Bio-skin: Mycelium Based Facade Panel System for Circularity in Architecture

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“Bio-skin: Mycelium Based Facade Panel System for Circularity in Architecture”

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AUD-Architecture and Urban Design

A.A. 2021/2022

Master’s Degree Thesis

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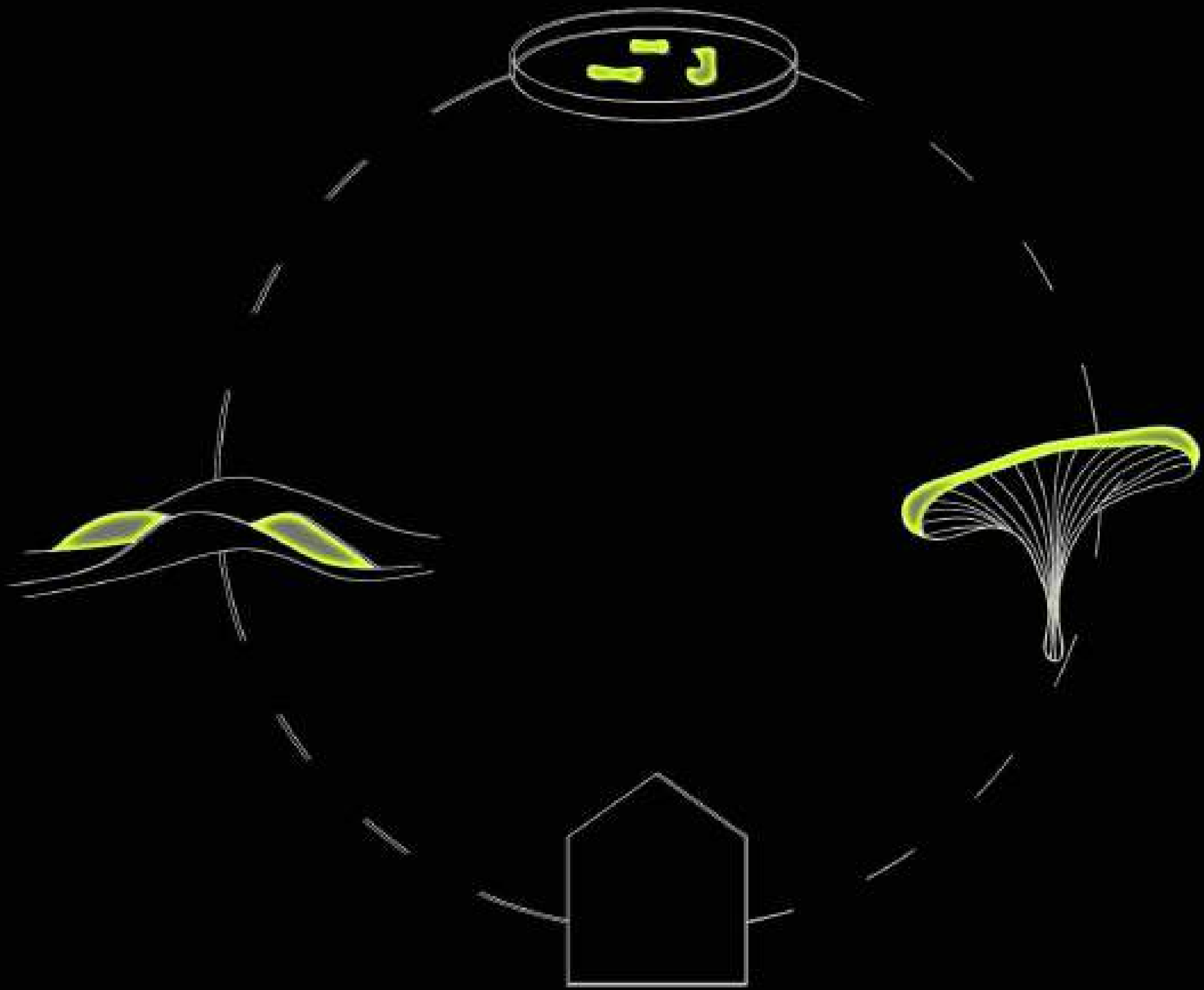
ACKNOWLEDGMENTS

First, I would like to state my gratitude to my supervisor Simone Giostra who guided me all through this thesis. I would also like to thank my co-supervisor Ingrid Maria Paoletti who supported the material practice work through Material Balance Research and to my co-supervisor Olga Beatrice Carcassi for her dedication and assistance with mycelium research. Finally, I would like to express my appreciation to my family and friends who encouraged me throughout the thesis and architectural journey.



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ABSTRACT

This thesis aims to address the negative impact of construction industry caused by the linear model it adopts, replacing with a circular approach built on closed-loop cycles, which decreases environmental footprint. A cycle set to eliminate waste, circulate materials, recycle, and regenerate by dividing the material flow. For circularity, design process must be reorganized under the logic of design-for-disassembly where resources are preserved by constructing in a layered system to dismantle and reuse in end-of-life.

The thesis responds to the question of, how to construct reducing the environmental impact in contrast to traditional methods by designing through biophilic design, introducing the possibility to utilize mycelium-based materials to reduce consumption and prevent excessive extraction of resources.

Research focused on the material practice, with mycelium, in the search of a product which provides both light transmittance and insulative performance together. The results demonstrate that the infill panels can be used as a facade element pursuing the concept of biophilic light, as the porous mycelium growth forms an interplay between light and shadow relating to sense of visual perception by experimenting the atmosphere, space, time.

Consequently, a material catalog and construction details for different application typologies are documented to display the use of “Bio-skin: Mycelium based facade panel systems” as an architectural tool. The research is concluded with a case study to demonstrate how the design can adapt to a specific site, corresponding to optimization of light illumination analysis and how the design follows a circular model through the material flow chart.

Keywords: Circular Economy, Biophilic-Design, Mycelium-Based Design

INTRODUCTION

The urgency to resolve the environmental problems caused by the linear economic model, "produce, use, and dispose" became the upmost task for the architecture and construction sector. In this search, there has been a paradigm shift to Circular Economy model in the construction industry targeting solutions for environmental problems by closing the loops where the end-of-life is top priority and waste is used as a resource.

As Kennedy et al. (2015) stated, architecture must be improved in terms of how it integrates with the larger system it belongs; ecosystem. The improvement based on circularity of design. How to design and build with positive effects on environment? How to construct by reducing the environmental impact in contrast to traditional methods? A more circular approach to sustain resources is to use materials from industrial waste and lignocellulose waste as components for the manufacture of innovative bio-based materials (Jedrzejczak, Collins ve Jes 2021). By designing architecture through the living the built environment can become integrated with the larger frame. With the integration of bio-based design, living systems as bacteria, algae, fungi, are introduced to architecture for sustainable solutions.

Bio design practices incorporate" biology-inspired approaches to design and fabrication" where" living organisms [are] essential components in design". (Myers 2018) Utilizing organic materials compared to traditional materials such as wood, steel, or concrete, help keep maintaining a circular design by reducing the consumption and preventing excessive extraction of finite resources. Among these materials, one which can be cultivated and replace current construction materials is mycelium-based bio-composites. These composites support renewable and environmental alternatives for architectural applications in a circular future.

The current use of mycelium-based materials has been explored to produce and replace businesses from packaging, furniture, fashion textile as leather, thermal and acoustic insulation materials. Although, there are research made across several disciplines as mechanical, industrial, chemical, and biological there is a gap both in the literature and application of mycelium-based materials in scaled up products to be used in the Architectural Engineering and Construction industry. Due to the lack of standardization in manufacturing and low mechanical properties the field has been limited to small-scale models and rebounds on the same findings instead of testing innovative proposals.

This research aims to examine further applications of mycelium-based materials in the architectural field gathering information from material practices, with the data assembled the end product will be applied to an architectural element, scaling up in the application process.

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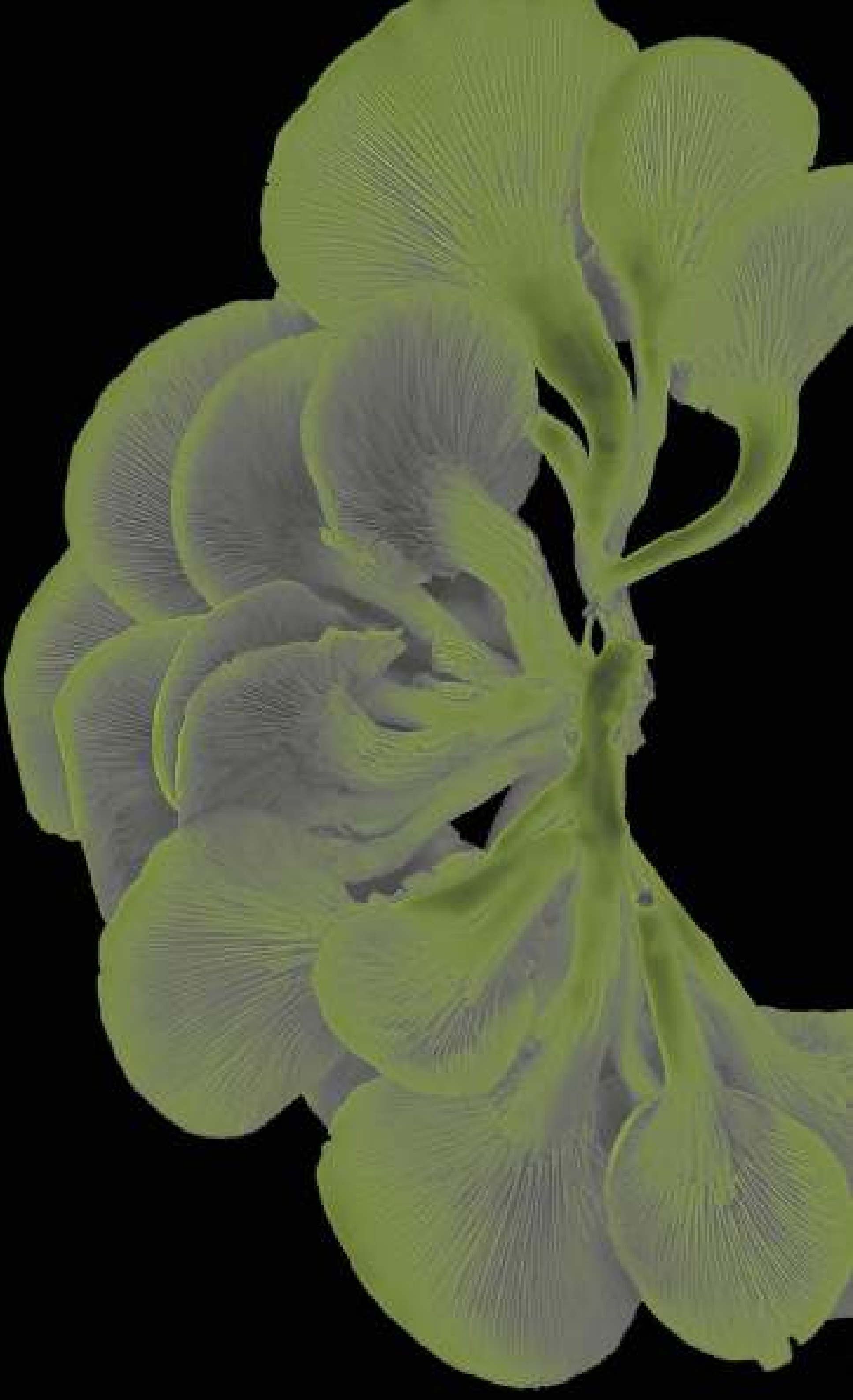


01 CIRCULAR ECONOMY

1.1 Construction Industry effects on the environment

The Construction sector has been accountable for the majority of natural resource consumption over the last decades. E&C sector is the largest consumer of raw materials, responsible for nearly fifty percent of overall steel manufacturing and consumption of over three billion tonnes of resources (Brennan 2020). Not only the extraction stage but the processing of raw materials requires high energy consumption through the manufacturing, fabrication, and transportation stages to be used in construction sites. In the construction stage many of the manufactured materials are unused and pile up forming construction waste. In the later life cycle, most of the building materials become waste by being demolished, causing pollution to air, water, and land, rather than being reused or recycled. As stated in the Ellen MacArthur Foundation the hazardous consumption in the construction industry is caused by the linear economic model it embraces. In this adopted model we extract the resources from earth, manufacture them into products and then throw them away as disposal waste.

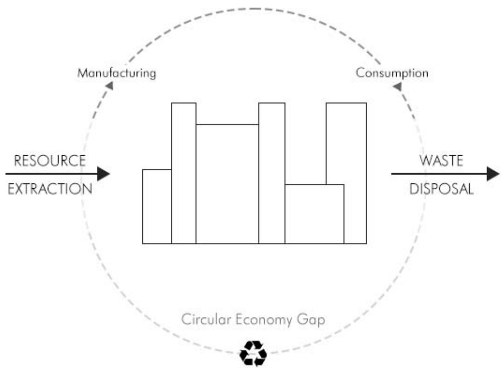


Figure 1.1 Linear Economic Model

[1] The Ellen MacArthur Foundation established in 2010 to promote the transition to the concept of circular economy in multidisciplinary areas.

Over the last decades resource scarcity has become a serious global threat to all industries, but especially to the construction sector. According to many researchers, the global resource extraction percentage increased in a drastic rate as it has become impossible to be replaced. The environmental impact of Europe's built environment is up to 20% of all water consumption, 20-40% of the energy use, 30-40% of greenhouse gas emissions and 30- 40% of waste generation. (europa.eu 2020) Therefore, in recent years, the urgent need to deal with global challenges as climate change, biodiversity loss, resource scarcity, waste generation and pollution, there has been a paradigm shift to a Circular Economy model. As stated by ARUP, the construction sector is put on the spot to minimize its impact on the environment. Therefore, a circular model approach could assist to decrease the ecological footprint and avoid further risks. (ARUP 2016)

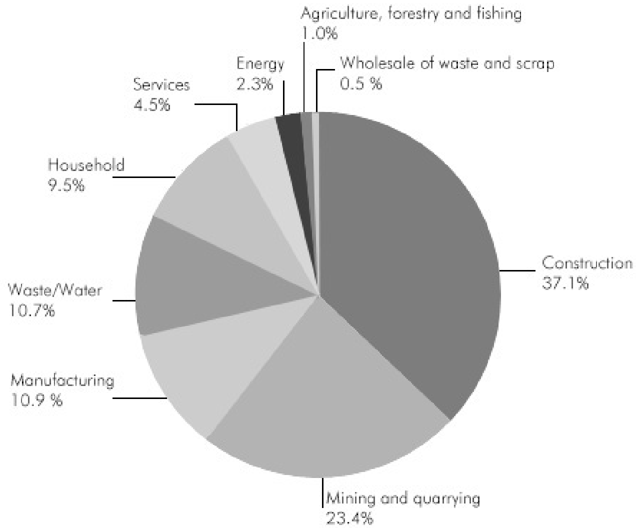


Figure 1.2 Waste generation by economic activities and households, EU,2020 (%share of total waste). Source: eurostat

1.2 What is and how to transform to Circular Economy

The definition of circular economy model bases on several important theories including John T. Lyle's Regenerative Design 1994, Walter R. Stahel's Performance Economy, and William McDonough and Michael Braungart's Cradle to Cradle[2] 2002 approach (Rau-Oberhuber ve Heisel 2020). Drawing on these earlier works, the Ellen MacArthur Foundation gained attention on the definition of the Circular Economy and advocated the global transformation by stating: "A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (Rau-Oberhuber ve Heisel 2020). In other words, the circular economy is a way to rethink and transform the linear system to a resilient system through three principles where waste and pollution is eliminated, materials and resources are circulated, and nature is regenerated.

Yet, with the growing population the resources become scarce creating the urgent need to discover alternative means of resources and ways to manufacture and use materials. Meaning that the management, manufacturing, consumption, and end of life cycles must be rethought and redesigned. Our current economic growth continues to be based on the unsustainable and intensive extraction of natural resources.

"In order to avoid contamination or loss of the planet's biodiversity, we must understand how nature can regenerate itself to provide sustainable natural capital" (Ellen McArthur Foundation, 2021).

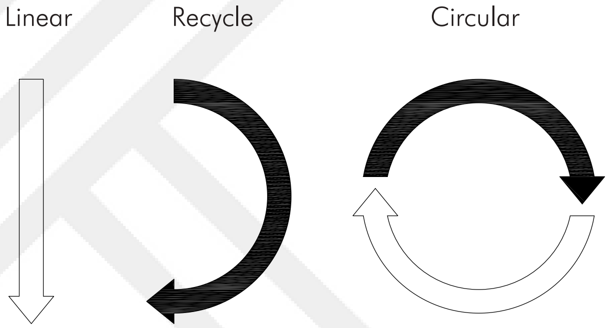


Figure 1.3 Types of Economic Models

The 'butterfly' diagram represented by the Ellen MacArthur Foundation clarifies this search by separating the material flow into two cooperating cycles as technical and biological resource cycles. The biological cycle aims to reduce material consumption, reduce waste production, and produce sustainable products by using renewable and plant-based resources which then restored back to the biosphere. Where the technical cycle, deals with the products which cannot be re-used for their original purpose at the end of their service life, by remanufacturing the components into new products to avoid waste production. Through circular economy a closed-loop cycle is generated for a sustainable built environment reducing the footprint and lowering costs of accessing goods and services.

[2] Cradle to cradle approach is where the design principles take in care the end of life as the product can be recycled by biodegrading with no waste supporting the biological cycle to reduce material consumption.

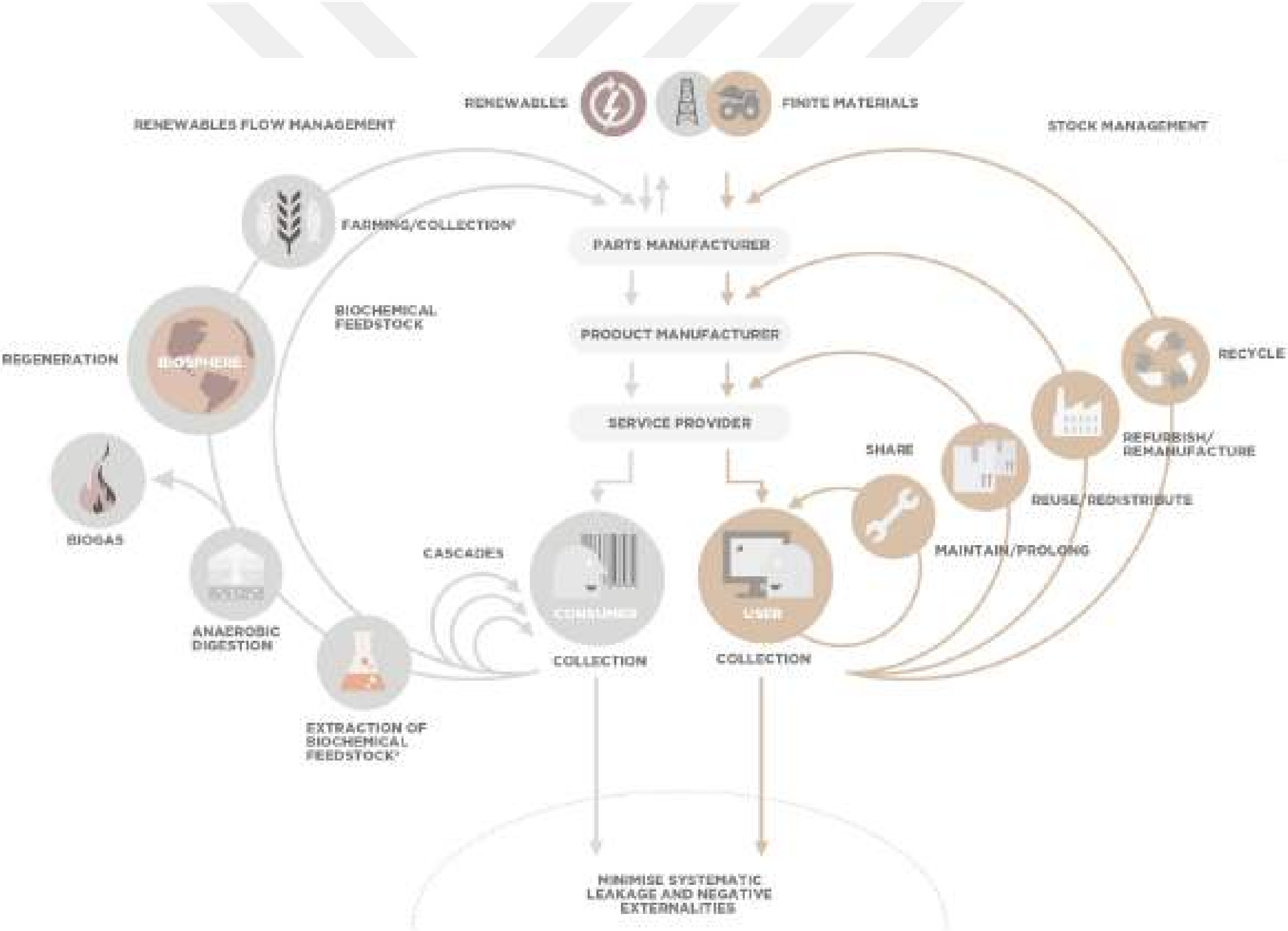
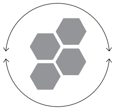


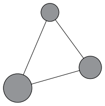
Figure 1.4 Circular economy systems diagram by, Ellen MacArthur Foundation, 2019

How to apply circular economy principles to form a circular city metabolism? Transforming the system and rethinking also means to apply the circular economy principles to the design practice aiming for a resilient future. The components of products and materials should be designed to be re-used, minimizing waste production following the idea of circulation. Through the transformation to a circular economy the Ellen MacArthur Foundation defined “The ReSOLVE framework” forming of six rules which can be utilized in different scales from the product design to build environment, from architecture to cities and even provinces.



