensional Printing of Living Mycelium-Based Composites: Material Compositions, Workflows, and Ways to Mitigate Contamination. Biomimetics, 8(2), 257. https://doi.org/10.3390/biomimetics8020257

Mushroom packaging By Ecovative. (n.d.). Technical Data. Retrieved April 23, 2024, from https://mushroompackaging.com/pages/about

Mycoworks. (n.d.). ReishiTM. Retrieved February 28, 2024, from https://www.mycoworks.com/materials

Nationalencyklopedin. (n.d.). Svampar. Retrieved April 29, 2024, from http://www.ne.se/uppslagsverk/encyklopedi/lång/svampar

Olsson, K. (2023). Grävde ner sitt växthus – kan nu odla bananer. Retrieved April 29, 2024, from https://www.svd.se/a/on8vxB/gravde-ner-sitt-vaxthus-odlar-bananer-utan-uppvarmning

Pownall, A. (2019). Pavilion grown from mycelium acts as pop-up performance space at Dutch Design Week. Dezeen. https://www.dezeen.com/2019/10/29/

growing-pavilion-mycelium-dutch-design-week/

Ratti, C. (2019). The Circular Garden. https://carloratti.com/project/the-circular-garden/

Ross, P. (2017). Fungal Mycelium Bio-Materials. In D. E. Hebel & F. Heisel (Eds.), Cultivated Building Materials (pp. 134–141). Birkhäuser. https://doi.org/10.1515/9783035608922-017

Rossi, A., Javadian, A., Acosta, I., Özdemir, E., Nolte, N., Saeidi, N., Dwan, A., Ren, S., Vries, L., Hebel, D., Wurm, J., & Eversmann, P. (2022). HOME: Wood-Mycelium Composites for CO2-Neutral, Circular Interior Construction and Fittings. IOP Conference Series: Earth and Environmental Science, 1078(1). https://doi.org/10.1088/1755-1315/1078/1/012068

Sahlqvist, O. (n.d.). SAHLQVIST DESIGN. Adorno. Retrieved April 21, 2024, from https://sahlqvistdesign.com/

Samsung. (n.d.). French door RF65DG9H0ESREF Family HubTM 646 l REAL STAINLESS. Retrieved May 1, 2024, from https://www.samsung.com/se/refrigerators/french-door/rf9000d-rf9000dc-t-style-french-door-21-5inch-family-hub-636l-silver-rf65dg9h0esref/

Sayner, A. (n.d.). How to Pasteurize Mushroom Substrate: 5 Easiest Methods. Grocycle. Retrieved May 2, 2020, from https://grocycle.com/how-to-pasteurize-mushroom-substrate/

Searchinger, T., Peng, L., Zionts, J., & Waite, R. (2023). The Global Land Squeeze: Managing the Growing Competition for Land. World Resources Institute. https://doi.org/10.46830/wrirpt.20.00042

Shen, S. C., Lee, N. A., Lockett, W. J., Acuil, A. D., Gazdus, H. B., Spitzer, B. N., & Buehler, M. J. (2023). Robust Myco-Composites as a Platform for Versatile Hybrid-Living Structural Materials. http://arxiv.org/abs/2305.12151

Stott, R. (2014). Hy-Fi, The Organic Mushroom-Brick Tower Opens At MoMA's PS1 Courtyard. ArchDaily. https://www.archdaily.com/521266/hy-fi-the-organic-mushroom-brick-tower-opens-at-moma-s-ps1-courtyard

Svamphuset. (n.d.). HALMPELLETS. https://svamphuset.com/products/halmpellets

Sydor, M., Cofta, G., Doczekalska, B., & Bonenberg, A. (2022). Fungi in Mycelium-Based Composites: Usage and Recommendations. Materials, 15(18), 1–34.

https://doi.org/10.3390/ma15186283

Tun, M. M., Juchelkova, D., Win, M. M., Thu, A. M., & Puchor, T. (2019). Biomass energy: An overview of biomass sources, energy potential, and management in Southeast Asian countries. Resources, 8(2). https://doi.org/10.3390/resources8020081

UNEP. (2019). Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources. https://wedocs.unep.org/20.500.11822/28163.

UNEP. (2024). Bend the trend: Pathways to a liveable planet as resource use spikes. https://resourcepanel.org/reports/global-resources-outlook-2024

U.S. Environmental Protection Agency. (2024). Sustainable Management of Construction and Demolition Materials. https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials

Vandelook, S., Elsacker, E., Van Wylick, A., De Laet, L., & Peeters, E. (2021). Current state and future prospects of pure mycelium materials. Fungal Biology and Biotechnology, 8(1), 1–10. https://doi.org/10.1186/s40694-021-00128-1

Warne, B. (1993). Naturhuset. In M. Fredriksson & B. Warne (Eds.), På akacians villkor. Warne förlag.

