Mare Schut

Rhythms of Renewal

exploring material cycles in regenerative architecture

graduation report

Technologies & Aesthetics

2023/2024

RHYTHMS OF RENEWAL

Exploring Material Cycles in Regenerative

Architecture

Mare Schut

4844327

Delft University of Technology

Department of Architecture

MSc. Architecture, Urbanism

and Building Sciences

Graduation studio:

Technologies & Aesthetics

Form Studies & Design of Construction

Fall semester 23/24

Research mentor: Ulrich Knaack

Architecture mentor: Geert Coumans

Building technology mentor: Claudia van Leest

CONTENTS

I. PROLOGUE

*Figure 1: Natural Processes (*Fricker et al., 2007)

Fascination

Imagine architecture as a dynamic, ever-evolving structure. A structure in which material temporality does not signifies definitive decay and which goes beyond being a static instance. Instead, visualize it as a dynamic cycle of growth, life and decay all occurring simultaneously. Imagine structures designed to synchronize into the rhythm of nature, fostering regeneration instead of wasteful endings. This fascination will form the foundation of my graduation research and design.

Introduction

In front of you lies my graduation report titled "Rhythms of Renewal." This booklet documents my year-long journey of research and design, during which I investigated material cycles in regenerative architecture.

The assignment for this studio involved designing a medium-sized building located in the rural landscape of Groningen, set a hundred years in the future. Through this project, we aimed to explore the technical developments associated with climate change in relation to architectural form language and aesthetics.

For me, it all began with exploring mycelium and its potential as a building material. Initially, I perceived mycelium's transient nature as a flaw. However, as I delved deeper, I came to realize that this property was something to embrace. My research revealed that mycelium thrives on cyclical processes of growth, maturity, and decay. I was particularly inspired by the idea of making these material cycles visible in architecture.

Later in the design process, I also realized that similar cycles exist in other, more enduring materials such as stone and wood. This understanding led to the design of an assembly of structures that not only harmonize with natural cycles but celebrate them as integral aspects of sustainable architecture. Through my exploration of the material cycles of mycelium, stone, and wood, I aimed to design a building that embodies resilience and regeneration, showcasing the value of integrating natural processes into architectural design and inspiring future innovations in sustainable building practices.

Acknowledgements

I would like to extend my sincere gratitude to my tutors, Geert Coumans, Claudia van Leest, and Ulrich Knaack, for their support throughout this journey. Reflecting on this year, I see it as an incredibly positive experience. Their guidance and encouragement allowed me the freedom to explore and discover a subject that deeply motivates and excites me.

Additionally, I am grateful to my fellow students, particularly Simone Hermans and Kim van den Bosch, for their support, inspiration, and the fun we had during this journey, which has become a valuable part of my experience.

II. RESEARCH

1. **Introduction**

1.1 Problem Statement

Mycelium, a root-like network forming the vegetative part of fungi, has emerged as a potential alternative to traditional building materials (Lim & Shu, 2022). The European building industry's reliance on linear production processes accounts for about half of all our extracted materials and for more than 30% of our waste generation (Elsacker, 2021). Mycelium offers a sustainable solution to minimize waste and resource consumption, fostering closed-loop systems rather than traditional linear systems (Hendrikx, 2019).

During the last two decades, multiple researchers and designers have showcased the potential of mycelium as a building material (McGaw et al, 2022). However, despite mycelium's regenerative nature, these projects all demonstrate a temporary character characterised by linear systems and a final endpoints.

In order to minimize waste and resource consumption a shift is needed toward regenerative architecture, embracing closed-loop systems. Hence, this research aims to explore the application of mycelium's cyclical nature within regenerative architecture, seeking to answer the question: "How can mycelium's cyclical nature find expression and practical application within architecture?"

1.2 Research Aims

The primary objective of this research is to investigate how mycelium's cyclical nature can find expression and practical application within architecture. The practical application of mycelium in architecture will be explored through literature studies. Through experiments and research by design, this research will explore different possibilities on the expression of mycelium's cyclical nature. Finally this research endeavours to produce insights for architects, designers, and builders regarding the cyclical expression of mycelium in architecture.

1.3 Methods

To explore how mycelium's cyclical nature can find expression and practical application within architecture, the research will first establish foundational knowledge about mycelium's role in architectural contexts. This foundational research will involve literature studies on the definition of mycelium, its historical and recent applications, its lifecycle and production process and its material properties.

Secondly, through a combination of literature studies and research by design, the research will explore how mycelium's cyclical process can be translated into architecture. This part will discuss the different phases of the cyclical process, the different ways to translate these phases into a composition, the extent of temporality, the duration of the cyclical process and the logistics.

2. **Mycotecture: Drawing the Context**

2.1 What is Mycelium?

Mycelium can be defined as the vegetative part of a fungus. Grown out of spores, mycelium consists of a network of thread-like filaments called hyphae. It often grows underground but can also thrive in other places that the fungus is feeding on such as wood, tree branches or agricultural residues. As a hidden but vital part of the fungal life cycle, it has a fundamental role in the growth, nutrition and reproduction of fungi. (Lim & Shu, 2022)

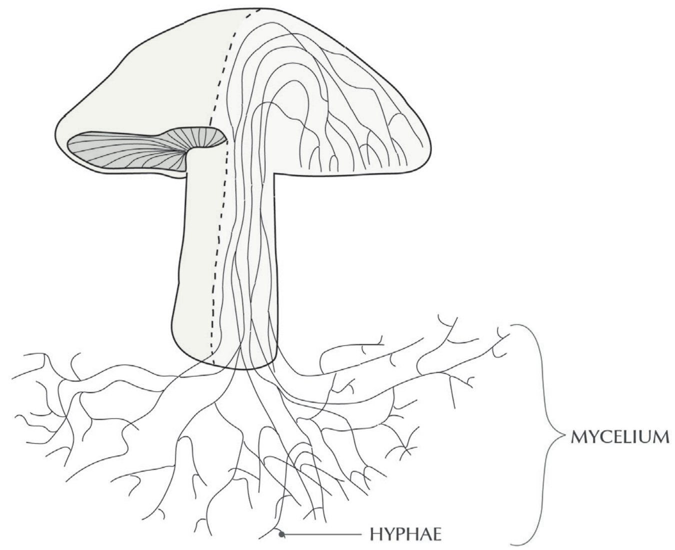


Figure 2: Mycelium as the roots of fungi (Own work, 2023)

2.2 Historical Applications

Fungi are believed to have emerged on Earth billions of years ago, making them among the oldest forms of life on our planet. Their resilience and adaptabilty have allowed them to survive through extreme environmental conditions including multiple mass extinctions. Their ability to thrive in various environments, coupled with their roles as decomposers, symbiotic partners, and nutrient recyclers, highlights their enduring significance in the Earth's ecosystems. (Elsacker, 2021)

The human interest in fungi dates back to prehistoric cultures between 6000 to 9000 BC, where fungi were utilized for purposes such as food, medicine, and as a source of natural dyes for textiles (Lim & Shu, 2022). It initially became a topic of scientific research after the term 'mycology' was created in 1836 by M.J. Berkley (Samanta, 2015). Furthermore from the 20th century fungi started playing a significant role in the pharmaceutical industry, with the development of antibiotics and other medicine (Lim & Shu, 2022).

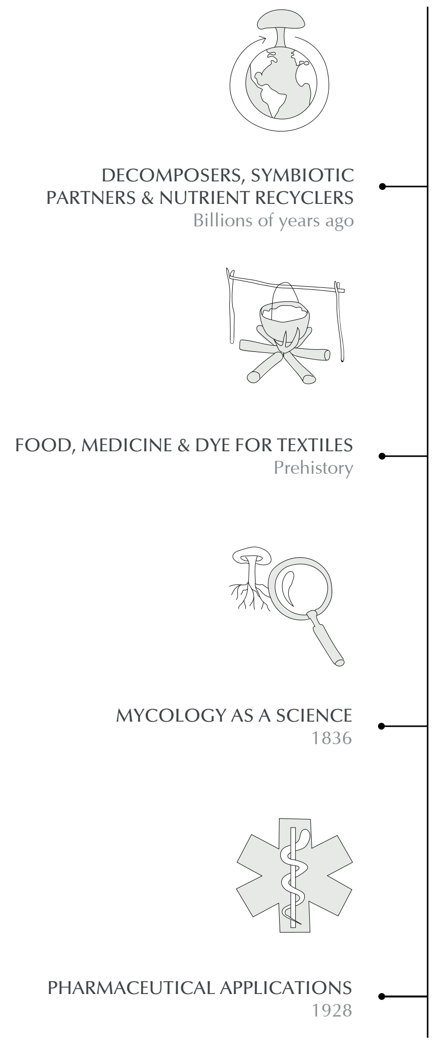


Figure 3: Timeline of historical applications of fungi (Own work, 2023)

2.3 Recent Applications

Although fungi have been used and researched for millennia, it wasn’t until the last two decades that experiments and research initiatives showcased the potential of mycelium as a building material (McGaw et al., 2022). From the early 2000s, researchers conducted groundbreaking experiments that demonstrated the potential of mycelium as a sustainable building material. These experiments aimed to prove the concept of using mycelium for building purposes (Lim & Shu, 2022). Since 2007, the first companies specialized in mycelium-based materials emerged in the United States (McGaw et al., 2022). Subsequent research efforts, together with extensive experimentation and prototyping from all over the world, have demonstrated the potential of mycelium as an insulation material, a construction material, facade claddings and acoustic panels (Almpani-Lekka et al., 2021). The subsequent pages will chronologically provide several projects that showcase these developments over the past 20 years.

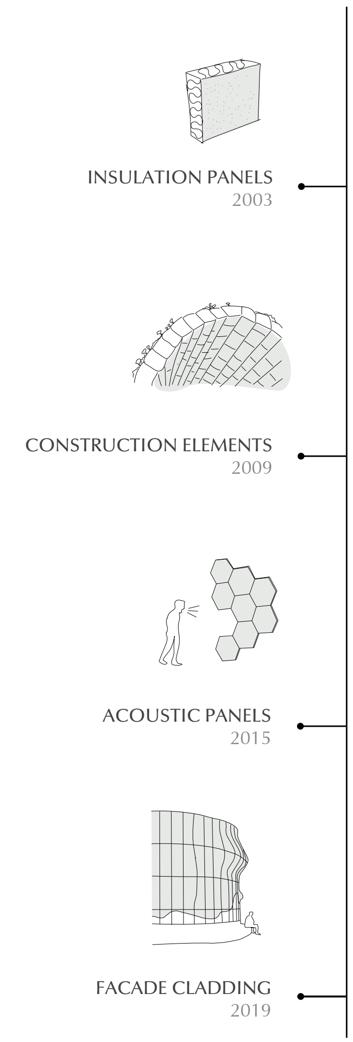


Figure 4: A Timeline of mycelium’s architectural applications (Own Work, 2023)

In 2007, Ecovative Design, one of the pioneering companies in mycotechnology, was founded by Eben Bayer and Gavin McIntyre. Initially, the company gained recognition for their mycelium-based packaging materials, but they expanded their research to explore the application of mycelium as an insulation material for buildings. In 2008, they developed a method of cultivating an insulation material from mushrooms, naming it Greensulate. The material was made of mycelium from the fungus "Pleurotus ostreatus", commonly known as the oyster mushroom, and agricultural waste as a substrate material. (Ecovative, n.d.)

Figure 5: Mycelium insulation material (Ecovative Design, 2007)

In 2008, scientist and designer Phil Ross came up with the term ‘mycotecture’ which expresses the art of designing and building with mycelium. In 2009 his first mycotectural sculpture debuted at the Kunsthalle Düsseldorf. This is one of the first small scale architectural projects made of mycelium bricks. These bricks were cultivated from sawdust using the fungus “Ganoderma lucidum,” commonly referred to as Reishi. In relation to its weight, this material exhibited strength surpassing that of concrete. (Superflux, 2014)

Figure 6: Mycotecture (Ross, 2009)

In 2013, designer Eric Klarenbeek displayed his design of the Mycelium Chair during Dutch Design Week, showcasing a 3D-printed chair made of living mycelium. The chair was made of the "Pleurotus citrinopileatus", commonly referred to as the golden oyster mushroom, together with straw as a substrate. A thin layer of printed PLA bioplastic covers the entire structure to contain the growing fungus in place. While capable of supporting weight when fully matured, the chair's primary purpose leans toward artistic expression rather than functional utility. (Fairs, 2013)

Figure 7: The Mycelium Chair (Klarenbeek, 2013)

At the 2014 Milan Design Week, Evocative Design launched their mycelium-based bricks, consisting of mycelium and agricultural waste. That same year, these bricks were displayed in the temporary Hy-Fi installation, designed by The Living for the MoMA Young Architects Program. This project consists of three merging cylinders strategically designed to optimize airflow within the mycelium structure. These bricks, capable of growing in just five days, are compostable after the installation's removal, after three months. (Stott, 2014)

Figure 8: HyFi (Graves, 2014)

In 2015, designer and entrepreneur Maurizio Montalti founded the company Mogu. Recognizing mycelium's inherent ability to trap and dampen sound waves, Montalti took this opportunity to create soundproofing panels made of mycelium and agricultural waste. Harnessing the natural properties of mycelium, MOGU's acoustic panels deliver sound absorption similar to the performance of some specialized synthetic materials designed explicitly for acoustic purposes. (Massoni 2023)

Figure 9: Acoustic panels (Mogu, 2015)

In 2016, Yassin Areddia and Beetles 3.3, designed the Shell Mycelium Pavilion for the Kochi Muziris Biennale in India. The project consists of a wooden framework covered with a mixture of mycelium and coconut marrow as a substrate. After several days, the mycelium started to take over the substrate covering the structure. Subsequently, the upper layer of the mycelium, exposed to sunlight, dried and hardened, resulting in the formation of an outer shell that protected the underlying layers. (Syed, 2017)

Figure 10: Shell Mycelium Pavilion (Raja, 2017)

Architect Dirk Hebel collaborated with engineer Philippe Block to create the MycoTree, as a part of the "Beyond Mining - Urban Growth" exhibition during the 2017 Seoul Biennale of Architecture and Urbanism. By a system mycelium components, attached by bamboo endplates and metal dowels, they managed to built a self supporting structure. The mycelium elements can be cultivated within two weeks, growing on sugarcane and sawdust as a substrate. This method probably can not be used for high-rise buildings but it shows a lot of potential for one or two-storey building structures. (Frearson, 2017)

Figure 11: MycoTree (Braun, 2017)

In 2017, Aleksi Vesaluoma, a student at Brunel University in London, came up with a new method of moulding mycelium. By using a tube-shaped cotton bandage he moulded the mycelium into long shapes which he called "mushroom sausages". Rather than moulding the material into a fixed shape, he created long and flexible elements which could bend and then grow together becoming one structural building element. This new method offers new shaping possibilities for architectural structures and building elements. (Morby, 2017)

Figure 12: Mushroom Sausages (Vesaluoma, 2017)

The Growing Pavilion is a temporary events space designed in collaboration with Erik Klarenbeek's studio Krown Design and Pascal Lebourc. During the Dutch Design Week in 2019, the pavilion was displayed to the public for the first time. The pavilion consists of a timber frame with facade panels grown from mycelium. Instead of drying the material and making it inactive, the mycelium panels were kept alive, allowing them to grow mushrooms. During the event, the mushrooms were harvested every day in front of an audience. (Pownall, 2019)

Figure 13: The Growing Pavilion (Company New Heroes, 2019)

In 2020, Blast Studio designed the Lovely Trash Column as a structural building element which can be implemented in the design of houses or other small buildings. The column was 3D printed from waste coffee cups as a substrate on which the mycelium was grown. Its shape is designed to enhance the column's structural capacity and provide optimum growing conditions for mycelium. The folded texture creates "microclimate pockets" that trap moisture along the length of the column and enhance its growth. (Hahn, 2022)

Figure 14: Lovely Trash Column (Blast Studio, 2020)

Led by Felicia Davis and Benay Gürsoy a research group of the Pennsylvania State University has been exploring the growth of mycelium on knitted textiles in a project which they called MycoKnit in 2021. The project involves the cultivation of mycelium-based composites on Knitted Textiles for large scale architectural structures. Taking advantage of mycelium's compression strenght and the tension strenght of the knitted fabric, combining these materials can create strong and lightweight building materials. (Davis, 2021)

Figure 15: MycoKnit (Davis, 2021)

Inhabiting Ecologies was one of the five temporary pavilions designed for the 2022 Chart Art Fair in Copenhagen. The pavilion was a collaboration between the architects Nikolaj Emil Svenningsen and Sean Lyon and designer Søs Christine Hejselbæk. It consists of a wooden structure where textiles embedded with mycelium spores are stretched. Growing on a substrate of sawdust and coffee grounds, the mycelium grows and spreads across the material. This project showcases how mycelium can be grown after the installation of the structure rather than prefabricating building elements. (Jordahn, 2022)

Figure 16: Inhabiting Ecologies (Züger, 2022)

In 2022, a team of scientists and designers from the Hub for Biotechnology in the Built Environment in Newcastle developed a self-supporting knitted dome reaching a diameter of 2 meters, facilitating the growth of mycelium. Their focus centered on employing knitted textiles as a foundational surface for mycelium cultivation. The dome was created by inserting the knitted textile with a mixture of mycelium and agricultural waste. The mycelium was grown through the structure before it was dried. (Kaiser et al., 2023)

Figure 17: BioKnit (Hub for Biotechnology in the Built Environment, 2023)

PLP Labs, the research department of PLP Architecture, designed the Symbiocene Living building elements which were showcased for the first time at the Clerkenwell Design Week 2023. The project involves a modular block system to make mycelium structures such as tables, planters and stools. To connect the blocks, a simple plug-and-play system with wooden dowels was used, creating endless configurations, and demonstrating its potential future as a structural builing material. (Souza, 2023)

Figure 18: Symbiocene Living (Fielding, 2023)

2.4 Lifecycle & Production Process

In the natural world, the fungal life cycle initiates with the release of spores. When environmental conditions are conducive, these spores undergo germination, giving rise to the development of hyphae. These hyphae then extend and branch out, creating an intricate network of mycelium. This mycelial network can spread widely, often colonizing substrates like soil, decaying wood, or organic matter. Fungi will grow out of nutrients form the substrate. Eventually, these fungi release spores, restarting the entire life cycle. The lifecycle of fungi in nature varies significantly depending on the distinct species, environmental conditions, presence of competing organisms and can take from a single day up to several years. (Lim & Shu, 2022)

The production process of mycelium-based materials starts with the isolation of mycelium from a fungus that is well-suited for the intended application. These are selected based on their growth characteristics, ability to bind with the chosen substrate and desired properties of the final material. Then the mycelium will be grown and sterilized on a base plate before it will be inoculated into the substrate.

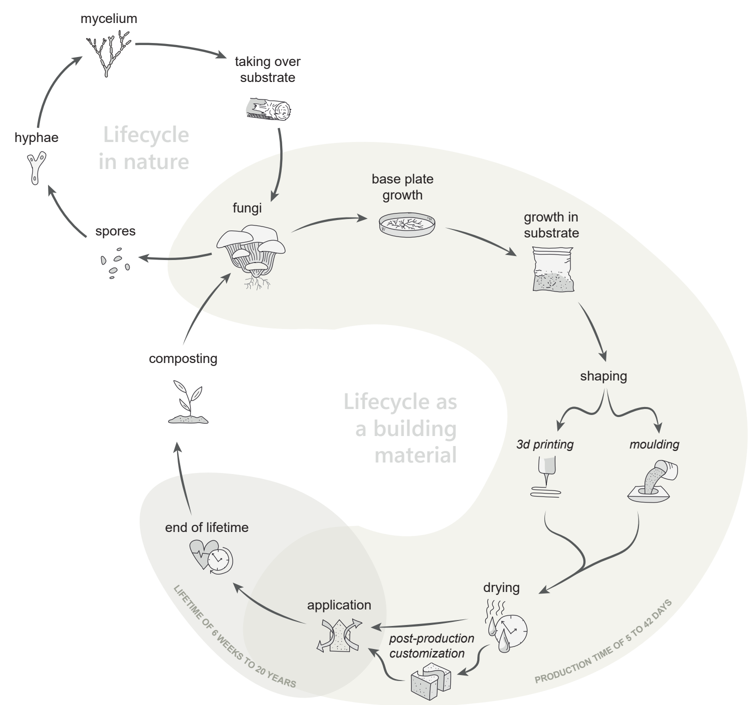


Figure 19: Mycelium's Lifecycle and Production Process (Own work, 2023)

The next stage is essential to the shaping process. The substrate together with the mycelium can be moulded, or 3D printed. After, the mycelium elements are placed in a controlled environment with appropriate temperature and humidity until the mycelium fully colonizes the substrate and is turned into a solid, structurally sound block. Subsequently, the mycelium elements will be dried to reduce moisture and stop the mycelium from growing. After the elements are dried, the mycelium elements optionally can be post-processed into different forms. By cutting or perforating, the form of the material can be adapted. Finally, the mycelium material can be used in various applications until its end of life when it will be composted again and the whole cycle can start over. During this process, there are three different moments which have a significant impact on the form: moulding, 3D printing, and post-processing. (Elsacker, 2021)

Figure 20: Mycelium growing process (Studio Volop, n.d.)

2.5 Experiment: Growth on Local Substrates

To better understand the growth process of mycelium and its visual appearance when cultivated on various substrates, an experiment was conducted using locally grown vegetables. This experiment aimed to explore how the substrate material impacts the visual appearance of mycelium, assessing both growth efficiency and aesthetic outcomes. The steps of this experiment are as follows, accompanied by the illustrative images shown in Figure 21:

1. Selecting the Substrates:
Locally grown vegetables were chosen as substrates for the mycelium growth experiment. The selected substrates included rutabaga, potato, beetroot, red onion, purple carrot, and orange carrot.

2. Cooking the Substrates:
Before adding the substrate to mycelium, it was sterilized by cooking it in a solution of water and ethanol. This process ensures that the substrate is free from contaminants to grow without interference from unwanted microorganisms.

3. Mixing the Ingredients:
The mycelium starter was then added to the substrate along with the addition of flour, serving as a 'kickstarter' for the mycelium growth. To facilitate optimal growth conditions, all the materials were thoroughly mixed to ensure even distribution and maximize the potential for successful mycelium colonization.

4. Filling the Molds:
The molds were then filled with the prepared substrate, and distributed evenly. Afterward, the openings of the mold were covered with plastic wrap, and small holes were made every 3 centimeters in order to allow the mycelium to breathe.

5. Letting the Mycelium Grow:
Then, the mycelium was grown for five days within the mold in a controlled environment of approximately 22°C. This growth period, ultimately resulted in the complete whitening of the products as the mycelium took over the substrate.

6. Growing out of the Molds

After five days of growth, the mycelium was carefully removed from the molds and allowed to continue growing for an additional two days in the same controlled environment at 22°C.

7. Drying the Products:

Finally the products were dried in an oven at 80°C for 2 to 3 hours to complete the drying process.

Figure 21: Steps in Mycelium Growth Experiment (Own Work, 2023)

Over the course of five days, the growth of mycelium on each substrate was evaluated and compared. In the initial two days, only condensation was noticeable. By day three, mycelium on potato and onion fully whitened as it colonized the substrates. Throughout days four and five, mycelium also began to dominate on orange carrot, rutabaga, and purple carrot. However, there was no growth observed on the beetroot substrate.

These results demonstrate the influence of substrate material on mycelium growth and appearance. Yet, it's important to acknowledge that this study is exploratory, and factors such as sterilization methods and environmental conditions may also have influenced the outcomes. Further research with controlled experiments is essential to fully comprehend and validate these findings for practical applications.

Figure 22: Growing Process of Mycelium Growth Experiment (Own Work, 2023)

The results of this experiment illustrate that mycelium can thrive on various materials, each producing distinct outcomes and variations. For instance, mycelium grown on potato resulted in a soft texture, while mycelium from orange carrot exhibited a marbled appearance, showcasing unique growth patterns.