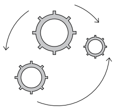
1. Regenerate

Regeneration aims for a circular built environment by utilizing the use of sustainable materials and natural resources in the design. It proposes to use biological materials as a source for them to go through anaerobic digestion later. By this the consumption of finite resources is reduced, and the environmental impact of waste production is lowered.



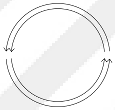
2. Share

The built environment can use spaces, buildings, infrastructure, and transportation means more efficiently by asset optimization through sharing. This way the use of assets is maximized as less space is occupied therefore, less footprint occurs, less resources are used as waste production is reduced. The idea of asset optimization encourages the movement of design for disassembly, and the use-reuse of sustainable materials which supports economic and social welfare.



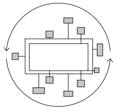
3. Optimise

By sustaining materials and components at their highest value, optimization guarantees maximum efficiency and performance while eliminating waste and encouraging the idea of circularity in materials by reusing them. Again, the idea of design for disassembly by maintaining a flexible design via off-site construction, modular component use and reuse of materials to construct new is adopted.



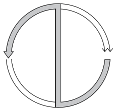
4. Loop

As pointed out through the ‘butterfly’ diagram, to obtain closed inner cycles within the construction industry, building materials or components should be reused, remanufactured, recycled or repaired for maximum efficiency. Hence longer lifespan is ensured less waste will be produced, as extraction of raw resources will be reduced.



5. Virtualise

With the introduction of Building information modelling (BIM) the physical resources are swapped with computer-generated services to gain information of an asset’s lifecycle. The optimization of the design processes is performed with BIM by integrating data about materials operation and maintenance acting as a ‘material bank’. Through virtualization, better communication among shareholders, reduced environmental and financial footprint is ensured.



6. Exchange

By selecting sustainable energy resources and virtual technologies which facilitate optimization and flexibility in design while minimizing significant cost, waste, and carbon emissions. To lower carbon emissions and follow a low- and zero-carbon strategy the renewable energy systems and materials should be embraced. The selection and application of materials should be replaced with innovative technologies and products to be designed for disassembly, modularity, and longer lifespan.

02

02 WHAT IS DESIGN FOR DISASSEMBLY?

02 What is Design for Disassembly?

Construction Industry follows the notion of closed-loop cycles, also known as cradle-to-cradle (C2C), which proposes a solution that this approach can reduce the environmental effects caused by the industries waste and improve the effective processing of resources. (Fernanda 2018) As pointed about in the 'butterfly' diagram by Ellen MacArthur Foundation and stated in the "The ReSOLVE framework", when a closed-loop cycle is obtained materials or components are reused, remanufactured, recycled or repaired for a longer lifespan without waste production. The main logic of circular economy adapted to the design process is to build with the logic of disassembly for reuse, known as design for disassembly (DfD). DfD stands for preserving resources and reducing consumption through building for recovery, as the materials and components are designed in a layered way making it simple to deconstruct and reuse.

2.1 Key principles for design

According to DfD there are some key principles to be followed through the process of design: documentation and labeling of materials and methods for efficient disassembly; choice of material which have superior quality and will be practical for reuse and recycling; designing accessible connection points with bolted, screwed and nailed ties to eliminate chemical binders; design a simple and standard open structure and divide some systems from the host such as (MEP) systems for easier repair, replacement, reuse (Guy ve Ciarimboli 2007). Therefore, Design for Disassembly has gained importance as it is essential for circular economy to be accomplished in the built environment. As there is a lack of knowledge on the environmental impact when a material is reused or recycled, the profits can be evaluated using life cycle assessment (LCA) which involves the processes from the extraction of resources to manufacturing, construction, preservation, and its deconstruction. The universal guideline for environmental management defines the life cycle assessment framework. (International Organization for Standardization, 2006).

Many industries use life cycle assessment framework to evaluate the environmental footprint of manufactured materials via course of life, however the construction industry commenced the assessment recently. (Cabeza et al., 2014). In a research (Md. Uzzal Hossain ve S. Thomas Ng 2018), LCA did not involve with the recycle options or waste management in majority. Another founding stated that LCA was applied to compare linear and circular components of a building. The findings show that the closed material loops do not give 100% circularity due to the need of input materials (Prince Antwi-Afari, ve diğerleri 2022). These articles demonstrate that it is crucial to incorporate CE framework into the LCA modules such as designing for disassembly to benefit and have reduced amounts of embodied carbon and energy in the end of life of a building. As it is stated in the key principles of DfD, the documentation and labeling of materials is important for effective disassembly. This documentation can relate to the concept of Building Material Passports (BMP)[3] , containing data of components for reuse in their end of life to sustain the loop. The existence of a consolidated database of BMPs can help the evaluation and optimization of recycling potential and environment impacts (Honic, Kovacic ve Rechberger 2019).

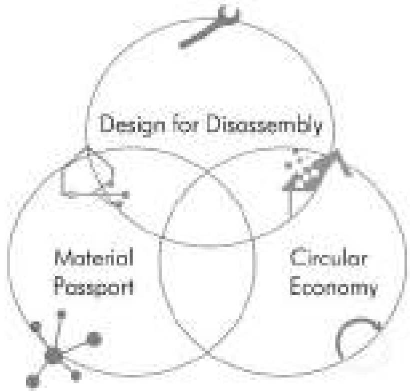


Figure 2.1 Key Principles

[3] Material Passports by BAMB are data sets including the material information from its properties, life cycle, value, reuse, and recovery to maintain the circularity.

2.2 Layers of design

In terms architectural scale the principles of design can be applied with the framework of the layers of a building. The framework of layers, “Shearing Layers”, was first thought by Frank Duffy in the 70’s and later revised by Stewart Brand in his book, “How Building’s Learn”, 1994. The concept is simplified by stating that buildings consist of six system layers:

Site - Structure - Skin - Services - Space Plan – Stuff

(Brand 1994), which all are interlocking but operate such as individual systems, so they have different lifespans and technique of construction. Later in 2016, ARUP further developed the layer system and added an additional layer called “system” to range far including a region or city. The advantage of building in layers is that it maintains the idea of disassembly of building components and promotes reuse, adaptation, replacing, removal, remanufacture and recycling without altering the whole. This gives flexibility to space and durability in years by preventing consumption of assets, waste production and reduces negative ecological impacts. This is assured as the seven system layers provide for the documentation of Building Material Passports (BMP) and the loop for reuse in their end of life.

To explain the 7S model in detail: ‘System’ involves structures and services that assist overall operation, ‘Site’ is the permenant context and geographical location, ‘Structure’ is the skeleton of a building consisting of the foundation and load-bearing elements with 30-300 years of typical lifespan, ‘Skin’ is the exterior envelope consisting of exterior finishes, glazing, frame and connection joints with 20+ years of typical lifespan, ‘Services’ consist of HVAC systems and utility zones with 7-20 years of typical lifespan, ‘Space’ is the solid interior including walls with 3 years of typical lifespan, ceiling and floors, ‘Stuff’ is the belongings, furniture or lighting systems that fill up the interior temporarily.

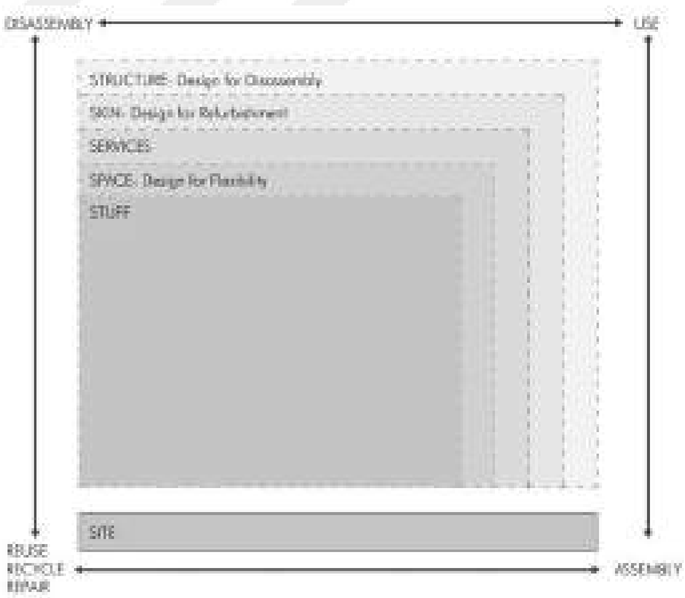


Figure 2.2 Six Layer Model

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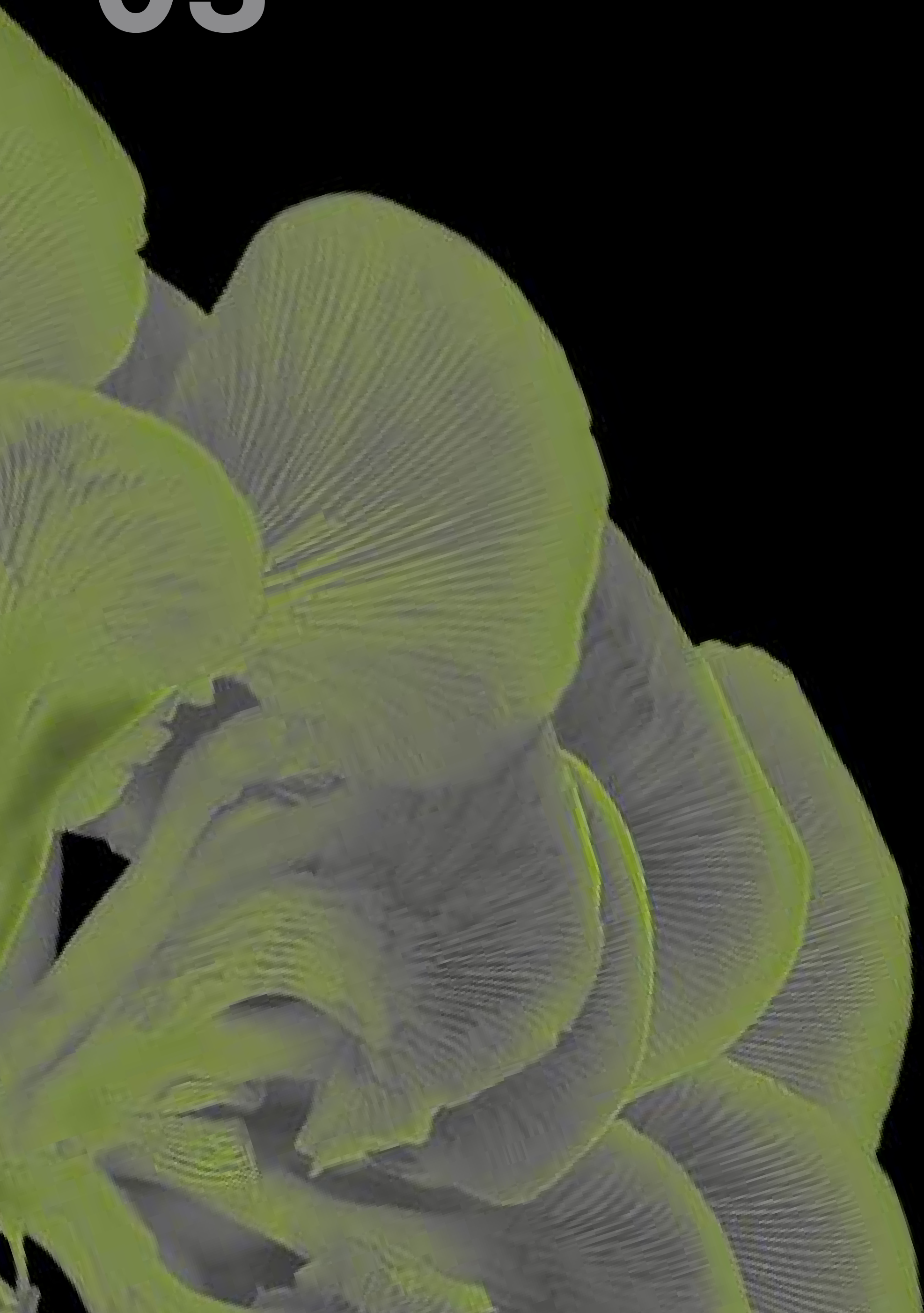
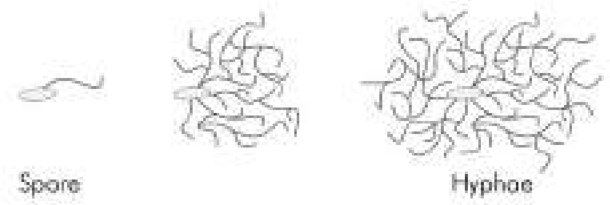


03 MYCELIUM

3.1 Material Properties

The mushroom belonging in the kingdom of fungi, is the soporiferous fruiting body of mycelium. Mycelium (plural mycelia) is the root structure of fungus built up by the branching of hyphae. (Fricker, Boddy ve Bebber 2007) Mycelium is the vegetative part of the fungi composed of organic polymers like chitin, cellulose, proteins. The fibrous root system of fungi hyphae networks multiplies via food source, collectively called mycelium tissue, are the key mean of vegetative growth. Mycelium keeps expanding by producing new offspring of mushrooms as sufficient food source and environmental conditions are ensured.



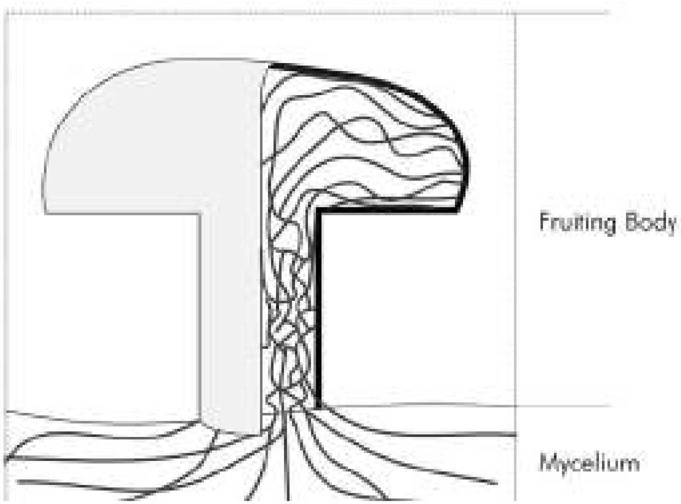


Figure 3.1 Mycelium Structure

Fungi are heterotrophic livings obtaining their source of food via other living or through decomposing the material on which they habit because they are not able to produce nutrients on their own. (McConnaughey 2014) Therefore, main role mycelium plays in ecology is to decompose surrounding organic waste with the hyphae releasing enzyme and breaking down the food into a carbon-based digestible nutrient. This action makes mycelium the keystone for ecosystems to stay on their evolutionary path by breaking down organic material from living to dead and creating a cycle in the food chain. As Paul Stamens describes, it is the neurological network of nature and without the system will fail.

The filaments began the growth by colonizing around the substrate for nutrient intake forming a dense, soft coating of fungal skin. To obtain mycelium, this skin can be removed from substrates as it is the result of total degradation of substrates when mycelium replaces them with fungus. (Freek V.W. Appels 2019) Therefore, mycelium-based composites are the outcome of the fungal growth of mycelium on organic substrates as hemp, sawdust, straw stops in colonization phase by heating which kills the mycelium and prevents growth permanently. The properties of pure and composite mycelium are reliant on several cultivation factors as fungal species, substrate used, environmental growth conditions as humidity, temperature, moisture, and sterilization are key requirements. As P. Ostreatus colonize in the direction of dark, during the production process it is key to prevent exposure to light for firmer growth. These species perform optimally between 22-27°C for the colonization and prevention from contamination. To keep the mycelium-based component moist it can be put inside plastic bag with air filter or wrapped around with holes for breathing and air circulation to prevent excessive humidity and contamination. The most critical concern of the circumstances is sterilization. Contamination occurs under unsterilized fabrication as undesired species colonize faster than the fungus. Therefore, through the preparation process the tools, surrounding and labor should be highly sterilized.

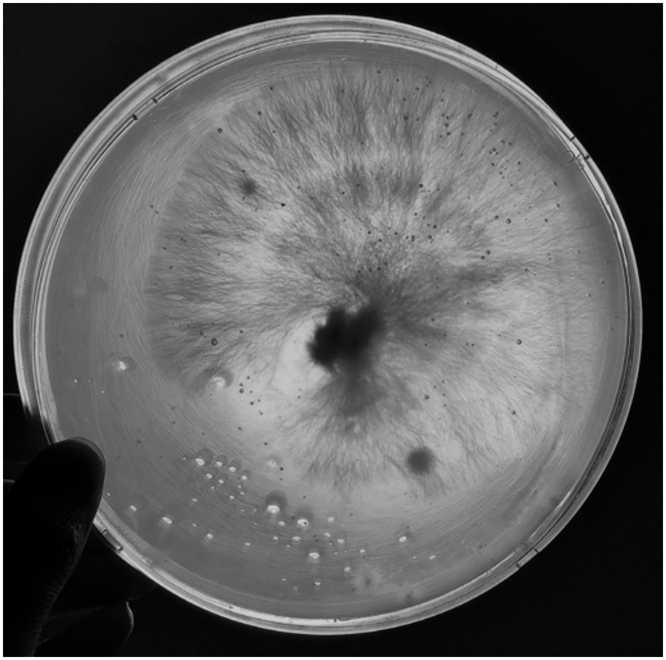


Figure 3.2 Mycelium filaments colonization

Figure 3.3 Mycelium filaments colonizing around the substrate for nutrient intake forming a dense, soft coating of fungal skin.

3.2 Biophilic Design and Mycelia

Through history there has been a divergence from nature in the process of improving living spaces and led to rapid urbanization resulting in unattached, overpopulated built environments dominated by concrete figures. The divergence not only divided the city from nature but also disconnected the humans from the living. Being unconnected to the nature has impacts both on the physical and psychological status of beings. In the search of more connected and healing spaces to continue our daily lives the concept of "biophilic design" is introduced as a tool to stay in touch with the nature. Biophilia is the human tendency to reconnect with nature to pursue a healthy state of mind and attain physical strength in the current realm. (Wilson 1986, Kellert, and Wilson 1993). Although most of the data and research collected are methodologically inadequate, the findings collected through variety of sectors from work life to schooling, from housing to healthcare, all support the assertion that association with nature has matter on its impact on human health. (Browning 2014)

Biophilic Design aims to propose spaces that reflect and bring the experience of nature into the built environment to reassociate the connection with nature by reducing the stress, improving cognitive function, and enhancing physical health. According to Determan (2019), biophilic surrounding encourages a reduced amount of anxiety, decreases patient recovery period, enhances cognition, and positive mindsets. This statement can be supported by the studies made in hospital settings and on patients. . In the studies of RS Ulrich (Ulrich 1984) the medical records of Pennsylvania hospital and compared the patients in terms of time of stay and if they could see through a window or not. The results were that hospitalization time of patients reduced by 8% they had view to the nature. The same as Ulrich, in other studies stated that 95% of patients exposed to greenery faced lower stress and faster healing. Likewise, some studies indicated that existence of plants, natural patterns, and natural day light in hospital rooms boosted the well-being of patients.

Biophilic design principles consist of visual or physical mimicry to nature through three types of experience as direct feel of nature, indirect knowledge of nature, and understanding of space. The direct experience refers to literal intersection of the built environment with natural elements as light, air, plants, animals, water, landscapes. The indirect experience refers to a visual connection to nature through imagery or exposure to patterns and geometry as in law of closure where the mind perceives a complete image. These can be the use of material, color or forms that evoke nature itself in the design. The understanding of space implies for spatial components of nature that associate with improving human health both physically and mentally as in attachment to a place.