Wiesinger, H., Wang, Z., & Hellweg, S. (2021). Deep Dive into Plastic Monomers, Additives, and Processing Aids. Environmental Science and Technology, 55(13), 9339–9351. https://doi.org/10.1021/acs.est.1c00976

Wolff, B. (2023). From Art To Bioengineering: How MycoWorks' Creative Heritage Guides Its Growth. Forbes. https://www.forbes.com/sites/benjaminwolff/2023/01/09/from-art-to-bioengineering-how-mycoworks-creative-heritage-guides-its-growth/

World Green Building Council. (2019). Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon. World Green Building Council, 67. https://www.worldgbc.org/sites/default/files/WorldGBC_Bringing_Embodied_Carbon_Upfront.pdf

Wuyts, W., Miatto, A., Sedlitzky, R., & Tanikawa, H. (2019). Extending or ending the life of residential buildings in Japan: A social circular economy approach to the problem of short-lived constructions. Journal of Cleaner Production, 231, 660–670. https://doi.org/10.1016/j.jclepro.2019.05.258

Youngs, I. (2023). Newcastle’s Farrell Centre explores if we can grow houses from fungus. BBC. https://www.bbc.com/news/entertainment-arts-65346052

All figures and photographs is produced by the author

Appendix

Experiments

LAB 1. Reproducing and try-outs

2023 09 28 – 2023 10 26


Lab setup, materials 20230928


Sterilizing sawdust/flour 20230928


Bag with inoculated mix 20230928


Lab setup 20230928

Goal

I want to start by reproducing the bought *Pleurotus ostreatus* on sawdust to be able to make more experiments in the future. I want to see how much water is needed, which is why I will try out three different amounts of water in three tests. A part of the substrate/mycelium mix is taken aside to be cast in a plastic box.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Plastic film
- Mycelium growing bags
- Gloves
- Metal spoon

Materials

- Wheat flour
- Sawdust/small wood-chips
- Inoculated sawdust
- Water

Method

500 g of sawdust together with 300 g of wheat flour is baked at 100°C for two hours to sterilize the substrate. The mix is then divided in to four parts:

- Mix 1: 200 g sawdust/flour mix, 20 g inoculated sawdust, 500 ml water

- Mix 2: 200 g sawdust/flour mix, 20 g inoculated sawdust, 720 ml water
- Mix 3: 200 g sawdust/flour mix, 20 g inoculated sawdust, 940 ml water

- Mix 4: 200 g sawdust/flour mix, 20 g inoculated sawdust, 720 ml water

Mix 1-3 is put in mycelium growing bags. The sawdust/flour mix is measured and put into the bags. Then the inoculated sawdust is added and mixed in thoroughly. The water is then added little by little while stirring with the metal spoon. The bags are then put to rest for ten minutes before getting stored in a dark, room-tempered cupboard.
Mix 4 is placed in a plastic box. A hole is poked through the lid and plastic film is wrapped around the box. The rest of the material that could not fit in the box was wrapped in plastic film. The materials where then put into storage in the same dark room-tempered cupboard.

Notes

20230928: I tried to make the environment as sterile as possible by spraying the gloves and tools after touching them. The conditions of the home-lab in the

kitchen was not optimal, mainly because of a lack of space.
20231001: White mycelium has grown in mix 1 and 2. It is the most spread in mix 1. Mix 3 and 4 have not shown any growth.
20231004: Black mould was discovered in mix 1 and 2, most spread out in mix 1. Both samples were taken away from the cupboard to store in another place for further observation. No growth visible in mix 3, probably due to too much water. No growth in mix 4, maybe because of a lack of oxygen.
20231017. The samples have been left to grow for 20 days. Mix 3 has not been able to grow, likely due to too much water. Mix 1 has the largest growth of mycelium and is also the firmest. Mix 2 has the largest spread of contamination.

Storage 20230928

Black mould growth
20231017

Mix 1 out-competed the mould and was able to grow through the whole substrate
20231026

Result

Mix 1 most successful, mix 2 most mould, mix 3 too much water

Learning outcomes

Sterilising the substrate sufficiently is vital to reduce the risk of contamination. Ideally it should be done in an autoclave. Less water than thought is needed. The relatively high amount of wheat flour could have potentially made the samples more vulnerable to mould.

The experiment failed since I can't use the reproduced mycelium to conduct other experiments due to the contamination. However, there was much to learn about the process.

Roughly one month after inoculation, fruiting bodies were visible in mix 1. The entire substrate was filled with white rot mycelium and was stiff at touch. The whole mix is now a lump and could be taken out of the bag. Even though some mould is still visible, it didnt seem to stop the growth of the mycelium.

LAB 2. Testing hang-drying technique

20231007 – 20240514

Signs of white mycelium growth in the growing bag 20231010

The growth is throughout the entire bag. 20231016

Goal

Creating a lampshade through the hang-drying method

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Plastic film
- Mycelium growing bags
- Gloves
- Metal spoon
- Paper towel

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Hay
- Sterilised straw pellets
- Hemp/jute rope

Method

Step 1:

20231007: inoculate 1 kg straw pellets with the 150 g mycelium and mix with 1,9 l water. Mix in a growing bag and close with a paper clip. Let it grow for 4-5 days.

Notes:

20231010: Signs of white mycelium growth is visible throughout the bag.
No signs of contamination visible. It doesn't grow as fast as anticipated. I will therefore wait longer until step 2.
20231016: When taken out of the bags, no signs of contamination is visible. The growth is throughout the entire bag. The bottom half was more firm than the top part, likely due to more water

Step 2:

20231016: I created a mould out of cardboard, ca. 50 × 50 cm and taped the inside.

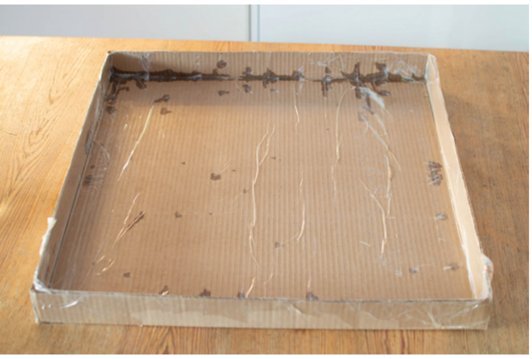
Notes:

20231016: It was difficult to make the mould water-tight, due to difficulties fitting the tape correctly and sealed in the corners. The tape created many creases that could be difficult to sanitise properly. Because the mould was not entirely water-proof, the sanitizer went through the tape and wetted the cardboard in some places (see fig. 38). In the next experiment, a different mould construction technique should be used.