Discussing these findings with Arthur Moree, Chief Technology Officer of Grown Bio, a Dutch mycelium technology company, it became evident that the substrate choice significantly influences appearance, but external factors also play a substantial role. Adjusting growth conditions, such as varying temperatures or duration of growth, can manipulate texture and appearance. For example, fluctuating temperatures can produce marble-like textures, whereas longer growth periods can result in softer textures on substrates. These insights underscore the complexity and potential versatility of mycelium-based materials in architectural elements.

Figure 23: Results of Mycelium Growth Experiment (Own Work, 2023)

2.6 Material Properties

Mycelium composite has multiple advantages as well as disadvantages as a building material. Growing from agricultural waste or byproducts, the lightweight material is completely biodegradable. Mycelium-based materials can be engineered for good thermal and sound insulation. The material being affordable and not very time consuming, the fabrication allows for unique and tailored architecture due to its flexibility in customization and form freedom. However, mycelium-based materials do come with drawbacks. They can be sensitive to moisture and therefore have a limited lifespan. (Elsacker, 2021)

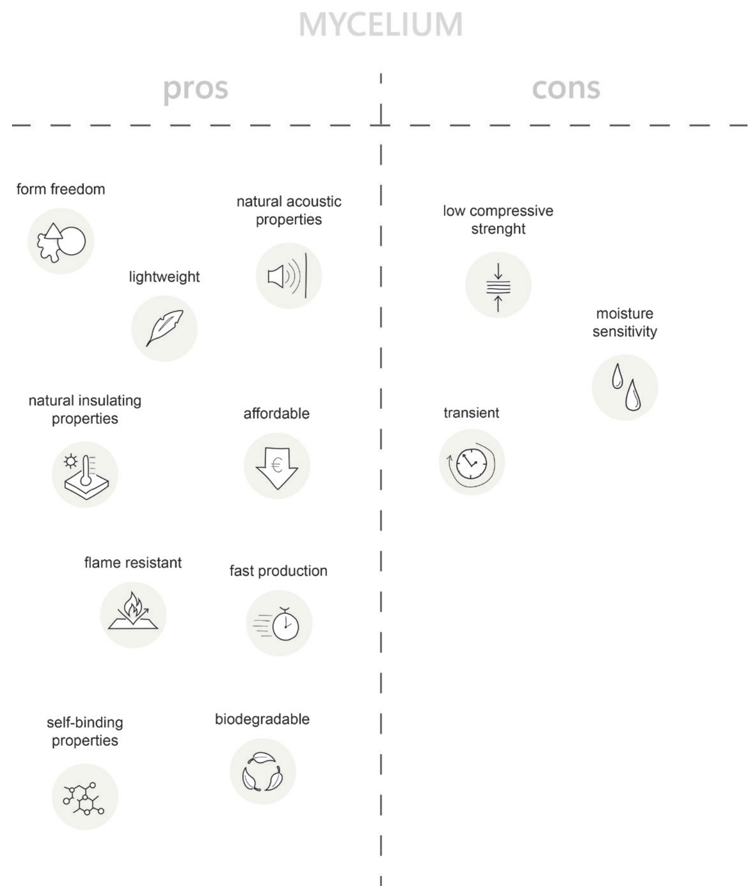


Figure 24: Pros and cons of mycelium as a building material (Own work, 2023)

Comparing the structural properties of concrete and light and heavy wood types shows that the compressive strength of mycelium is significantly lower. However, relative to their weight, mycelium is much stronger because of its low density. It has a comparable flexural strength to concrete, but since it has a lower compression strength, it is not able to bear a lot of load. This means it's still possible to build up to twelve meters high, however, it can not serve as a structure for heavy loads. In comparison to concrete, the temperature to produce mycelium is way lower. Additionally, mycelium has an embodied carbon footprint of 0 kg CO2/m³. This means that the process of creating mycelium-based materials, has minimal to no carbon emissions associated with it, making it a sustainable choice for construction. It also has a low production temperature. In terms of fire resistance mycelium is classified as fire class A, meaning that it has excellent fire resistance properties and that it does not catch fire or spread flames. (Redhouse studio, n.d.)

	mycelium	concrete	pine wood	oak wood
ultimate compression	6,7 MPa	24 MPa	30 - 55 MPa	60 - 90 MPa
flexural strenght	2,9 MPa	3 - 6 MPa	40 - 80 MPa	60 - 120 MPa
density	43 kg/m3	2.400 kg/m³	350 - 600 kg/m³	590 - 900 kg/m³
production temperature	15 - 30 °C	1400 °C	0 °C	0 °C
carbon footprint	0 kgCO2/m³	200 kgCO2/m³	300 KgCO2/m	200 KgCO2/m
fire resistance class	A (1 hour)	A (1 hour)	D (15 minutes)	D (15 minutes)

Figure 25: Comparing structural material properties (Own work, 2023)

Next to its structural properties, mycelium has good insulating properties which are comparable with traditional insulation materials such as rock wool and polystyrene. In comparison, mycelium has a good sound absorption performance with an NRC value which can go up to 0,6. In addition, it can be produced under significantly lower temperatures and it has a lower carbon footprint. It also has excellent fire resistance properties just like rock wool. (Elsacker, 2019)

	mycelium	rock wool	extruded polystyrene
thermal conductivity	0,035 to 0,05 W/m.K	0,030 - 0,040 W/m.K	0,028 - 0,035 W/m.K
density	43 kg/m3	15 - 175 kg/m3	28 - 45 kg/m3
sound absorbation (nrc)	0,3 - 0,6	1,0	0,1
production temperature	15 - 30 °C	1500 - 1600 °C	180 - 210 °C
carbon footprint	0 KgCO2/m	20 - 40 KgCO2/m	30 - 60 KgCO2/m
fire resistance class	A (1 hour)	A (1 hour)	D (15 minutes)

Figure 26: Comparing insulating material properties (Own work, 2023)

3. **Architecture as a Cyclical Process**

3.1 Phases of the Cyclical Process

The cyclical process of mycelium consists of the three phases: growth, maturity and decay. This natural phenomenon can serve as an inspiration for architectural design, fostering a cyclic approach to building instead of linear processes.

The growth phase, symbolized by mycelium's expansion and branching, can be seen as the phase in which the building is starting to take shape. The second phase between mycelium's growth and decay, can be called the "maturity" phase. During this stage, the mycelium network has reached a state of stability and strength, establishing a stable structure that persists for a significant period of time before transitioning into the decay phase. During this phase of decay, the building structure undergoes decomposition, gradually breaking down and dissolving back into nature. After this the whole cycle can start over again.

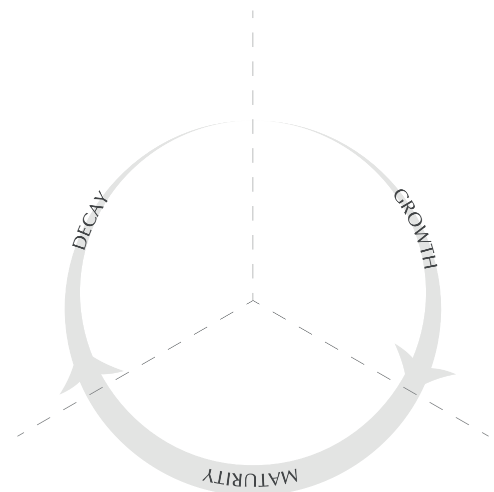


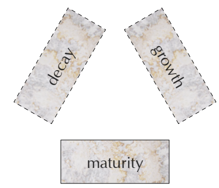
Figure 27: A diagram of mycelium's cyclical process (Own work, 2023)

3.2 Cyclical Process through Composition

The cyclical progression of Mycelium, characterized by its stages of growth, maturity, and decay, can be expressed architecturally through the creation of three distinct volumes, each representing a unique phase within this cycle. These volumes, constructed to mirror the different phases, offer various compositional arrangements.

Initially, these volumes may stand separately, emphasizing the three different phases. A second composition can be a circular sequence facilitating a gradual transition from one volume to another, expressing a more natural progression. Another possibility involves interconnecting the three volumes at a central point. This composition allows the integration of a permanent core suitable for installations or other static elements. This last composition expresses the cyclic nature of Mycelium while providing opportunities for functional additions within a central, cohesive space.

1. SEPARATION



A composition of three seperate volumes emphasizes the three phases of the mycelium lifecycle.

2. SEQUENCE

A circular sequence of the three volumes creates a gradual transition from one volume to antother in a natural way.

3. CONNECTION

Connecting the three volumes in a central point gives the possibility for a permanent central core for installations.

Figure 28: Composition studies of the three volumes (Own work, 2023)

3.3 Extend of Temporality

Figure 29 is an explorarion to the extend of temporality through building materials. As the diagrams show, the extend of temporality is significantly influenced by which building parts are made of mycelium and which building parts are made of permanent materials.

In the first diagram, mycelium is only used for the interior walls. In this case the exterior is made out of a permanent material. This leads to a flexible interior, however the exterior remains static. The second diagram consists of a permanent structure with mycelium exterior and interior walls. In this case the mycelium facades will decay but the structure leave traces of where the building used to be. The permanent structure gives a framework for the dynamic facades to grow again after time. The third diagram illustrates a building which is completely made out of mycelium. In this scenario the building will completely decay and leaves no traces over time. This dynamic structure, leaves no traces and the past state of the building. However, after the phase of decay, it will be more difficult to bring the building back into the same state.

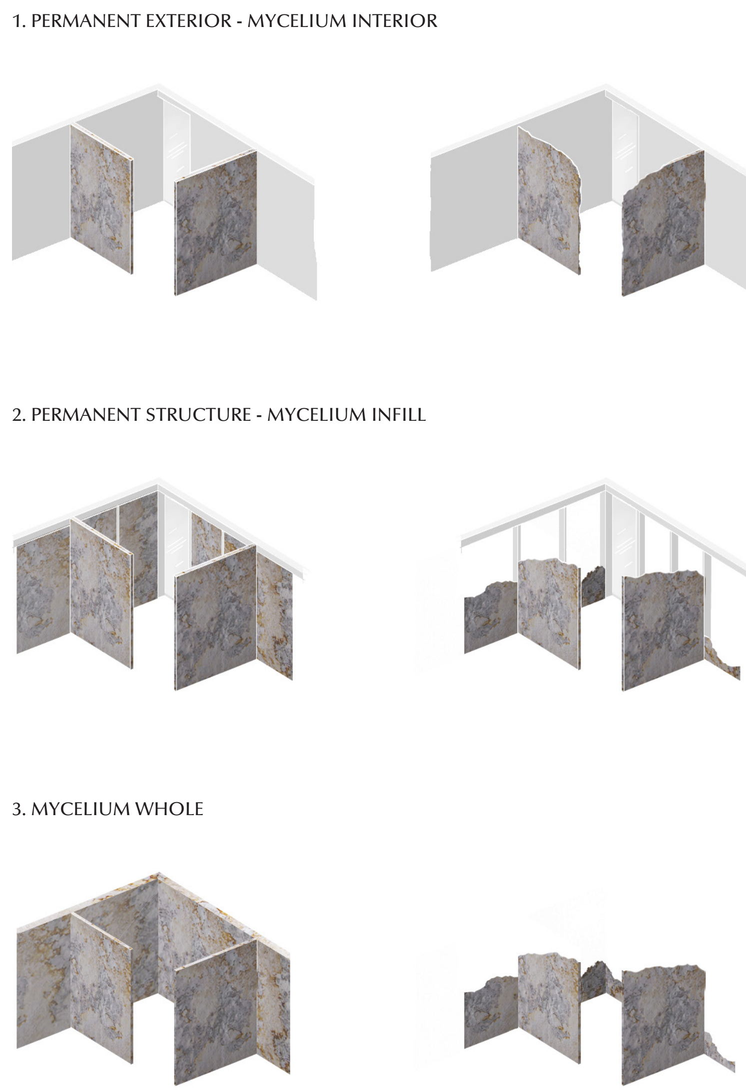


Figure 29: Extend op temporality through building elements (Own work, 2023)

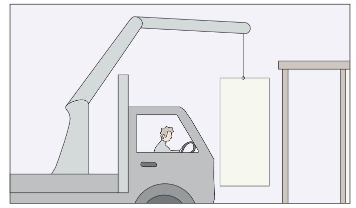
3.4 Logistics: Fabrication and Placement

There are multiple ways of fabricating the mycelium building elements and placing the building parts. First of all the elements can be fully grown in a factory and transported with flexible crane. This is a efficient method, which allows for controlled conditions ensuring optimal growth, uniformity and quality. However, the fabrication will not be visible on site and it requires a lot of transport.

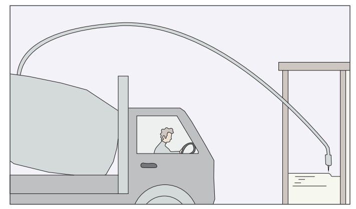
Another approach is on site manufacturing with a 3D printer. This approach allows for greater adaptability in constructing customized elements, flexibility and precision.

A third possibility is to grow the building elements on site and placing it by hand. This approach introduces an organic, interactive and site specific dimention to the building process. While this technique might require more time and effort on-site, it establishes a direct connection between the construction process and the environment, potentially reducing transportation needs and fostering a more sustainable construction approach. (Hendrikx, 2019)

PREFAB: BY TRUCK



ON SITE: 3D PRINTING



ON SITE: BY HAND

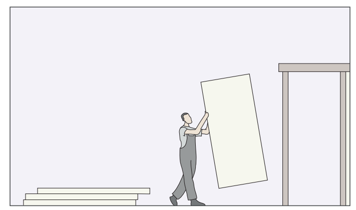


Figure 30: Logistic (Own work, 2024)

3.5 Duration of the Cyclical Process

Predicting the duration of mycelium's cyclical process remains speculative. This duration is dependant on numerous factors, primarily the environmental conditions. In optimal and stable environments, mycelium-based materials, such as mycelium bricks, have demonstrated the capacity to endure for up to two decades. However, fluctuations in temperature, humidity levels and exposure to moisture significantly impact the lifespan of mycelium structures. According to an article from the International Journal of Engineering Research & Technology in 2022 the lifespan of mycelium in architectural applications ranges from approximately 6 weeks to a potential maximum of 20 years. (Hatkar & Lanke, 2022)

Also the phase of decay and growth remain unpredictable due to an unpredictable climate. The duration of decay can vary from several months to several years. The phase of growth is dependent on the type of fabrication. For instance, in controlled laboratory settings optimized for mycelium cultivation, growth can be relatively fast and may take only a few weeks to fully colonize a substrate. In less controlled environments the phase of growth might take longer, potentially spanning several months to achieve full colonization.

Given this unpredictability, assumptions regarding the durations of different phases were discussed with Arthur Moree, Chief Technology Officer of Grown Bio. In envisioning a scenario set in the Dutch landscape a century ahead, the uncertainty of environmental circumstances adds to the material uncertainties. While contemplating potential advancements in mycelium technology, there's a probability of a longer lifespan. However, it's essential to acknowledge the anticipated changing climate, estimated to become wetter and more extreme. Considering these expected technical advancements and climate shifts, an estimation is made of the three phases. The maturity phase, as well as the decaying phase are expected to take about 5 years. The phase of growth will be a bit faster and will only take several months.

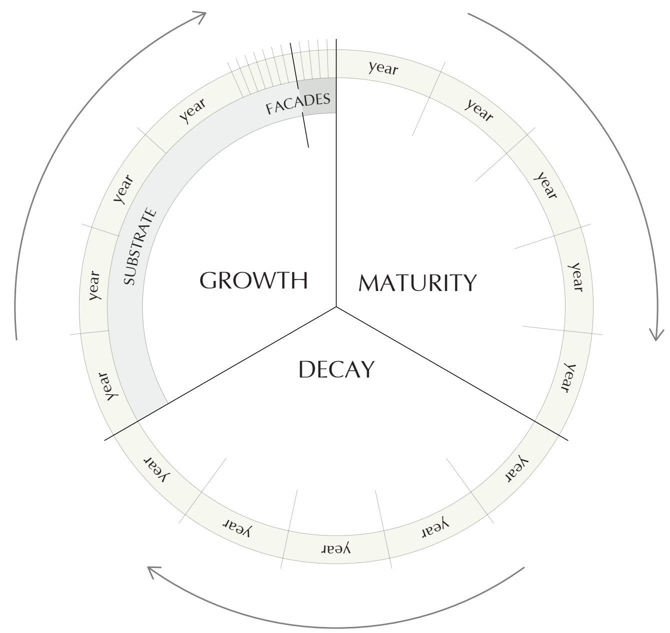


Figure 31: Assumed duration of the cycle (Own work, 2024)

4. **Conclusion**

This research investigated how mycelium's cyclical nature can find expression and practical application within architecture. Based on literature studies and research by design, it becomes apparent that mycelium's cyclical nature can be expressed in architecture by conceptualizing three distinct volumes, each symbolizing a different phase of the mycelium cycle. While one volume signifies growth, another represents maturity, and the third portrays decay.

These volumes first of all offer versatility in their arrangement, thereby influencing their expression and practicality. Research by design demonstated how these volumes can be arranged as separate entities, forming a circular sequence, or converging at a central point, allowing for a static core suitable for installations or fixed functions.

The choice of exclusively using mycelium or using the material in combination with more enduring materials impacts the longevity of structures. While a full mycelium structure embraces the cyclical nature of the material, it raises questions about restoration and renewal.

Methods of fabrication, ranging from controlled factory growth to on-site organic growth, allow architects and builders to align their projects with sustainability goals and specific project needs.

Additionally, it is inevitable to consider the duration of mycelium's life cycle, as it highly influences practical considerations. Given its unpredictability, determining the precise duration of each phase remains an assumption. Taken into account the fluctuating environmental conditions and advancing technology an assumed timeframe is taken of approximately 5 years for the growth phase, followed by 5 years of maturity, and a relatively shorter span of a few months for the growth phase. To ensure a harmonious alignment of the cycle, all phases should share the same duration. Consequently, the growth volume will primarily exist symbolically, encompassing the cultivation of the substrate rather than the growth of mycelium itself.

In conclusion, combining all these considerations and possibilities leads to a design proposal that integrates them into a cohesive whole. In this proposal, the architectural object can consist of a static structure, in combination with a mycelium infill. This decision allows for regeneration in a practical way and accepts mycelium's disability to bear load and function in a static way. Additionally, the building layout involves connecting three volumes and one or several inner cores, fostering on-site mycelium production within the building itself. This approach ensures that mycelium elements are cultivated in a controlled environment before seamlessly integrating them into the growth volume.

5. **Discussion**

This research has addressed the integration of mycelium's cyclical nature within architecture. However, certain limitations can not be disregarded. One of the limitations of this research is the unpredictability of environmental conditions. Mycelium's growth and behaviour are influenced by factors such as temperature, humidity, and moisture levels, which can vary significantly across different locations, climates and moments in time. Therefore, the assumed timeframes for the various phases of the mycelium cycle should be interpreted with caution, as actual conditions and duration may deviate from these estimates.

While this research offers valuable theoretical insights, practical implementation in real-world architectural projects is necessary to validate the assumptions made. Long-term monitoring of mycelium structures and their performance in various climates and conditions will provide valuable data for further refinement.

In addition, another follow-up research should be done, regarding the specific types of fungi employed in mycelium-based architecture. The choice of fungal strains, along with varying climatic conditions and the assumed five-year duration of each phase, leads to a complex interplay of variables. Different fungal species may exhibit different properties and tolerances to environmental fluctuations. It is therefore crucial to delve deeper into the selection and performance of specific fungal strains.

III. FUTURE SCENARIO

1. **The Hunze a Century Ahead**

1.1 The Hunze River Valley

The Hunze River Valley covers the area between the city of Groningen and Lauwersoog. The area has been subject to change and developments for decades. Since the 20th century the Hunze River Valley underwent a gradual transition from a natural wetland area with winding rivers into a man made agricultural landscape. The Hunze river used to be a winding stream connecting Drenthe with the Waddensea, but has been largely straightened and dissapeared. In 1995, the first "Hunzevisie" a vision for the area has been presented as a collaboration of "het Groninger Landschap", "het Drentse Landschap" and the "World Wildlife fund". This vision involved restoring the natural landscape by reintroducing the meandering stream and allowing it to flow freely through the landscape.

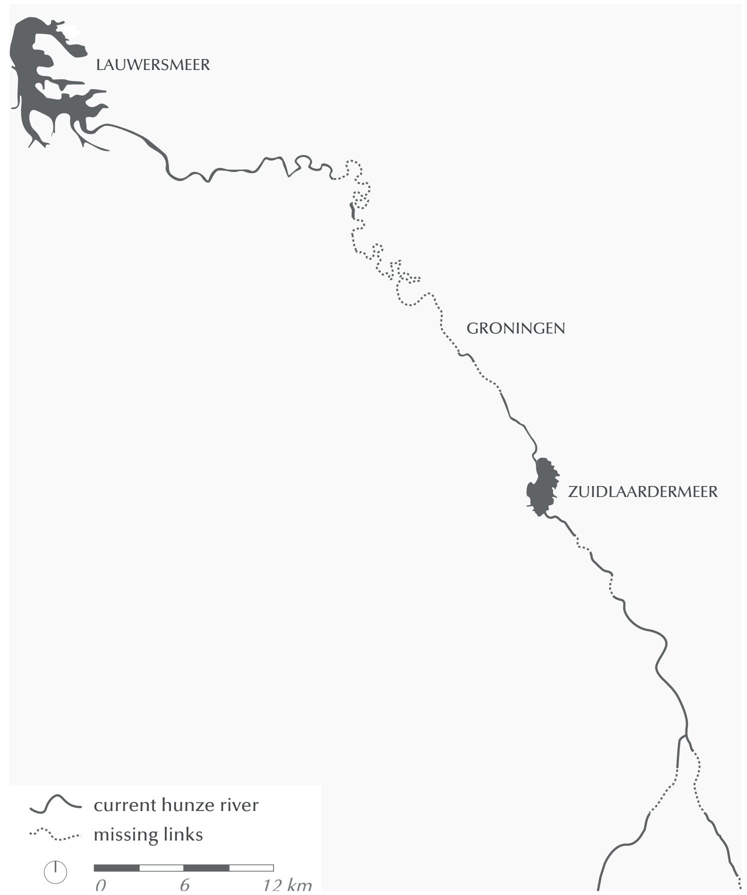


Figure 32: Current Hunze River and its Missing Links (Own work, 2023)

The adoption of the "Hunzevisie" has brought about profound changes to the Drenthe area over the past fifteen years. As you can see in figure 33, the Hunze river now meanders again through the landscape of Drenthe. Over the last two decades, along these riverbanks, over 3000 hectares of new wetland nature has emerged in between the dikes. Water plants, fish, and insects have returned, and the area has become a flourishing habitat for beavers and birds. In the meantime, the Hunze area between Groningen and Lauwersoog is still characterized by a cultivated and straightened landscape as you can see in figure 34.

Figure 33: The Hunze in Drenthe (CNK, 2013)

Figure 34: The Hunze in Groningen (Paris, n.d.)

1.2 A Future Scenario

Following the 1995 Hunzevision, an updated vision was formulated five years ago, outlining a renewed perspective for 2030. This vision aims to create a continuous stream from Drenthe to Lauwersoog. The Hunzevisie of 2030, together with anticipated sea-level rise and the need for climate restoration, sets the stage for a future scenario a century ahead.

Envisioned as a wetland natural park along the Hunze River, spanning between Drenthe and Groningen's dikes, the area will serve as a protective buffer against rising water levels. Utilizing its natural dynamics, the wetland prevents potential flooding while nurturing diverse ecosystems. The meandering river provides habitats for flora and fauna, promoting biodiversity and providing safe grounds for indigenous species such as birds and fish. Moreover, the area will both serves recreational and educational purposes, inviting visitors to learn about the significance of wetlands in environmental conservation. Integrated trails, and viewing platforms, will enhance the visitor's experience and understanding of the wetland ecosystems.