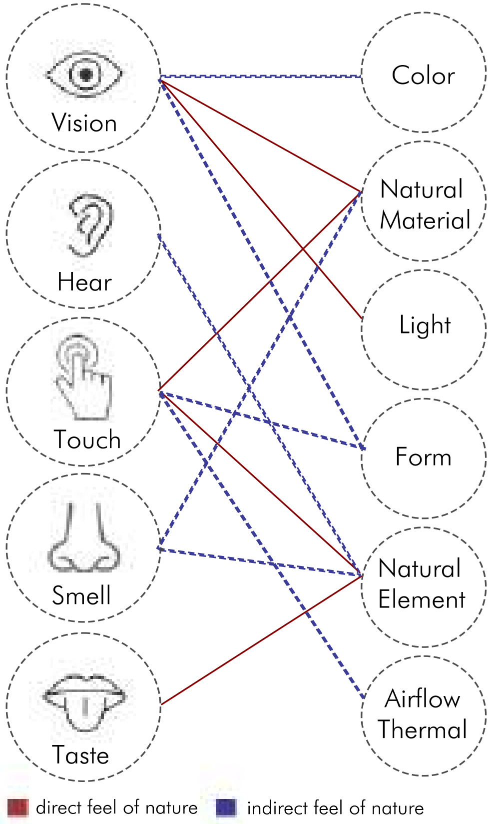


Figure 3.4 Biophilic design and experience of nature through senses

As this framework states the biophilic design is a sensory experience which in human senses are stimulated. The sense of sight, visuality and perception is the most effective approach to reconnect the human to natural spaces. Perception refers to the processing of visual information of the environmental stimuli. To stimulate visual perception of the environment we need light. Not only for well-being but to perceive the space, dimension, and time. The human body relies on the change of time for circadian rhythms. Therefore, there is an utmost importance given to the use of daylight as a design tool for spatial organization in architecture. A reason for the disconnection of nature and human is due to the fact that people are bound to spend most of their time under artificial light stabilized around 10 – 500 lux while the natural setting changes. The concept of biophilic light is a solution to this monotonous state as it refers to the interplay between light and shadow to create a dynamic experience mimicking the change in the surrounding.

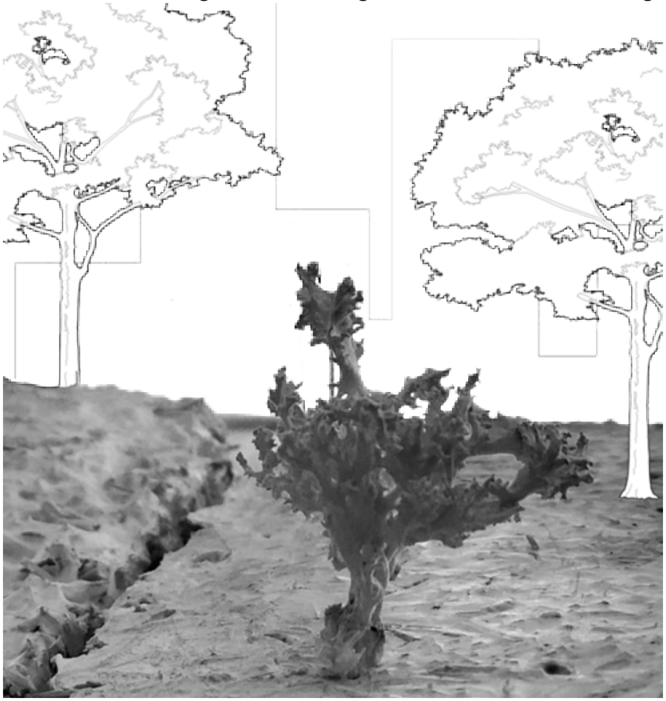


Figure 3.5 Closure of biophilic perception: human mind and spatial experience with nature reconnecting the senses.

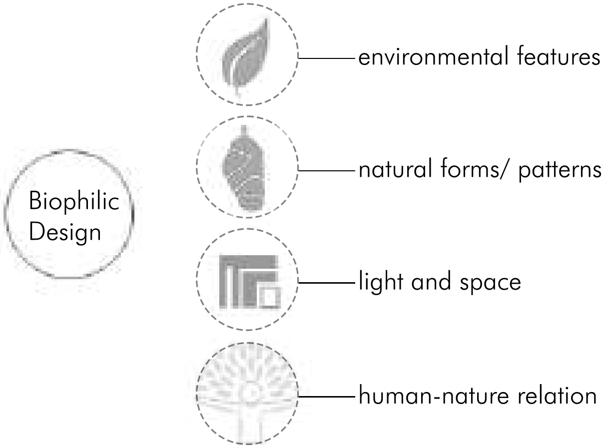


Figure 3.6 Main principles for Biophilic Design

As stated in the Gestalt principles of human perception, the mind recognizes what the eye sees by perceiving partial elements, assembling the outline. The patterns, similar elements, colors piece together to form the unity under the principle of 'Closure (Reification)'. The mind tries to match the familiar stored in the memory. Therefore, in biophilic light the use of closure principle directs the human mind to perceive the spatial experience as is it associated with nature reconnecting the senses.

The biophilic design is the integration of nature and man-made. This concept is met through 6 main principles that can be followed in the architectural field to establish harmony within the built and natural environment in search for a sustainable world. (Stephen R. Kellert 2008) The design should have; environmental features in the man-made structures as color, light, material; incorporation of natural shapes, forms, and patterns which represent the nature by evoking sensual experience; display a play of light and spatial characteristics; a place-based and human-nature relation inheriting the environmental factors. Application of natural and sustainable materials in the design can enhance the function of these principles.

The choice of material plays and important role in biophilic design. Mycelium based composites, being an innovative and newly adaptive material to the search of sustainable architecture and design, allows the integration of biophilic design as it a part of nature itself. As mycelium can replace many traditional materials it can become an answer to the question of how to heal the built environment with the association of nature and man-made structure.

3.3 Mycelium in Construction Industry

Mycelium being a renewable resource ensures biodegradable design, therefore is an alternative building material preventing consumption of assets, waste production and reduces negative environmental impacts. Throughout history mycelium has been used in medical industries to produce antibiotics and molecular compounds. Later the possibility to use mycelium as a biomaterial with the proof of its environmental benefits through the research of (Stamets 2005). In the recent years the idea of using mycelium-based composites as an alternative to current materials assimilated with product design and architecture. The first products include leathers, tools, packaging, product design, acoustic and thermal panels, and brickwork.

Companies like MycoWorks and MOGU initiated the application of vegan leather to replace animal-based leather for sustainable purposed products as alternatives to conventional materials without animal cruelty and use of toxic chemicals during the production process. Later, Ecovative, one of the pioneers for industrial application of mycelium-based products, commenced the application of mycelium in the construction industry by replacing polystyrene and plastic packaging with mycelium shields and using mycelium on behalf of glue for its binding quality. Similar to the packaging, many other companies proposed designs such as kitchen utensils, furniture, lighting made of mycelium to be used and then decomposed for circularity. In terms of innovative architectural products companies like Mogu initiated the use of acoustic, insulative and fire-resistant properties to produce acoustic, floor, wall, and ceiling panels from mycelium and textile remains. The mycelium panels will replace with chemical or petroleum-based materials can reduce the environmental impact of the construction industry and its carbon footprint.

Some pioneers of mycelium in the architectural field are: The Growing Pavilion, built in 2019 by Pascal Leboucq in collaboration with Krown Design for the Dutch Design Week, is a biophilic structure showing the potential of biodegradable materials and components as it is made from self-assembled mycelium panels integrated to timber frames which allow removal and reuse; The Shell Mycelium Installation, built in 2016 by BEETLES 3.3 and Yassin Areddia Designs, is designed as an alternative to temporary event structures displaying the use of mycelium as a building material to be affordable and more environmentally friendly. The design is based on a lightweight canopy structure where mycelium binds itself to the wooden structure. As the mycelium grows it binds and merges with the wooden structure. Supporting the circular economy, in the end of life the pavilion starts to disintegrate.

Another alternative for biodegradable construction is the brick units from mycelium composite. As hyphae decompose lignocellulosic substrates, the mycelium colonizes and bind into the form of the mold. Some of the architectural projects that used mycelium brick units: The Hy-Fi Tower, designed by The Living in 2014 to be exhibited at MoMA, displays the use of innovative building materials as is self-assembled into a lightweight solid object made from low-valued crop waste and mycelium composite packed into brick shaped mold. In the end of life, the structure is disassembled and composted in 3 months; The Mycotecture Alpha, by Philip Ross, is a pavilion composed of an arch from bricks of mycelium with sawdust substrate where the mycelium tissue kept colonizing and binding the structure without any adhesive; The MycoTree, a collaboration between Karlsruhe Institute of Technology (KIT) and Swiss Federal Institute of Technology (ETH) Zürich, was assembled at the 2017 Seoul

Architecture Biennale to uncover how mycelium could be used as the integral structural support of a building with an optimized geometry. The tree form based on mycelium blocks and timber hinges. The functioning of mycelium to decompose on organic wastes, growing and regenerated demonstrates how mycelium is a better material choice as they are emission-free, recyclable, cost friendly and provides a low environmental impact for buildings encouraged the use in architecture rapidly advancing (Waill A. Elkhateeb and Ghoson M. Daba 2019).

One of the main research topics in architecture is the knowledge on solving constraints of producing mycelium based composites in scaled up projects with enhanced the mechanical and chemical properties for improved properties and designs against environmental factors.

PRODUCT DESIGN

A- Artificial leather
example companies: MOGU / mycoworks

Figure 3.7 Mycoworks Leather

B- Packaging
example companies: ecovative

Figure 3.8 Ecovative Packaging

C- Furniture
example chair: Eric Klarenbeek

Figure 3.9 Mycelium Chair

CONSTRUCTION MATERIAL

A- Insulation Panels: thermal, acoustic
example companies: MOGU

Figure 3.10 Mogu Acoustic panels

B- Bricks

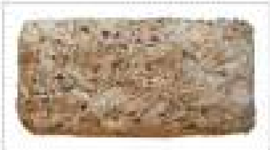


Figure 3.11 Mycelium Brick

C- Load-bearing structure

Figure 3.12 Mycelium Structure

ARCHITECTURAL SCALE

A- The Growing Pavilion, 2019, Pascal Leboucq & Krown Design

Figure 3.13 Mycelium Panel Pavilion

B- The Shell Mycelium installation, 2016, BEETLES 3.3 and Yassin Areddia Designs

Figure 3.14 Mycelium Shell Pavilion

C- The Hy-Fi Tower, 2014, The Living

Figure 3.15 Mycelium Brick Tower

D- The Mycotecture Alpha, 2009, Philip Ross

Figure 3.16 Mycelium Brick Pavilion

C- The MycoTree, 2017, KIT & ETH Zurich

Figure 3.17 Mycelium Brick Structure

?

Within these studies and designs there is a gap in the field to find alternative ways to use mycelium other than as masonry or panels in buildings. The next section of the thesis is the workflow and results of a material practice aimed to discover the possibility to use mycelium-based design as a translucent component which can be later used as an alternative in building envelopes, as a window infill or as interior panels. The research aims for two properties as light transmittance and insulation in this mycelium-based design. However, the insulative property of mycelium composites are achieved with the organic substrates as hemp, sawdust, straw. Therefore, the aim is to generate transparency designing an armature which can direct the mycelium colonization and arrange the porosity. Meanwhile the thickness of the panel and infill will prevent convection for insulative means.

This idea is based on the system of OKALUX[4] , a design of insulating glass formed by placing infills as capillary tubes, metal, wood fiber and other materials in the cavities of insulating glass. These ensure atmospheric light and use of optimal daylight for low energy consumption. Thermal insulation is made by the inserted panels as they the heat transfer in the cavity between panels in terms of convection and heat radiation. So, the thickness of cavity, the filling and material thickness determine the Ug value. Taking this into consideration the insulative performance of the material practice results dependent on the thickness of the mycelium-armature infill.

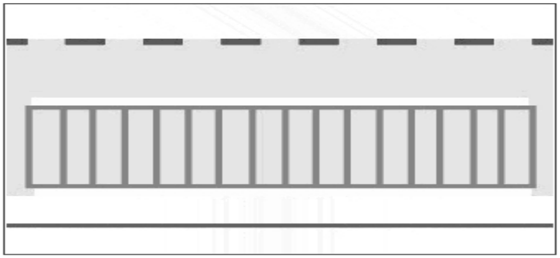


Figure 3.18 OKALUX + Build up, horizontal glazing

[4] OKALUX, established in 1965, is a company expertise in production of insulative glass, daylighting, and energy efficiency. The design focus is to optimize the use of daylight while inserting cavities of insulating glass to regulate the energy input.

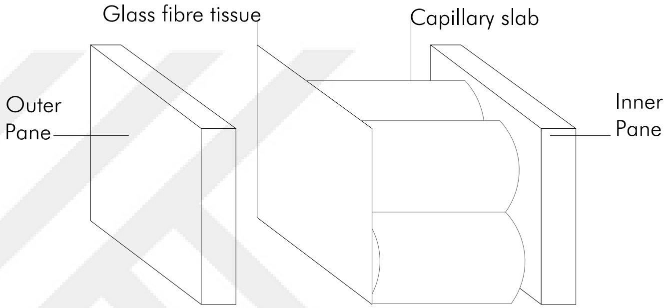


Figure 3.19 OKALUX + Build up, outer pane with low E

Mycelium has attracted the construction industry with its potential to lower the environmental impact, carbon footprint, waste production by being a biodegradable source contributing to circular economy. It binds organic matter from agricultural to industrial waste through decomposing with a network of hyphae it is possible to produce various alternative products. mycelium composites have customizable material properties dependent on the composition of fungus type and substrate used as well as to the fabrication method to meet the required mechanical values. Therefore, it can replace many traditional materials as insulation, paneling, flooring or furnishings with its controllable fire, thermal and acoustic insulation and many other. (Jones, et al. 2020)

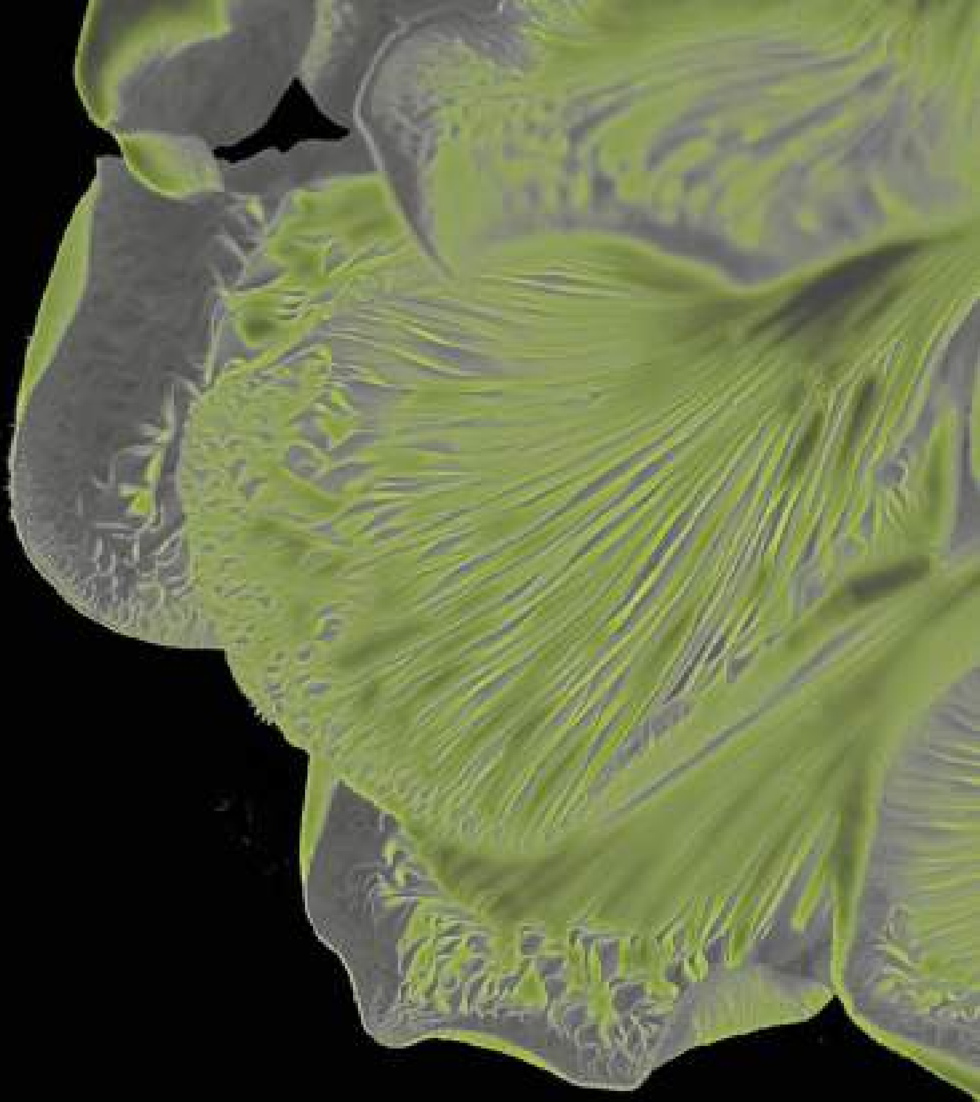
As mycelium paves the way to new alternatives for a sustainable and circular economy in construction industry there are several limiting factors. Due to its mechanical property of a foam-like porous structure, mycelium has high water absorption and is not appropriate for structural construction applications. Therefore, there is not much practice on the engineering of mycelium composites, but it is mostly utilized for non-structural building applications with respect to their properties of thermal conductivity, acoustic insulation, and fire-resistance. From the table below (Figure 3.10) the mycelium's cost, physical, mechanical, fire, thermal conductivity, acoustic absorption, moisture uptake, termite resistance, manufacturing and end of life properties can be compared to traditional synthetic foam and wood products. (Jones, et al. 2020)

They are much lighter than the compared materials even with various substrates used in the production of the composite; are cost friendly and easier to manufacture; they have similar compressive, tensile, and flexural strengths to foams but are weaker compared to wood products making it hard to use in structural applications; they have exceptional fire resistance compared to other insulative materials; they are better thermal or acoustic insulations compared to synthetic foams or wood products; their moisture uptake is higher compared to other materials that can affect other properties of the material in use. Although their manufacturing process is longer compared to other products as wood or synthetic foams, the environmental advantage of mycelium overshadows it. They are biodegradable materials which can decompose naturally in the end of life, without waste production, however the traditional materials take decades to decompose to the environment.