Hay is sterilised by boiling for 10 minutes 20231016

Step 3:
20231016: I cut 500g of hay into smaller pieces and sterilized it by letting it boil in water for 10 minutes.
The mould for the plate was taped on the inside but it was hard getting it entirely water proof. The mould was sterilized multiple times by alcohol and wiped with paper towels. A mixing bowl is also sterilized. I then broke apart the grown mycelium from the bag and mixed it with 100g of wheat flour.

Step 4:
20231016: Sterilize the mould and pour in the mix. It should be at least 3 cm thick in every place. Cover with plastic film and poke a few holes with a sterilized needle. Store in a clean area out of direct sunlight for 4 days



Mould out of cardboard and tape. 20231016

Notes:
202317: No visible growth in the mould.

Step 5:

Poke holes in the four corners and let jute rope go through the holes. Store it again for 2 days and let the mycelium heal around the ropes.
Due to low growth rate and mould infestation, the experiment was abolished after a month and this step was not conducted.

Step 6:

Hang the mycelium board in the ropes and let it dry
Due to low growth rate and mould infestation, the experiment was abolished after a month and this step was not conducted.

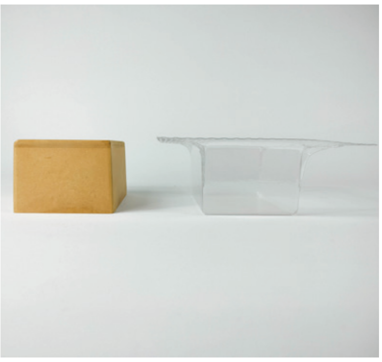
Fruiting body that grew through the plastic film 20240514

Result
The growth was very slow in the growing bag as well as in the cardboard mould. After some time the sample showed signs of mould. It was then destroyed. Wheat flour should be used to make initial growth rate higher. Boiling the hay for 10 min is perhaps not enough to sterilise it.

The sample was left to grow and the 14 of may 2024, a large fruitng body was found growing outside of the plastic film layer.

LAB 3.1 Brick growing

2024 01 23 – 2024 03 01



A plastic mould is created by vacuum heat forming 20240123

Pasteurisation of wheat flour 20240123

Substrate, flour and mycelium mix.

Goal
Creating bricks of mycelium casted in a plastic brick mould.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Plastic film
- Mycelium growing bags
- Gloves
- Metal spoon
- Paper towel
- Thermometer

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Heat treated oak pellets

Mould

- Brick-shaped vacuum mould
- 1 mm thin plastic

Method
Step 1: Create mould.
Build ca 8 × 10 × 15 cm box in wood. Use 1 mm thin PET plastic to create two moulds with heat vacuum.

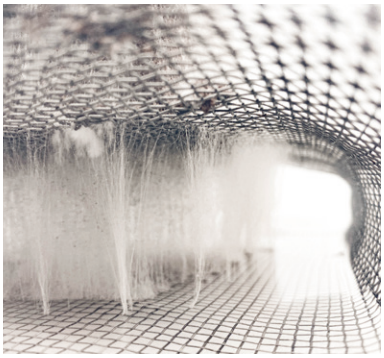
Notes:
It was difficult getting the original wooden box out of the plastic due to the vacuum. Therefore, the box was sanded to get a slight angle, which made it easier to separate it from the plastic. Some of the plastic moulds bursted a bit in the corners when i tried to separate the box from them.

Step 2:
Pasteurise 100 g of wheat flour by letting it sit in a container in water between 65 and 75 degrees for two hours. Mix ca. 1 kg of heat treated oak pellets with the wheat flour in a sterilized pot. Add ca. 150 g of inoculated sawdust and 1,9 l of water. Sterilize plastic moulds three times by spraying it with alcohol and wipe with paper towels. Add the mix into the moulds but leave ca. 3 cm to the top. Cover the moulds with plastic film and poke a few holes with a sterilized needle.

Growth is more on the surface than inside the sample it seems. 20240212

Notes:
The pasteurisation was carried out in a water bottle than floated. To be submerged into the water, a weight had to balance on top. The container was not practical and couldn't pasteurise more than 200 g of wheat flour at a time. In next lab, a better method and tools should be used.
The substrate was prepared together with the substrate for lab 4, for a total of 200 g wheat flour, 2 kg oak pellets, 4 l water and 300 g of inoculated sawdust. The big amount made it difficult to mix everything thoroughly and therefore, some variations at the top of the mixing pot compared to the bottom was found during the mould filling.
Due to the difficult pasteurisation, a smaller amount of wheat flour than previous successful labs was used (10% wheat to sawdust ratio compared to 60% of lab 1). This might lead to slow growth rate. In next lab, more wheat flour should be used.

Step 3:
Wait for ca. 14 days.



Mycelium growth towards the water in the bottom of the box, ca 5 cm. 20240212

Notes:
After two days, a few spots of white mycelium growth is spotted on the top of one sample.
Mould was found in two out of three samples.