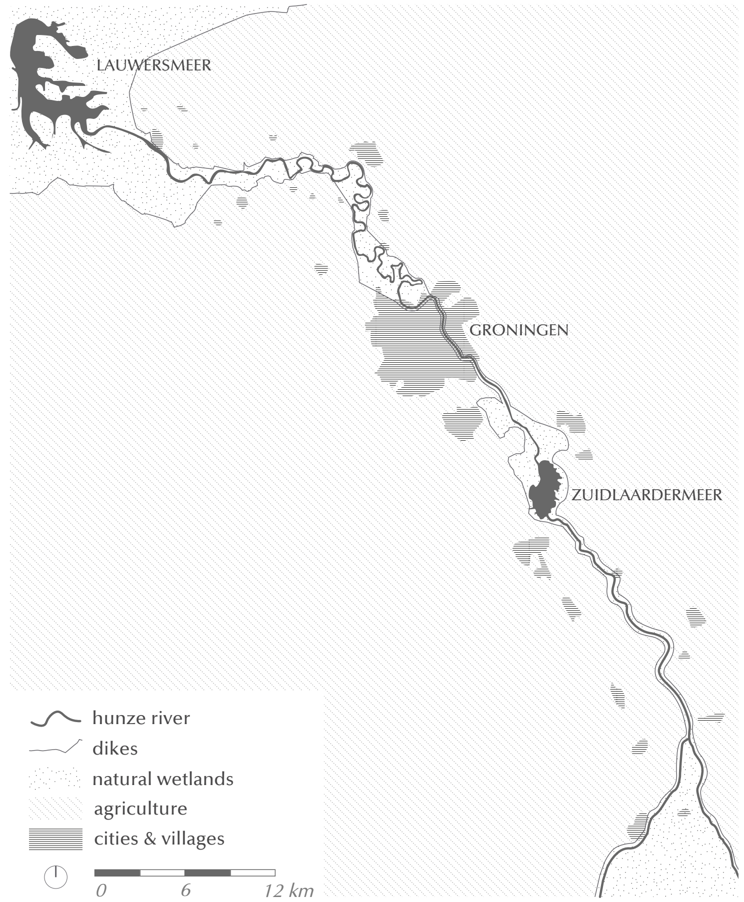


Figure 35: Future scenario for the Hunze River Valley (Own work, 2023)

2. **Defining the Program**

2.1 Potential for a Nature Centre

Situated within this evolving landscape, a nature centre seems like a fitting addition to the envisioned future scenario. A nature centre is a facility dedicated to environmental education and conservation initiatives. Typically situated within natural settings like parks or forests, these centres provide a range of educational programs, interactive displays, exhibitions, and trails, serving the general purpose of enhancing awareness of local ecosystems and fostering conservation efforts. These public institutions serve the purpose of connecting individuals with nature, aiming to educate and underscore the significance of preserving these environments. Given their multifunctional character, the program of a nature centre should incorporate spaces designed for exhibitions and educational activities.

The Hunze River Valley presents an ideal setting for a nature centre due to its rich and evolving natural landscape. Acting as a central point to a diverse ecosystem, a nature centre here would serve as a hub for environmental education and conservation efforts. The Hunze area is expected to transform from a heavily modified agricultural landscape into a flourishing wetland habitat. By showcasing this transformation, a nature centre can highlight the importance of ecological restoration and the significance of preserving natural habitats. Moreover, the Hunze's proximity to Groningen and its relative unfamiliarity among locals make it a perfect location to bridge the gap between urban communities and the natural world. Offering educational programs, interactive exhibits, guided tours, and hands-on experiences, a nature centre would not only raise awareness about the Hunze's ecological value but also inspire visitors to appreciate and actively participate in its conservation. This building will be a hub for fostering a deeper understanding of the local environment and promoting sustainable practices for future generations.

2.2 Target Groups

The first target group of visitors predicted to utilise the nature centre are short-stay tourists visiting the location for sightseeing. For this group the building will serve as an informational hub to guide visitors throughout the area, aiming to foster a deeper comprehension of the site, its historical context and its significance in nature. The main functions needed for this target group are an exhibition space, an information place, a café and toilets.

A second target group are the organised study groups. The nature centre could serve as an educational hub for these groups, focussing primarily on sharing knowledge about the location's natural importance. This involves a place for lectures and additional workshops to facilitate learning.

A third group, considered as a main user of the nature centre is the local community. Comprising residents of the area and frequent visitors, the centre would function as a cultural hub, offering lectures, exhibitions, and cultural events tailored to the community's interests and preferences.

Additionally, flora, fauna and fungi represent a final but crucial target group for the nature centre. Understanding their pivotal roles in the local ecosystem, the centre is dedicated to creating an environment that supports and nurtures not only birds and insects, but also plants and mushrooms.

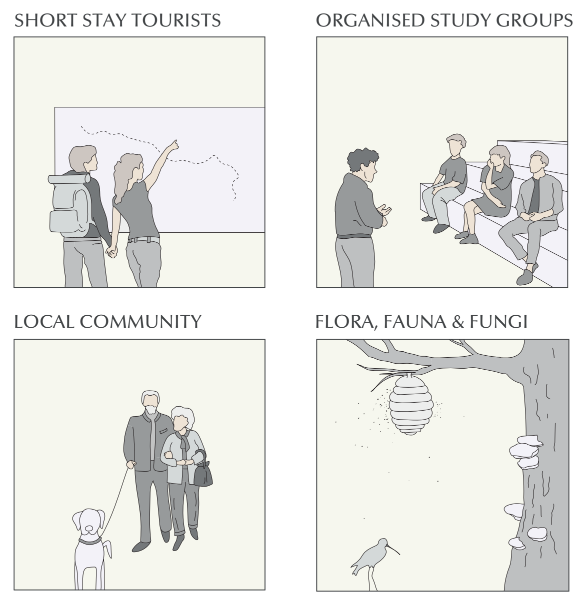


Figure 36: Target Groups (Own work, 2024)

2.3 Exhibition Themes

Exhibition themes for a nature centre should ideally align with the centre's goals of education, conservation, and fostering an appreciation for the local environment.

A theme that could fit well in these topics is the biodiversity and ecosystems. The variety of life forms in the local ecosystem, including flora, fauna and fungi could be highlighted. Within this topic, visitors can be educated about environmental challenges and the importance of conservation efforts.

A second exhibition theme could be the local cultural and natural history. This invoves an exploration of the geological formations and the impact of human of the landscape.

A third exhibition theme could be showcasing local artwork inspired by the natural landscape of the area, emphasizing the connection people have with the natural world. This could include photography, paintings, sculptures, or installations.

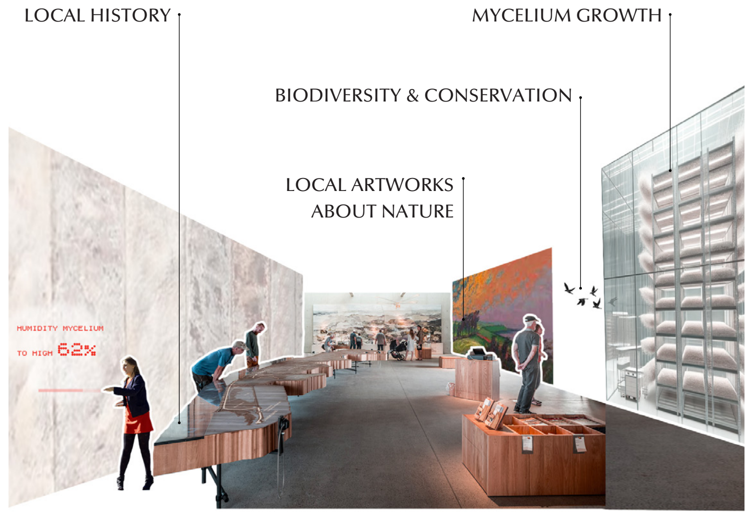


Figure 37: Exhibition themes collage (Own work, 2023)

3. **Defining the Location**

3.1 A Location for a Nature Centre

The selected site for the Nature Centre is located in the heart of the Hunze River Valley, in an area anticipated for future development, since it is right at a spot where the Hunze will be restored to its original state. Situated approximately 15 kilometers from the city of Groningen, its strategic accessibility ensures a good accessibility for city residents, providing a hub for urban dwellers to immerse themselves in this natural landscape, fostering a deeper connection between the citizens and the captivating landscapes that surround them.

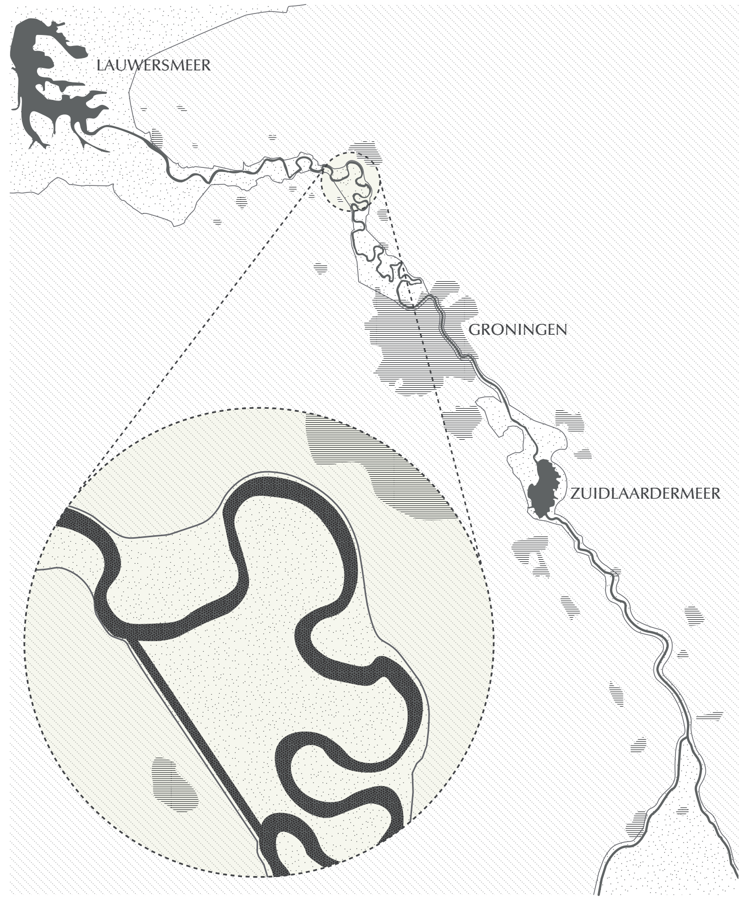


Figure 38: Location for the nature centre (Own work, 2024)

Surrounded entirely by the winding Hunze River, this location offers a unique natural setting. Positioned at a slightly elevated point within the wetlands, it's a site that harmonizes with the surrounding landscape. However, due to the use of mycelium as the primary building material, which lacks inherent water resistance, a dwelling mound will be created to protect the building from the water. This mound not only protects the structure from water but also connects to the traditional dwelling mounds that characterize the Groningen landscape.

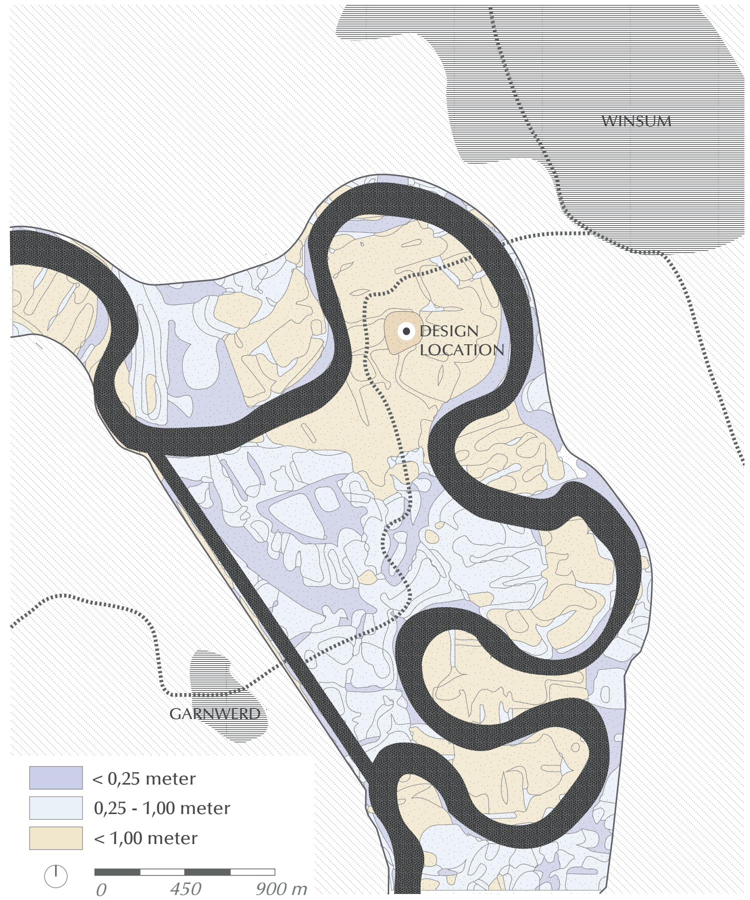


Figure 39: Location for the nature centre (Own work, 2024)

IV. The Design

1. Architecture as a Cyclical Process

1.1 Design Concept

In the heart of Groningen's future wetlands, nestled on a dwelling mound to protect against water, 'Rhythms of Renewal' embodies a design approach that celebrates the cyclical processes of mycelium, wood, and stone. This design aligns the duration of material cycles with the intended lifespan of the building parts and functions they are used for, ensuring harmony between natural processes and architectural longevity.

Building parts with a long intended lifespan are made of stone, a more enduring material, while parts or functions with a shorter intended lifespan are constructed from mycelium, a more transient material. Intermediate components are made from wood, striking a balance between permanence and transience. This approach allows for adaptability, reduced waste upon removal, and even natural decay, eliminating the need for removal.

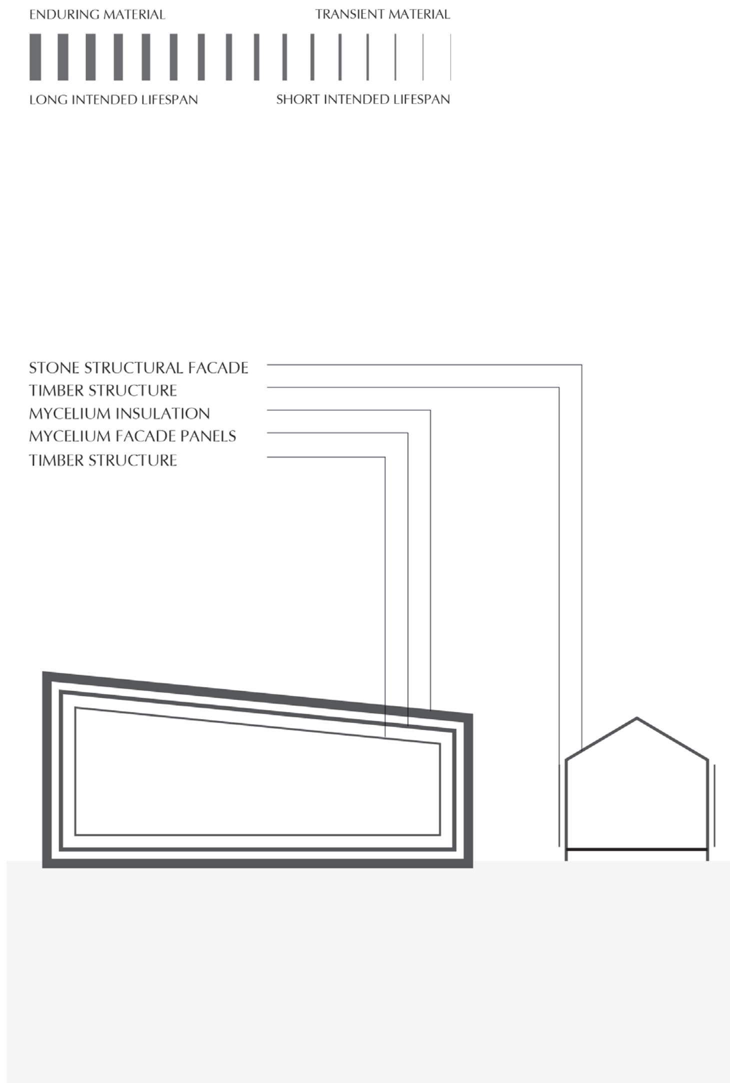


Figure 40: Material Diagram (Own work, 2024)

1.2 Composition

The project showcases a dual composition: three dynamic structures, each representing one of the phases of the mycelium lifecycle: Growth, maturity, and decay,. Additionally, it features three sturdy structures housing more static functions.

The volumes are positioned around an inner garden, with openings towards the landscape, allowing you to observe all the different structures simultaneously while maintaining a connection with the surrounding environment. While the dynamic structures are arranged in a triangular formation, the static structures are interconnected through extended lines, creating a cohesive ensemble.

Visitors arrive along a long path positioned alongside a line of trees, passing an entrance building with a café. From there, they can either proceed to the auditorium or take the continuous route through the mycelium galleries and laboratory, engaging with the themes of growth, maturity, and decay as they move through the space.

Figure 41: Site model 1:500 (Own work, 2024)

1.3 Lifecycle and Functions of the Galleries

The gallery of growth can be seen as an empty timber structure with vegetables growing through. These vegetables will be the substrate from which the mycelium panels are grown in the laboratory. Only the walking path is covered by the roof while the plants are not covered, allowing rainwater to reach the plants. After 5 years the mycelium panels are placed and the space will transform into the gallery of maturity.

The gallery of maturity is a fully developed interior space, accommodating exhibitions about the local history, local artworks about nature, biodiversity, conservation and biobased materials. At the end of this phase, the overhang of the roof and parts of the floor will be removed initiating the process of decay.

The gallery of decay serves as a conservation space for flora, fauna and fungi. This space can offer nesting grounds for birds, and offer spaces for fungi and plants. Finally the healthy soil will be the starting ground for growth to start again.

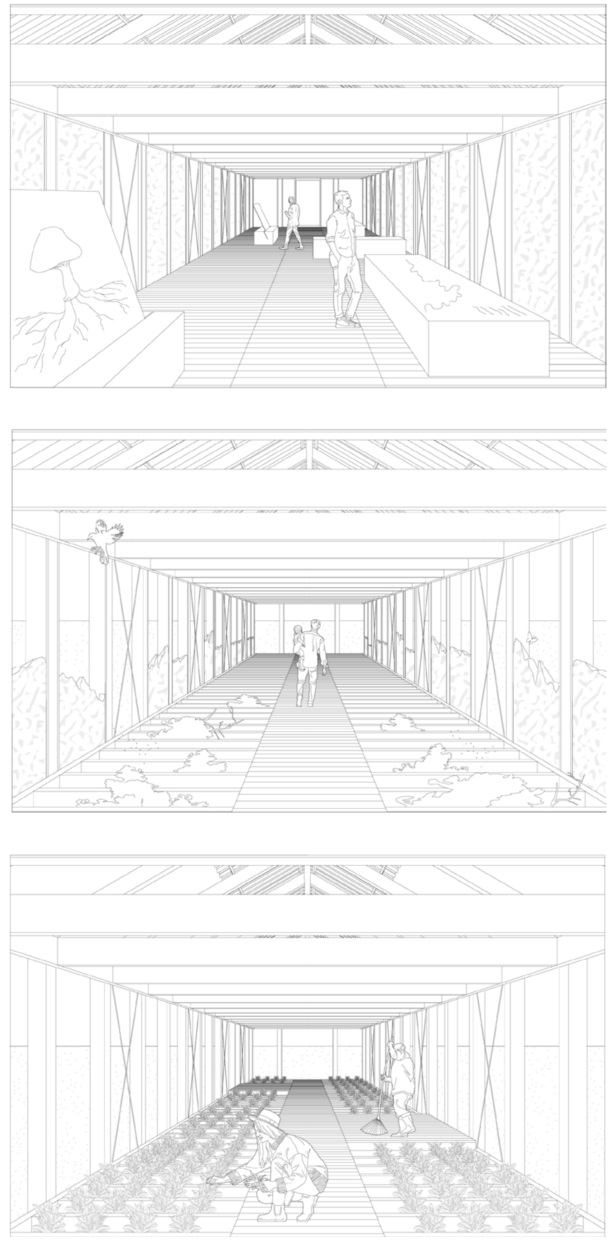


Figure 42: Transformations of the Galleries (Own work, 2024)

1.4 Dynamic Structures

The dynamic structures consist of a timber framework with a mycelium infill. Aesthetically, they embody the principle often seen in art and design where a rule is established and then intentionally broken to create visual interest. The timber framework sets a strict rhythm with its regular, orderly pattern, establishing a sense of stability and structure. In contrast, the mycelium panels introduce a dynamic element, breaking the uniformity and drawing attention, making the design more engaging and visually captivating.

To further complement the design, the mycelium panels are placed in front of floor and roof beams, enhancing the rhythmic structure. Aditionally, the long mycelium galleries are crafted with a linear direction that stimulates movement and guides visitors through the space. Elevated slightly to create a sense of lightness, the polycarbonate corrugated roofing adds to the lightness, aligning with the design aesthetic.

Figure 43: Model 1:20 (Own work, 2024)

1.5 Static Structures

In contrast to the dynamic structures, the static elements of the design feature enduring natural stone facades housing the café, auditorium, and mycelium laboratory. These structures evoke a sense of permanence and timelessness with their einduring, solid natural stone facades, offering a striking contrast to the adjacent dynamic structures. This contrast enhances the overall aesthetic by juxtaposing the transient qualities of mycelium with the enduring solidity of natural stone, creating visual interest.

Inside, these structures, a timber frame supports the roof, while mycelium panels are used as insulation to meet the energy efficiency standards. This approach positions the stone facade as the primary exterior wall, enabling future adaptations to interior insulation without compromising the facade's integrity. This method ensures longevity for the stone facades while maintaining flexibility for interior spaces. The static structures Equipped with advanced climate control systems, these areas maintain optimal environmental conditions crucial for the café, auditorium, and laboratory functions.

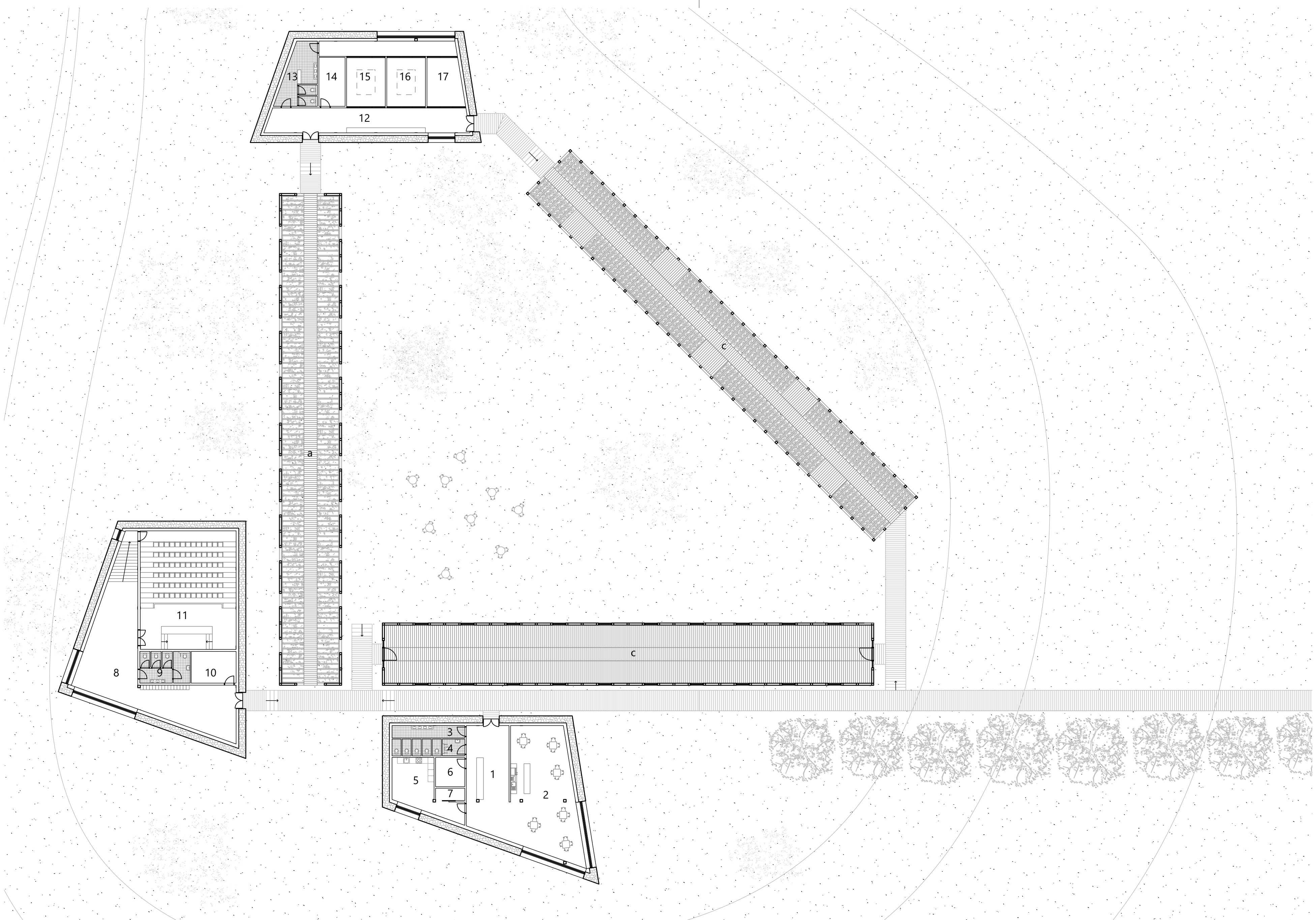
Figure 44: Model 1:50 (Own work, 2024)

2. Documentation

2.1 Architectural Drawings

The architectural drawings presented in this section provide a detailed overview of the project's spatial organization and structural elements. They include floorplans, elevations, sections, facade details, and specific construction details. These drawings are essential for understanding how the design concepts translate into physical form, offering insights into both the overall layout and the intricate architectural features crucial to the project's construction.