Material property	Mycelium composites		Synthetic foams		Wood products	
Density (kg/m³)	+	59-552	++ ++ ++	PS:11-50 PU:30-100 PF:35-120	- - --	PW: 460-680 SW:440-600 HW:850-1030
Material cost (SUS/kg)	++	0.07-0.17	+ + +	PS:2.1-2.3 PU:8.2-10.4 PF:1.7-1.9	+ + --	PW:0.5-1.1 SW:0.7-1.4 HW:3-111
Tensile strenght (MPa)	- -	0.03-0.18	- + -	PS:0.15-0.7 PU:0.08-109 PF:0.19-0.46	++ ++ ++	PW:10-44 SW:60-100, 3.2-3.9 HW:132-162, 7.1-8.7
Compressive strenght (MPa)	- -	0.17-1.1	-- + --	PS:0.03-0.69 PU:0.002-48 PF:0.2-0.55	++ ++ ++	PW:8-25 SW:35-43, 3-9 HW:68-83, 12.7-15.6
Flexural strenght (MPa)	- -	0.05-0.29	-- + --	PS:0.07-0.70 PU:0.21-57 PF:0.38-0.78	++ ++ ++	PW::35-78 SW:9.9-11.5 HW:10.3-11.5
Fire resistance	-+	no silica:low 50 wt% silica:high	-- -- ++	PS:very low PU: very low PF:very high	- - -	PW:low SW:low HW:low
Thermal conductivity (W/mK)	+	0.04-0.18	++ + ++	PS:0.03-0.04 PU:0.006-0.8 PF:0.03-0.04	- + -	PW:0.3-0.5 SW:0.08-0.3 HW:0.2-0.5
Acoustic absorption (NRC)	++	>70-75%	+ +	PS:0.2-0.6 PU:0.2-0.8	- -	PW:0.1-0.23 SW/HW:0.05-0.15
Moisture uptake (wt%)	--	40-580	++ - +	PS:0.03-9 PU:0.01+72 PF:1-15	- --	PW:5-49 SW/HW:5-190
Termite resistance	-	Low-moderate	-	low, vulnerable to nesting	-	Low, excluding heartwood or treated wood
Production time	--	Days-months	++	min-days	++	min-hours
Feedstock	++	Wastes	- - -	PS: styrene PU:isocyanate,polyol PF:Phenol formaldehyde resin	+ +	PW:wood chips, resin SW/HW:wood
Manufacturing process	++	Fungal growth		Polymerization and expansion		PW:lathing,pressing,resin infusion SW/HW:milling
Biodegradability	++	All constituents	--	None	++	Wood constituemts
Degradation time	++	Weeks-months	--	Decades-centuries	+	Years-decades
End of life	++	Garden composting	-	Recycling, landfill	-	Recycling, incineration, landfill

Figure 3.20 Mycelium's cost, physical, mechanical, fire, thermal conductivity, acoustic absorption, moisture uptake, termite resistance, manufacturing and end of life properties compared to traditional synthetic foam (polystyrene (PS), polyurethane (PU), phenolic formaldehyde resin (PF)) and wood products (plywood (PW), softwood (SW), hardwood (HW)) (Jones, et al. 2020)

04

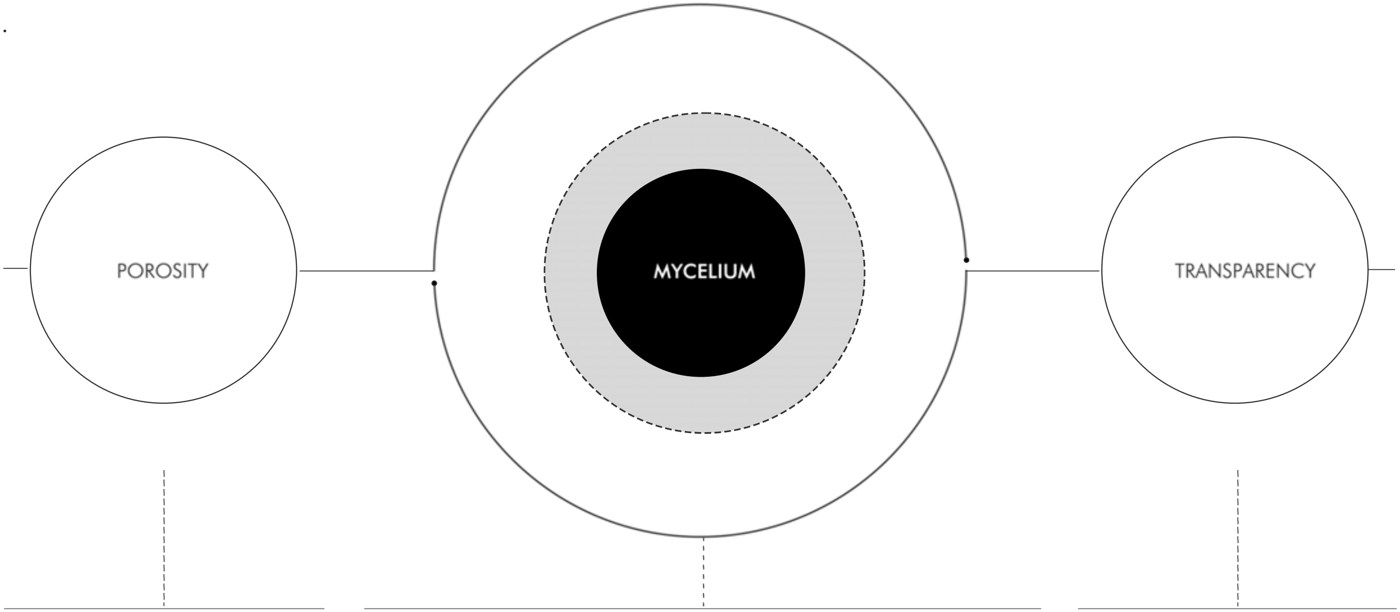


04 MATERIAL PRACTICE

04 MATERIAL PRACTICE

The material practice aims to experiment with mycelium in the search of a product which provides both light transmittance and insulative performance together later to be used as an infill for façade panel structure. To achieve these qualities the research is divided into two starting points: transparency and porosity. The material practice consists of Pleurotus Ostreatus (Gray Oyster mushroom) mycelium grains, mycelium grains on agar petri dishes, and the composite of Pleurotus Ostreatus with hemp fibers to test the effective factors for the growth of mycelium's structure. The material practice is divided into 3 main subject areas for testing substrate types, armature design forms, and mediums of growth all including several phases of experimentation:

1- Mycelium Petri Dish
2- Mycelium in PLA Armature
3- Mycelium in PLA Armature with Jute Fiber String



Research, analysis and experimentation on both mycelium structure and 3D printed PLA armature structure for porous forms.

In these material practice tests, Pleurotus Ostreatus fungus grain, mycelium composite and mycelium grains on agar substrate petri dishes are tested.

Research, analysis and experimentation with mycelium grain growth on agar substrate petri dishes and 3D printed PLA armature forms.

4.1 Fabrication of Mediums

4.1.1 Fabrication of Agar Medium

This method of fabrication is done on petri dishes using Pleurotus Ostreatus grains, an agar medium prepared with the measurements of 4.6g agar + 185g distilled water for 8 petri dishes, and the substrate that is to be tested for the colonization of mycelium. First the agar mixture is prepared in a heat resistant jar and put to the autoclave for 40 minutes at 120C° to prevent from contamination. Then it is poured onto the alcohol rubbed petri dishes while still hot and left to cool down to room temperature. Next the mycelium grains are put inside the dish with the extra substrate to be tested and the dish is sealed with a parafilm for sterile environment. In the following days the growth rate, size, direction of mycelium can be tested by comparing the rings formed around the grains.

4.1.2 Mycelium Composite

The fabrication method of mycelium composite consists of numerous steps. Step one is to choose the mycelium strain, Pleurotus Ostreatus, to be used. Step two is to prepare the cellulose substrate, hemp fiber, sterilizing it by initially soaking in water for 24 hours then letting the fibers to dry out. Later they are mixed with distilled water and flour as food source in a plastic filter bag and autoclaved for 40 minutes at 120C° to prevent from contamination. After the fibers are cooled down to room temperature, they are ready for inoculation. After the mycelium is added into the sterilized plastic bag, it is sealed and left for step 3, inoculation, for 5 to 7 days inside a sterilized box under the right temperature, darkness and moisture levels for the mycelium colonize the substrate. Following the one-week period of inoculation, the colonized mycelium is ready for the molding, being transferred into the sterilized formwork, covered with a bag with holes for it to breathe and put in a sterilized box under the right temperature, darkness, and moisture levels for the mycelium to fully colonize and bind. The last step is the drying or deoxygenating the mycelium composite to kill and stop the growth. This method results with mycelium-based bio-composites.

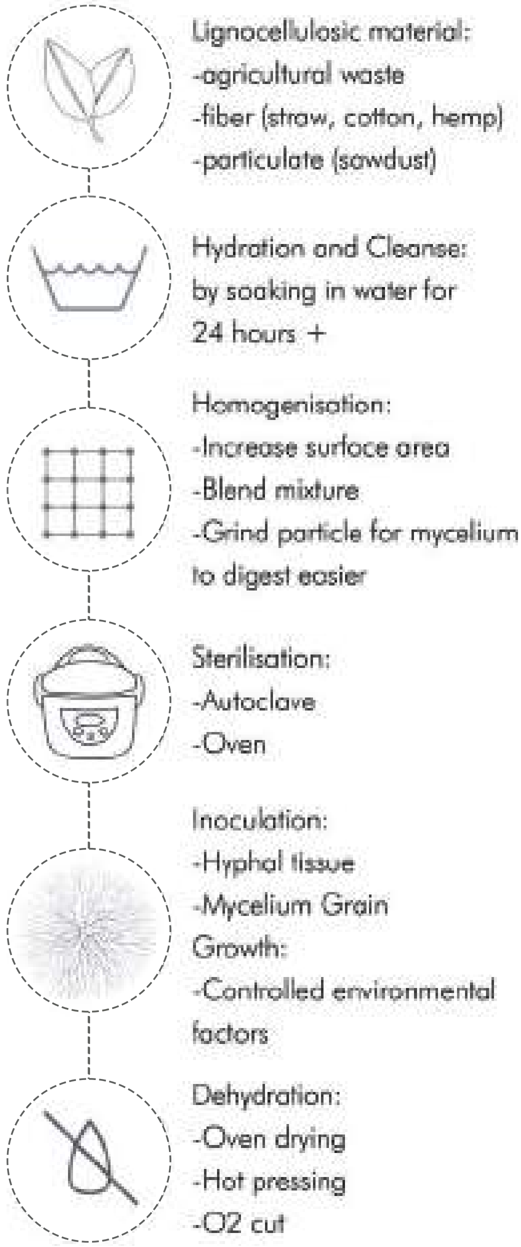


Figure 4.1 Mycelium Growth Process

4.2 Preparation of Mockup Models

The material practices are done using Pleurotus Ostreatus grains. Through the mock-up modelling wood PLA filament (composition PLA and 30% industrial hemp shive), white PLA filament and transparent PLA are used for 3D printing the structure. All PLA used have diameter of 1.75mm and are printed with 60° bed temperature along with 190° nozzle temperature. Different PLA forms were generated through Grasshopper Voronoi script in order to obtain; structural armatures to test translucent quality of mycelium, porous armatures from transparent PLA to test the insulative quality, wood PLA filament to test porosity of mycelium. The Voronoi tessellation is a mathematical technique where natural patterns can be imitated. The pattern is selected to design the armatures to pursue biophilic design principles by creating an indirect experience of nature in space. In the grasshopper script each Voronoi cell is formed from a seed point. The partition of the plane into pieces to the nearest path is defined by its location to the seed point. The lines set to define each cell including all the points on the plane that are closer to the set seed points of each cell. As an additional material to the PLA armature, the 3rd topic consists of mycelium grains in PLA armature with jute fiber strings dipped into agar. The jute string become a food source for mycelium to grow and follow. This way the models tested the possibility to manually orient mycelium colonization to direct the density for translucent design. To test the adhesive quality of mycelium to imitate a glass, acrylic plexiglass plates of 101.6 x 152.4 x 1.1mm were used to obtain the sandwich structure. No extra adhesive was used during this model making to test the adhesive quality of mycelium itself towards glass and PLA. As an alternative for the lamination of the structure is to seal the edges of the PLA and plexiglass plates with silicon glue. Another extra adhesive selection is the use of pourable silicone gel or epoxy resin to glue the sandwich structures to each other while also cutting the oxygen intake of mycelium and stopping the growth.

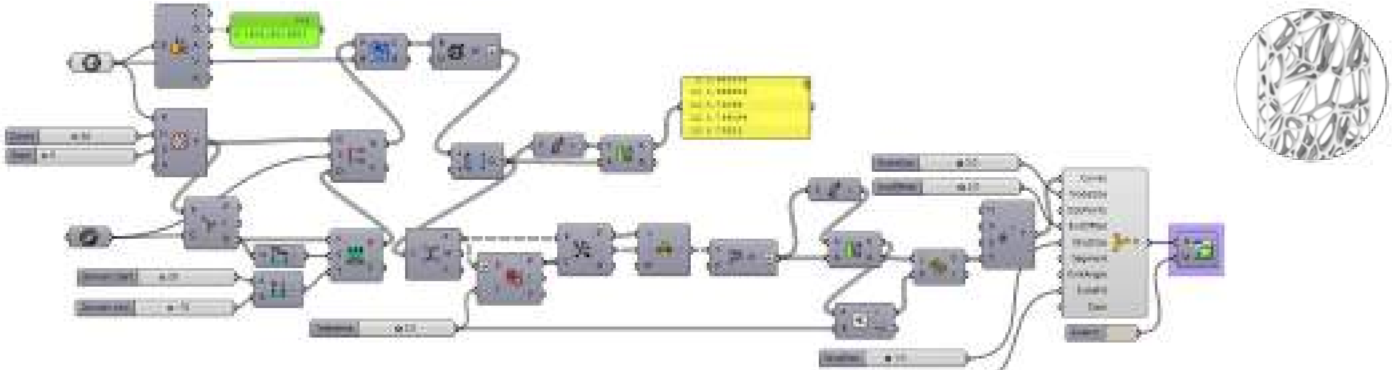


Figure 4.2 Voronoi Script A

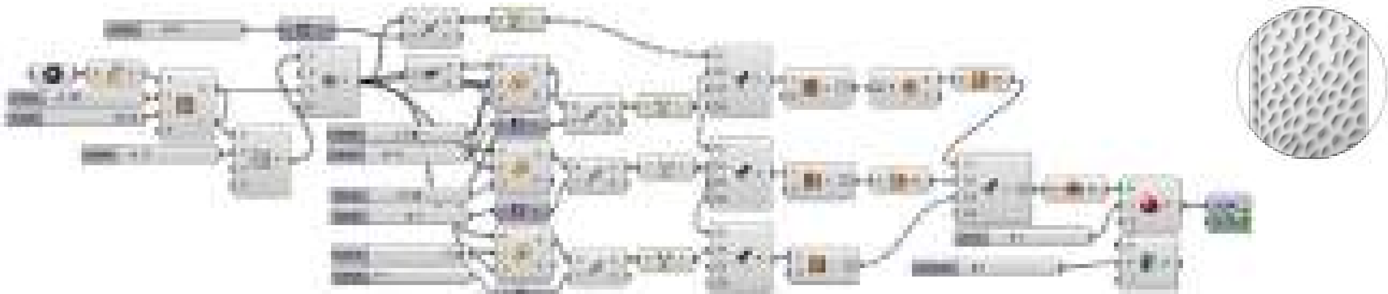


Figure 4.3 Voronoi Script B

4.3 Material Practice Tests

MYCELIUM

1 Mycelium Petri Dish

PHASE1
- 1.a Mycelium Growth on Agar Plate
- 1.b Mycelium Growth on Agar Plate with Jute Fiber String

PHASE2
- 1.c- Mycelium Growth on Agar Plate with Jute Fiber String
- 1.d- Mycelium Growth on Agar Plate with PLA-Wood Armature
- 1.e- Mycelium Growth on Agar Plate with Knitted Jute

PHASE3
- 1.f- Mycelium Growth on Agar Plate with Organic Material

2 Mycelium in PLA Armature

PHASE1
- 2.a Mycelium Growth on Armature Form A
- 2.b Mycelium Growth on Armature Form B

PHASE2
- 2.c Mycelium Growth on Armature Form C
- 2.d Mycelium Growth on Armature Form D

PHASE3
- 2.e Mycelium Growth on Armature Form E
- 2.f Mycelium Growth on Armature Form F
- 2.g Mycelium Growth on Armature Form G

PHASE4
- 2.h Mycelium Growth on Armature Form H
- 2.i Mycelium Growth on Armature Form I

3 Mycelium in PLA Armature with Jute Fiber String

PHASE1
- 3.a Mycelium Growth on PLA Armature Frame with Jute Fiber String Dipped into Agar

PHASE2
- 3.b Mycelium Growth on PLA-Wood armature with Knitted Jute Fabric

PHASE3
- 3.c Mycelium Growth on PLA armature with Knitted Jute Fabric

4.3.1 Mycelium Petri Dish

This category of the material practice is done on petri dishes using Pleurotus Ostreatus grains, an agar medium prepared with the measurements of 4.6g agar + 185g distilled water for 8 petri dishes, and the substrate that is to be tested for the colonization of mycelium. First the agar mixture is prepared in a heat resistant jar and put to the autoclave for 40 minutes at 120C° to prevent from contamination. Then it is poured onto the alcohol rubbed petri dishes while still hot and left to cool down to room temperature. Next the mycelium grains are put inside the dish with the extra substrate to be tested and the dish is sealed with a parafilm for sterile environment. In the following days the growth rate, size, direction of mycelium can be tested by comparing the rings formed around the grains.

MATERIAL PRACTICE

❶ Mycelium Petri Dish PHASE1

1.a Mycelium Growth on Agar Plate

The aim of this practice is to test the result of mycelium growth on agar petri dishes to discover the level of light transmittance and color quality. The material practice with petri dishes were done using Pleurotus Ostreatus grains. An agar mix is prepared with the measurements of 4.6g agar + 185g distilled water for 8 petri dishes. After autoclaving for sterilization, mycelium grains are put inside and left for growth.

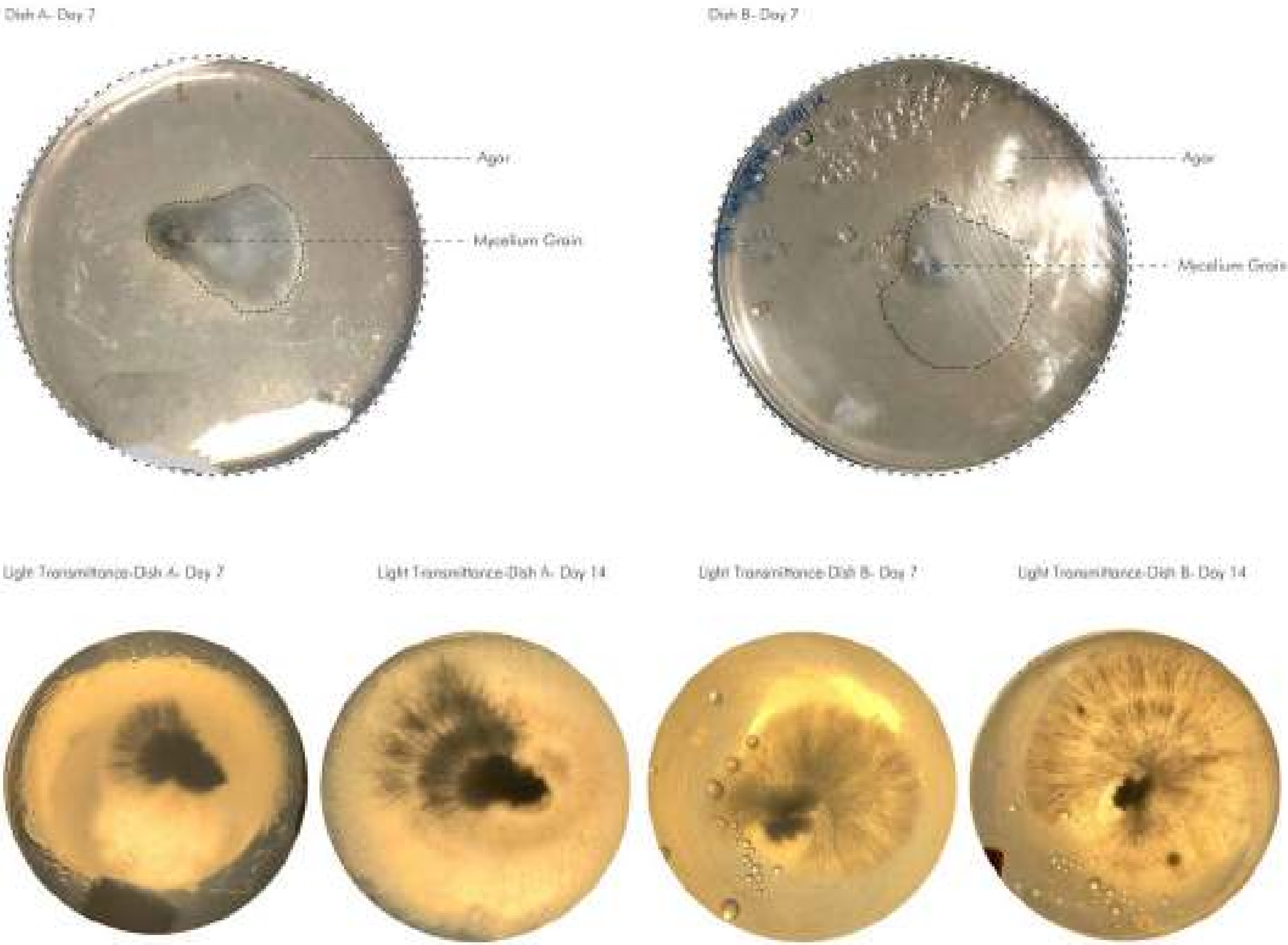


Figure 4.4 Material Practice Petri Dish

The outcome on day 7 and day 14 of this experiment demonstrate that with the agar plates mycelium grows as thin layers, with a semi transparent quality which can allow light transmittance. However, without the hemp or jute insulation performance is not adequate.

MATERIAL PRACTICE

➊ Mycelium Petri Dish PHASE1

1.b Mycelium Growth on Agar Plate with Jute Fiber String

The aim of this practice is to test the result of mycelium growth on agar petri dishes with jute strings dipped in agar to discover the level of light transmittance and color quality. The material practice with petri dishes were done using Pleurotus Ostreatus grains. An agar mix is prepared with the measurements of 4.6g agar + 185g distilled water for 8 petri dishes. After autoclaving for sterilization, the jute fibers are dipped into agar to be a food source for mycelium and the grains are put inside and left for growth.

Day 1

Day 4-Growth Check

Day 14-Growth Check

Figure 4.5 Material Practice Petri Dish

The growth check day 4 demonstrates that with the agar plates mycelium growth is oriented and mainly colonizing where the jute fibers dipped in agar are denser and shows thinner, fibrous layers, where lighter agar and fiber is with a semitransparent quality which can allow light transmittance.