Step 4:
The one brick that was healthy enough was moved into a growing box after

Notes:
The growth in the plastic box is different from anticipated. Instead of growing an even skin of mycelium, a fluffy web of mycelium sprouts from the sample. The threads seek down to the water on the bottom of the box. Some mould is found in this sample as well. Maybe that is what makes the growth so slow compared to 3.3.

Mould out-competed the oyster mushroom and the sample crumbles when dried. 20240301

Result
All three samples were contaminated and got mouldy. They were kept a while for observation and later destroyed.

Learning outcomes
Two samples got contaminated quickly, one did better even though it also had signs of mould. The one that did better was transferred into a growing box with water on the bottom. Instead of growing a skin, it grew long threads on the surface and down to the water. Pasteurisation method was not good enough. I should use more wheat flour.
The thin cotton-like threads may be some type of panic reaction that the fungal mycelium creates when attacked by mould. Healthy mycelium creates a denser skin.

LAB 3.2 Brick growing

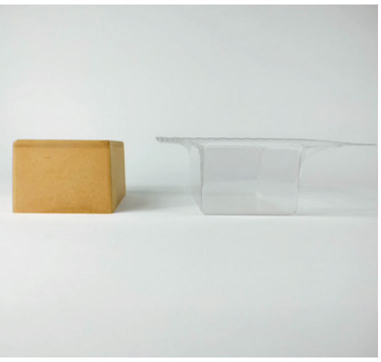
2024 01 25 – 2024 02 01

Goal

The goal is the same as 3.1, but with some adjustments in the recipe and method.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Plastic film
- Mycelium growing bags
- Gloves
- Metal spoon
- Paper towel
- Hood: plastic see-trough box with taped holes
- Thermometer



A plastic mould is created by vacuum heat forming 20240123

Pasteurisation of wheat flour 20240125

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Heat treated oak pellets Paper towel

Mould

- Brick-shaped vacuum mould
- 1 mm thin plastic

Method

Step 1: Create mould.

Use the same wooden box as in lab 3.1. Use 1 mm thin PET plastic to create 3 new moulds with heat vacuum.

Notes:

This time I was more careful when separating the plastic from the box, and no plastic mould burst.

Step 2:

Pasteurise 600 g of wheat flour by letting it sit in a piece of cloth in 65-75 degrees warm water for two hours. Mix ca. 1 kg of heat treated oak pellets with the wheat flour in a sterilized pot. Add ca. 250 g of inoculated sawdust and 1,6 l of water. Sterilize plastic moulds three times by spraying it with alcohol and wipe with paper towels. Add the mix into the moulds but leave ca. 3 cm to the top. Cover the moulds with plastic film and poke a few holes with a sterilized needle.

Mouldy sample 20240201

Notes:
This time, the moulds didn’t have any imperfections. More flour was used, which should make the growth rate faster. The growth rate of lab 3.1 and 3.2 will be further observed.

Step 3:
Wait for ca 14 days.

Notes:
After ca five days, mould was found in all three samples. Maybe a higher amount of wheat flour is not beneficial after all, because more mould is found in lab 3.2 than 3.1, with similar mycelium growth.

I should use less wheat flour: 10% is probably adequate.
Could be that the heat treated oak pellets should be pasteurized together with the wheat to make it even more sterile.

In the next experiment, the oak pellets should be pasteurised together with the flour.

Step 4:
-

Notes:
Heavy green mould in all samples. They are destroyed.

Results

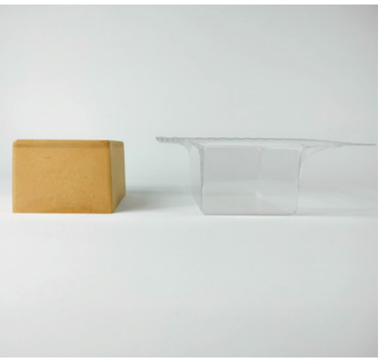
Mouldy samples, destroyed.

Learning outcomes

All three samples got heavily contaminated quickly. Perhaps too much wheat flour is not beneficial after all as this creates perfect conditions for moulds. Oak pellets should be sterilised together with the wheat flour.

LAB 3.3 Brick growing

2024 01 31 – 2024 02 27



A plastic mould is created by vacuum heat forming 20240123

Pasteurisation of substrate in pillowcase 20241031

Goal

The goal is the same as 3.1 and 3.2, but with some adjustments in the recipe and method. This time, i use the same amount of wheat flour as 3.1 and pasteurize the oak pellets as well. The bricks should be grown in a ventilated plastic hood with tape covered holes rather than in clinging film.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Plastic film
- Mycelium growing bags
- Gloves
- Metal spoon
- Paper towel
- Hood: plastic see-trough box with taped holes
- Thermometer

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Heat treated oak pellets Paper towel

Mould

- Brick-shaped vacuum mould
- 1 mm thin plastic

Method

Step 1: Create mould.

Use the same wooden box as in lab 3.1. Use 1 mm thin PET plastic to create 3 new moulds with heat vacuum.

Notes:

This time I was more careful when separating the plastic from the box, and no plastic mould burst.

Step 2:

Pasteruise 100 g of wheat flour together with 1 kg of oak pellets by letting it sit in a pillowcase in 65-75 degrees hot water for two hours. Drain some of the water so that ca 2 kg of water is left in the substrate. Sterilize plastic moulds three times by spraying it with alcohol and wipe with paper towels. Add the mix into the moulds but leave ca. 3 cm to the top. Cover the moulds with plastic film and poke

Three bricks growing 20241031

The samples are structurally stable and does not crumble 20240227

a few holes with a sterilized needle. Cover the holes with micro-pore tape.