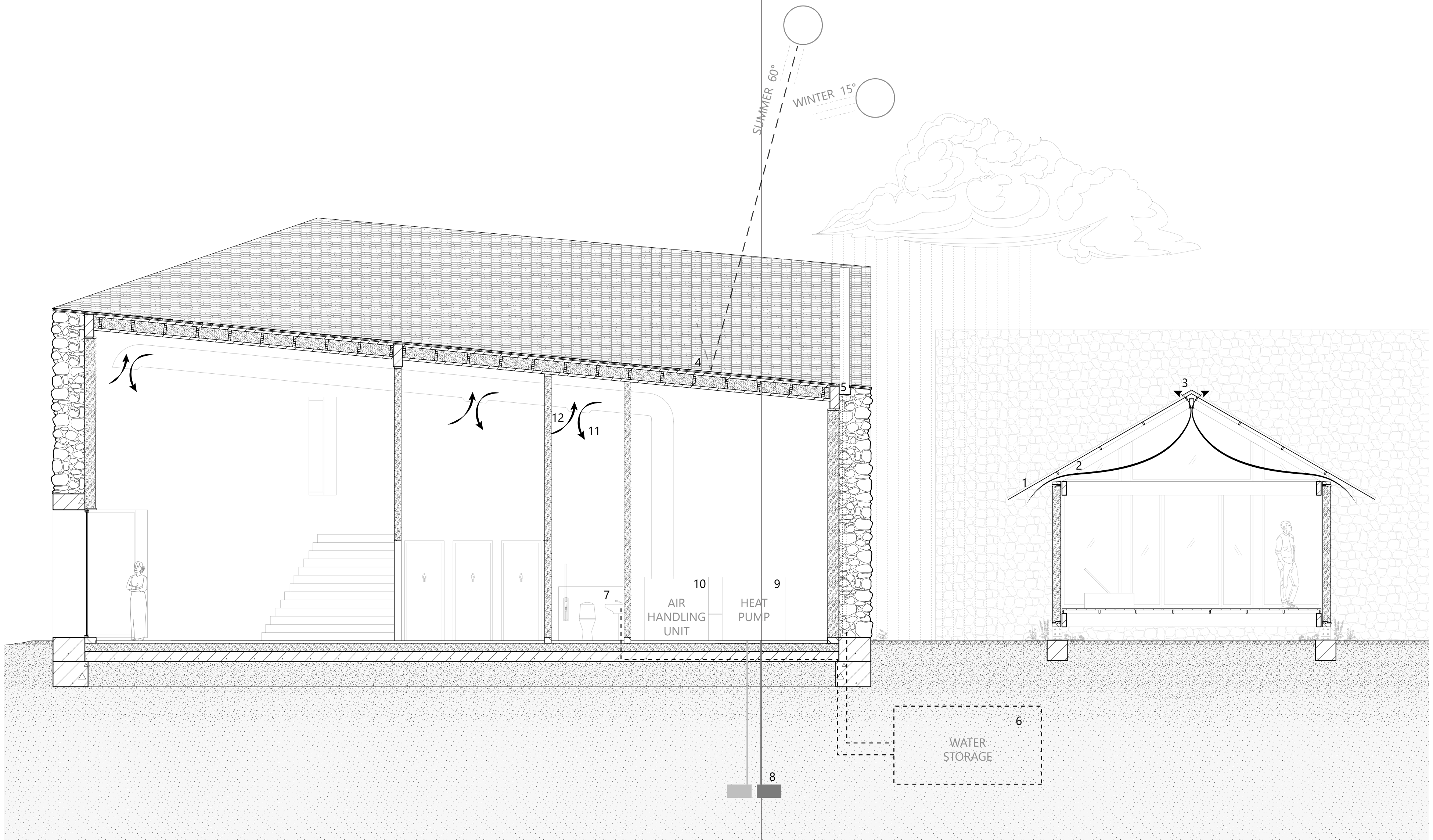
Figure 45: Floorplan 1:100 (scaled to 25%)



- *a.* *gallery of decay*
- *b.* *gallery of growth*
- *c.* *gallery of maturity*
- *1.* *info desk*
- *2.* *cafe*
- *3.* *toilets*
- *4.* *disabled toilet*
- *5.* *kitchen*
- *6.* *technical space*
- *7.* *storage*
- *8.* *foyer*
- *9.* *toilets*
- *10.* *technical space*
- *11.* *toilets*
- *12.* *lab gallery*
- *13.* *sanitary room*
- *14.* *technical room*
- *15.* *preparation space*
- *16.* *production space*
- *17.* *post-production space*

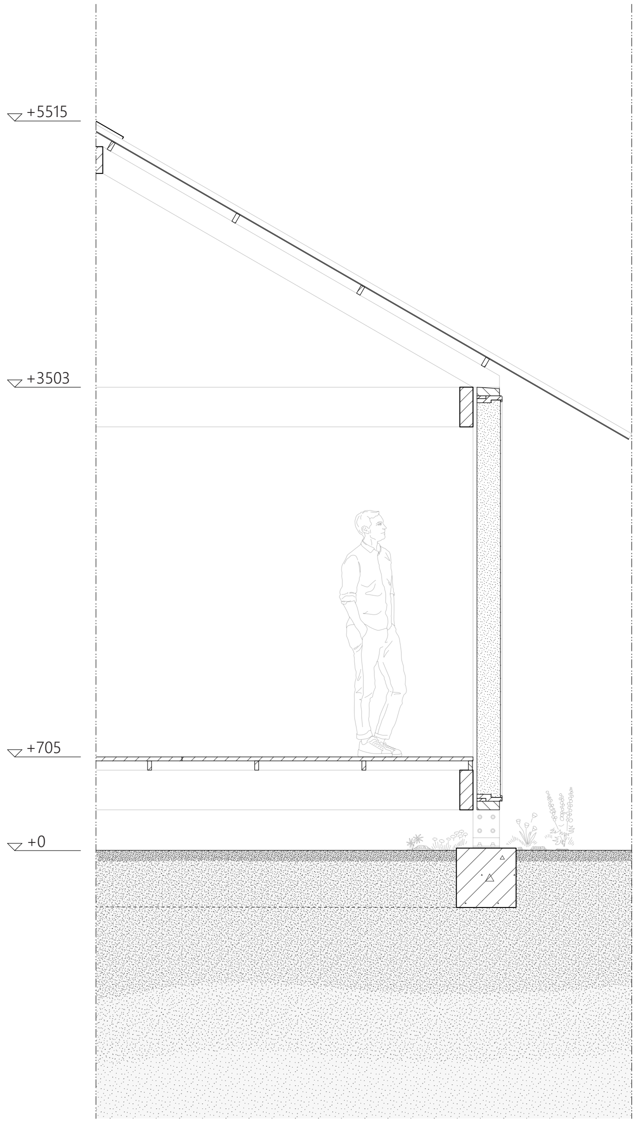
Figure 46: South Elevation 1:100 (scaled to 25%)

Figure 47: Section 1:50 (scaled to 45%)



1. *Water drains off the sloping roof.*
2. *Natural ventilation intake.*
3. *Natural ventilation exhaust.*
4. *Energy is generated through PV roof tiles.*
5. *Water is collected via a roof gutter.*
6. *The collected water is filtered and stored.*
7. *Filtered and stored water is utilized for taps and toilets.*
8. *In summer, excess heat from the building is stored in the ground, while in winter, cold from the building is stored in the soil.*
9. *In summer, the extracted cold is used to cool water circulating through the air handling unit, whereas in winter, the extracted heat is further elevated to an appropriate level for heating.*
10. *In summer, the air handling unit operates to cool the building through ventilation air while in winter, it is used for heating.*
11. *Fresh cold air is supplied in summer, and warm air is supplied in winter through supply ducts.*
12. *Warm, stale air is extracted from the building through the extraction ducts.*

Figure 48: Facade Fragment 1:20 (scaled to 35%)



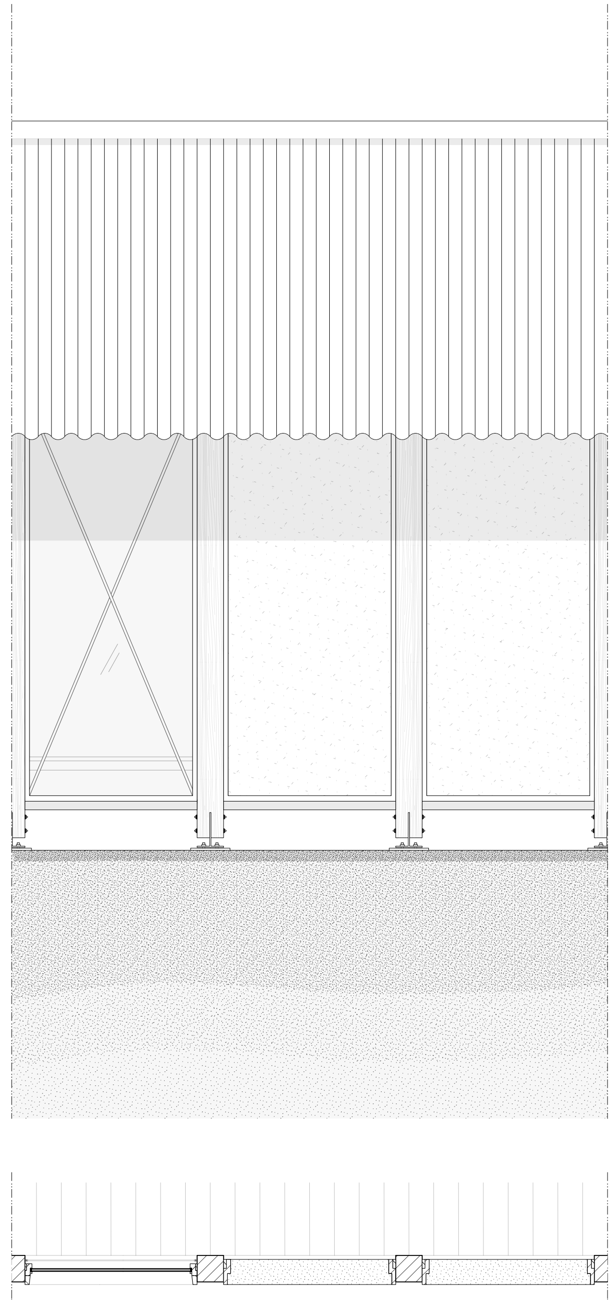


Figure 49: Facade Fragment 1:20 (scaled to 35%)

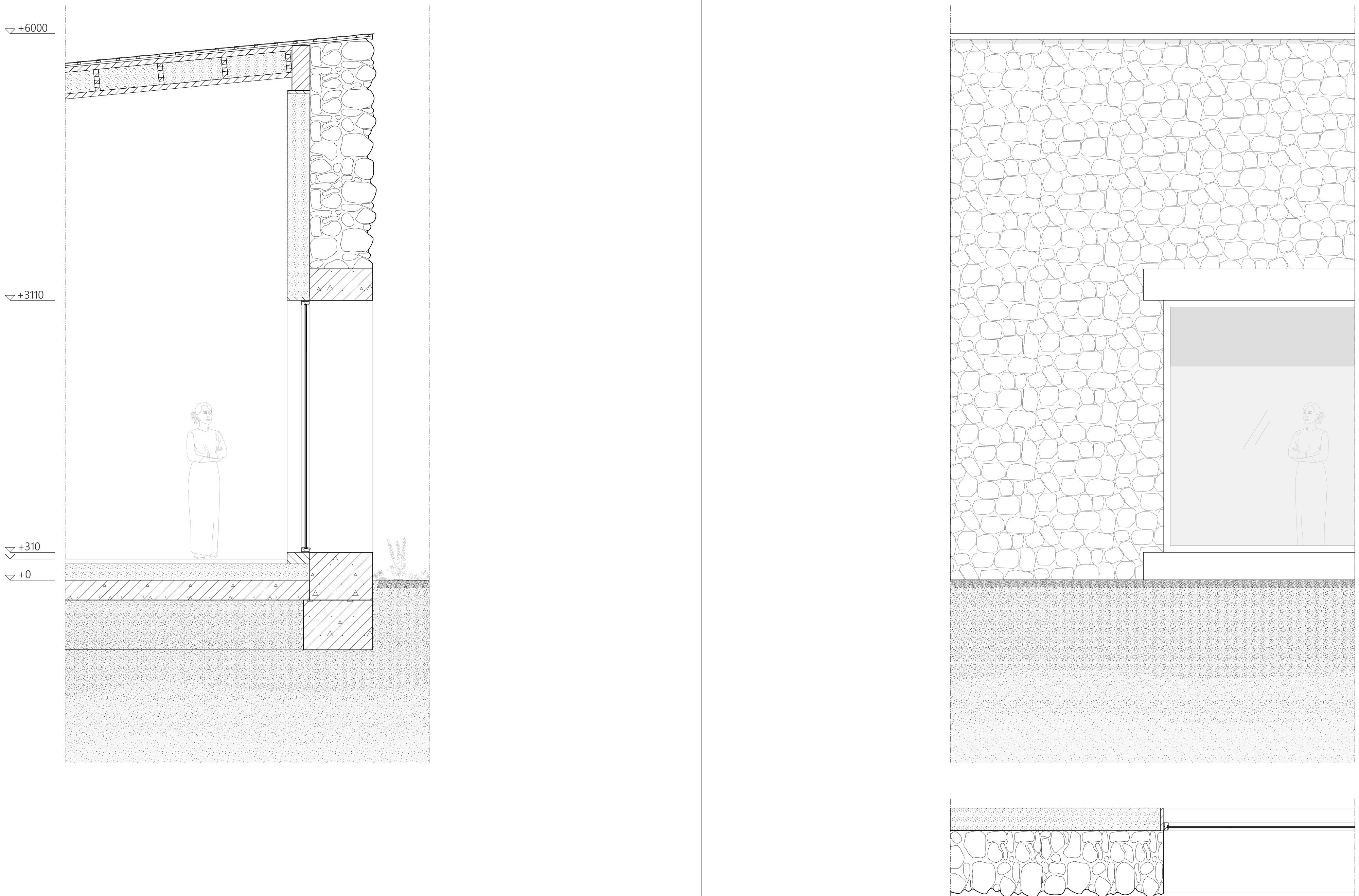
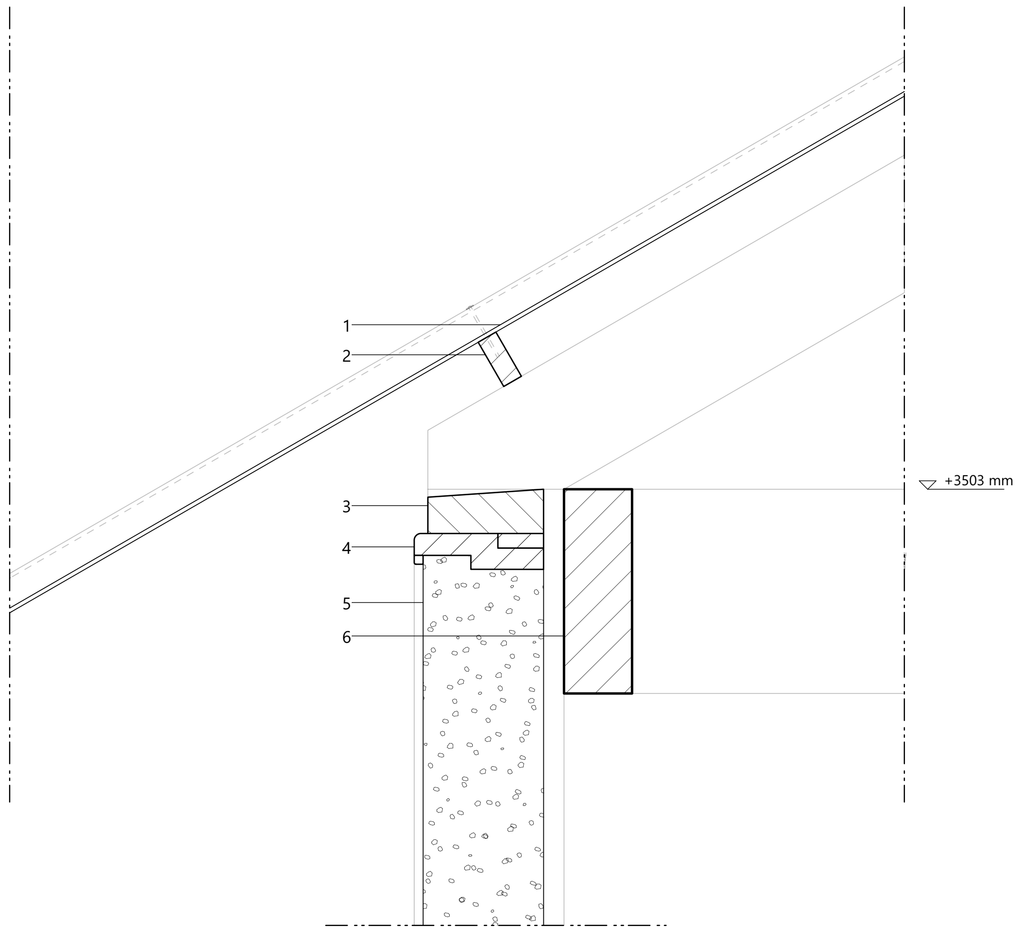


Figure 50: Roof details 1:5 (scaled to 50%)



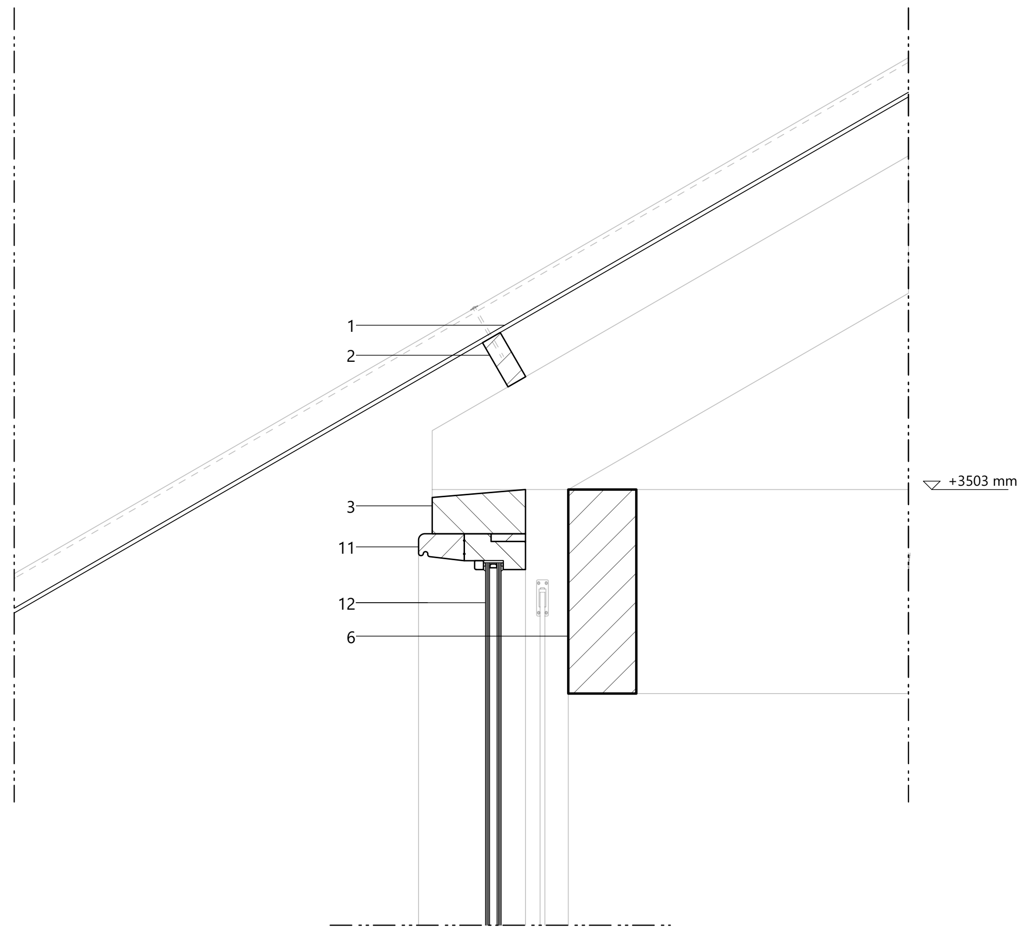
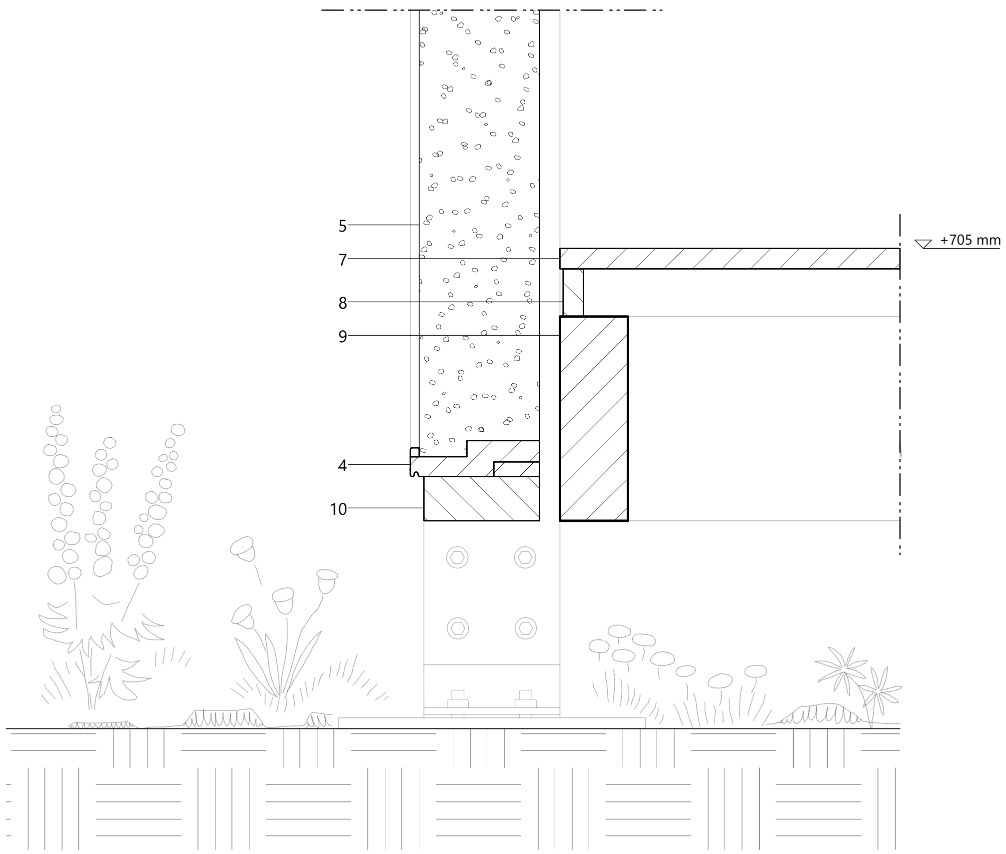