MATERIAL PRACTICE

❶ Mycelium Petri Dish PHASE2

1.c Mycelium Growth on Agar Plate with Jute Fiber String

The aim of this practice is to test the result of mycelium growth on agar petri dishes with jute strings put into agar to discover the growth direction. The material practice with petri dishes were done using Pleurotus Ostreatus grains. An agar mix is prepared with the measurements of 4.6g agar + 185g distilled water for 8 petri dishes. After autoclaving for sterilization, the jute fibers are put on agar to set a route for mycelium to follow and the grains are put inside and left for growth.

Day 1

Day 14-Growth Check

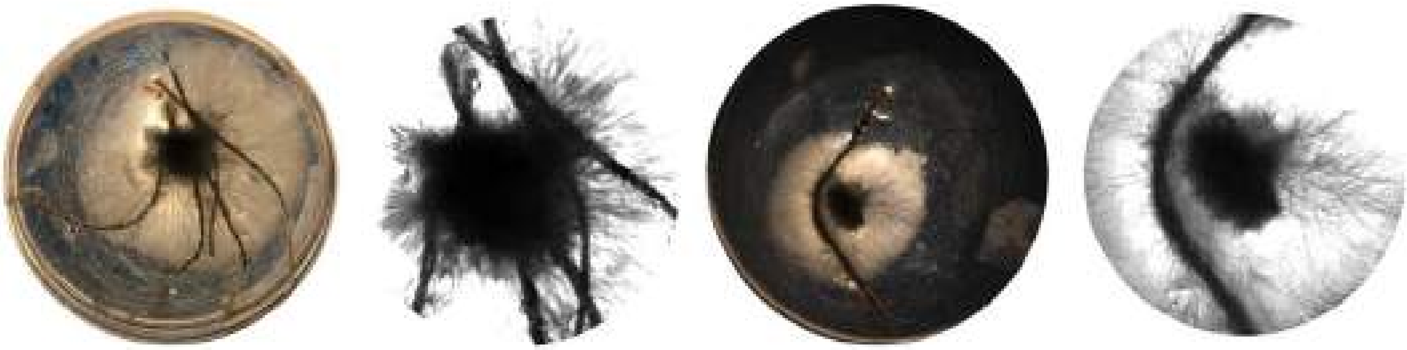


Figure 4.6 Material Practice Petri Dish

The growth check of this experiment demonstrates that with the agar plates mycelium growth is oriented and mainly colonizing were the jute fibers dipped in agar are denser and shows thinner, fibrous layers, where lighter agar and fiber is with a semitransparent quality which can allow light transmittance. The growth rings first form around the strings and later stretch towards the agar.

Figure 4.7 Material Practice Petri Dish

MATERIAL PRACTICE

❶ Mycelium Petri Dish PHASE2

1.d Mycelium Growth on Agar Plate with PLA-Wood Armature

The aim of this practice is to test the result of mycelium growth on agar and PLA-Wood structure dishes to discover the growth direction, density, and level of light transmittance. The material practice with petri dishes were done using Pleurotus Ostreatus grains. An agar mix is prepared with the measurements of 4.6g agar + 185g distilled water for 8 petri dishes. After autoclaving for sterilization, the PLA-Wood structure was put into the petri dish as a guide for its growth and the grain is put inside and left for growth.

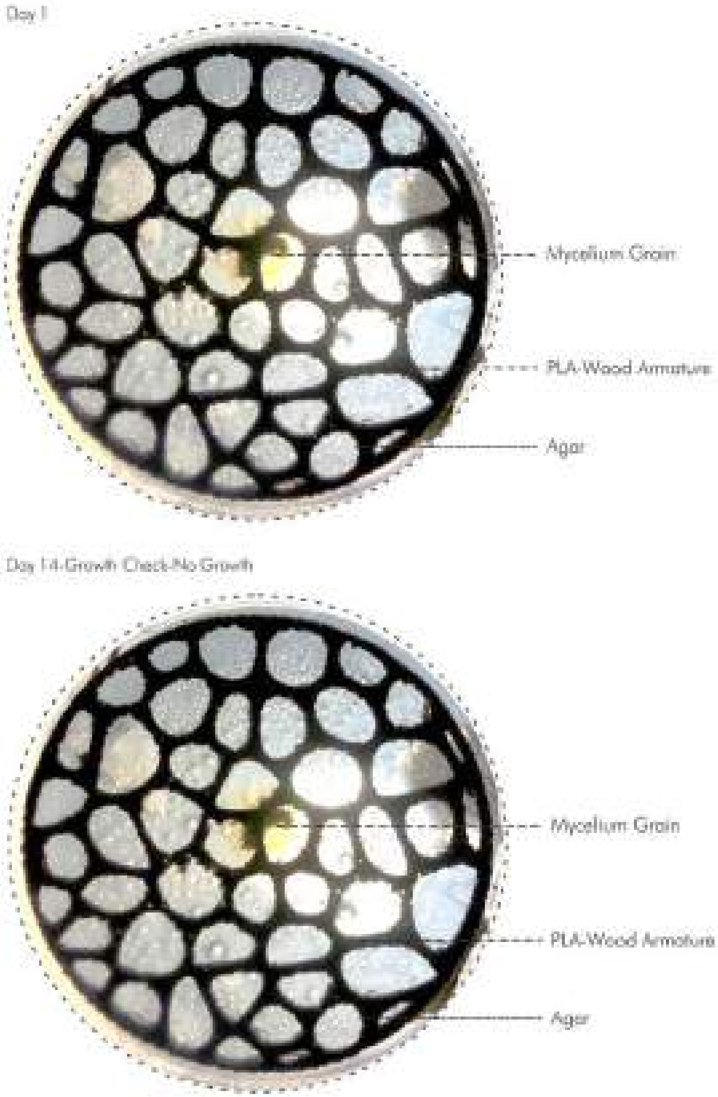


Figure 4.8 Material Practice Petri Dish

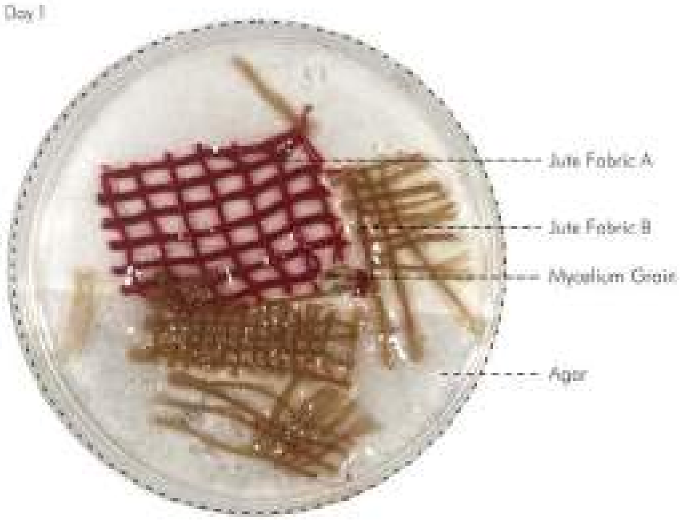
The growth check of this experiment did not have a result as the mycelium displays no growth.

MATERIAL PRACTICE

❶ Mycelium Petri Dish PHASE2

1.e Mycelium Growth on Agar Plate with Knitted Jute

The aim of this practice is to test the result of mycelium growth on agar petri dishes with knitted jute put on to discover the growth direction and density. The material practice with petri dishes were done using Pleurotus Ostreatus grains. An agar mix is prepared with the measurements of 4.6g agar + 185g distilled water for 8 petri dishes. After autoclaving for sterilization, the knitted jute fabrics with different densities are put onto agar to set a route for mycelium to follow and the grains are put inside and left for growth.



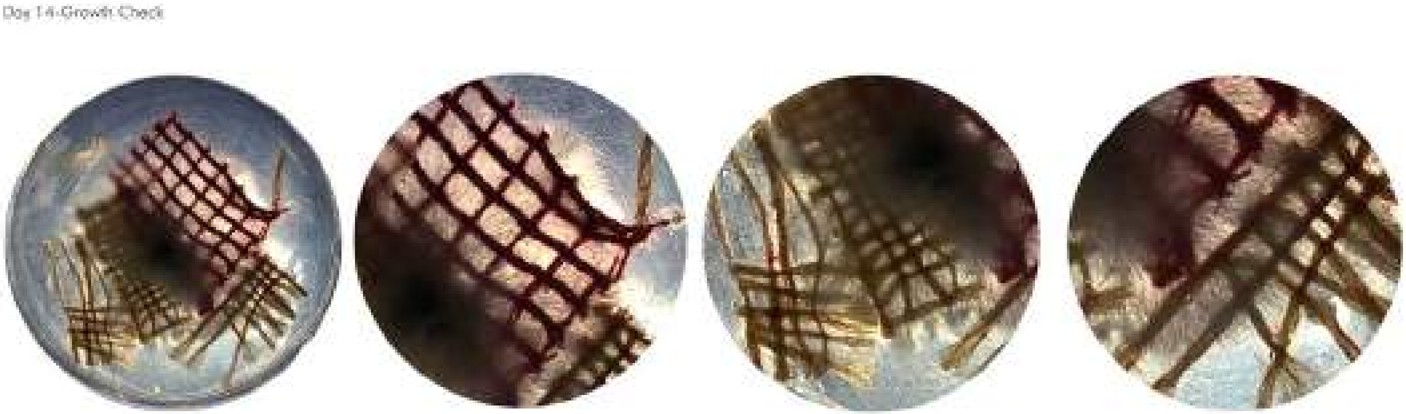


Figure 4.9 Material Practice Petri Dish

The growth check of this experiment demonstrates that with the agar plates mycelium growth is oriented and mainly colonizing where the knitted jute fabrics are placed. The growth rings first colonize around the denser fabric and follows to the lighter parts with thinner, fibrous layers. This test results with a mycelium growth that allows variety of light transmittance levels.

MATERIAL PRACTICE

❶ Mycelium Petri Dish PHASE3

1.f Mycelium Growth on Agar Plate with Organic Material

The aim of this practice is to test the result of mycelium growth on agar petri dishes with organic material as leaf and grass put on to discover the growth direction and density. The material practice with petri dishes were done using Pleurotus Ostreatus grains. An agar mix is prepared with the measurements of 4.6g agar + 185g distilled water for petri dishes. After autoclaving for sterilization, the organic materials were put on the agar medium with the mycelium grains and left for growth.

Day 1

Day 5-Growth Check

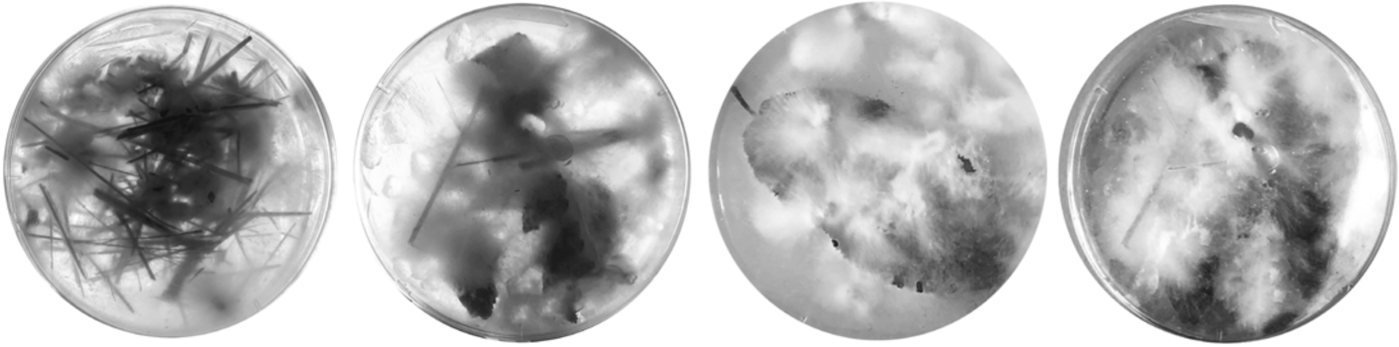
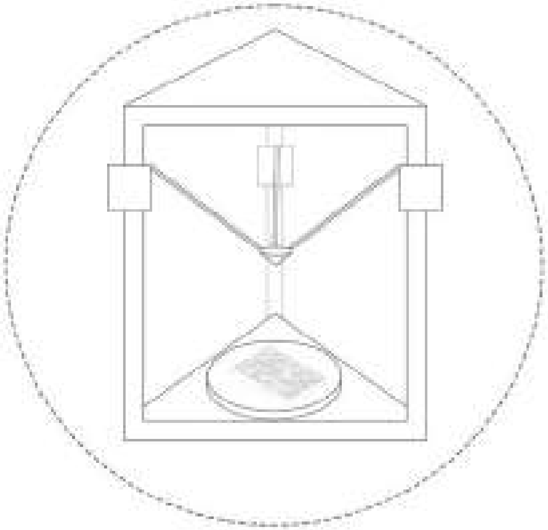


Figure 4.10 Material Practice Petri Dish

The growth check of this experiment demonstrates that with the agar plates which have the organic material such has leaves and grass pieces boost the growth rate of mycelium. The growth is oriented and mainly colonizing where density of organic material is placed. This results with a low light transmittance quality in material dense areas. Where through the agar plate the mycelium spreads in a lighter density.

4.3.2 Mycelium in PLA Armature

The material practices are done using Pleurotus Ostreatus grains. Through the mock-up modelling wood PLA filament (composition PLA and 30% industrial hemp shive), white PLA filament and transparent PLA are used for 3D printing the structure. All PLA used have diameter of 1.75mm and are printed with 60° bed temperature along with 190° nozzle temperature. Different PLA forms were generated through Grasshopper in order to obtain structural armatures to test translucent quality of mycelium, porous armatures from transparent PLA to test the insulative quality or wood PLA filament to test porosity of mycelium.



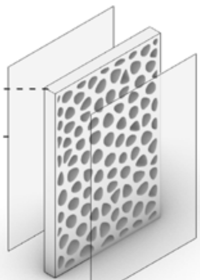
MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE1

2.a Mycelium Growth on Armature Form A

This practice aims to design porous armatures with transparent PLA to allow light transmittance while the mycelium composite with hemp fibers provide an insulative performance. In the experiment "form A" PLA is designed with closed edges but a porous inner surface for the mycelium to grow through. The plexiglasses are added each side and the sandwich structure is composed. Through this process no extra adhesive is used to test the adhesive quality of mycelium and understand the need for a lamination material.

Figure 4.11 Material Practice PLA Armature



The outcome of this growth check- day 4 demonstrates that the PLA structure without any pening on edges, the growth rate decreases, since the oxygen intake is less. The mycelium growth starts with pre grown composite then colonize where the agar is denser. Since growth is slow the adhesive quality was not tested efficiently. The need of connection through mycelium network is clear.

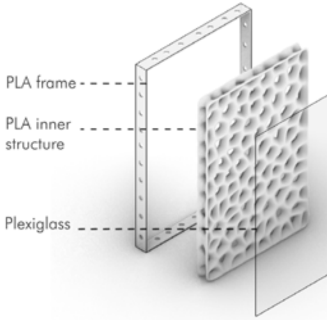
MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE1

2.b Mycelium Growth on Armature Form B

This practice aims to design porous armatures with transparent PLA to allow light transmittance while the mycelium composite with hemp fibers provide an insulative performance. In the experiment “form B” PLA is designed with a frame with openings which the porous inner surface follows for mycelium to grow through and breathe. The plexiglasses are added on each side and the sandwich structure is composed. Through this process no extra adhesive is used to test the adhesive quality of mycelium and understand the need for another lamination material.

Figure 4.12 Material Practice PLA Armature



The outcome of this growth check- day 14 demonstrates that the PLA structure with a frame that has openings increase the growth rate since the oxygen intake improves. On side of the structure demonstrates that mycelium binds to the glass. However, the adhesive quality was tested not enough to perform as a sandwich structure. To test more ways of lamination, the other side which did not bind to the plexiglass was attached together using transparent silicone glue on the edges.

Figure 4.13 Material Practice PLA Armature

MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE2

2.c Mycelium Growth on Armature Form C

This practice aims to design porous armatures with wood-PLA filament to allow light transmittance through the lighter parts while the mycelium composite with hemp fibers provide an insulative performance. In the experiment “form C” PLA is designed with certain openings using Voronoi design. Later the structure is dipped into agar mixture for the mycelium to follow as a food source and cover the structure.

Figure 4.14 Material Practice PLA Armature

The outcome of this experiment’s growth check- day 14 demonstrates that with the wood-PLA structure, dipped in agar, with a frame that has openings directs the growth of mycelium. The mycelium growth starts from the grains and stretches to colonize around the agar therefore covers the structure. The outcome of this experiment’s growth check- day 20 demonstrates that with the wood-PLA structure, dipped in agar, with a frame that has openings directs the growth of mycelium. In 2 weeks, period the mycelium has colonized through the gaps and covered the structure. The mycelia are blocking the light mostly on the edges and around the structure but has a lighter opacity through the gaps.

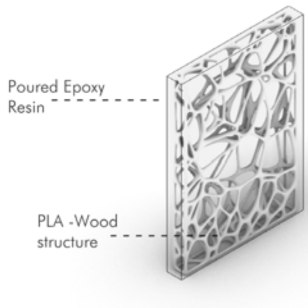


Figure 4.15 Material Practice PLA Armature

MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE2

2.d Mycelium Growth on Armature Form D

This practice aims to design multiple layers of thin armatures with PLA filament to allow light transmittance through the lighter parts while the mycelium put in between the layers provide an insulative performance. The PLA armatures are dipped into agar mixture for the mycelium to follow as a food source and cover the structure.

Figure 4.16 Material Practice PLA Armature

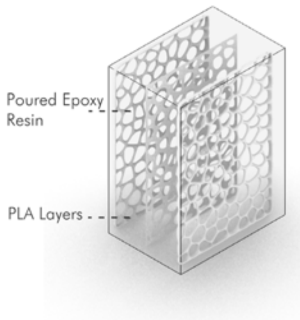
The outcome of this growth check- day 20 demonstrates a 3-dimensional growth of mycelium through the 3 layers of PLA-armatures. The mycelium growth starts with the pre grown composite then colonize where the agar is denser. The adhesive quality is tested to be better in this form as the mycelium tends to bind through x-y-z planes.

❷ Mycelium PLA Armature PHASE2

2.d Mycelium Growth on Armature Form D

Day 20- Growth Check

Figure 4.17 Material Practice PLA Armature



MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE3

2.e Mycelium Growth on Armature Form E

This practice aims to design porous armatures with transparent PLA filament to allow light transmittance through the armature while the mycelium composite with hemp fibers provide an insulative performance. In the experiment “form E” PLA is designed with certain openings using Voronoi design. Later mycelium grains and composite material is added, and the structure is dipped into agar mixture for the mycelium to follow as a food source and cover the structure.

Day 1

Day 10- Growth Check

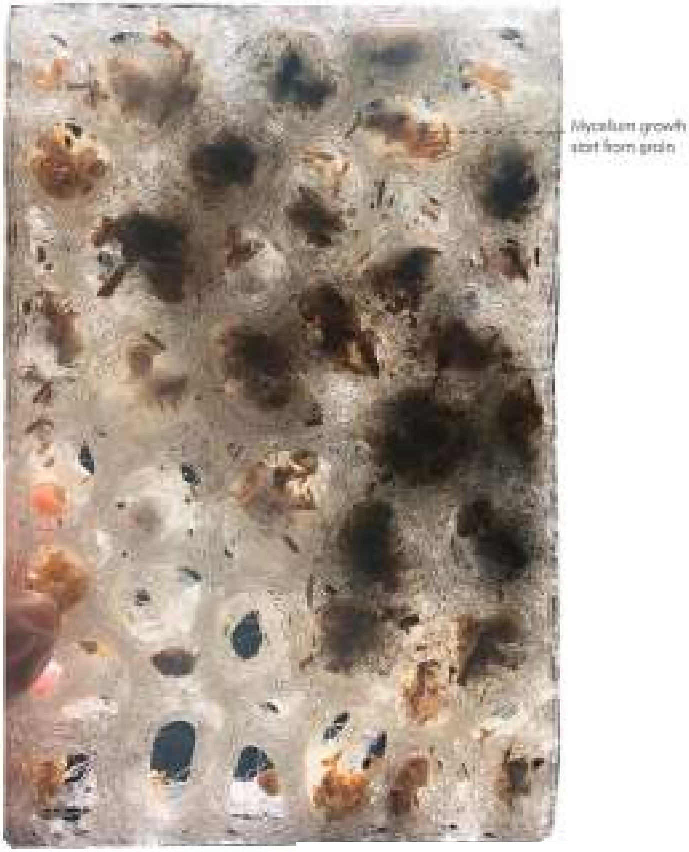
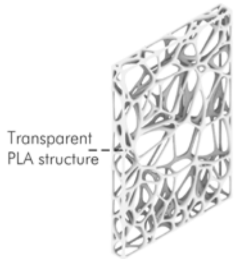


Figure 4.18 Material Practice PLA Armature

The outcome of this experiment’s growth check- day 10 demonstrates that with the Transparent PLA structure and with a frame that has openings directs the growth of mycelium. The mycelium growth starts from the grains and stretches to colonize throughout the openings in x-y-z axis covering the structure. The armature itself allows light while the mycelium operates as a thermal break.



MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE3

2.f Mycelium Growth on Armature Form F

This practice aims to design porous armatures with transparent PLA filament to allow light transmittance while the mycelium composite with hemp fibers provide an insulative performance. In the experiment “form F” PLA is designed with tubular openings which the inner surface follows for mycelium to grow through and breathe.

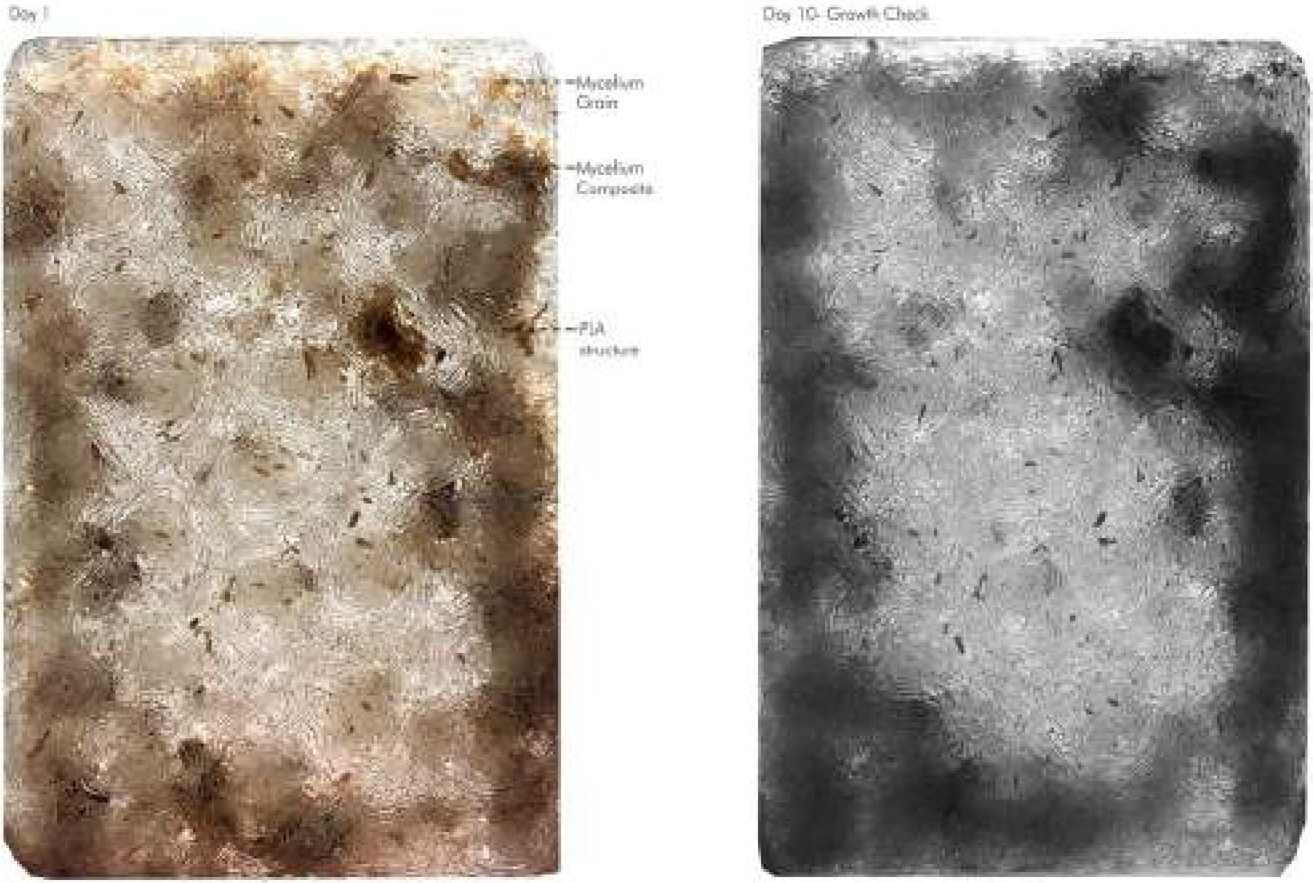


Figure 4.19 Material Practice PLA Armature

The outcome of this experiment’s growth check- day 10 demonstrates that with the Transparent PLA structure and with a frame that has tubular openings increases the growth rate since the oxygen intake improved. The mycelium growth starts from the grains and stretches to colonize throughout the openings in x-y-z axis covering the structure. The transparent armature itself allows light while the mycelium operates as a thermal break

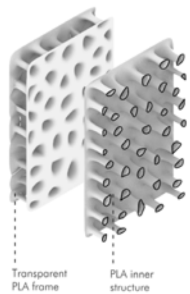



Figure 4.20 Material Practice PLA Armature

MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE3

2.g Mycelium Growth on Armature Form G

This practice aims to design porous armatures with PLA to allow light transmittance through the pores while the mycelium composite with hemp fibers provide an insulative performance. In the experiment "form G" PLA is designed with small openings and mycelium is pressed into the mold to imitate the shape to be taken out after growth.

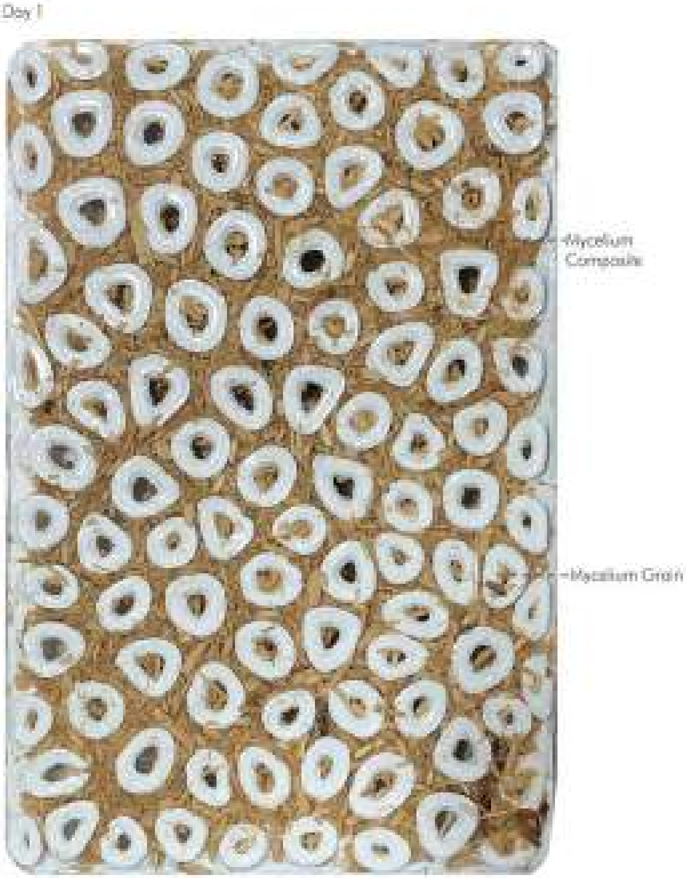
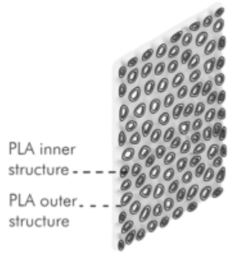


Figure 4.21 Material Practice PLA Armature



The outcome of this experiment's growth check- day 14 demonstrates no growth due to the environmental conditions.

MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE4

2.h Mycelium Growth on Armature Form H

This practice aims to design porous armatures with transparent PLA to allow light transmittance while the mycelium composite with hemp fibers provide an insulative performance. In the experiment “form H” a partial frame of the panel is printed with PLA. This design has tubular openings which the inner surface, filled with agar, directs the mycelium growth, and lets it breathe.

Day 1

Day 10- Growth Check

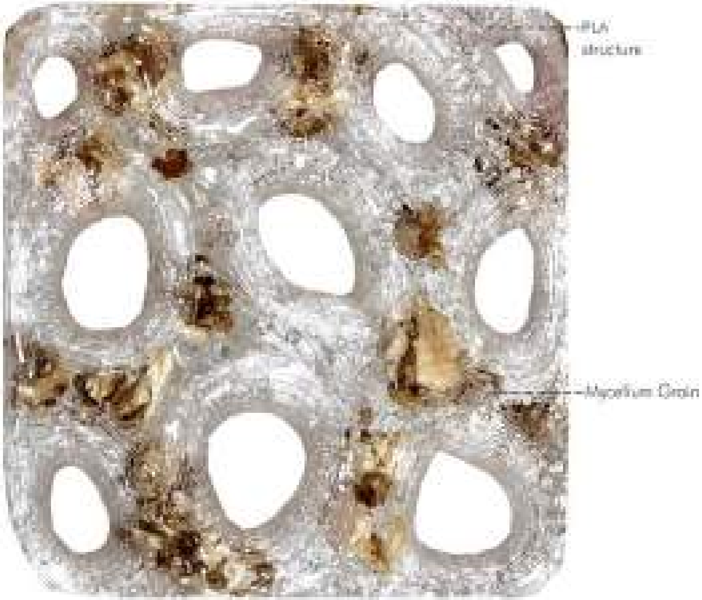
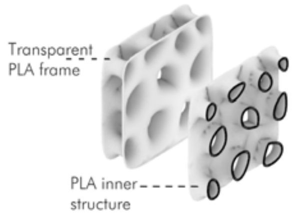


Figure 4.22 Material Practice PLA Armature

The outcome of this experiment’s growth check- day 14 demonstrates no growth due to the environmental conditions, limit temperature exceeded.

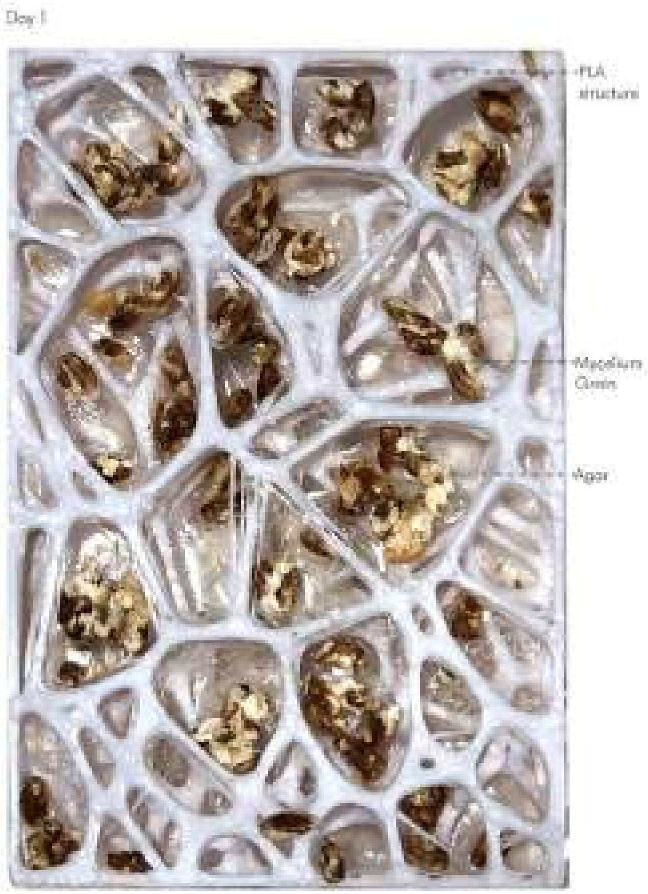


MATERIAL PRACTICE

❷ Mycelium PLA Armature PHASE4

2.i Mycelium Growth on Armature Form I

This practice aims to design porous armatures with PLA filament to allow light transmittance through the mycelium porosity while the mycelium composite with hemp fibers provide an insulative performance. In the experiment “form I” PLA is designed with certain openings using Voronoi design. Later mycelium grains and composite material is added, and the structure is dipped into agar mixture for the mycelium to follow as a food source and cover the structure.



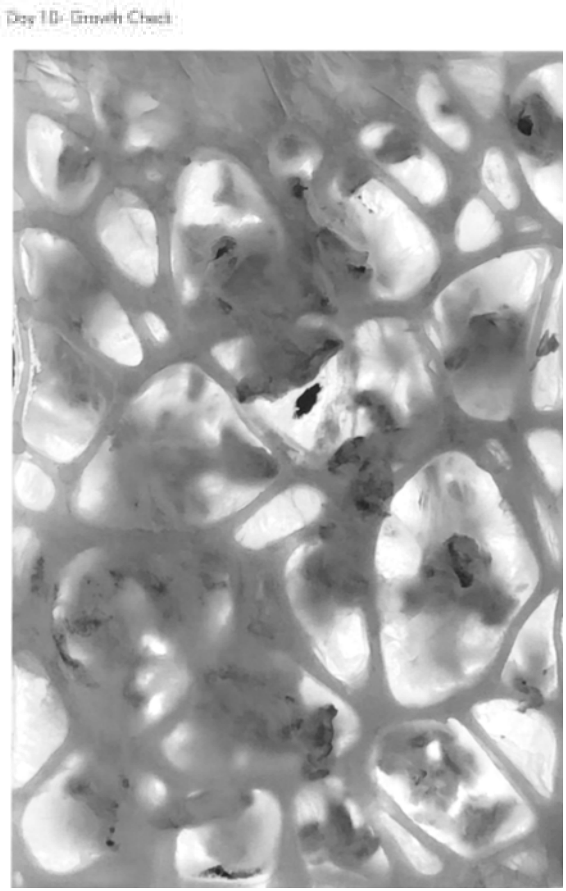
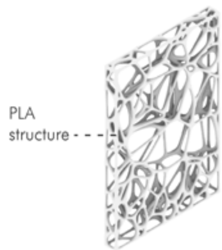


Figure 4.23 Material Practice PLA Armature

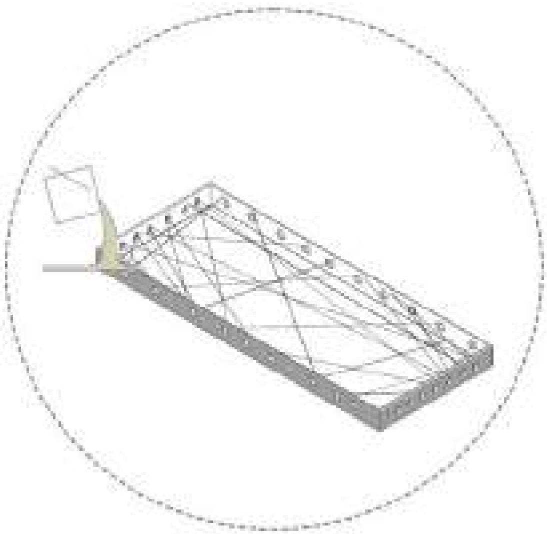


The outcome of this experiment’s growth check- day 14 demonstrates that mycelium growth starts from the grains and stretches to colonize around the agar gradually covering the structure. The mycelia are blocking the light mostly on the edges and around the structure but has a lighter opacity through the gaps.

Figure 4.24 Material Practice PLA Armature

4.3.3 Mycelium in PLA Armature with Jute Fiber String

The material practices are done using Pleurotus Ostreatus grains. Through the mock-up modelling wood PLA filament (composition PLA and 30% industrial hemp shive), white PLA filament and transparent PLA are used for 3D printing the structure. All PLA used have diameter of 1.75mm and are printed with 60° bed temperature along with 190° nozzle temperature. As an additional material to the PLA armature, the 3rd topic consists of mycelium grains in PLA armature with jute fiber strings dipped into agar. The jute string become a food source for mycelium to grow and follow. This way the models tested the possibility to manually orient mycelium colonization to direct the density for translucent design.



MATERIAL PRACTICE

❸ Mycelium PLA Armature PHASE1

3.a Mycelium Growth on PLA Armature Frame with Jute Fiber String Dipped in Agar

This practice aims to design porous armature and a framework with holes with transparent PLA to allow light transmittance while the mycelium which grows on the jute strings can provide an insulative performance. In the experiment the holes and the frame follow the tubes of the inner layer so the mycelium can also continue growing inside the structure but also breathe. The plexiglasses are added on each side and the sandwich structure is composed.

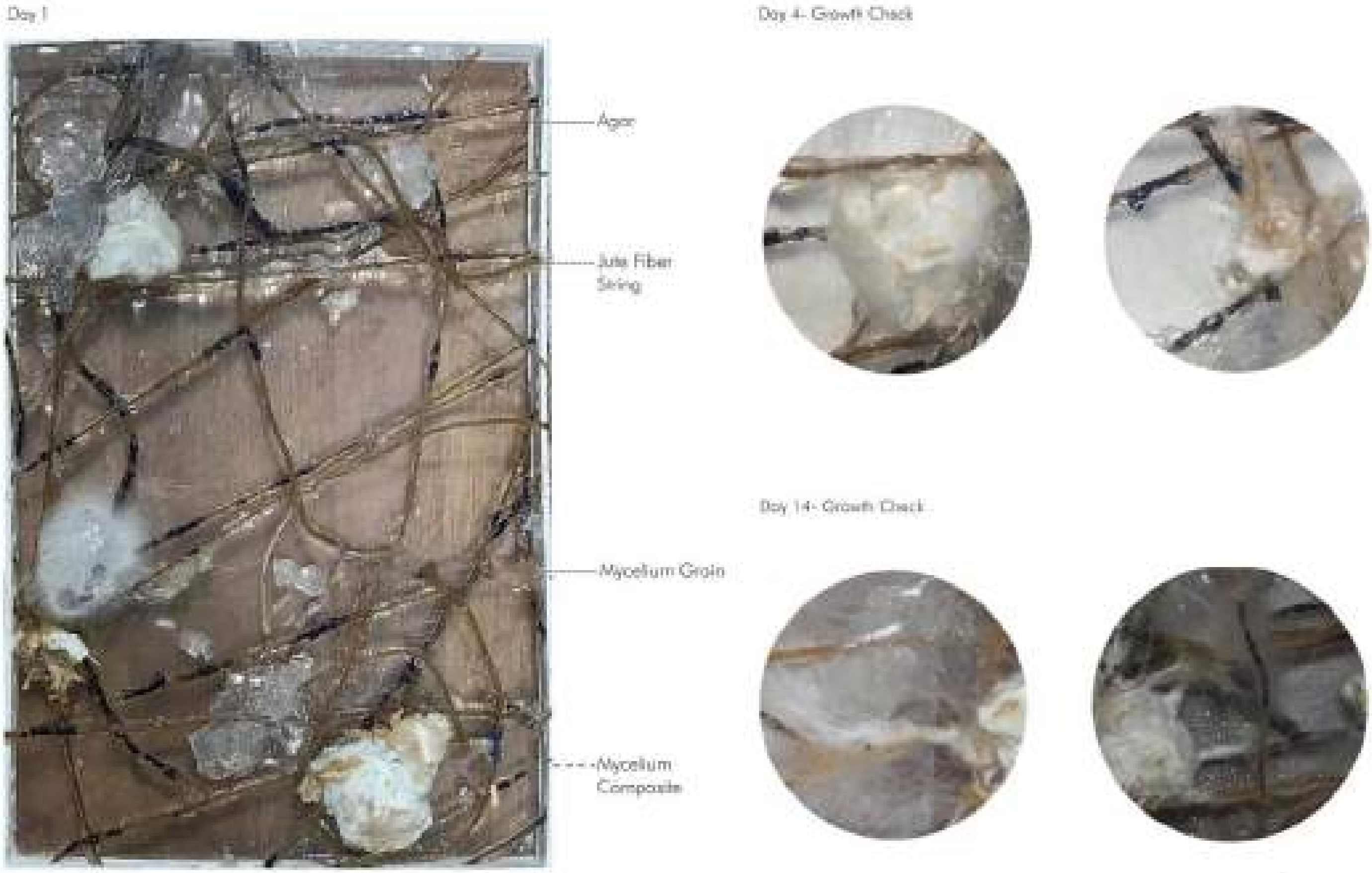
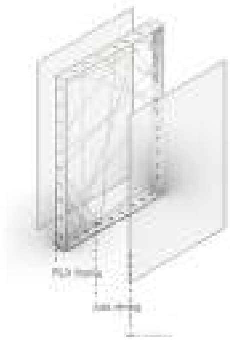


Figure 4.25 Material Practice Jute Fiber Strings



The outcome of this growth check- day 4 demonstrate that mycelium colonized around the jute strings dipped into agar, where the cross-connection is denser. After the growth is checked and no adhesive performance from the mycelium occurred, to test more ways of lamination, epoxy resin was poured in to create the sandwich structure.