Notes:
This time, the moulds didn't have any imperfections. More flour was used, which should make the growth rate faster. The growth rate of lab 3.1 and 3.2 will be further observed.

Step 3:
Wait for ca 14 days.

Notes:
Good growth is visible fast. No mould is visible in the samples. Growth is fast and even throughout the moulds. This method seems to be the best one so far.

Step 4:
Take out the bricks from the moulds and let them grow in a growing box to develop a skin.

Notes:
The skin was developing surprisingly slow, but some growth on the outside is visible. After five days, the bricks were removed from the box and taken to dry out.

Step 5:
Let dry out on a metal mesh.

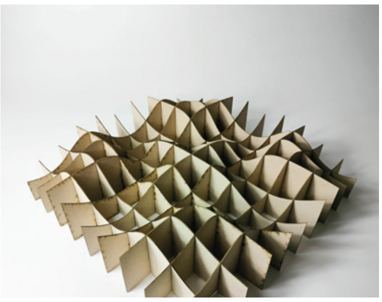
Notes:
The samples were small enough to be able to air dry. They are structurally stable and does not crumble. One of the bricks is used for lab 7 and one for lab 8.

Result
Three healthy and strong bricks fit for using in other experiments.

Learning outcomes
The pasteurisation method seems to be working. Growth is even throughout the mould. The samples were small enough to be air dried.

LAB 4. Internal scaffolding to create complex shaped panel

2024 01 24 – 2024 02 28



The cardboard waffle mould based on a sinus curved parametric pattern.

Substrate and mycelium mix.

Soaked cardboard mould is filled with substrate, one cell at a time.

Goal

Create a complex shaped mycelium plate by using a waffle shaped internal scaffold as mould.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Plastic film
- Gloves
- Metal spoon
- Paper towel
- Laser-cutter
- Thermometer

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Heat treated oak pellets Paper towel
- Plastic sheet table top sheet.
- Plastic box
- Micropore tape

Mould

- 2 mm thick cardboard

Method

Step 1:

Create a preferred shape in rhino and put in a waffle script in grasshopper. Arrange and send to laser-cutter. After cutting, build the waffle structure together.

Step 2:

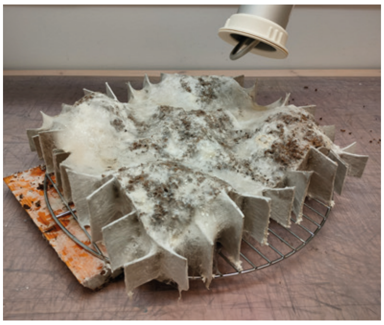
Pour hydrogen peroxide into a container and soak the waffle mould in the fluid for ca one minute. The hydrogen peroxide will kill contaminants on the mould as well as saturate the cardboard with fluids so that it doesn't dry out the substrate mix. Sterilize 100 g of wheat flour by boiling it in a piece of cloth for two hours. Mix ca 1 kg of heat treated oak pellets with 100 g wheat flour in a sterilized pot. Add ca 150 g of inoculated sawdust and 1,9 l of water. Add the mix into the now wet scaffold and fill all the way to the top in the holes.

Prepare a plastic box by drilling holes in the lid and cover the holes with micropore tape. Lift up an oven rack by placing it on two pieces of wood on the bottom. Place the sample on top of the rack and pour ca 1 l of water on the bottom of the box.

Growth after 15 days 20240206

Notes:
The substrate was prepared together with the substrate for lab 4, for a total of 200 g wheat flour, 2 kg oak pellets, 4 l water and 300 g of inoculated sawdust. The big amount made it difficult to mix everything thoroughly and therefore, some variations at the top of the mixing pot compared to the bottom was found during the mould filling.
Due to the difficult pasteurisation, a smaller amount of wheat flour than previous successful labs was used (10 % wheat to sawdust ratio compared to 60 % of lab 1). This might lead to slow growth rate. In next lab, more wheat flour should be used.

Step 3:
Wait for ca. 14 days.



After 27 days, the sample was taken out to dry. 20240220

Notes:
More growth than the samples from 3.1 is spotted after 3 days. Maybe the growing conditions in a larger container with water underneath allows for a faster growth rate with higher access of air.

When mould was found in other samples made from the same batch was found with mould, this sample didn't show any signs of mould. Maybe it is more beneficial for the mycelium to grow in a bigger closed off container. This will be considered in more experiments.

Because the development of mycelium is slower than expected, the sample is left in the growing box for additionally two weeks. After 27 days, the sample was taken out to air-dry

Step 4:
Take out and let dry in air.

After one week of drying fruiting bodies emerge from the surface. 20240227

Notes:
After one week of drying on both sides, small fruiting bodies were visible on the top of the sample. The sample was perhaps too thick to fully dry out in air drying.

Result
Successful panel, sprouting fruiting bodies when air-dried

Learning outcomes
Even though the sample was grown with the same mix as 3.1, it was more successful. Perhaps because of better growing conditions in a larger growing box, gaining more air-flow. Still slow growth and some black dotted mould when growing. The finished sample is very loosely filled and crumbles on the bottom. When air-dried, the sample sprouted fruiting bodies, likely due to a slow drying process and more air-flow.