Figure 51: Floor details 1:5 (scaled to 50%)



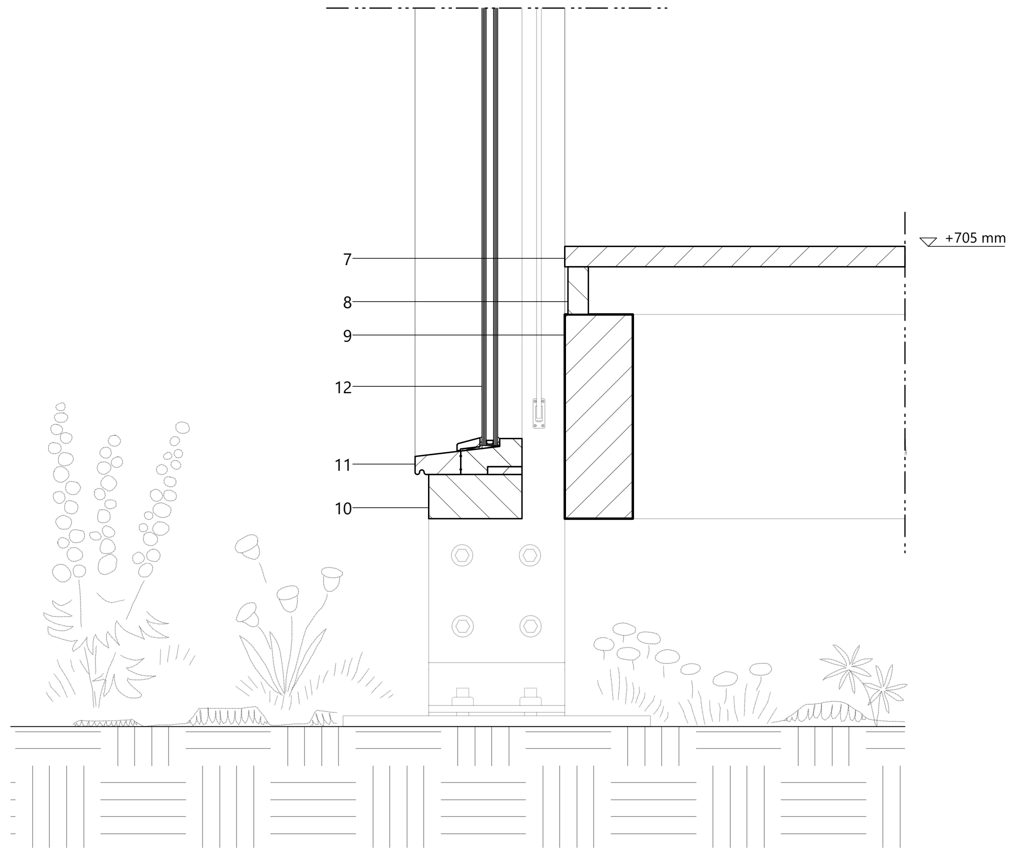


Figure 52: Ridge detail 1:5 (scaled to 50%)

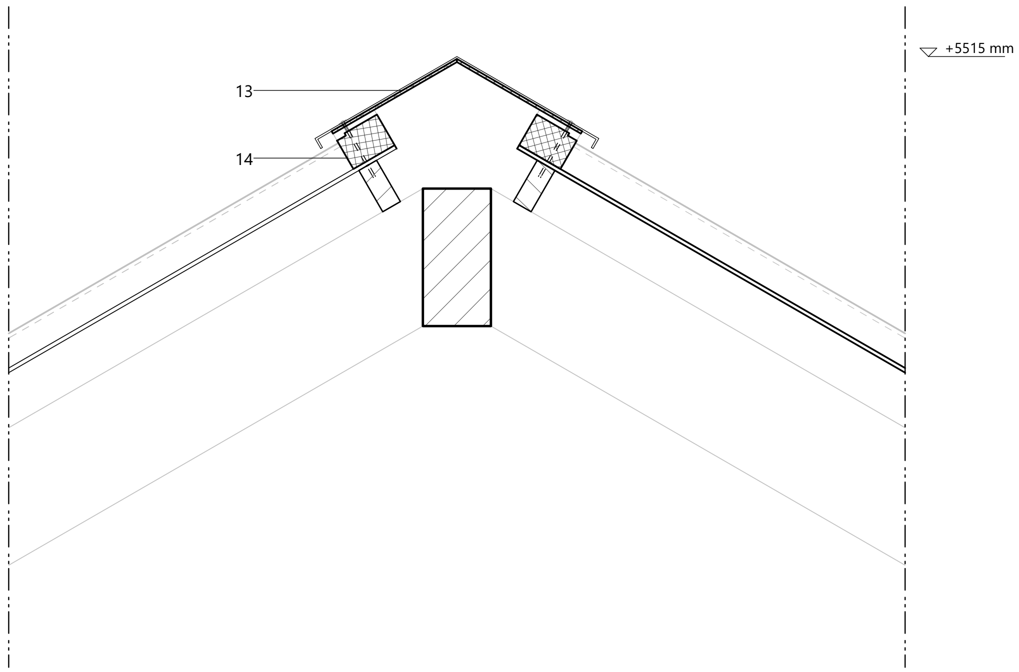


Figure 53: Horizontal detail 1:5 (scaled to 50%)

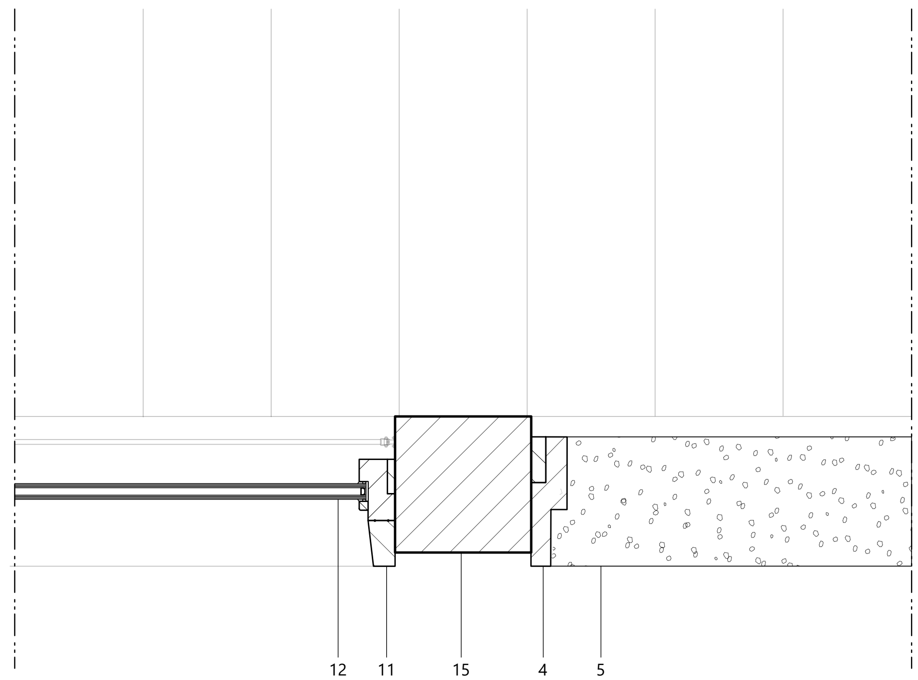
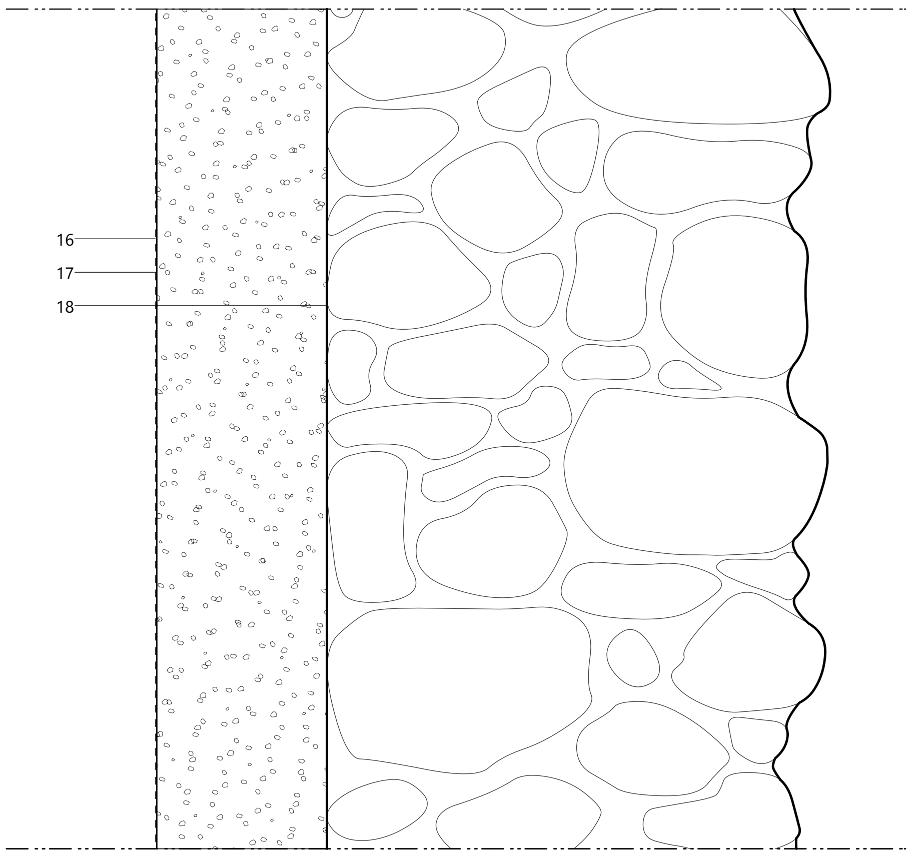


Figure 54: Facade detail 1:5 (scaled to 50%)



1. *polycarbonate corrugated sheet*
2. *timber battens 70 x 30 mm*
3. *frame supporting beam 160 x 65 mm*
4. *timber mycelium frame*
5. *mycelium panel 180 mm*
6. *timber roof beam 300 x 100 mm*
7. *timber floorboards*
8. *secondary beam 70 x 30 mm*
9. *timber floor beam 300 x 100 mm*
10. *frame supporting beam 170 x 65 mm*
11. *timber window frame*
12. *HR++ glass*
13. *steel ridge cap*
14. *ridge vent*
15. *timber column 200 x 200 mm*
16. *vapourtight coating*
17. *mycelium insulation panel between timber frame 250 mm*
18. *natural stone 700 mm*

V. TECHNICAL REPORT

1. **Dynamic Volumes |** Load-bearing Structure

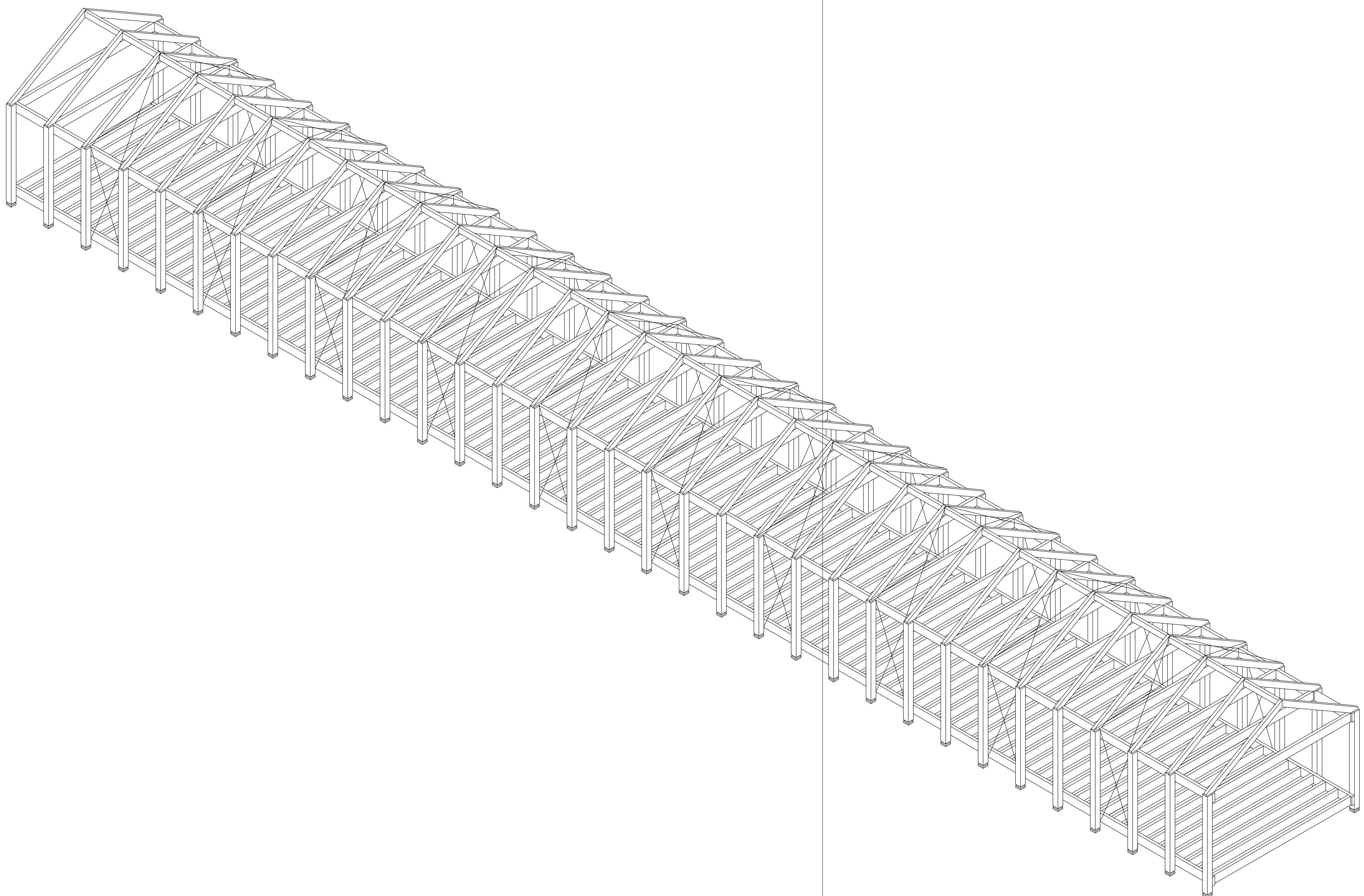


Figure 55: Axonometric drawing (Own work, 2024)

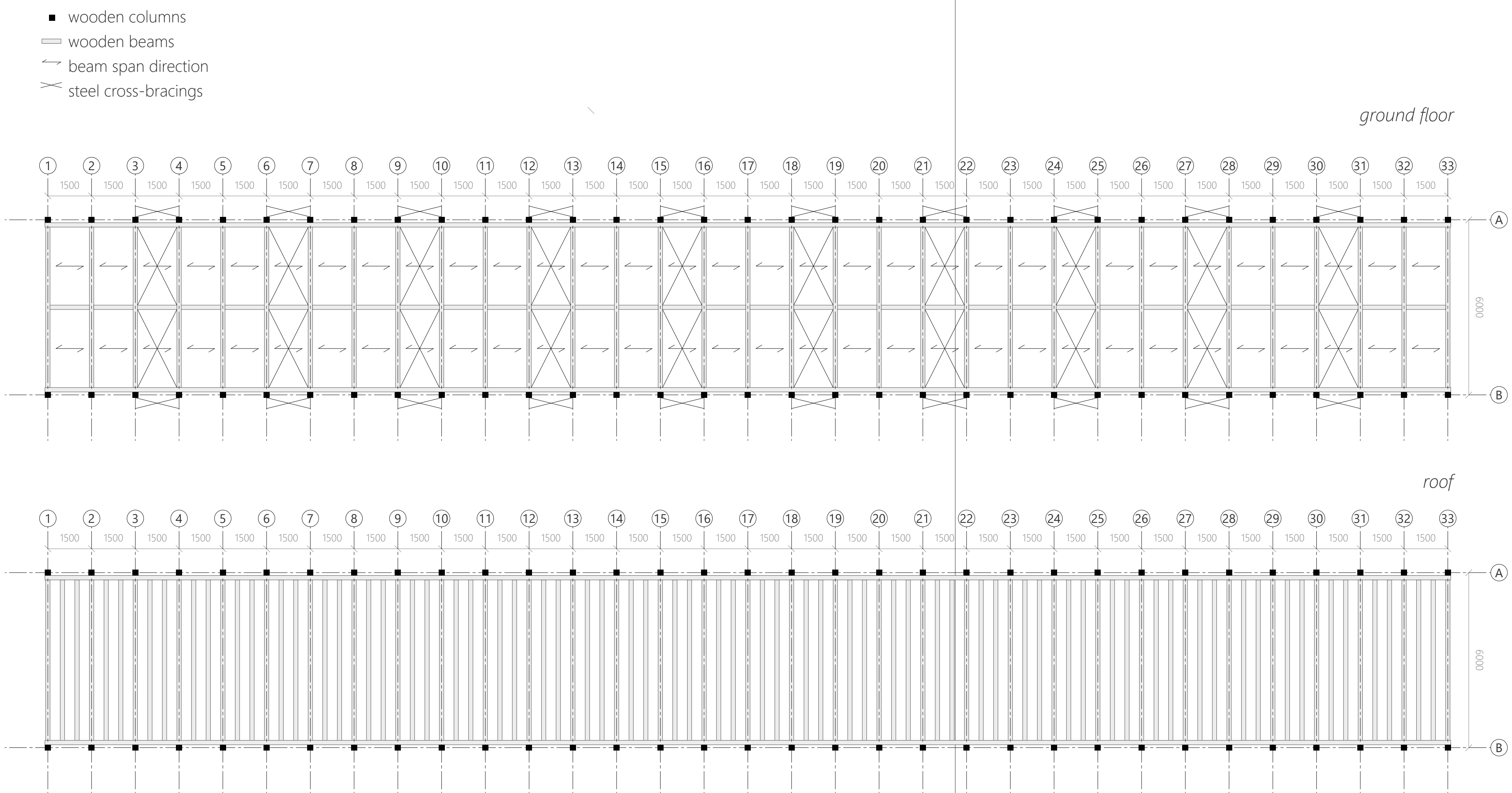


Figure 56: Load-bearing floorplan 1:200 (Own work, 2024)

1.1 Construction material

For the construction Accoya wood has been employed. Accoya is the trade name for wood that has been enhanced through a process called acetylation. This process involves treating the wood with acetic anhydride, a highly concentrated form of household vinegar. This treatment makes it less prone to moisture-related issues such as mold growth and rot, which was a contributing factor in choosing this type of wood. Additionally, it has a light grey color, which aligns well with the aesthetic considerations of the project.

The source wood comes from the Pinus Radiata trees, which belong to the pine family and are grown in Chile, New Zealand and Northern Spain. According to the supplier, this treatment allows the wood to last up to 50 years above ground and up to 25 years underground or in contact with freshwater. (Accoya, 2020)

The columns and roof beams are constructed from sawn softwood, while the floor beams, are made of glulam softwood, are better suited to support the floor structure due to their enhanced strength and stability.

Technical Properties		Accoya C22 - Sawn softwood
Flexural strength	$f_{m,k}$	22 N/mm^2
Average E-modulus longitudinal	$E_{0,mean}$	10 kN/mm^2
Density	0_k	340 kg/m^3
Average density	P_{mean}	410 kg/m^3

Figure 57: Technical properties of sawn softwood (Accoya, 2020)

Technical Properties		Accoya GL32 - Glulam softwood
Flexural strength	$f_{m,k}$	32 N/mm^2
Average E-modulus longitudinal	$E_{0,mean}$	14,2 kN/mm^2
Density	0_k	440 kg/m^3
Average density	P_{mean}	490 kg/m^3

Figure 58: Technical properties of glulam softwood (Centrum Hout, 2017)

1.2 Transfer wind load

Cross-bracings made of stainless steel, are positioned behind every window, extending into the roof, to effectively distribute and transfer wind loads as shown in Figure 59. This system covers approximately one-third of the facade, ensuring stability. The selection of stainless steel is crucial due to its resistance to corrosion, especially when combined with Accoya wood. This combination ensures long-term durability and reliability, as it prevents the risk of corrosion that could weaken the structural integrity of the cross-bracings and compromise the stability of the building.

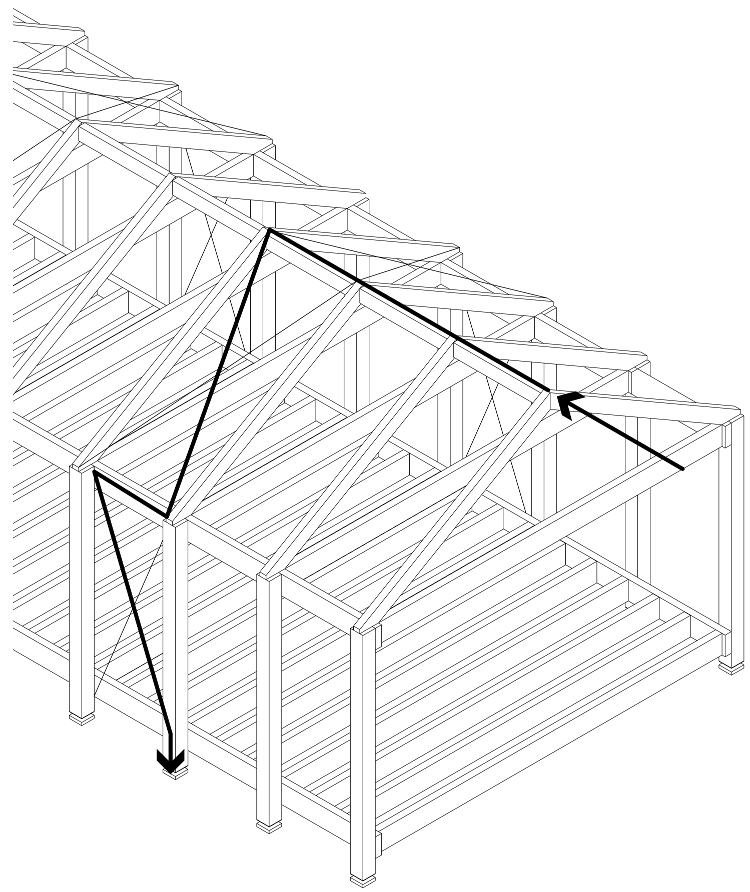


Figure 59: Transfer wind load (Own work, 2024)

1.3 Floor beam calculation

Through the Excel sheet in Figure 61, a verification calculation is conducted for the dimensions of the floor beams.

Using the thumb rules, an initial estimation will first be made for the height and width of the floor beams:

height = 1/20 x length = 1/20 x 6000 = 300 mm

width = 1/3 x height = 1/3 x 300 = 100 mm

As previously explained in paragraph 1.1, glulam softwood is utilized for the floor beams. From the table in Figure 4, the flexural strength and elastic modulus can be extracted as follows:

$f_{c,d} = 32\ N/mm^2$

$E = 14{,}2\ kN/mm^2 = 14200\ N/mm^2$

A standard center-to-center distance for wooden floor beams with a span of 6 meters typically falls between 400 mm to 600 mm. Therefore, a center-to-center distance of 500 mm has been chosen.