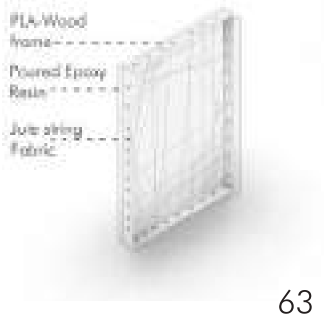
MATERIAL PRACTICE

❸ Mycelium PLA Armature PHASE2

3.b Mycelium Growth on PLA-Wood Armature with Knitted Jute Fiber Fabric Dipped in Agar

This practice aims to design a holed frame with wood-PLA filament where the knitted jute fabric can be attached through. The fabric is dipped into agar mixture for the mycelium to follow as a food source and cover the structure. The density of the knitted fabric differentiates in certain parts to allow light transmittance through the lighter parts while the mycelium in denser parts provide an insulative performance.

Figure 4.26 Material Practice Jute Fiber Strings



The outcome of this growth check- day 20 demonstrates that the colonization of mycelium grown first around the strings forming a dense relation. Later the growth continues around the gaps as mycelia binds to each other forming a lighter structure where the light transmittance can occur.

Figure 4.27 Material Practice Jute Fiber Strings

MATERIAL PRACTICE

❸ Mycelium PLA Armature PHASE3

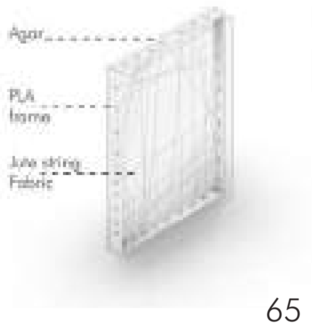
3.c Mycelium Growth on PLA Armature with Knitted Jute Fiber Fabric Dipped into Agar

This practice aims to design a holed frame with PLA filament where the knitted jute fabric can be attached through. The fabric is dipped into agar mixture for the mycelium to follow as a food source and cover the structure. The density of the knitted fabric differentiates in certain parts to allow light transmittance through the lighter parts while the mycelium in denser parts colonize providing insulative performance.

Day 1

Day 20- Growth Check

Figure 4.28 Material Practice Jute Fiber Strings



The experiment differs in depth size from the “3b” 10 mm and “3c” being 20 mm. The thickness of this layers allows for more colonization of mycelium and a better insulative performance. The outcome of this growth check- day 14 demonstrates no growth due to the mycelium grains and environmental conditions, limit temperature exceeded.

4.4 Material Practice Outcome

Phase 1

After Phase 1 experiments the outcome in the search of a translucent and insulative sandwich structure; the transparency and porosity of mycelium and its growth on 3D printed PLA models were examined. The first result was that; to maintain the insulative performance, hemp fibers or jute strings need to be used inside the structure. Therefore, the practice turned towards a search to design a porous inner armature from 3D printed translucent PLA that would ensure the light transmittance rather than focusing on making the mycelium transparent. This way the mycelium composite could grow following the armatures shape. Another practice was with the jute strings forming a canvas for the mycelium colony to follow, while growing in a non-uniform density to allow again light transmittance. Through these practices no extra adhesive was used to test the adhesive quality of mycelium itself towards glass and PLA. However, the growth rate was not enough to test this property successfully, since the mycelium only attaches itself but does not become one with these materials, it is estimated that there would be need for another lamination material in further phases of experimentation.

Phase 2

In the 2nd phase of these experiments in the search of a translucent and insulative sandwich structure; the transparency and porosity of mycelium and its growth on 3D printed PLA models were examined. From the results of Phase 1 experimentation further methods were tested in Phase 2 with jute strings, fabrics and more trials were done on the form and type of PLA armature material used. The outcomes are that mycelium tends to grow on jute stings if they are dipped in agar medium and the growth could be enhanced by using an extra substrate as food source or by missing mycelium composite, which have already been growing, next to the plain grains. The wood-PLA experiments testing whether mycelium will stick to the PLA better than normal PLA failed, since the filaments were only %30 wood and %70 PLA. Although the binding property of mycelium worked better with the wood-PLA armature. In some experiments the binding of mycelium to plexiglass was tested to see the need of lamination. To increase this binding quality the growth of mycelium and its strength should be increased. In these testes the end results were not sufficient to use mycelium itself for lamination. Therefore, other trials as silicon glue, pourable silicone gel and epoxy resin were used to glue the sandwich structures to each other. Through the experiments on Phase 2, the focus is shifted towards maintaining the thermal insulation by increasing the mycelium-armature thickness in the cavity between panels to prevent convection, reducing the heat transfer rather than using substrates for insulative performance. This enhances the use of mycelium for the translucent behavior over the gradually varying colonization zones.

Phase 3

In Phase 3 from the outcomes of Phase 2 experimentation further methods were tested with transparent PLA armatures that would allow light transmittance where the mycelium and composite could operate as the insulative element of this sandwich structure. The outcomes are that mycelium tends to grow on faster with the structures that have more surface area exposed to oxygen and that can trap humidity inside. Also compared to Phase 2 experimentation, the agar dipped armatures gave a higher growth rate by feeding the mycelium. In the Phase 3 of “Mycelium in PLA Armature with Jute Fiber String practices” and Phase 4 of “Mycelium in PLA Armature” practices did not give much result due to the environmental conditions the experiments were tested out at. Due to high humidity and temperature the growth rate slowed down and the contamination rate increased.

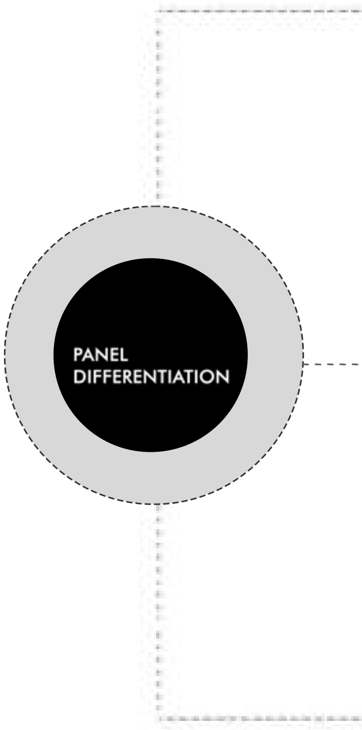
Concluding all three phases of material experimentation, the end product of each practice differed in terms of the material used, armature design, porosity level, thickness or insulative quality, sealant. The results demonstrate that these panels can be used as a facade element pursuing the design concept of biophilic light, as the porous mycelium growth creates an interplay between light and shadow relating to the sense of visual perception by experimenting the environment, spatial perceptions, and time. Therefore, the design can be altered according to optimization of environmental factors for the product to be flexible for use in different architectural typologies. Consequently, a catalogue can be used to document how these experiments can be scaled up and used as an architectural tool.

05

05 MATERIAL CATALOG

05 MATERIAL CATALOG

The material catalog displays three typologies for the mycelium PLA armature panels application in architectural scale. The first one is the use as an infill panel of window structure. The second is the infill panel use for a curtain wall. The third is the use as interior partition wall panel. All applications offer light illumination and shading through the porosity level of the armature design aiming for the principles of design for disassembly and biophilic design.



❶ Application as Window: In the application of mycelium panel as infill to window structure for exterior use; fiberglass frame is used due to it being more environmentally friendly during manufacturing process and having high energy efficiency, glass is used for its clear transparency and environmental benefits being fully recyclable.

1.a Mycelium Growth on 3D printed translucent PLA Armature
Components: mycelium grain embedded PLA armature (20mm) + Glass (2mm) + Steel Frame (20mm) + Glass (2mm)

1.b Mycelium Growth on 3D printed opaque PLA Armature
Components: mycelium grain embedded PLA armature (20mm) + Glass (2mm) +Steel Frame (20mm) + Glass (2mm)

❷ Application as Interior Partition Wall: In the application of mycelium panel as partition panels for interior use; no framing used other than the armature itself, therefore silicone/silica gel is used to mold the structure and stabilize it for use. It is a lightweight material with low thermal, electrical, and acoustic conductivity.

2.a Mycelium Growth on 3D printed wood-PLA Armature
Components: mycelium grain embedded wood PLA armature (20mm) + Silicone Gel (20mm) + Steel Frame (20mm)

2.b Mycelium Growth on 3D printed PLA Armature with Jute Fiber Strings
Components: mycelium grain embedded PLA Armature with Jute Fiber Strings (20mm) + Silicone Gel (20mm)+Steel Frame (20mm)

❸ Application as Curtain Wall: In the application of mycelium panel in curtain wall structure for exterior use; fiberglass frame is used due to it being more environmentally friendly during manufacturing process and having high energy efficiency, polycarbonate sheet is used due to being stronger while easy to produce and twice as lightweight to glass.

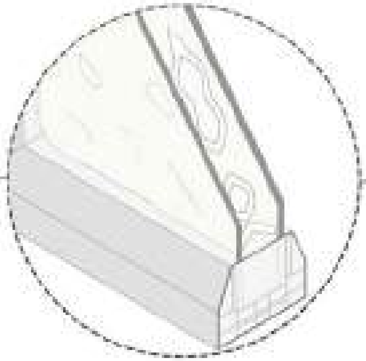
3.a Mycelium Growth on 3D printed opaque PLA Armature
Components: mycelium grain embedded PLA Armature (20mm) + Polycarbonate Sheet (4mm) +Steel Frame (20mm)

3.b Mycelium Growth on 3D printed wood-PLA Armature
Components: mycelium grain embedded wood PLA armature (20mm) + Polycarbonate Sheet (4mm) + Steel Frame (20mm)

Material Catalog Diagram

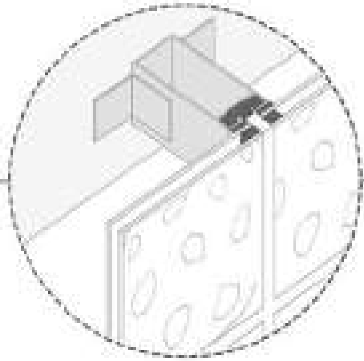
The material catalog displays three types of use for the mycelium PLA armature panels. The first one is the use as an infill of window structure. The second is the use as a curtain wall. The third is the use as interior partition wall. All applications offer shading through the porosity level of the armature design

APPLICATION AS
WINDOW



APPLICATION AS
INTERIOR PARTITION

APPLICATION AS
CURTAIN WALL



Components:

+ mycelium grain embedded
PLA armature (20mm)

+ Glass (2mm)

+ Steel Frame (20mm)

+ Glass (2mm)

Components:

+mycelium grain embedded
wood PLA armature (20mm)

+ Silicone Gel (20mm)

+ Steel Frame (20mm)

Components:

+mycelium grain embedded
PLA Armature (16mm)

+ Polycarbonate Sheet (4mm)

+ Steel Frame (20mm)

MATERIAL CATALOG

❶ Mycelium-PLA Window

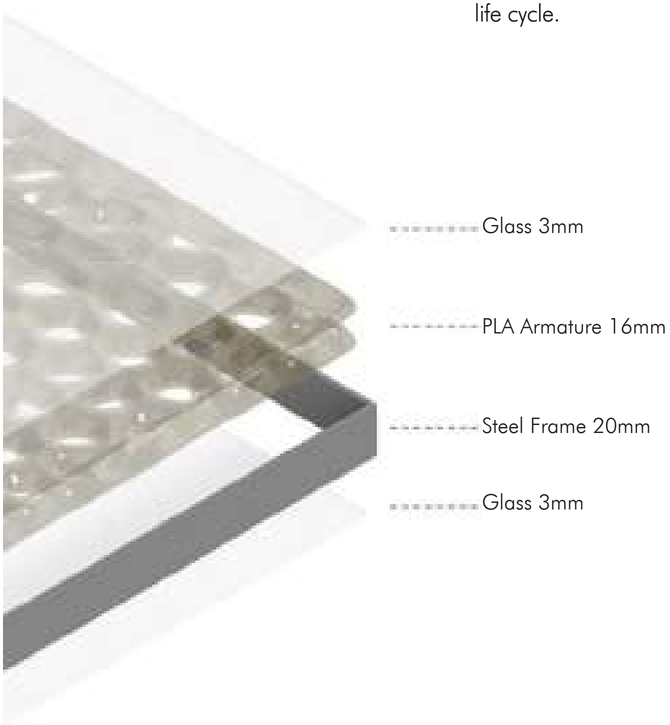
1.A Mycelium Growth on 3D printed opaque PLA Armature

Figure 5.1 Mycelium-PLA Window

This structure offers shading and insulative properties depending on the design of the armature porosity, density of the mycelium colonization and the thickness of the panel. Through changing these factors the design can be applied to various scenarios.

Assembly: Armature is designed according to wanted porosity level and 3D printed. The mycelium grains grow on the 3D printed PLA Armature. After the wanted density is maintained the structure is sealed inside the glass and steel frame. This way oxygen for mycelium growth is cut and the material is stabilized performing as an inner insulative and light diffusing panel.

Disassembly: The design considers end of life of the structure, as the components; glass, mycelium PLA armature and the steel frame can be dismantled into pieces and reused accordingly to their life cycle.



ⓐ Material Components:
Mycelium grain embedded PLA Armature (16mm) + Glass (3mm) + Steel Frame (20mm)

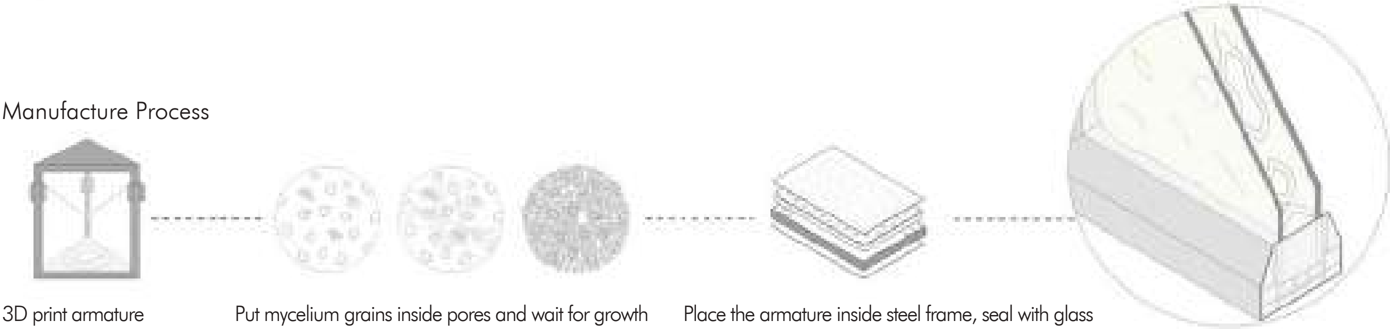
ⓑ Place of Use:
Exterior

ⓒ Architectural Application:
Outer Facade Applications

ⓓ Typology:
Public and Private Buildings

ⓔ Lux Ratio:
Lower %75-80

Manufacture Process



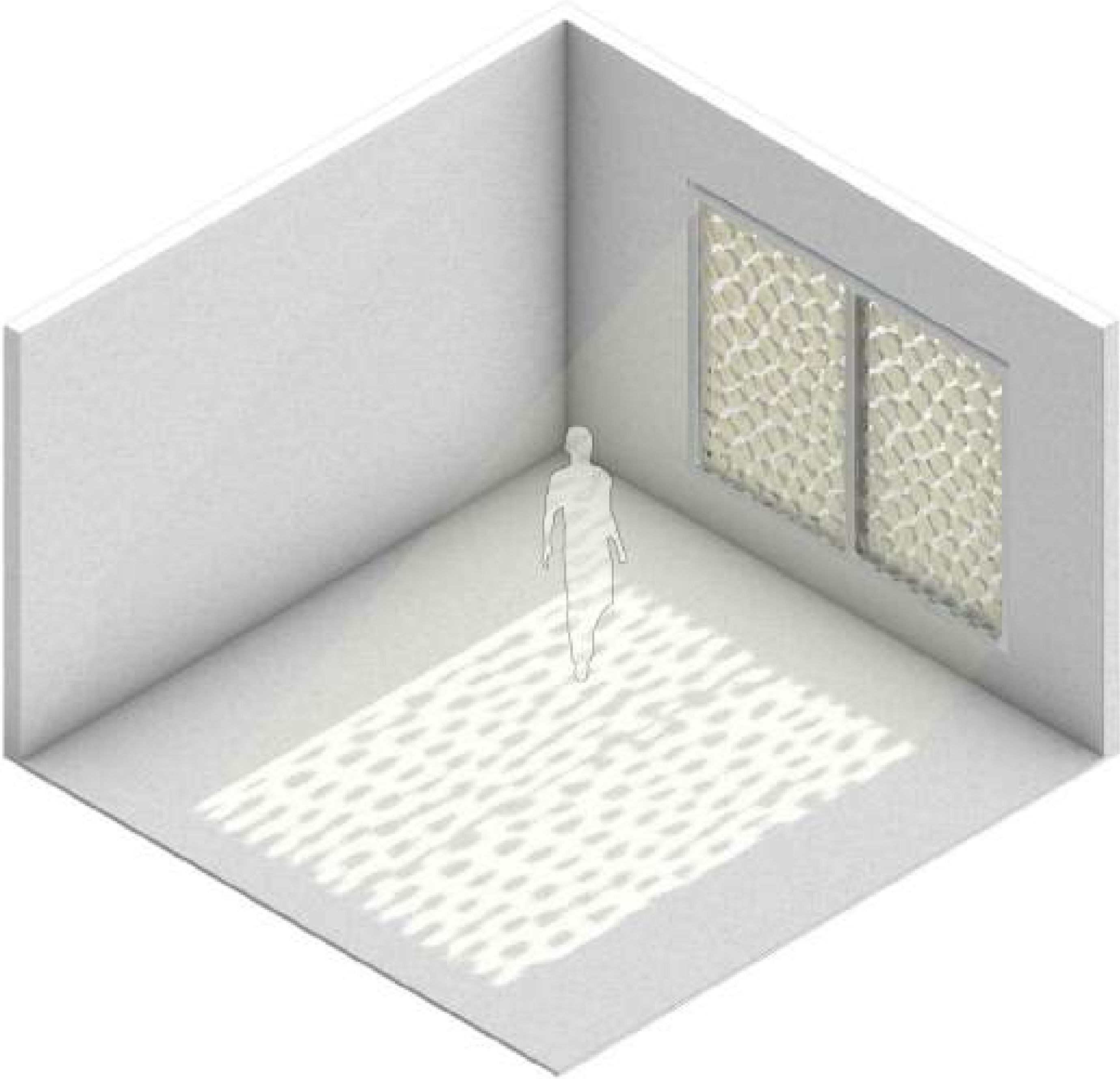


Figure 5.2 Mycelium-PLA Application as Window

MATERIAL CATALOG

➊ Mycelium-PLA Window

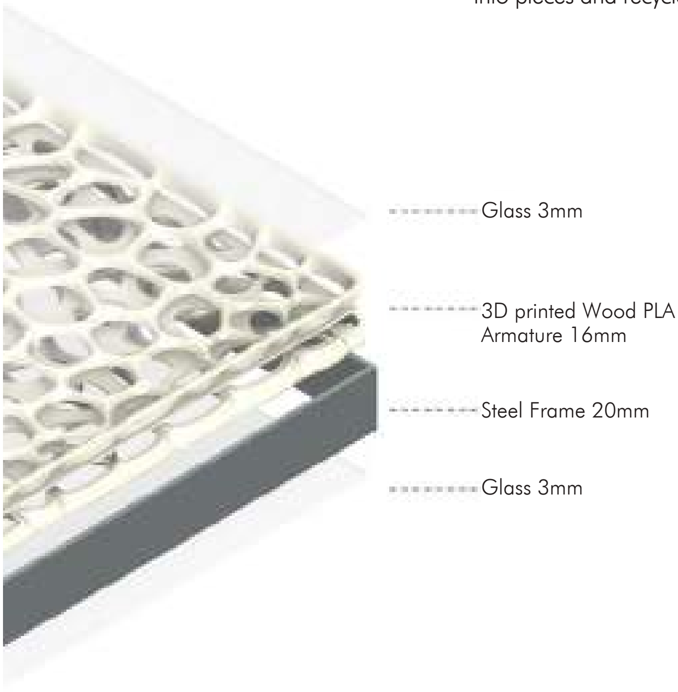
1.B Mycelium Growth on PLA Armature

Figure 5.3 Mycelium-PLA Window

This structure offers shading and insulative properties depending on the design of the armature porosity, density of the mycelium colonization and the thickness of the panel. Through changing these factors the design can be applied to various scenarios.

Assembly: The armature is designed according to wanted porosity level and 3D printed. Later mycelium grains are put to grow inside the pores, binding with PLA Armature. After the density is maintained the structure is sealed inside glass and steel frame for waterproofing. This way oxygen for mycelium growth is cut and the material is stabilized.

Disassembly: The design considers the end of life of the structure or building, as each frame can separate from each other as the components; glass, mycelium, PLA armature can be taken down into pieces and recycled or reused according to their life cycle.