LAB 5. Create mycelium leather

2024 01 24 – 2024 05 10

Tools 20240124

Honey is used as substrate 20240124

The jars were pasteurised 20240124

Goal
Create mycelium leather

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Plastic film
- Gloves
- Metal drill
- Stove plate
- Pot
- Aluminium foil
- Iron
- Thermometer
- Baking paper

Materials

- Reishi liquid culture
- Malt extract + yeast extract (or Honey)
- Water, preferably distilled
- Glycerol

Mould

- Glass jar with metal lid
- Micropore tape

Method
Step 1: Create mould. (Reuse brick mould)

Drill a hole in the metal lid. Sand the edges. Sterilize the jar and lid by boiling it for ca 2 min. Tape the hole in the lid with micropore tape. Add 300 ml water and 6 g of honey into the jar. Cover the lid with aluminium foil to avoid the filter getting wet. Pasteurise by heating water to 65 to 75°C and put in the jar for two hours. Let cool.

Notes:

I used a glass Tupperware with plastic lid well as a glass jar with metal lid. I used alcohol to sterilise the plastic lid instead. I didn't have distilled water. I didn't have a pressure cooker so I tried to pasteurise the jars with the substrate in water for two hours.

Growth after 19 days 20240212

PMM in liquid substrate. Taken out to be heatpressed 20240509

Small sample of heat-pressed mycelium leather 20240509.

Step 2:
Inoculate with liquid reishi culture, ca 8 ml. Leave in room temperature (or warmer) for ca. 30 days until mycelium grows to the surface and becomes thick.

Notes:
It takes long time for the mycelium to grow. Some circular growth is spotted in rectangular glass container after ca. 15 days.
After 30 days, more growth is visible. Some of it has reached the surface. However, the growth is very slow.
The growth was so slow so the sample was let to grow during 4 months.

Step 3:
Unstick the mycelium disc from the jar and take it out. Heat press 3 × 20 with an iron with baking paper in between.

Step 4:
Prepare 30 % glycerol bath with 250 ml water and 150 ml glycerol. Let the leather soak in the bath overnight.

Step 5:
Dry in room temperature for one day

Result
I was able to create a small sample of the leather. The leather is flexible and bendable.

Learning outcomes
Pasteurisation of jars was difficult, the round jar leaked an let in water, making imbalance in the substrate. Growth is very slow without incubation chamber.
Honey might not be the best substrate, instead malt and yeast extract can be used. A pressure cooker is better for sterilisation.
More substrate and liquid culture could be used for a faster growth period.

LAB 6.1 Create a lamp shade by moulding

2024 01 26 – 2024 02 05

Goal

Create a lampshade by casting.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Plastic film
- Gloves
- Metal spoon
- Paper towel
- Thermometer

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Heat treated oak pellets

Mould

- Lamp shade out of metal
- Plastic film
- Micropore tape

Signs of white mycelium growth in the growing bag 20231010

Method

Step 1: Create mould.

Sterilize the metal lamp shade three times with alcohol and wipe it.

Step 2:

Sterilize 300 g of wheat flour by boiling it in a juice filter for two hours. Mix ca. 0,5 kg of heat treated oak pellets with the wheat flour in a sterilized pot. Add ca. 75 g of inoculated sawdust and 1,9 l of water. Add the mix into the metal lampshade mould and fill all the way to the top in the holes. Shape the inside so it is ca. 2 cm thick in all places. Cover with plastic film and poke a few holes with a sterilized needle.

Step 3:

Wait for ca 14 days.

Notes:

After ca 12 days, mould was found in the sample. It was removed and destroyed. Next sample should be made with the whole substrate being pasteurized for two hours, including the oak pellets.

Mould is found in the sample. 20240205

Result
Mould, destroyed

Learning outcomes
Pasteurisation should include the oak pellets.

LAB 6.2 Create a lamp shade by moulding

2024 02 06 – 2024 03 07


Let pregrow in bags


Filled mould is covered in cling film with poked holes cover with micro-pore tape. 20240208

Goal
Create a lampshade by casting.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Mycelium growing bags
- Gloves
- Metal spoon
- Paper towel
- Hood: plastic see-trough box with taped holes
- Thermometer

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Heat treated oak pellets

Mould

- Lamp shade out of metal
- Plastic film
- Micropore tape

Method
Step 1:
Sterilize the metal lamp shade three times with alcohol and wipe it.

Step 2:
Pasteurise 100 g of wheat flour together with 1 kg of oak pellets by letting it sit in a pillowcase in 65-75 degrees hot water for two hours. Drain some of the water so that ca 2 kg of water is left in the substrate. Mix with 250 grain spawn and add into a growing bag. Seal the bag and let grow for 7 days.

Step 3:
Pour the mix from the bag and break it into pieces. Add the mix into the metal lampshade mould and fill all the way to the top. Shape the inside so it is ca. 1 cm thick in all places. Prepare a plastic box by drilling holes in the lid and cover the holes with micropore tape. Place a metal mesh lifted ca 5 cm up from the bottom. Sterilize everything in the box with alcohol spray and place the sample on top of

Growth has stopped and is very limited in the sample. 20240307

the rack and pour ca 1 l of water on the bottom of the box.

Notes:
The growth in the bag as well as the mould is very slow. After ca two weeks, the growth stopped. To try to activate the growth, inoculated saw dust was spread on the surface. The action didn't succeed in activating growth on original substrate. The sample was thereafter discontinued.

Result:
Limited growth, destroyed

Learning outcomes
It is hard to tell why the growth was so slow. The growing preconditions are the same as the successful 3.3. It could perhaps be bacteria contamination, or lack of airflow. Perhaps a thicker layer of substrate mix can make it grow better.