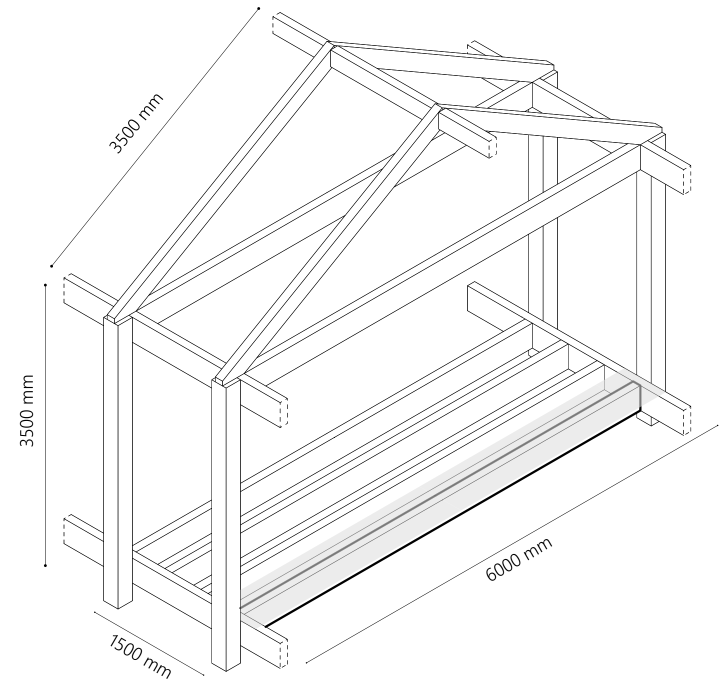


Figure 60: Axonometric drawing with load on the floor beam (Own work, 2024)

For a wooden floor construction with an assembly function, an estimated total design value, $q_{tot\ rekenw}$, of 10 kN/m2 and a characteristic value, $q_{Q;kar.w}$, of 5 kN/m2 can be assumed. The lenght of the span is 6 meters.

When all this input is entered into the Excel sheet, the beam does not meet the requirements as the floor's unity check $UC_{vloer,}$ > 1.

To ensure that the beams meet the requirements, a width of 150 mm is used instead of 100 mm. In this case, the floor's unity check $UC_{vloer,}$ = 0,88 which is smaller than 1.

Analysis of the Excel data showed that the initial beam dimensions didn't meet requirements, with a floor unity check value exceeding 1. Adjusting the beam width to 150 mm reduced the check value to 0.88, meeting design standards. Thus, final dimensions for the floor beams are set at a height of 300 mm and a width of 150 mm.

Accoya:	ℓ_{hoh} =	0,5	[m]	b =	150	[mm]
gelamineerd	$q_{tot\ rekenw}$ =	10	[kN/m^2]	h =	300	[mm]
	q_{UGT} =	5	[kN/m]	W =	2250000	[mm^3]
	$q_{Q;kar.w}$ =	5	[kN/m^2]	I =	337500000	[mm^4]
	$q_{BGT\ vb}$ =	2,5	[kN/m]	f_{cd} =	32	[N/mm^2]
	ℓ_{oversp} =	6	[m]	E =	14200	[N/mm^2]
sterkte						
veld mom =	22500000	[Nmm]		σ_m =	10,0	[N/mm^2]
	UC =	0,31		$W_{benodigd}$ =	703125	[mm^3]
stijfheid						
	$q_{BGT\ kruip}$ =	2	[kN/m]	$U_{bij\ norm\ vloer}$ =	18,00	[mm]
	U_{bij} =	15,85	[mm]	$U_{bij\ norm\ vl\text{-}wand}$ =	12,00	[mm]
	UC_{vloer} =	0,88		$I_{benodigd}$ =	297095070	[mm^4]

Figure 61: verification of the floor beam dimensions (Own work, 2024)

1.4 Roof beam calculation

Through the Excel sheet in Figure 63, a verification calculation is conducted for the dimensions of the roof beams.

Using the thumb rules, an initial estimation will first be made for the height and width of the roof beams:

height = 1/20 x length = 1/20 x 3500 = 175 mm

width = 1/3 x height = 1/3 x 300 = 60 mm

As previously explained in paragraph 1.1, sawn softwood is utilized for the floor beams. From the table in Figure 3, the flexural strength and elastic modulus can be extracted as follows:

$f_{c,d} = 22\ N/mm^2$

$E = 10\ kN/mm^2 = 10000\ N/mm^2$

The center-to-center distance of the roof beams is set at 1500 mm to accommodate the facade panels in between, ensuring alignment with the building's design framework.

Figure 62: Axonometric drawing with load on the roof beam (Own work, 2024)

For a wooden roof construction without a terrace an estimated total design value, $q_{tot\ rekenw}$, of 2 kN/m2 and a characteristic value, $q_{Q;kar.w}$, of 1 kN/m2 can be assumed. The lenght of the span is 3,5 meters.

When all this input is entered into the Excel sheet, the beam does not meet the requirements as the floor's unity check $UC_{vloer,}$ > 1.

To ensure that the beams meet the requirements, a width of 100 mm is used instead of 60 mm. In this case, the roof's unity check $UC_{roof,}$ = 0,84 which is smaller than 1.

Analysis of the Excel data showed that the initial beam dimensions didn't meet requirements, with a roof unity check value exceeding 1. Adjusting the beam width to 150 mm reduced the check value to 0.88, meeting design standards. Thus, final dimensions for the roof beams are set at a height of 175 mm and a width of 100 mm.

Accoya: gezaagd	ℓ_{hoh} =	1,5	[m]	b =	100	[mm]
	$q_{tot\ rekenw}$ =	2	[kN/m²]	h =	175	[mm]
	q_{UGT} =	3	[kN/m]	W =	510416,6667	[mm³]
	$q_{Q;kar.w}$ =	1	[kN/m²]	I =	44661458	[mm⁴]
	$q_{BGT\ vb}$ =	1,5	[kN/m]	f_{cd} =	22	[N/mm²]
	ℓ_{oversp} =	3,5	[m]	E =	10000	[N/mm²]
sterkte						
veld mom =		4593750	[Nmm]	σ_m =	9,0	[N/mm²]
	UC =	0,41		$W_{benodigd}$ =	208807	[mm³]
stijfheid						
	$q_{BGT\ kruip}$ =	1	[kN/m]	$U_{bij\ norm\ dak}$ =	14,00	[mm]
	U_{bij} =	11,81	[mm]			
	UC_{dak} =	0,84		$I_{benodigd}$ =	37683105	[mm⁴]

Figure 63: Verification of the roof beam dimensions (Own work, 2024)

1.5 column calculation

Through the Excel sheet in Figure 65 a verification calculation is conducted for the dimensions of the columns.

Using the thumb rules, an initial estimation will first be made for the height and width of the columns:

height = 1/20 x length = 1/20 x 3500 = 175 mm

However, for aesthetic reasons, the chosen dimensions for the columns are 200 x 200 mm.

As previously explained in paragraph 1.1, sawn softwood is utilized for the columns. From the table in Figure 3, the flexural strength and elastic modulus can be extracted as follows:

$f_{c,d} = 22\ N/mm^2$

$E = 10\ kN/mm^2 = 10000\ N/mm^2$

The center-to-center distance of the columns is set at 1500 mm to accommodate the facade panels in between and for aesthetic reasons.

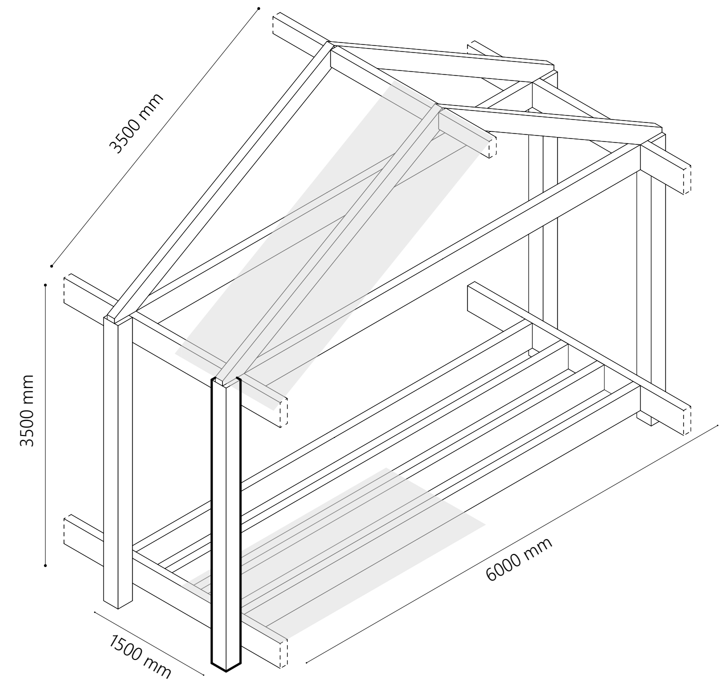


Figure 64: Axonometric drawing with load on the column (Own work, 2024)

When all this input is entered into the Excel sheet, the column does meet the requirements as the floor's unity check UC is 0,29 < 1.

Analysis of the Excel data showed that the initial column dimensions did meet requirements, with a unity check value lower than 1. Thus, final dimensions for the columns are set at a height of 200 mm and a width of 200 mm.

	lengte			breedte			rekenwaarde			
opp.vl dak =	1,5	[m]	x	3,5	[m]	x	2	[kN/m^2]	=	10,5
opp.vl verd.1	1,5	[m]	x	3	[m]	x	10	[kN/m^2]	=	45
									$F_{c;d}$ =	55,5

$A = F_{c;d}/f_{c;d}$ =	2522,72727	[mm^2]	-->	d =	50,226759	[mm]	-->	b =	200
$f_{c;d}$ =	22	[N/mm^2]						h =	200
ℓ_{cr} =	3500	[mm]		$E_{d\ (UGT)}$ =	10000	[N/mm^2]		I_z =	1,33E+08
F_{cr} =	1,07E+06	[N]							
UC =	0,26			$I_{z\ ben}$ =	3,44E+07	[mm^4]		-->	200 x 200

Figure 65: Verification of the column dimensions (Own work, 2024)

1.6 Buckling calculation

The force at which buckling occurs, the buckling strength of the column, can be determined using the following formula:

$$F_{cr} = \frac{\pi^2 \times E \times I}{l_{cr}^2}$$

Where:

F_{cr}= the buckling strength in Newton (N)

E= the modulus of elasticity of the material (N/m^2)

I = the moment of inertia of the column's cross-section (m^4)

l_{cr} = the critical buckling length (mm)

The modulus of elasticity of the column made of sawn softwood is 10000 N/m^2. The moment of inertia is provided in Figure 11 and amounts to 1.33×10^8 m^4. The critical buckling length is equal to the full length of the column and amounts to 3500 mm.

Filling in the formula leads to the following buckling strength:

$$\frac{\pi^2 \times 10000 \times 1{,}33 \times 10^8}{3500^2} = 1{,}07 \times 10^6\,N$$

To determine the safety factor, the following formula is used, where this factor must be greater than 5:

$$\frac{F_{cr}}{F_{cd}} = n > 5$$

Where:

F_{cr}= the buckling strength in Newton (N)

F_{cd}= the design load in Newton (N)

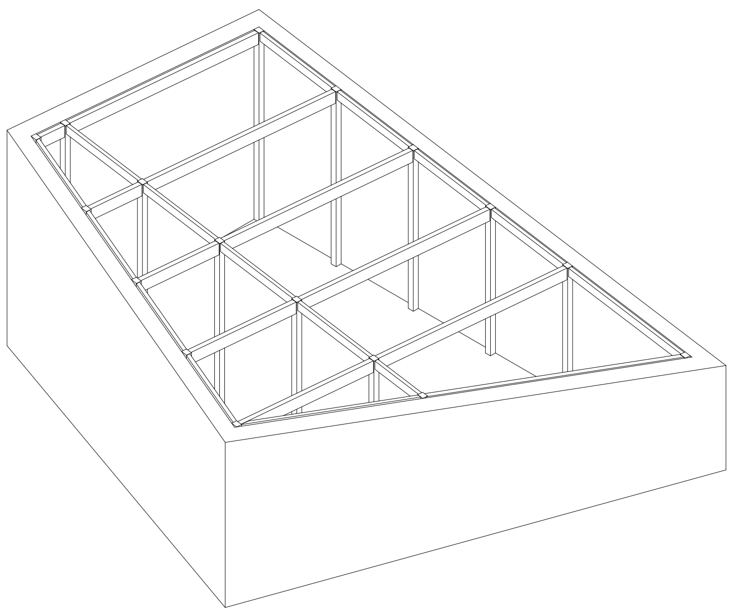
n = the safety factor

The design load is provided in Figure 11 and amounts to 55500 Newton. Filling in the formula leads to the following buckling strength:

$$\frac{1{,}07 \times 10^6}{55500} = 19{,}3 > 5$$

With a safety factor of 19.3, which is significantly higher than 5, it meets the safety requirement.

2. **Static Volumes** | Load-bearing Structure



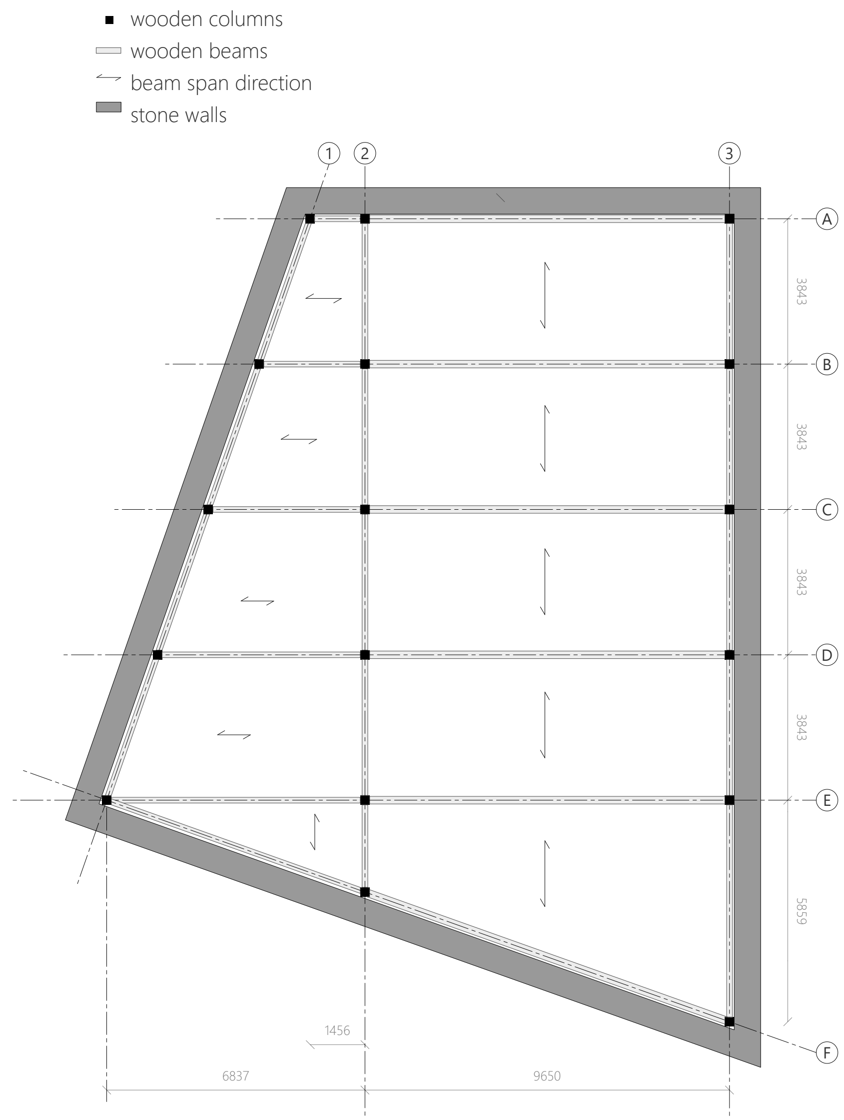
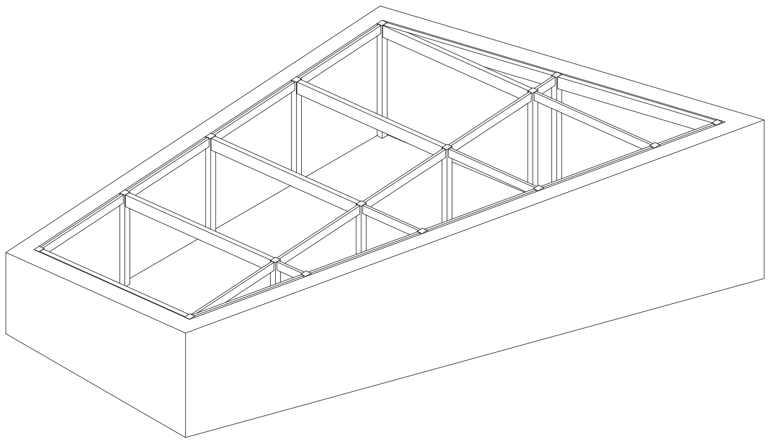


Figure 66: Structural drawings of the auditorium 1:200 (Own work, 2024)



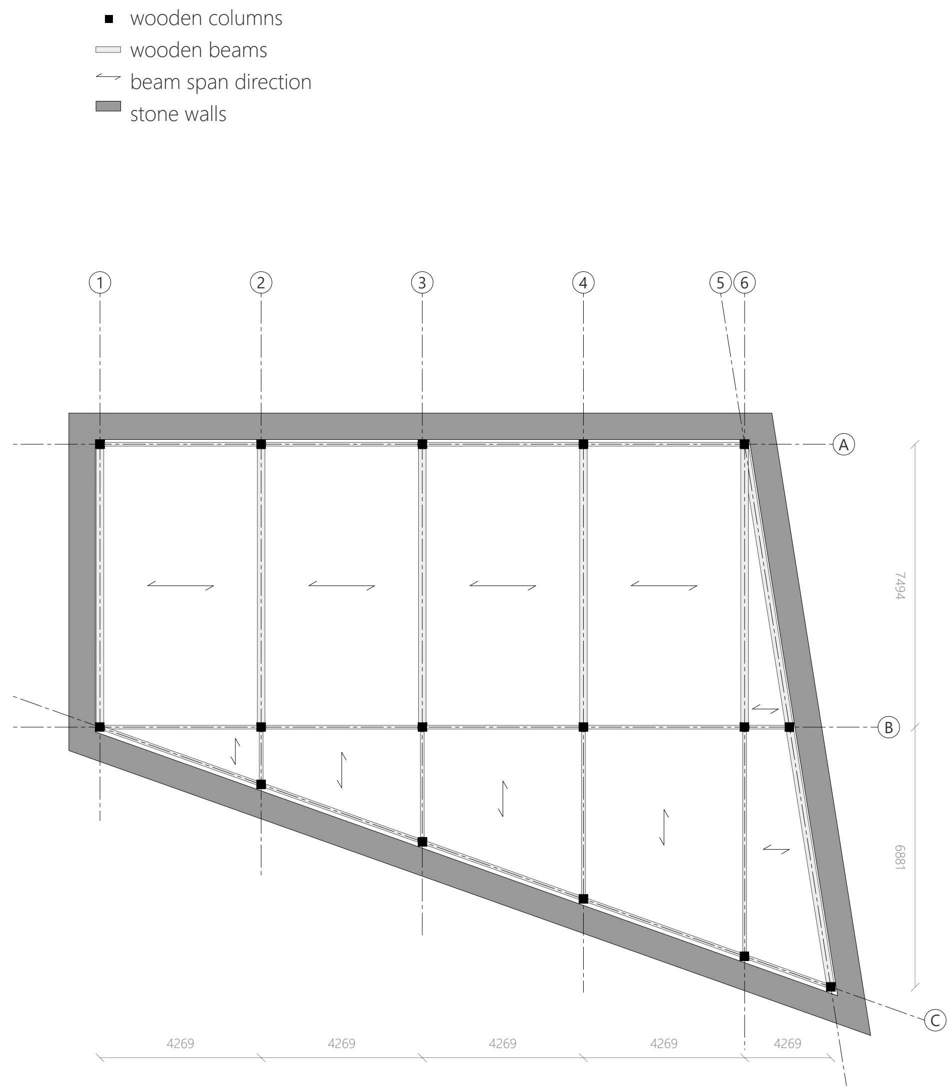
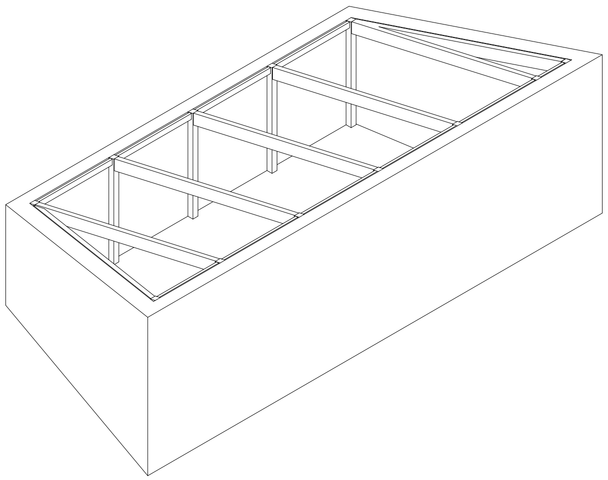


Figure 67: Structural drawings of the cafe 1:200 (Own work, 2024)



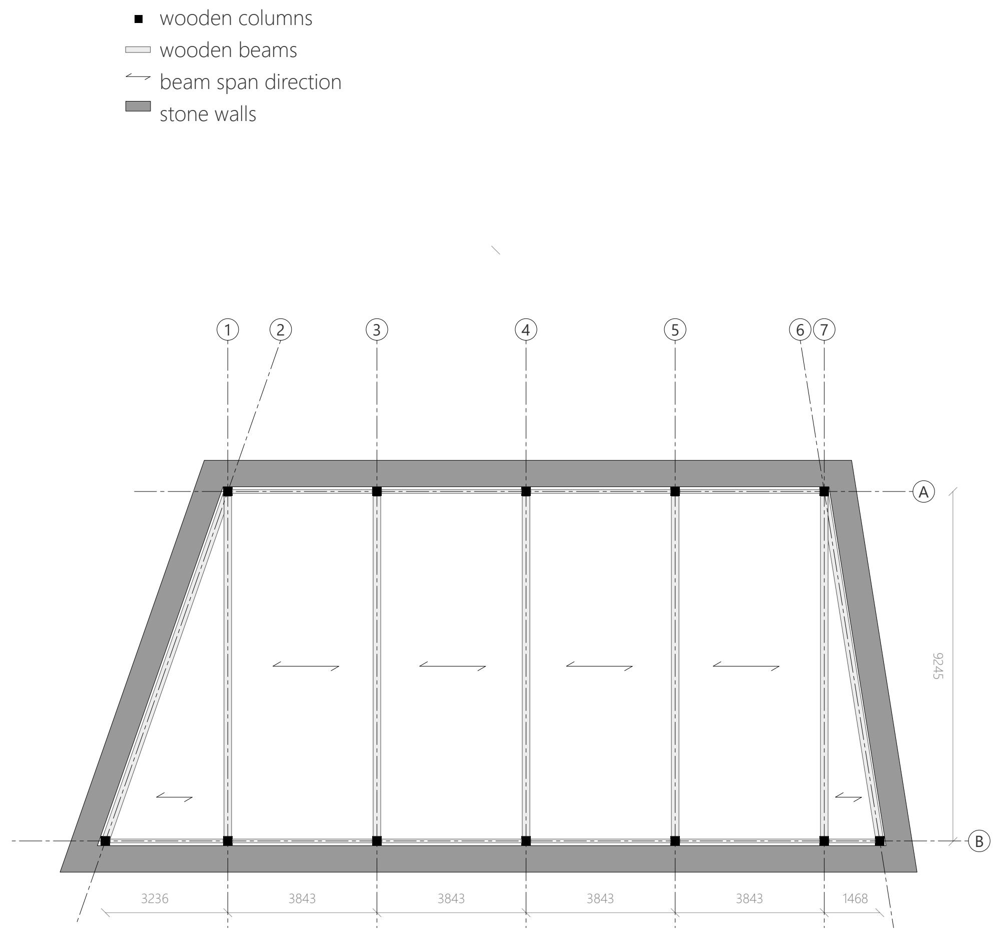


Figure 68: Structural drawings of the laboratory 1:200 (Own work, 2024)

2.1 Construction material

The static volumes consist of two distinct structures, each serving a specific purpose. The outer structure is characterized by its robustness and durability, crafted from natural stone to form an autonomous facade. This exterior facade showcases its solidity and permanence to the external environment.

In contrast, the inner structure is made of a lightweight timber frame construction, which is completely insulated and air tight. This lighter inner framework allows for removal and accommodating future transformations as needed over time. The timber frame is made of sawn accoya wood just like the dynamic volumes with a flexural strenght of 22 N/mm^2 and an average E-modulus of 10,000 N/mm^2.

2.2 Transfer wind load

The double construction, consists of a robust stone facade and a lightweight timber frame. The stone facade, with its inherent strength and mass, acts as the primary barrier against wind forces. As wind interacts with the exterior surface, the stone facade absorbs and distributes these forces, guiding them downward towards the foundation.

2.4 Roof Beam Calculation Auditorium

The verification calculation for the dimensions of the roof beams of the auditorium was conducted using the Excel sheet in Figure 70. This calculation specifically targeted beam E2-3, as it bears the highest load among all the beams.

Using the thumb rules, an initial estimation will first be made for the height and width of the roof beams:

height = 1/20 x length = 1/20 x 9685 = 484 mm

width = 1/3 x height = 1/3 x 484,25 =161 mm

Therefore an estimation of 500 x 200 mm is made.

As previously explained in paragraph 2.1, sawn softwood is utilized for the roof beams. The flexural strength and elastic modulus are as follows:

$f_{c,d} = 22\ N/mm^2$

$E = 10\ kN/mm^2 = 10000\ N/mm^2$

The center-to-center distance of the beams is 3,85 m.

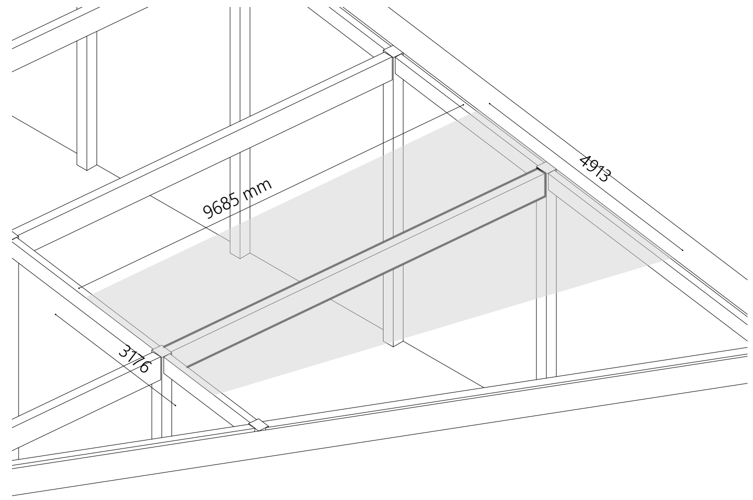


Figure 69: Axonometric drawing with load on the roof beam (Own work, 2024)

For a wooden roof construction without a terrace an estimated total design value, $q_{tot\ rekenw}$, of 2 kN/m2 and a characteristic value, $q_{Q;kar.w}$, of 1 kN/m2 can be assumed. The lenght of the span is 9,6 meters.

When all this input is entered into the Excel sheet, the beam does meet the requirements as the roof's unity check of 0,99 is lower than 1. Therefore, it can be concluded that the roof beams should have dimensions of 500 x 200 mm.

gezaagd	ℓ_{hoh} =	3,85	[m]	b =	200	[mm]
	$q_{tot\ rekenw}$ =	2	[kN/m^2]	h =	500	[mm]
	q_{UGT} =	7,7	[kN/m]	W =	8333333,333	[mm^3]
	$q_{Q;kar.w}$ =	1	[kN/m^2]	I =	2083333333	[mm^4]
	$q_{BGT\ vb}$ =	3,85	[kN/m]	f_{cd} =	22	[N/mm^2]
	ℓ_{oversp} =	9,69	[m]	E =	10000	[N/mm^2]
sterkte						
veld mom =	90374996,25	[Nmm]		σ_m =	10,8	[N/mm^2]
	UC =	0,49		$W_{benodigd}$ =	4107954	[mm^3]
stijfheid						
	$q_{BGT\ kruip}$ =	3	[kN/m]	$U_{bij\ norm\ dak}$ =	38,76	[mm]
	U_{bij} =	38,19	[mm]			
	UC dak =	0,99		$I_{benodigd}$ =	2052500891	[mm^4]

Figure 70: Verification of the roof beam dimensions (Own work, 2024)

2.5 Column Calculation Auditorium

The verification calculation for the dimensions of the columns of the auditorium was conducted using the Excel sheet in Figure 72. This calculation specifically targeted column D2, as it bears the highest load among all the beams.

Using the thumb rules, an initial estimation will first be made for the height and width of the columns:

height = 1/20 x length = 1/20 x 7126 = 356,3 mm

Therefore an estimation of 350 x 350 mm is made.

As previously explained in paragraph 2.1, sawn softwood is utilized for the floor beams. The flexural strength and elastic modulus are as follows:

$f_{c,d} = 22\ N/mm^2$

$E = 10\ kN/mm^2 = 10000\ N/mm^2$

The column carries a surface area of approximately 8 by 3.8 meters.

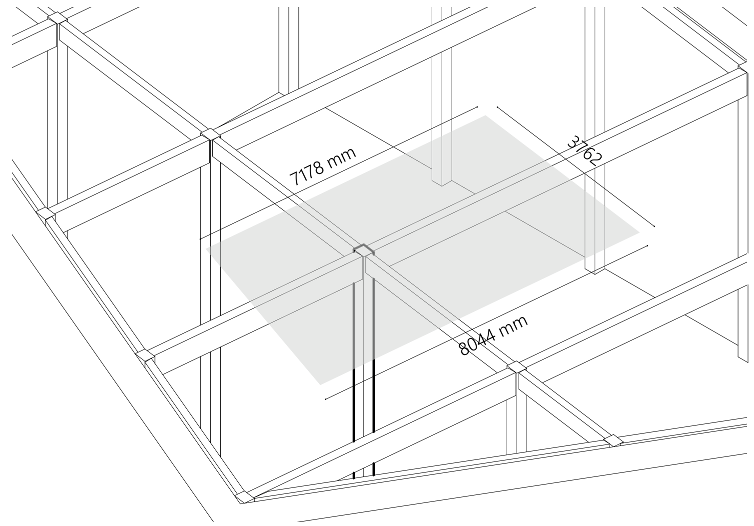


Figure 71: Axonometric drawing with load on the column (Own work, 2024)

When all this input is entered into the Excel sheet, the column does meet the requirements as the floor's unity check. The columns can be even smaller. Making the columns 250 x 250 leads to a Unity Check of 0,45.

Analysis of the Excel data showed that the initial comumn dimensions did meet requirements, with a unity check value lower than 1. Thus, final dimensions for the columns are set at a height of 250 mm and a width of 250 mm.

	lengte				breedte			rekenwaarde			
opp.vl dak =	8	[m]	x		3,8	[m]	x	2	[kN/m^2]	=	60,8
										$F_{c;d}$ =	60,8
A = $F_{c;d}/f_{c;d}$ =	2763,63636	[mm^2]	-->	d =	52,570299	[mm]	-->			b =	250
$f_{c;d}$ =	22	[N/mm^2]								h =	250
ℓ_{cr} =	7126	[mm]		$E_{d\ (UGT)}$ =	10000	[N/mm^2]				I_z =	3,26E+08
F_{cr} =	6,33E+05	[N]									
UC =	0,48			$I_{z\ ben}$ =	1,56E+08	[mm^4]				-->	200 x 200

Figure 72: Verification of the column dimensions (Own work, 2024)

2.5 Buckling calculation auditorium

The force at which buckling occurs, the buckling strength of the column, can be determined using the following formula:

$$F_{cr} = \frac{\pi^2 \times E \times I}{l_{cr}^2}$$

Where:

F_{cr}= the buckling strength in Newton (N)

E= the modulus of elasticity of the material (N/m^2)

I = the moment of inertia of the column's cross-section (m^4)

l_{cr} = the critical buckling length (mm)

The modulus of elasticity of the column made of sawn softwood is 10000 N/m^2. The moment of inertia is provided in Figure 11 and amounts to 3.26 x 10^8 m^4. The critical buckling length is equal to the full length of the column and amounts to 7126 mm.

Filling in the formula leads to the following buckling strength:

$$\frac{\pi^2 \times 10000 \times 2{,}26 \times 10^8}{7126^2} = 6{,}33 \times 10^5 \, N$$

To determine the safety factor, the following formula is used, where this factor must be greater than 5:

$$\frac{F_{cr}}{F_{cd}} = n > 5$$

Where:

F_{cr}= the buckling strength in Newton (N)

F_{cd}= the design load in Newton (N)

n = the safety factor

The design load is provided in Figure 11 and amounts to 60800 Newton. Filling in the formula leads to the following buckling strength:

$$\frac{6{,}33 \times 10^5}{60800} = 10{,}4 > 5$$

With a safety factor of 10.4, which is significantly higher than 5, it meets the safety requirement.

2. **Climate Design**

2.1 Climate Principles

This design for a nature centre consists of three dynamic volumes that serve as exhibition galleries and three static volumes that serve as entrance building, auditorium, and mycelium laboratory.

The dynamic volumes are not climatised and expose visitors to the real conditions and elements found in nature, including temperature fluctuations. However, they do provide shelter from these natural elements such as rain to ensure a comfortable experience. Ventilation is facilitated through natural means, with a ventilation ridge on the roof and ventilation grilles above the windows. Regarding utilities, the building does not have heating, cooling or running water.

On the other hand, the static volumes are equipped with climate control systems to ensure a fully controlled environment. In these volumes ventilation type D is implemented which ensures precise control over the indoor environment, which is crucial for spaces like auditoriums and laboratories where consistent conditions are necessary for optimal functionality and comfort.

The heating and cooling in both the entrance building and the laboratory will be managed through underfloor heating. This method allows for efficient use of low-temperature heating, which ensures a comfortable environment while minimizing energy consumption.

In the auditorium, where occupancy levels can fluctuate and quick adjustments to temperature are often required, heating and cooling will be achieved through ventilation air. This approach ensures rapid response times to changing conditions, optimizing comfort for all occupants.

2.2 Ventilation

The auditorium, laboratory, and café are all equipped with ventilation type D, which requires mechanical intake and exhaust. This system functions through an air handling unit, which circulates air through ventilation ducts. The ventilation ducts are dimensioned using the formula:

$A = V / (3600 \times v)$

Where:

A= the cross-sectional area of the duct in square meters (m²)

V= the ventilation flow rate in cubic meters per hour (m³/h)

v= the air velocity in meters per second (m/s)

An air velocity of 3 m/s is assumed and round ventilation ducts are chosen to prevent noise pollution. To calculate the radius of the ducts, the following formula is used:

$r = \sqrt{(A / \pi)}$

According to these calculations, the ventilation shafts in the auditorium should have a diameter of 0,68 meter. The ventilation shafts in the laboratory and café will measure 0,38 meter.

	Auditorium	Laboratory	Café	Gallery
Ventilation type	D	D	D	A
Number of people	80	40	40	40
Ventilation flow rate per person	50 m³ / h / person	30 m³ / h / person	30 m³ / h / person	N/A
Ventilation flow rate	4000 m³ / h 50 x 80	1200 m³ / h 30 x 40	1200 m³ / h 30 x 40	N/A
Surface area *1 duct*	0,3703 m² 4000 / (3600 x 3)	0,1111 m² 4000 / (3600 x 3)	0,1111 m² 4000 / (3600 x 3)	N/A
Surface area *2 duct*	0,1852 m²			
Radius *1 duct*	0,34 m √(0,3703 / π)	0,19 m √(0,1111 / π)	0,19 m √(0,1111 / π)	N/A
Radius *2 duct*	0,24 m √(0,1852 / π)			

Figure 73: Ventilation Requirements (Own work, 2024)

To decrease the size of the ventilation ducts in the auditorium a solution was devised to split the ventilation flow into two ducts in the auditorium, each maintaining the same total cross-sectional area. As a result, the diameter of each duct in the auditorium was adjusted to 0.4856 meters, reducing the size of the lowered ceiling while ensuring good ventilation.

Based on the air flow rate of 4000 m3/h in the auditorium, the Daikin air handling unit catalog specifies that a modular R system size 4 is required. This unit measures 1.2 meters in width, 1.9 meters in length, and 1.74 meters in height to meet the ventilation requirements efficiently.

For the laboratory and the café, which have an air flow rate of 1200 m3/h each, a modular R system size 1 is suitable. These units are 0.72 meters in width, 1.7 meters in length, and 1.32 meters in height, providing adequate ventilation for their respective spaces.

Modular R			**1**	**2**	**3**	**4**	**5**
Airflow		m^3/h	1,200	1,700	2,700	4,100	5,500
Temp. efficiency winter		%	76.9	76.7	77	77.2	78.5
External static pressure	Nom.	Pa					20
Current[1]	Nom.	A	2.6	3.65	2.24	3.27	4.23
Power input[1]	Nom.	kW	0.6	0.84	1.36	1.98	2.56
SFPv[2]		$kW/m^3/s$	1.553	1.507	1.451	1.521	1.387
Electrical supply	Phase	ph	1				
	Frequency	Hz					5
	Voltage	V	230				
Dimensions unit	Width	mm	720	820	990	1,200	1,4
	Height	mm	1,320		1,540	1,740	
	Length	mm	1,700		1,800	1,920	2,080
Weight unit		kg	325	350	475	575	750

Figure 74: Dimensions of Air Handling Units (Daikin, 2023)

2.3 Heating & Cooling

Heating and cooling in the auditorium will be facilitated through ventilation air. This process allows for quick adjustments to temperature which is crucial for fluctuating occupancy. This system operates by circulating air through a network of ducts connected to a ground source heat pump. The heat pump extracts heat from the ground during the heating season and transfers it to the ventilation air which is blown into the auditorium. Conversely, during the cooling season, heat from the indoor air is transferred to the ground. Additionally, a heat recovery system is integrated to maximize energy efficiency by capturing and reusing heat from exhaust air.

The café and laboratory will be heated and cooled through underfloor heating. This allows for efficient low-temperature heating. This system captures heat the ground. The warmth from the ground is transferred to the fluid circulating through the heat pump, which is then used for the underfloor heating. Additionally, a heat recovery system will be integrated into this system.

The Mycelium Galleries will not be cooled or heated. The nature centre should immerse visitors in the real conditions and elements found in nature, including temperature fluctuations. Rather than prioritizing artificial comfort through controlled heating or cooling systems, the emphasis is on allowing visitors to engage with the natural climate.

	Auditorium	Laboratory	Café	Gallery
Required temperature	20 - 22 °C	24 - 28 °C	20 - 22 °C	no requirements
Heating & cooling transfer system	ventilation air	floor heating & cooling	floor heating & cooling	N/A
Required Installations	Ground source heat pump / Air handling unit / Heat recovery system	Ground source heat pump / Heat recovery system	Ground source heat pump / Heat recovery system	N/A

Figure 75: Heating system and requirements (Own work, 2024)

2.4 BENG calculation

Through the excel sheet in figure 76 a calculation is made of the energy performance of the auditorium.

The auditorium features two enclosed facades facing north and west, each with a minimal number of windows. In contrast, the other two facades facing south-southwest and east-northeast are more open, with a higher percentage of windows.

The auditorium employs thermal resistances (Rc values) of 4.5 m^2K/W for the walls, 3.5 m^2K/W for the floor, and 6 m^2K/W for the roof. For its windows, HR++ glass is utilized, featuring a solar heat gain coefficient (g value) of 0.6 and a U value of 1.2 W/m^2K.

The heating and cooling system operates through a ground source heat pump, complemented by an electric boiler for heating water centrally.

The building is fully mechanically ventilated with ventilation type D. Modern heat recovery systems can achieve efficiencies of even above 95%. For this calculation, an efficiency of 80% is assumed. A higher efficiency would be beneficial for the design.

In the auditorium itself there are no windows, however, the surrounding spaces will have big windows, allowing for daylight. An estimation is made that in 30% of the floors, there is enough daylight for more than 70% of the time occupants spend there. For the lighting power, a value of 8 W/m^2 is used, which is a common value for modern LED lighting. The concrete floor, with a mass exceeding 400 kg/m2, combined with a closed, suspended ceiling, results in a thermal mass of 180 kJ/(m2K).

Energy is generated through PV shingles placed between real the slate shingles. In order to fulfill the requirements of teh BENG 5500 kWh per year should be generated. Calculations are based on the assumption that PV panels generate 150 $kWh/year/m^2$. This means a surface area of With a surface area of 37 m2 pv singles is needed. This means about 15% of the roof should consist of these pv tiles.

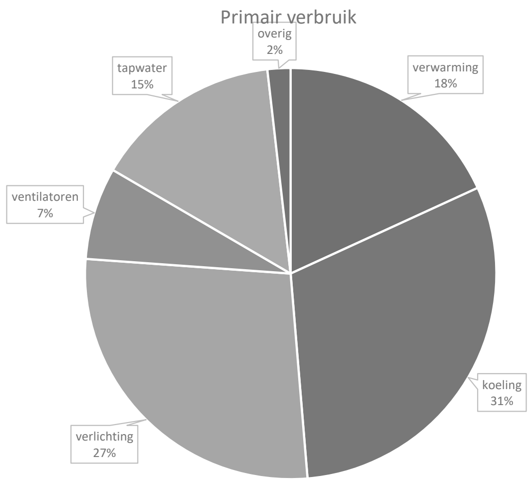
Projectnaam	Graduation Project		Rhythms of Renewal
Studentnummer			4844327
Totale gebruiksoppervlakte	248	m^2	gebruiksoppervlakte van alle gebruiksfuncties samen
Bouwvolume V	1244	m^3	totaal gebouwvolume

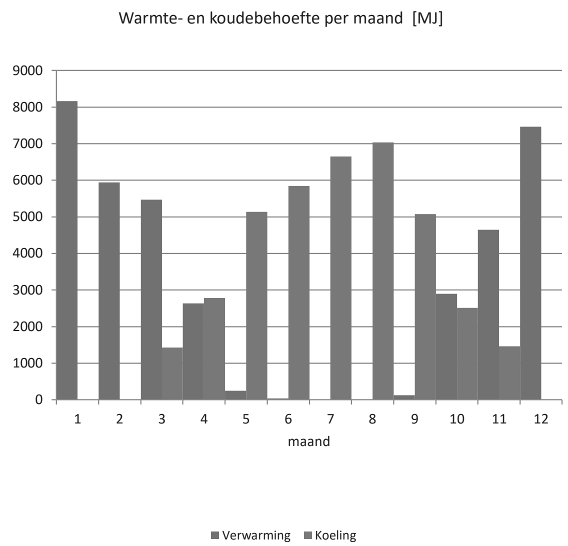
	1	2	3		het gebouw kan tot 3 gebruiksfuncties hebben
Gebruiksfunctie	Bijeenkomstfunctie - over				gebruiksfuncties
Percentage van totale oppervlakte	100	0	0	%	aandeel gebruiksfuncties
Aantal woningen			totaal aantal woningen		

	Gevels (zonder kelderwanden) Noord	NO	Oost	ZO	Zuid	ZW	West	NW	Dak	Vloer en kelderwanden Aan grond	Boven lucht		
Oppervlakte	77	97				128	36		251	248		m^2	totale oppervlakte uitwendige scheidingsconstructie
Raampercentage	0	19				19	0					%	raampercentage (glas+kozijn) t.o.v. geveloppervlakte
Gemiddelde Rc-waarde dichte delen	4,5	4,5				4,5	4,5		6	3,5		m^2K/W	gemiddelde Rc-waarde dichte delen
Gemiddelde U-waarde ramen	1,2	1,2				1,2	1,2					$W/(m^2K)$	gemiddelde U-waarde van de ramen, incl kozijn
g-waarde glas	0,6	0,6				0,6	0,6					-	bij zonwering op
g-waarde glas+zonwering	0,6	0,6				0,6	0,6					-	bij zonwering neer

Type verwarming	Bodemwarmtepomp		type verwarming dat wordt toegepast in de meeste verblijfsruimten
Type warmtapwater	Elektrische boiler(s)		type tapwaterbereider dat wordt toegepast in de meeste verblijfsruimten
Tapwater centraal / decentraal	Centraal		centrale tapwaterbereiding voor meerdere tappunten of decentraal per tappunt
Percentage douchewater WTW	0	%	gemiddeld percentage warmteterugwinning bij de douches
Zonneboiler t.b.v. warmtapwater	0	kWh/jaar	opgewekte warmte door een zonneboiler ***LET OP:*** *enkel opwekking van warmte!*
Type koeling	Bodemwarmtepomp		type koeling dat wordt toegepast in de meeste verblijfsruimten
Percentage natuurlijke ventilatie	0	%	vloeroppervlakte met koeling door natuurlijke ventilatie in tussenseizoenen en zomer (voorwaarde voldoende te openen ramen)
Type ventilatie (luchtverversing)	D		type ventilatie dat wordt toegepast in de meeste verblijfsruimten
Percentage warmteterugwinning	80	%	gemiddeld percentage warmteterugwinning van de ventilatie (alleen bij C en D)
Percentage daglicht	30	%	vloeroppervlakte met 70% van de gebruikstijd voldoende daglicht (daglichtsector)
Vermogen verlichting	8	W/m^2	gemiddeld geïnstalleerd vermogen aan verlichting
Thermische massa Dm	180	$kJ/(m^2K)$	default waarde 110 of bepaal Dm volgens tabblad Thermische massa
Energieopwekking	5.500	kWh/jaar	opgewekte elektriciteit (bijvoorbeeld PV-panelen) ***LET OP:*** *warmte door zonnecollectoren moet bij de zonneboiler worden ingevuld, niet hier!*

Figure 76: BENG calculation (Own work, 2024)





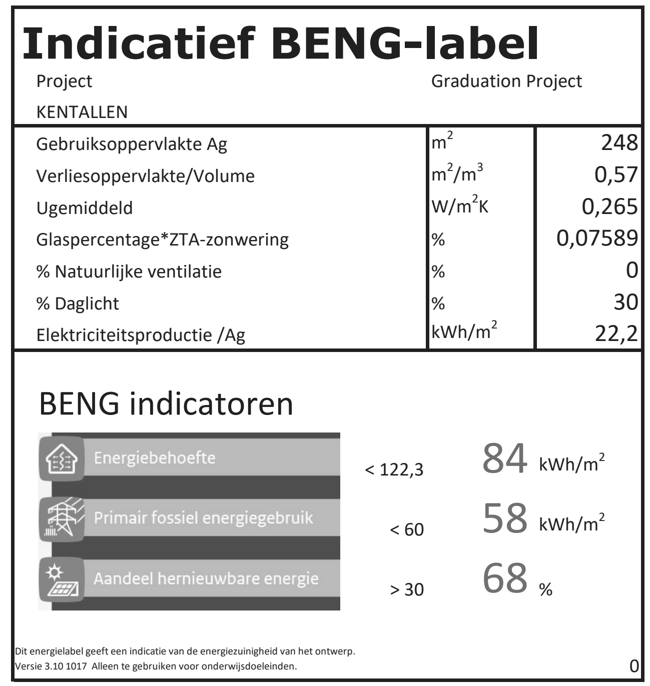


Figure 77: BENG results (Own work, 2024)

2.5 Thermal Comfort

Through a heat balance calculation the thermal performance and requirements of the auditorium is determined through the excel sheet on the next page.

The auditorium has two more closed facades facing north and east, and two more open facades oriented towards the south-southwest and northwest-west. The required indoor temperature ranges between 20°C and 22°C.