LAB 6.3 Create a lamp shade by moulding

2024 03 20 – 2024 05 06


Pregrowth in bags

Goal
Create a lampshade by casting.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Plastic film
- Mycelium growing bags
- Gloves
- Metal spoon
- Paper towel
- Thermometer
- Micropore tape


Sample covered with mycelium growth. Some areas has limited growth 20240424

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Saw dust/wood chips

Mould

- Lamp shade out of metal

Method
Step 1: Create mould.


Dried sample 20240506

Step 2:
Pasteurise 100 g of wheat flour together with 500 g saw dust by letting it sit in a pillowcase in 65-75 degrees hot water for two hours. Drain some of the water so that ca 1 kg of water is left in the substrate. Mix with 250 inoclulated saw dust and add into a growing bag. Seal the bag and let grow for ca 21 days.

Notes:
Growth in bags is going well, showing growth throughout the whole bag. No contamination visible

Step 3:
Sterilise the metal lamp shade three times with alcohol and wipe it. Pour the mix from the bag and break it into pieces. Add the mix into the metal lampshade. Shape the inside so it is ca. 3 cm thick in all places. Cover with plastic and poke a few air-holes. Let grow for 14 days.

Installed lighting. The mycelium lamp can support itself. 20240513

The lamp sprouted small fruiting bodies while dried 20240513

Notes:
White mycelium is covering the whole mould, though it is in uneven. I let the sample grow for 26 days in the mould.

Step 4:
Let air-dry. Make a hole for the lamp to run through. Install the lighting.

Result
The lampshade holds together but is very brittle. To fasten the light armature in the lampshade hole, a circular piece of cardboard was put in place in between the armature and the lampshade.

Learning outcomes
The brittleness of the lampshade is likely due to the low density of the substrate used. The saw dust mostly contained wood shavings, creating a low density substrate. If more dense saw dust would have been used, the lamp would have probably turned out stronger.

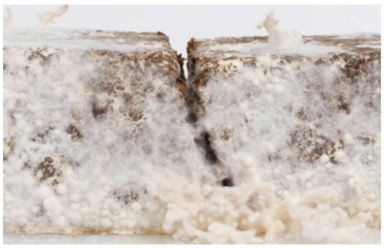
Mycelium shrinks a lot when dried. To reduce cracks, the lampshade needed to be carefully removed from the metal mould before drying.

LAB 7. Experiment with self-healing properties

2024 02 21 – 2024 03 28

2024 02 21 (0 days)

2024 03 04 (12 days)



2024 03 12 (20 days)

2024 03 21 (29 days)

Mould infestation forced the experiment to be discontinued, 2024 03 28

Goal

To see how the self-healing properties of mycelium work.

Tools

- Water spray bottle
- Growing box with micro-pore taped holes
- Knife

Materials

- Active brick sample from 3.3

Method

Step 1: One of the bricks from 3.3 is used for this experiment. Cut it in half with a sterilised knife. Place the two halves close to eachoter in a growing box with micro-pore taped holes.

Step 2: Wait for the halves to grow together and observe. If needed, spray some water on the sample.

Notes:

After 12 days, the sample sprouted fruiting bodies

Step 5:

Observe if samples grow together. Photograph two times per day.

Notes: The distance of the crack between the two parts was probably too large. The growing box had to be opened to be photographed and this likely caused contamination that forced the experiment to stop.

Step 5:

Dry out by removing the growing box

Notes: Because of mould contamination in the active sample, the experiment was discontinued.

Result

The sample grew together partly, but separates when dried. Mould started growing, experiment discontinued

Learning outcomes

The distance of the crack between the two parts was probably too large. The growing box had to be opened to be photographed and this likely caused contamination that forced the experiment to stop.

LAB 8.1. Activate hibernated mycelium with water spray

2024 03 07 – 2024 03 20

One of the bricks from 3.3 is used for this experiment.

Goal

To see if hibernated mycelium sprayed regularly with water can sprout fruiting bodies

Tools

- Water spray bottle

Materials

- Dried brick sample from 3.3

Method

Step 1:

Use one of the dried bricks from 3.3. Place on a clean surface.. Spray with water on top surface 4 times per day. Observe changes and growth.

Water spray is used

Notes:

Nothing happens. After two weeks of spraying, the experiment is changed into 9.2

Result

Nothing happened

Learning outcomes

Dried hibernated mycelium cannot be reactivated by only water spray

LAB 8.2. Activate hibernated mycelium with growing box

2024 03 20 – 2024 04 08

2024 03 20. Sample placed in box and sprayed with water

Goal

To see if hibernated mycelium can sprout fruiting bodies by returning to a humid environment

Tools

- Water spray bottle
- Growing box with micro-pore taped holes

Materials

- Dried brick sample from 3.3

Method

Step 1:

Use one of the dried bricks from 3.3. Place in the growing box. Spray many times with water on top of the sample. Observe changes and growth.

2024 04 08 Sample covered with small black mould. Experiment discontinued

Notes:

After 18 days in the box, small black dotted mould was found on the sample in the box. The experiment was discontinued.

Result

Mould started growing, experiment discontinued

Learning outcomes

The sample got mould on the surface, but not inside the brick. The water was probably not entering the middle of the sample. Even though my experiments didn't show reactivation, literature shows that it is possible (Appels 2019) Reactivation has to happen in combination with some sort of sterilisation.