As previously stated in the BENG calculation the thermal resistances (Rc value) of 4.5 m²K/W, for the walls, 3.5 m²K/W for the floor, and 6 m²K/W for the roof are utilized. HR++ glass with a solar heat gain coefficient (g value) of 0.6 and a U value of 1.2 W/m²K is employed.

To calculate the ventilation rate, the following formula was used:

Ventilation rate = ventilation flow rate / volume

4000 (m^3 per hour) / 1244 (m^3) = 3.2

The auditorium accommodates up to 80 individuals. Lighting power is estimated at 8 W/m², along with an additional 1000 W for equipment, including a projector and laptops.

All this information has been inputted into the Excel sheet on the following page. Subsequently, the cooling and heating capacities are calculated using the following formula:

$$T_i = T_e + \frac{Q_{sun} + Q_{intern} + Q_{heating} - Q_{cooling}}{H_{tot}}$$

In summer this gives the following result:

$22 = 28 + (8252.9 + 10984 – Q_{cooling}) / 1597.189$

$Q_{cooling} = 28820\ W$

In the transitional season this gives the following result:

$21 = 10 + (10400 + 10984 - Q_{cooling}) / 1597.189$

$Q_{cooling} = 3817$

Finally, in winter this gives the following result:

$20 = -10 + Q_{heating} / 535.643$

$Q_{heating} = 16069.29$

Naam ontwerp of vertrek:	Naam:	Rhythms of Renewal	
Locatie ontwerp:	Breedtegraad:	52	°
Netto vloeroppervlak:	Vloeroppervlakte:	248	m^2
	Volume:	1244	m^3

Ontwerp binnen -en buitentemperatuur	Seizoen:			
	Zomer	T_{binnen}	22	°C
		T_{buiten}	28	°C
	Tussen	T_{binnen}	21	°C
		T_{buiten}	10	°C
	Winter	T_{binnen}	20	°C
		T_{buiten}	-10	°C

		Orientatie	Oppervlakte m^2	R_c-waarde m^2K/W	%Raam	g-waarde (-)	g-waarde zonwering (-)	Oppervlakte raam m^2
Gebouwschil:	Vloer	boven grond	248	3,5				
	Gevel 1	N	77	4,5	0%	0,6	0,6	0 m^2
	Gevel 2	W	36	4,5	0%	0,6	0,6	0 m^2
	Gevel 3	ZZW	128	4,5	19%	0,6	0,6	24,32 m^2
	Gevel 4	NNO	97	4,5	19%	0,6	0,6	18,43 m^2
	Dak	Horizontaal	251	6	0%	0,6	0,6	0 m^2

Stationaire warmtebalans

Deze Excelsheet berekent de stationaire warmtebalans van een ruimte of gebouw.

De gele vakjes zijn variabelen, deze zijn specifiek voor het ontwerp en de wensen voor de ruimte.

Uitgangspunt:
Kozijn percentage = 10% raam
Uraam = 0,1Ukozijn + 0,9 Uglas

U-waarde					Zomer	Tussen	Winter	
Gemiddelde U-waarde raam:	1,2			W/m^2K				
Gemiddelde U-waarde schil:	0,25			W/m2K				
ΣU.A	208,1			W/K	5,0	-9,2	-25,2	W/m^2

Bereken ventilatie	Zomer	Tussen	Winter		Zomer	Tussen	Winter	
Ventilatievoud:	3,2	3,2	3,2	(-)	3980,8	3980,8	3980,8	m^3/h
Warmteterugwinpercentage wtw:	0%	0%	80%					
Infiltratievoud:	0,15	0,15	0,15	(-)	186,6	186,6	186,6	m^3/h
					34	-62	-40	W/m^2

Zon belasting: A_{glas} * g-waarde * q(zon)	Zomer	Tussen	Winter		Zomer	Tussen	Winter	
Zonwering:	Nee	Nee						
Zonbelasting:	8252,9	10400	NVT	W	33	42	NVT	W/m^2

Interne warmtelast:			Zomer	Tussen	Winter	
Aantal personen:	80	(-)				
Vermogen verlichting:	8	W/m^2				
Vermogen apparatuur:	1000	W	44,29	44,2903	NVT	W/m^2
Totaal:			116,3	15,1	-65,2	W/m^2

Weet je het verwarmings- en koelvermogen, dan kun je ook de binnentemperatuur uitrekenen.	Zomer	Tussen	Winter		Zomer	Tussen	Winter	
Q-koeling:	28820	3817	0	W	-116	-15		
Q-verwarming:	0	0	16069,29	W		0	65	W/m^2
Binnentemperatuur:					22,0	21,0	20,0	°C

	Zomer	Tussen	Winter	
Hvent	1326,933	1326,933	265,3867	W/K
Hinf	62,2	62,2	62,2	W/K
Htrans	208,0561	208,0561	208,0561	W/K
Htot	1597,189	1597,189	535,6428	W/K
Qzon	8252,9	10400	0	
Qint	10984	10984	0	
Qverw	0	0	16069,29	
Qkoel	28820	3817	0	
Te	28	10	-10	
Ti bereken	22,00002	20,99895	20,00001	

Figure 78: Heat balance calculation (Own work, 2024)

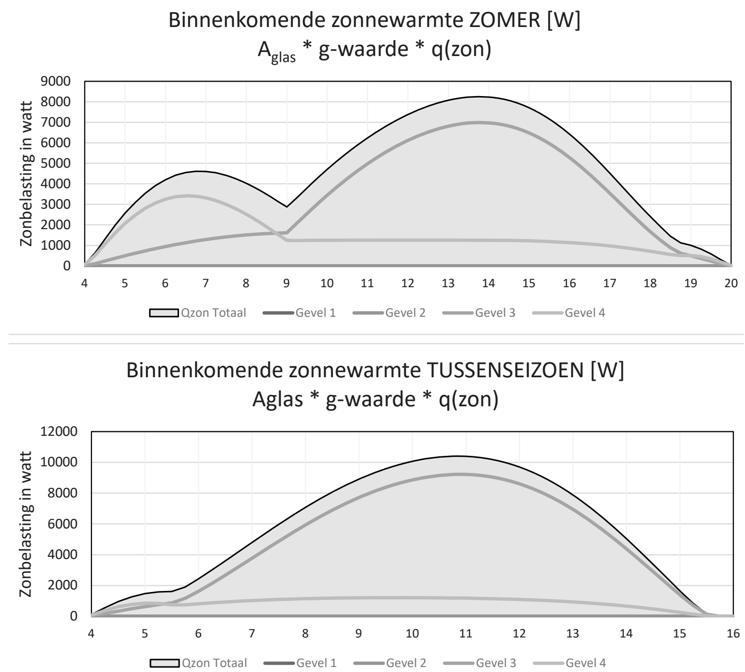


Figure 79: Calculation results (Own work, 2024)

T_{buiten} =	28	T_{binnen} =	22	°C
Resultaten zomer			W/m²	
Q ventilatie & Q infiltratie			34	
Q Transmissie			5	
Q intern			44	
Q Zonbelasting			33	
Koudebehoefte			**116**	

T_{buiten} =	10	T_{binnen} =	21	°C
Resultaten tussenseizoen				
			W/m²	
Q ventilatie & Q infiltratie			-62	
Q Transmissie			-9	
Q intern			44	
Q Zonbelasting			42	
Warmte- of koudebehoefte			**15**	

T_{buiten} =	-10	T_{binnen} =	20	°C
Resultaten winter				
			W/m²	
Q ventilatie & Q infiltratie			-40	
Q Transmissie			-25	
Q intern			NVT	
Q Zonbelasting			NVT	
Warmtebehoefte			**-65**	

negatief getal = warmte stroom uit de ruimte
positief getal = warmtetoevoer aan de ruimte

	Zomer	Tussen	Winter	
Berekende binnentemperatuur	**22,0**	**21,0**	**20,0**	°C

Figure 80: Calculation Results (Own work, 2024)

VI. Conclusion & Reflection

1. **Conclusion**

Concluding Remarks

This design for a nature centre, titled 'Rhythms of Renewal,' focuses on expressing material cycles by aligning the endurance of mycelium, stone, and wood with the intended lifespan of their respective building parts. Initially highlighting mycelium's transient nature, the project evolved as other enduring materials revealed similar cyclical processes at varying rates. This exploration delved into how mycelium, stone, and wood express differing degrees of endurance and transience.

The design contrasts the transient and enduring, the static and dynamic, and lightness and heaviness, blending aesthetics with technology. By integrating material lifecycles with the intended lifespan of building functions and elements, it exemplifies a sustainable approach that minimizes waste and maximizes adaptability.

Ultimately, this project fosters appreciation for sustainable aesthetics, synchronizing the rhythms of material cycles with our patterns of use.

2. **Reflection**

For my graduation project, “Rhythms of Renewal,” I explored how material cycles could be integrated into architectural design, focussing on mycelium, stone and wood. In this reflection, I will evaluate how the project aligns with the studio assignment and master track, analyze the relationship between research and design, assess the effectiveness of my approach and methods, and consider the social values and transferability of the project outcomes.

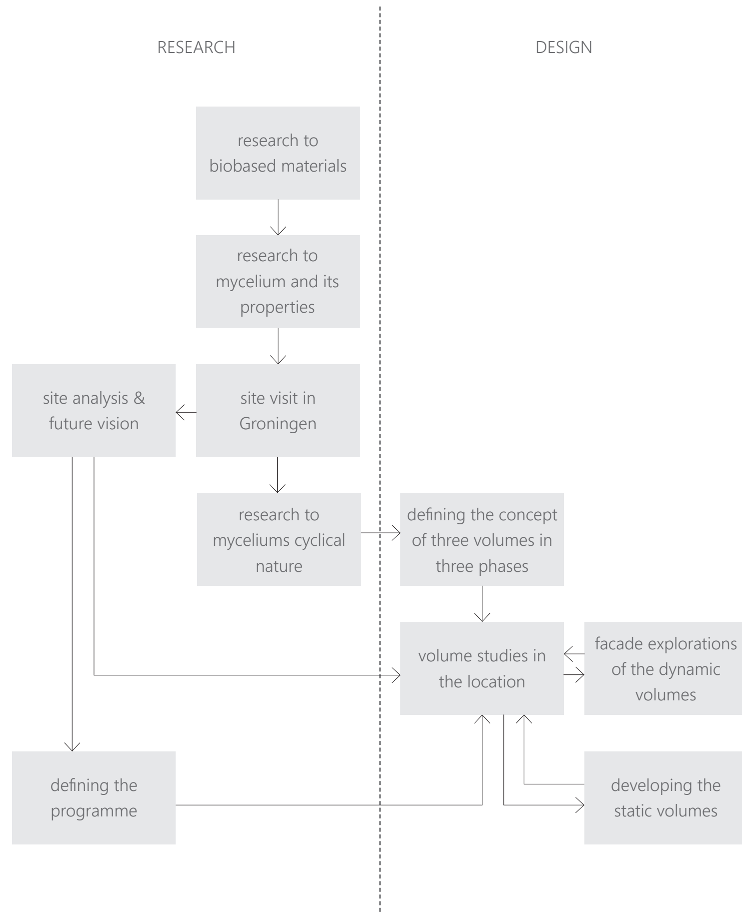


Figure 81: Research & Design Diagram (Own work, 2024)

2.1 Project & Studio Assignment

Looking back at the relationship between my project and the studio assignment, the design studio 'Technologies & Aesthetics' aimed to explore architectural expression and aesthetics driven by technical innovations and climate change challenges. In response, my project focusses on how the endurance of materials can be aligned with the intended lifespan of buildings to minimize waste and resource consumption. Initally focussing on the expression of mycelium, a transient material which is fully renewable and biodegradable.

While my research addresses the practical and technical aspects of implementing mycelium as a building material, it goes beyond that. It also focuses on developing a unique form language and expression that resonates with the cyclical nature of mycelium. In other words, my research doesn't only treat mycelium as a functional material, but it also seeks to explore how its inherent cyclical properties can be architecturally expressed.

2.2 Project & Master Track

The master track of Architecture emphasizes learning to use design as a tool for addressing technical, social, and spatial challenges encountered in the built environment. My project aligns with these principles by exploring how material durability can be aligned with the intended lifespan of buildings, thus contributing to sustainable construction practices. By focusing on mycelium as a renewable and biodegradable building material, my project addresses environmental challenges while also promoting innovative design solutions within the field of architecture.

2.3 Research & Design

For my research I investigated the question: "How can mycelium's cyclical nature find expression and practical application within architecture?". When I started the research I didn't know anything about mycelium. Initially, I perceived the transient nature of mycelium as a flaw, something to be solved. However, as I delved deeper into my research, I came to the realization that this characteristic should be embraced rather than to overcome. This realization led to the formulation of my research question.

This shift in perspective greatly influenced my design approach. Instead of viewing mycelium's cyclical nature as a limitation, I began to explore how it could be embraced and integrated into an architectural design. I came to the conclusion that a design could consist of all three phases of the lifecycle: growth, maturity and decay. These three phases can be translated to architecture through the creation of three distinct volumes, each representing a unique phase within this cycle. So, when one volume is growing, a second one is in a state of maturity, and the third volume is in decay. This way, a mycelium building can remain a permanent use while expressing its dynamic and transient character. It leads to a cyclical design rather than a design with a final endpoint.

This research not only laid the foundation for my design concept but also set the stage for the actual design process. It provided the guiding principles and inspiration necessary to develop a design that embraces and expresses the transient character of mycelium. As I continued on with the design, I realized similar processes exist in more enduring materials such as stone and wood, and I incorporated these cycles as different rythms.

2.4 Approach and Methodology

Reflecting on my approach, I primarily used modeling as a key tool throughout my project. Creating physical models allowed me to experiment with concepts and ideas across scales. Additionally, I used 2D computer drawings to add clarity and detail to my designs. Unlike previous master's projects heavily reliant on computer-generated 3D models, this time I embraced a more traditional, hands-on approach. This shift enabled greater creativity and experimentation, fostering an intuitive and playful design process.

While physical modeling and 2D drawings facilitated experimentation, they also posed limitations. Relying on these methods made the process more time-consuming, requiring adjustments to multiple drawings when changes were made. Despite these challenges, the hands-on process nurtured creativity and deepened my understanding of materiality and form.

2.5 Acedemic and Societal Significance

The academic significance of the project lies in its innovative approach to using mycelium as a sustainable building material and intertwining material durability with the intended lifespan of buildings. The project therefore offers valuable insights into minimizing waste and optimizing resource usage within the building industry. By showcasing the transient and dynamic nature of renewable and biodegradable materials like mycelium, in contrast with the static and enduring qualities of traditional materials such as stone, the design serves as statement to raising awareness of sustainable design practices.

2.6 Transferability of the Project

Looking ahead, the transferability of the project lies not only in its technical innovations but also in its conceptual framework. Its principles can be applied across diverse contexts and scales, from individual building projects to urban planning initiatives. The concept of intertwining material durability with the intended lifespan of the function, alongside embracing mycelium's transient qualities, offers an innovative approach to sustainable design. Specifically, the idea of creating three volumes that continually express the phases of growth, life, and decay is a concept which can be explored in multiple different contexts, and in many different ways.

VII. Bibliography

References

Accoya. (2020). *Houtinformatiegids*. V3.9, 1-53. Retrieved May 2, 2024, from https://www.accoya.com/app/uploads/2020/06/Houtinformatiegids_LOW.pdf

Almpani-Lekka, D., Pfeiffer, S., Schmidts, C. et al. (2021). A review on architecture with fungal biomaterials: the desired and the feasible. *Fungal Biology and Biotechnology*, 8(1), 17-25. https://doi.org/10.1186/s40694-021-00124-5

Centrum Hout. (2017). Houteigenschappen infoblad. 8. Retrieved May 2, 2024, from https://www.houtdatabase.nl/infobladen/Infoblad_Houteigenschappen-Sterktegegevens.pdf

Davis, F. (2021). *Mycoknit.* PennState College of Arts and Architecture. Retrieved December 12, 2023, from https://arts.psu.edu/projects/mycoknit/

Ecovative. (n.d.). *Our Story*. Retrieved November 28, 2023, from https://www.ecovative.com/pages/our-story

Elsacker, E. (2019). Mechanical, physical and chemical characterisation of mycelium-based composites with different types of lignocellulosic substrates. *Vrije Universiteit Brussel*. https://doi.org/10.1101/569749

Elsacker, E. (2021). Mycelium Matters - an interdisciplinary exploration of the fabrication and properties of mycelium-based. [Master's thesis, Vrije Universiteit Brussel] https://doi.org/10.13140/RG.2.2.23578.77764

Fairs, M. (2013, October 20). Mycelium Chair by Eric Klarenbeek is 3D-printed with living fungus. *Dezeen.* Retrieved November 20, 2023, from https://www.dezeen.com/2013/10/20/mycelium-chair-by-eric-klarenbeek-is-3d-printed-with-living-fungus/

Frearson, A. (2017, September 4). Tree-shaped structure shows how mushroom roots could be used to create buildings. *Dezeen.* Retrieved November 29, 2023, https://www.dezeen.com/2022/09/01/chart-art-fair-2022-mycelium-pavilion/

Hahn, J. (2022, January 18). Blast Studio 3D prints column from mycelium to make "architecture that could feed people". *Dezeen.* Retrieved November 12, 2023, from https://www.dezeen.com/2022/01/18/blast-studio-tree-column-mycelium-design/

Hendrikx, B.P.W. (2019). *An Exploration of Nature-Based Materials to Grow Architecture*. [Master's thesis, Delft University of Technology]. TU Delft Repositories

Jordahn, S. (2022, September 1). Chart Art Fair pavilion aims to investigate the potential of mycelium. *Dezeen.* Retrieved November 12, 2023, from https://www.dezeen.com/2022/01/18/blast-studio-tree-column-mycelium-design/

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*. https://doi.org/10.3389/fbioe.2023.1229693

Lim, M. S., & Shu, Y. (2022). *The future is fungi: How Fungi Can Feed Us, Heal Us, Free Us and Save Our World*. Thames & Hudson.

Massoni, E. (2023, February 23). Bio-based industry: is it possible?. *Interni Magazine*. Retrieved November 29, 2023, https://www.internimagazine.com/features/industria-bio-based-si-puo/

McGaw, J., Andrianopoulos, A., & Liuti, A. (2022). Tangled Tales of Mycelium and Architecture: Learning From Failure. *Frontiers in Built Environment*, 8. https://doi.org/10.3389/fbuil.2022.805292

Morby, A. (2017, June 20). Structure grown from "mushroom sausages" shows potential for zero-waste architecture. *Dezeen*. Retrieved November 29, 2023, from https://www.dezeen.com/2017/06/20/aleksi-vesaluoma-mushroom-mycelium-structure-shows-potential-zero-waste-architecture/

Pownall, A. (2019, October 2019). Pavilion grown from mycelium acts as pop-up performance space at Dutch Design Week. *Dezeen*. Retrieved November 10, 2023, from https://www.dezeen.com/2019/10/29/growing-pavilion-mycelium-dutch-design-week/

Redhouse studio. (n.d.). Bioterials. *Redhouse studio*. Retrieved November 9, 2023, from https://www.redhousestudio.net/pages/research/bioterials

Stott, R. (2014, June 27). Hy-Fi, The Organic Mushroom-Brick Tower Opens At MoMA's PS1 Courtyard. *ArchDaily*. Retrieved November 20, 2023, from https://www.archdaily.com/521266/hy-fi-the-organic-mushroom-brick-tower-opens-at-moma-s-ps1-courtyard

Souza, E. (2023, July 20). Symbiocene Living: Exploring the Potential of Mycelium Blocks for Sustainable Architecture. *ArchDaily*. Retrieved November 30, 2023, from https://www.archdaily.com/1004032/symbiocene-living-exploring-the-potential-of-mycelium-blocks-for-sustainable-architecture

Superflux. (2014, February 12). Mycotecture (Phil Ross). *MoMA: Design and Violence*. Retrieved November 10, 2023, from https://www.moma.org/interactives/exhibitions/2013/designandviolence/mycotecture-phil-ross/

Syed, S. (2017, August 13). This Pavillion Lives and Dies Through Its Sustainable Agenda. *ArchDaily*. Retrieved November 29, 2023, https://www.archdaily.com/878519/this-pavillion-lives-and-dies-through-its-sustainable-agenda?ad_campaign=normal-tag

Illustrations

Blast Studio. (2020). *Lovely Trash Column*. [Photograph]. Dezeen. https://www.dezeen.com/2022/01/18/blast-studio-tree-column-mycelium-design/

Braun, Z. (2017). *MycoTree*. [Photograph]. Deutsche BauZeitschrift. https://www.dbz.de/artikel/dbz_Baumaterial_ernten_und_aehen-3721229.html

Company New Heroes. (2019). *The Growing Pavilion.* [Photograph]. Company New Heroes. https://companynewheroes.com/project/the-growing-pavilion/

CNK. (2013). *Hunzedal Torenveen-Bonnerklap*. [Photograph]. Coalitie Natuurlijke Klimaatbuffers. https://www.klimaatbuffers.nl/projecten/hunzedal-toorenveen-Bonnerklap

Davis, F. (2021). *Mycoknit.* [Photograph]. PennState College of Arts and Architecture. https://arts.psu.edu/projects/mycoknit/

Ecovative Design. (2007). *Mycelium insulation material.* [Photograph]. BuildingGreen. https://www.buildinggreen.com/blog/greensulate---fungus-based-insulation-material-thats-grown-rather-manufactured

Fielding, G. (2023). *Modular Building Blocks*. [Photograph]. ArchDaily. https://www.archdaily.com/1004032/symbiocene-living-exploring-the-potential-of-mycelium-blocks-for-sustainable-architecture

Fricker, M.D., Boddy, L., & Bebber, D.P. (2007). *13 Network Organisation of Mycelial Fungi.* [Photograph]. ResearchGate. https://www.researchgate.net/publication/226743773_Network_Organisation_of_Mycelial_Fungi

Graves, K. (2014). *HyFi.* [Photograph]. Architectenweb. https://architectenweb.nl/nieuws/artikel.aspx?ID=34987

Hatkar, A., & Lanke, A. (2022). Mycelium: an Eco-Friendly construction material. *IJERT*, 10(03), 240–245. https://doi.org/10.17577/IJERTCONV10IS03042

Hub for Biotechnology in the Built Environment. (2023). *BioKnit*. [Photograph]. Elise Elsacker. https://www.eliseelsacker.com/research/bioknit-strategies-for-living-textile-architectures

Klarenbeek, E. (2013). *The Mycelium Chair.* [Photograph]. Dezeen. https://www.dezeen.com/2013/10/20/mycelium-chair-by-eric-klarenbeek-is-3d-printed-with-living-fungus/

Mogu. (2015). *Acoustic panels by Mogu.* [Photograph]. Mogu. https://mogu.bio/

Raja, G. (2017). *Shell Mycelium Pavilion.* [Photograph]. Designboom. https://www.designboom.com/architecture/shell-mycelium-degradation-movement-manifesto-07-25-2017/

Paris, P. (n.d.). *Middag-Humsterland en Reitdiep.* [Photograph]. Rijksdienst voor het Cultureel Erfgoed. https://kennis.cultureelerfgoed.nl/index.php/Panorama_Landschap_-_Middag-Humsterland_en_Reitdiep

Ross, P. (2014). *Mycotecture*. [Photograph]. Mycoworks. https://www.mycoworks.com/our-heritage

Studio Volop. (n.d.). Mycelium Growing Process. [Photograph]. https://studiovolop.nl/2019/wp-content/uploads/2020/06/Mycelium-plakken-600x630.jpg

Vesaluoma. (2015). *Mushroom Sausages by Aleksi Vesaluoma.* [Photograph]. Dezeen. https://www.dezeen.com/2017/06/20/aleksi-vesaluoma-mushroom-mycelium-structure-shows-potential-zero-waste-architecture/

Züger, J. (2022). *Chart Art Fair Pavilion*. [Photograph]. Dezeen. https://www.dezeen.com/2022/09/01/chart-art-fair-2022-mycelium-pavilion/