LAB 9: Bio-knit parabola

2024 02 01 – 2024 02 26

Knitted tube 20240131

Mycelium grows through the cotton fabric 20240201

Mycelium grows through the cotton fabric 20240206

Goal

Create a parabola shaped mycelium tube by filling knitted textile.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Gloves
- Metal spoon
- Paper towels
- Stove plate
- Pot

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Heat treated oak pellets

Mould

- Knitted cotton tube ca 1 m

Method

Step 1:

Create a tube from a knitting machine, ca 0,8 m long.

Notes:

Thin cotton wool is used to work in the knitting machine. It was easier making it one-sided and sew them together by hand than making a tube in the machine.

Step 2:

Pasteurise 100 g of wheat flour together with 1 kg of oak pellets by letting it sit in a pillowcase in 65-75 degrees hot water for two hours. Drain some of the water so that ca 2 kg of water is left in the substrate. Mix with 250 grain spawn.

Notes:

The same method as in 3.3.

Step 3:

Fill the tube with the mixture. Try to spread the substrate as evenly as possible in the tube. Prepare a plastic box by drilling holes in the lid and cover the holes with micro-pore tape. Lift up a metal mesh by placing it on two pieces of wood on the bottom. Place the filled tube on top of the mesh. Pour 0,5 l water in the bottom of the box.

Mycelium grows through the cotton fabric 20240212

Dried tube has formed lumps of mycelium. 20240220

The dried parabola can stand when leaned against a wall 20240220

Notes:
The tube was filled by holding it in the air to avoid contamination. With a larger sample, this will not be possible. Then, a large, clean surface should be prepared. It can be difficult getting an even spread in the tube due to the flexibility in the knitted texture.

Step 4:
Let grow for ca 14 days

Notes:
After 11 days, good growth is visible throughout the entire tube. No mould is visible and the experiment seems successful.

Step 5:
Hang the sample in the ends of the tube to create a parabola. Let it dry out

Notes:
Because the tube has been growing rolled up, there was a greater angle in the growing phase that was straightened in the hanging. This angle changes was likely too large in some parts. Combined with the uneven spread in the tube, some parts of the substance inside the knit broke apart from each other. Next time, the tube should be let grow in a straight line to reduce the angle change when hanging.

Step 6:
Due to the uneven spread and lumpification of the substance in the tube, the parabola was placed in its hanging shape in a growing box and sprayed with water in an attempt of letting the lumps grow together.

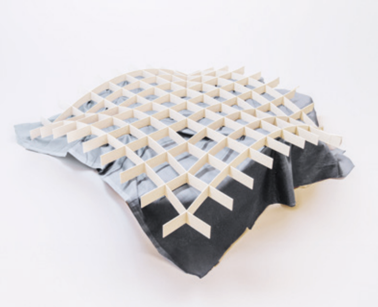
Notes:
After a few days of re-activating the tube, mould was found and the reactivation was cancelled.

Result
Uneven filling of tube, uneven growth, lumps when dried. Reactivation attempt failed due to contamination.

Learning outcomes
The sample grew curled up in a box and was hung in the parabola shape when dried. The angle change was too big and this broke up the mycelium material that dried into lumps. The uneven spread and growth is due to the difficulty filling the tube by hand. Some sort of filling tool would be beneficial to use. Reactivation has to happen in combination with some sort of sterilisation.

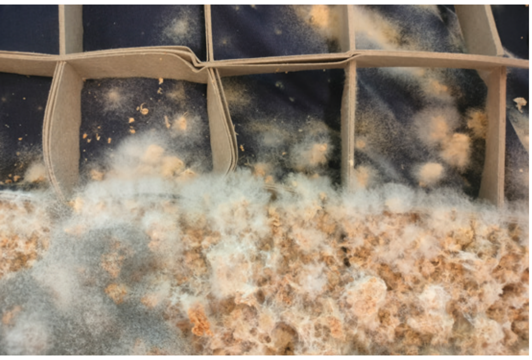
LAB 10: ceiling slab prototype

2024 0



Waffle structure with fabric for the prototype 20240428

Filled prototype growing in a growing chamber made of wood and plastic 20240428



The prototype got contaminated after opening the growing box 20240516

Goal

Create a 1:5 scale model of the suggested ceiling slab.

Tools

- Kitchen scale
- Alcohol-based sanitizer in spray bottle
- Oven
- Mycelium growing bags
- Gloves
- Metal spoon
- Paper towels
- Stove plate
- Pot

Materials

- Inoculated sawdust
- Wheat flour
- Water
- Saw dust

Mould

- Cardboard waffle structure
- Cotton fabric
- Stapler

Method

Step 1: The mould is

Notes:

Thin cotton wool is used to work in the knitting machine. It was easier making it one-sided and sew them together by hand than making a tube in the machine.

Step 2:

Pasteurise 100 g of wheat flour together with 1 kg of oak pellets by letting it sit in a pillowcase in 65-75 degrees hot water for two hours. Drain some of the water so that ca 2 kg of water is left in the substrate. Mix with 250 grain spawn.

Notes:

The same method as in 3.3.

Result

Very limited growth. When growing box was opened, it gained more growth, but after a while it got mouldy.

Learning outcomes

The growing box was sprayed with very much alcohol to sanitise it. This alcohol was not allowed to air out before the sample was placed. This overly use of sanitiser could lead to a hostile environment for the fungus, and cause the limited growth.

To gain more airflow, I opened up holes in the plastic on the underside of the growing box. It led to growth but also mould. Airflow is important but it needs to be more closed for contamination.

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