ⓐ Material Components:
Mycelium grains+ PLA Armature Layers (16mm) +Glass (3mm) + Steel Frame(20mm)

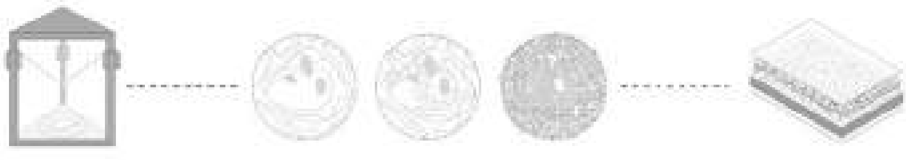
ⓑ Place of Use:
Exterior

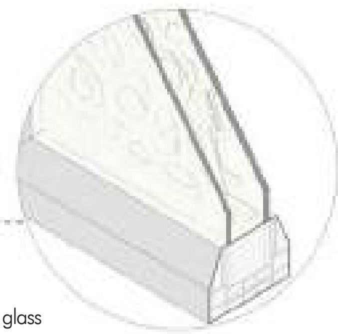
ⓒ Architectural Application:
Outer Facade Applications

ⓓ Typology:
Public and Private Buildings

ⓔ Lux Ratio:
Lower %50-60

Manufacture Process





3D print armature — Put mycelium grains inside pores and wait for growth — Place the armature inside steel frame, seal with glass

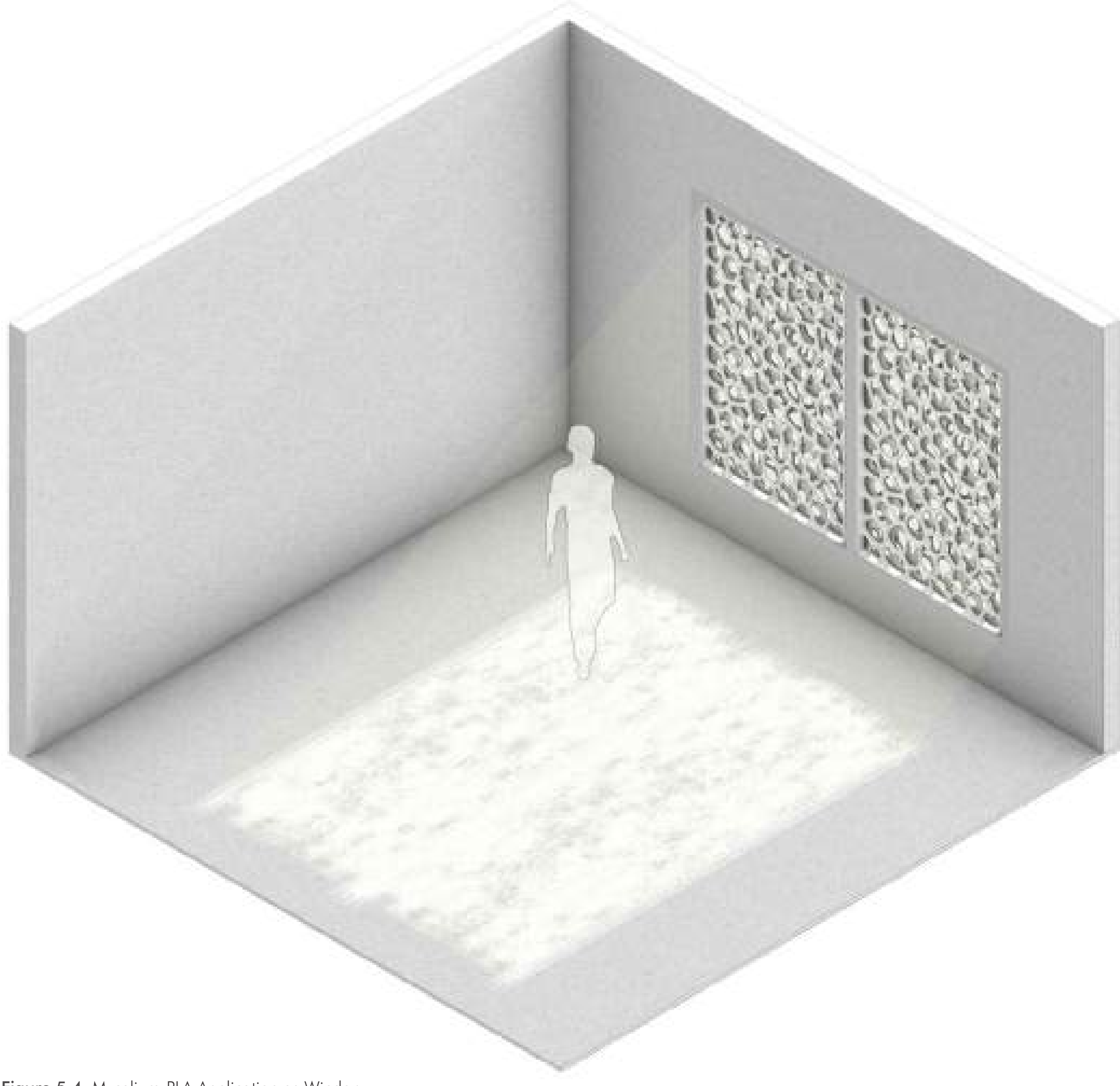


Figure 5.4 Mycelium-PLA Application as Window

MATERIAL CATALOG

❷ Mycelium- Wood PLA

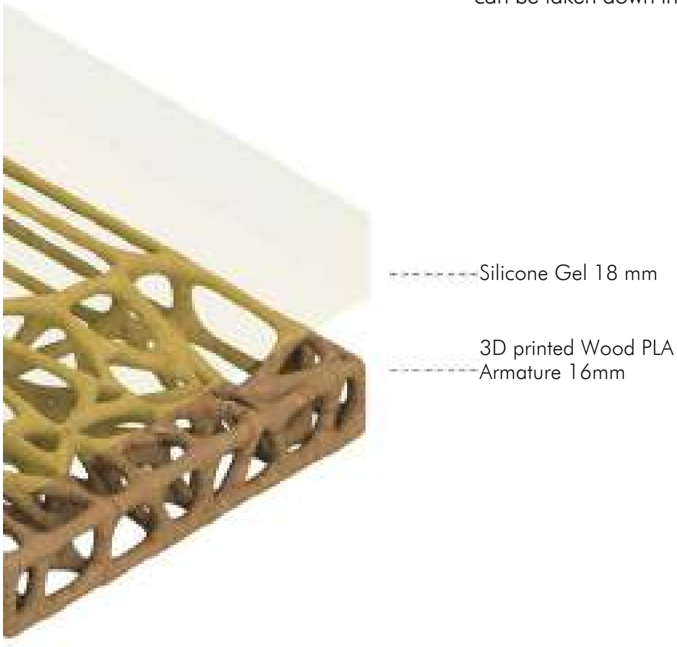
2.A Mycelium Growth on 3D printed Wood-PLA Armature

Figure 5.5 Mycelium-PLA Partition Wall

This structure offers shading and light lumination depending on the design of the wood armature porosity, density of the mycelium colonization and the thickness of the panel. Through changing these factors, the design can be applied to various scenarios.

Assembly: The armature is designed according to wanted porosity level and 3D printed. The mycelium grains grow binding with the PLA-Wood Armature. After the wanted density is maintained the structure is sealed with silicone gel for waterproofing and protection.The panels can be integrated to each other and to the ceiling from the joints.

Disassembly: The design considers the end of life of the structure or building, as each frame can separate from each other as the components; silicone, mycelium, wood PLA armature and the joints can be taken down into pieces and recycled or reused according to their life cycle.



ⓐ Material Components:
Mycelium grains+ Wood-PLA Armature (16mm) + Silicone Gel (18mm)

ⓑ Place of Use:
Interior

ⓒ Architectural Application:
Interior Partition Wall

ⓓ Typology:
Public and Private Buildings

ⓔ Lux Ratio:
Lower %60-70

Manufacture Process

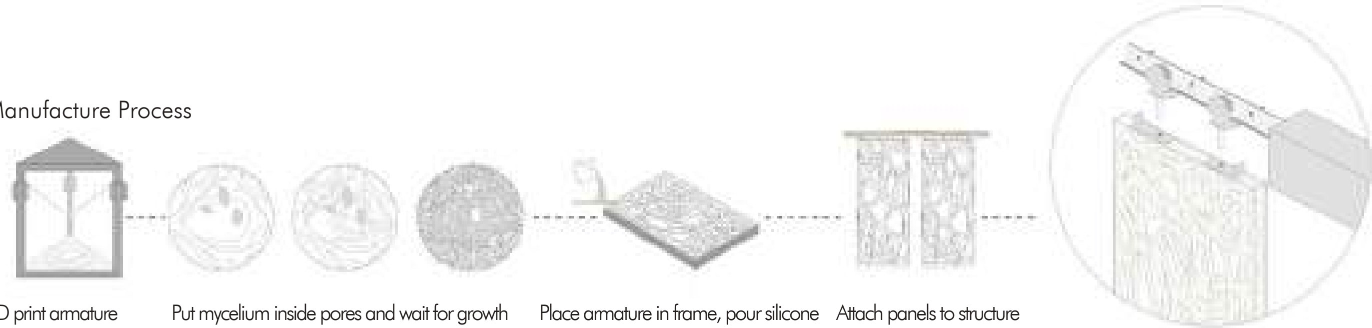


Figure 5.6 Mycelium-PLA Application as Interior Partition Wall

MATERIAL CATALOG

❷ Mycelium-PLA-Jute Fiber String

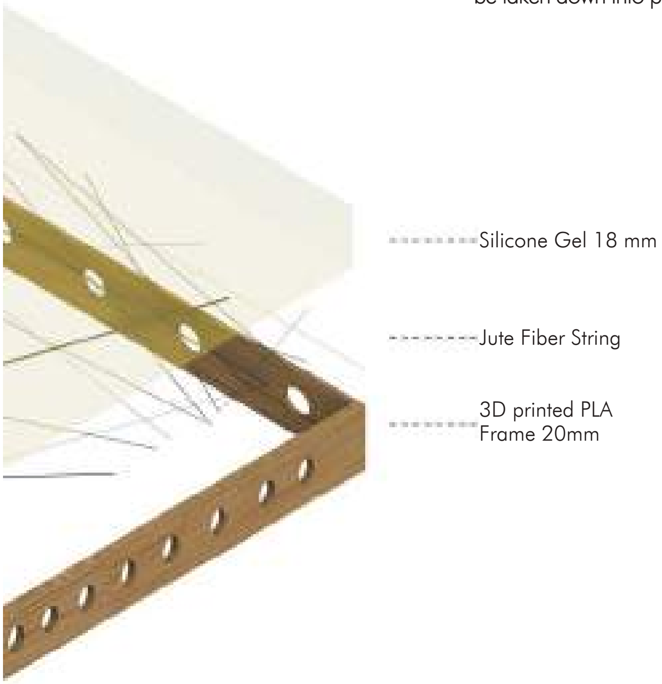
2.B Mycelium Growth on PLA Armature with Jute Fiber String

Figure 5.7 Mycelium-PLA Partition Wall

This structure offers shading depending on the design of the armature porosity, density of the mycelium colonization and the thickness of the panel. Through changing these factors, the design can be applied to various scenarios.

Assembly: The jute fiber strings are set along the 3D printed PLA frame. The mycelium grains grow along the jute strings following the form. After the wanted density is maintained the structure is sealed with silicone gel for waterproofing and protection. This way oxygen for mycelium growth is cut and material is stabilized. The panels can be integrated to each other and to the ceiling from the joints.

Disassembly: The design considers the end of life of the structure or building, as each frame can separate from each other as the components; silicone, mycelium, PLA armature, Jute string fibers and the joints can be taken down into pieces and recycled or reused according to their life cycle.



ⓐ Material Components:

Mycelium grains + PLA Frame (20mm) + Jute Fiber String + Silicone (18mm)

ⓑ Place of Use:

Interior

ⓒ Architectural Application:

Interior Partition Wall

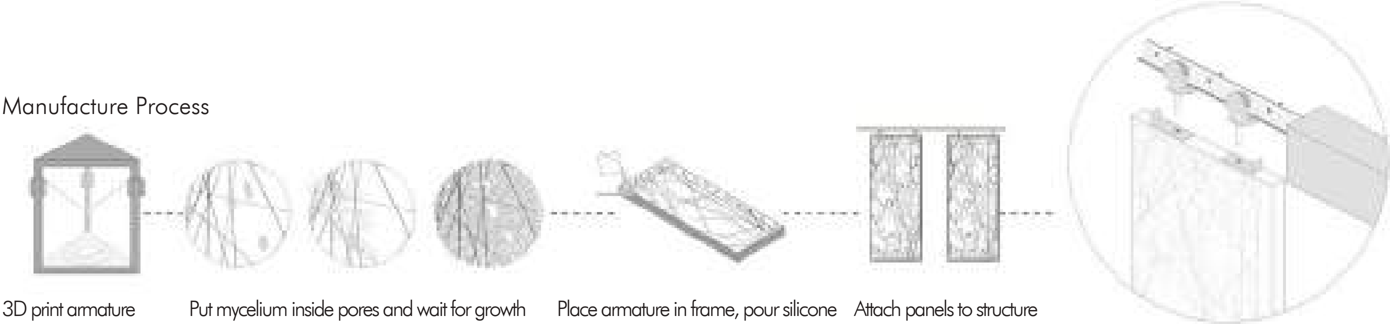
ⓓ Typology:

Public and Private Buildings

ⓔ Lux Ratio:

Lower %55-65

Manufacture Process



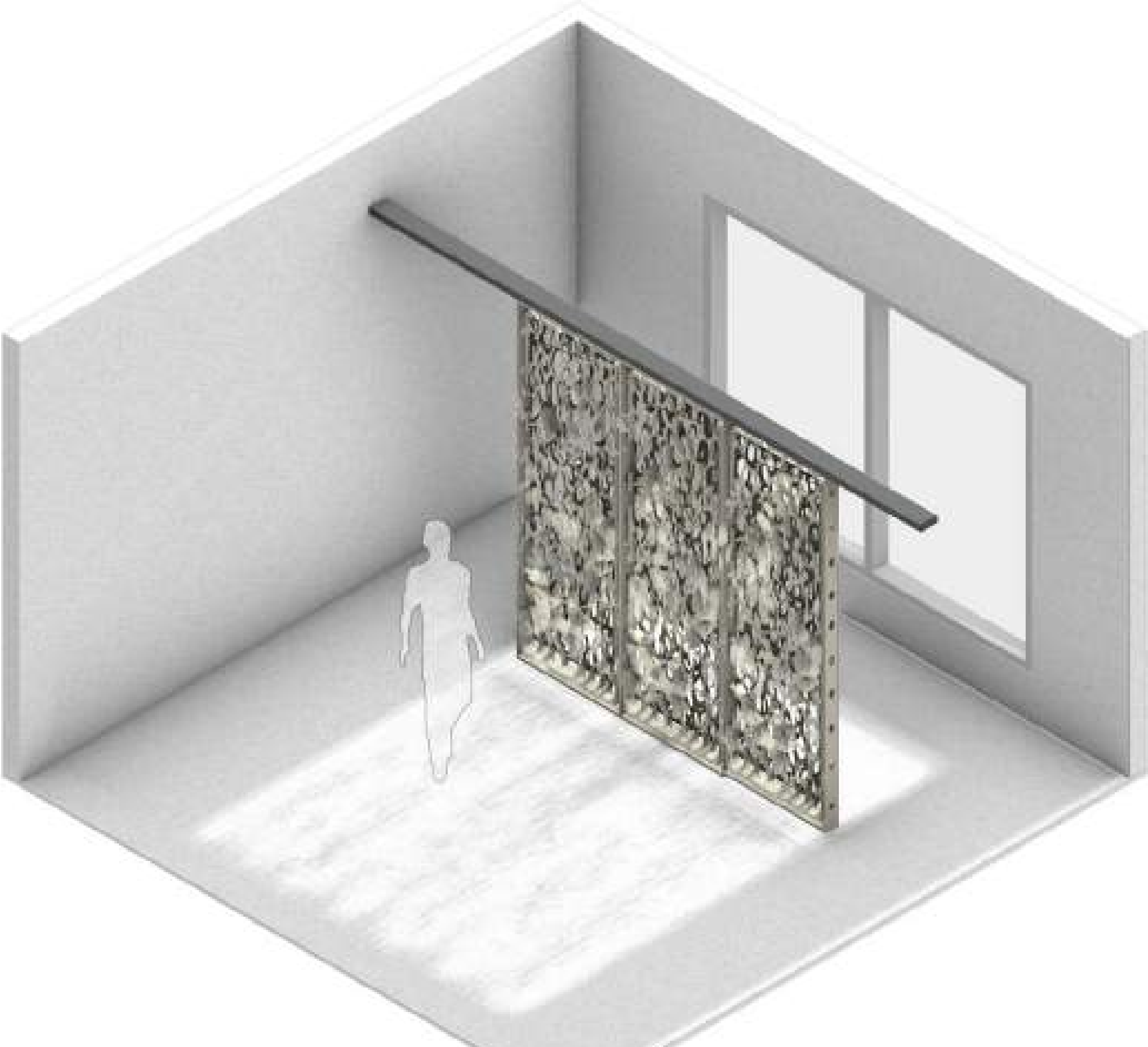


Figure 5.8 Mycelium-PLA Application as Interior Partition Wall

MATERIAL CATALOG

❸ Mycelium- PLA

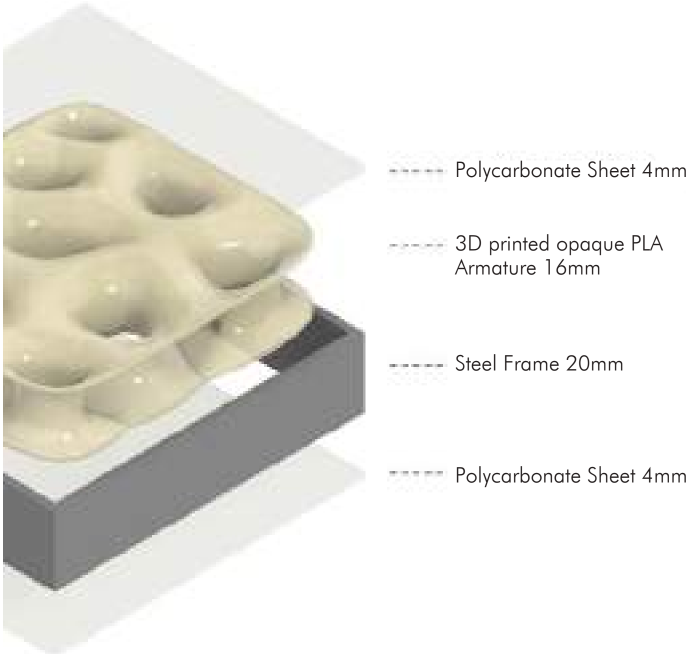
3.A Mycelium Growth on 3D printed opaque PLA Armatur

Figure 5.9 Mycelium-PLA Curtian Wall

This structure offers shading and light lumination depending on the design of the armature porosity, density of the mycelium colonization and the thickness of the panel. Through changing these factors, the design can be applied to various scenarios.

Assembly: The armature is designed according to wanted porosity level and 3D printed.The mycelium grains grow inside tubular PLA Armature. After the wanted density is maintained the structure is sealed inside polycarbonate sheet and steel frame for waterproofing. This way oxygen for mycelium growth is cut and the material is stabilized. The panels can be integrated to each other from joints and placed on facade.

Disassembly: The design considers the end of life of the structure or building, as each frame can separate from each other as the components; polycarbonate, mycelium, wood PLA armature and the joints can be taken down into pieces and recycled or reused according to their life cycle.



ⓐ Material Components:
Mycelium grain +PLA Armature Layers (16mm) + Polycarbonate (4mm) + Steel Frame(20mm)

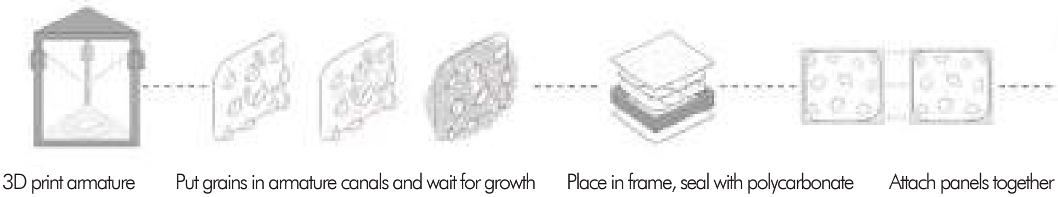
ⓑ Place of Use:
Exterior

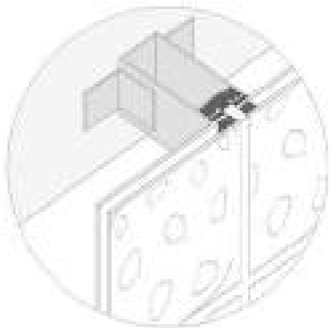
ⓒ Architectural Application:
Outer Facade Applications

ⓓ Typology:
Public Buildings

ⓔ Lux Ratio:
Lower %75-80

Manufacture Process





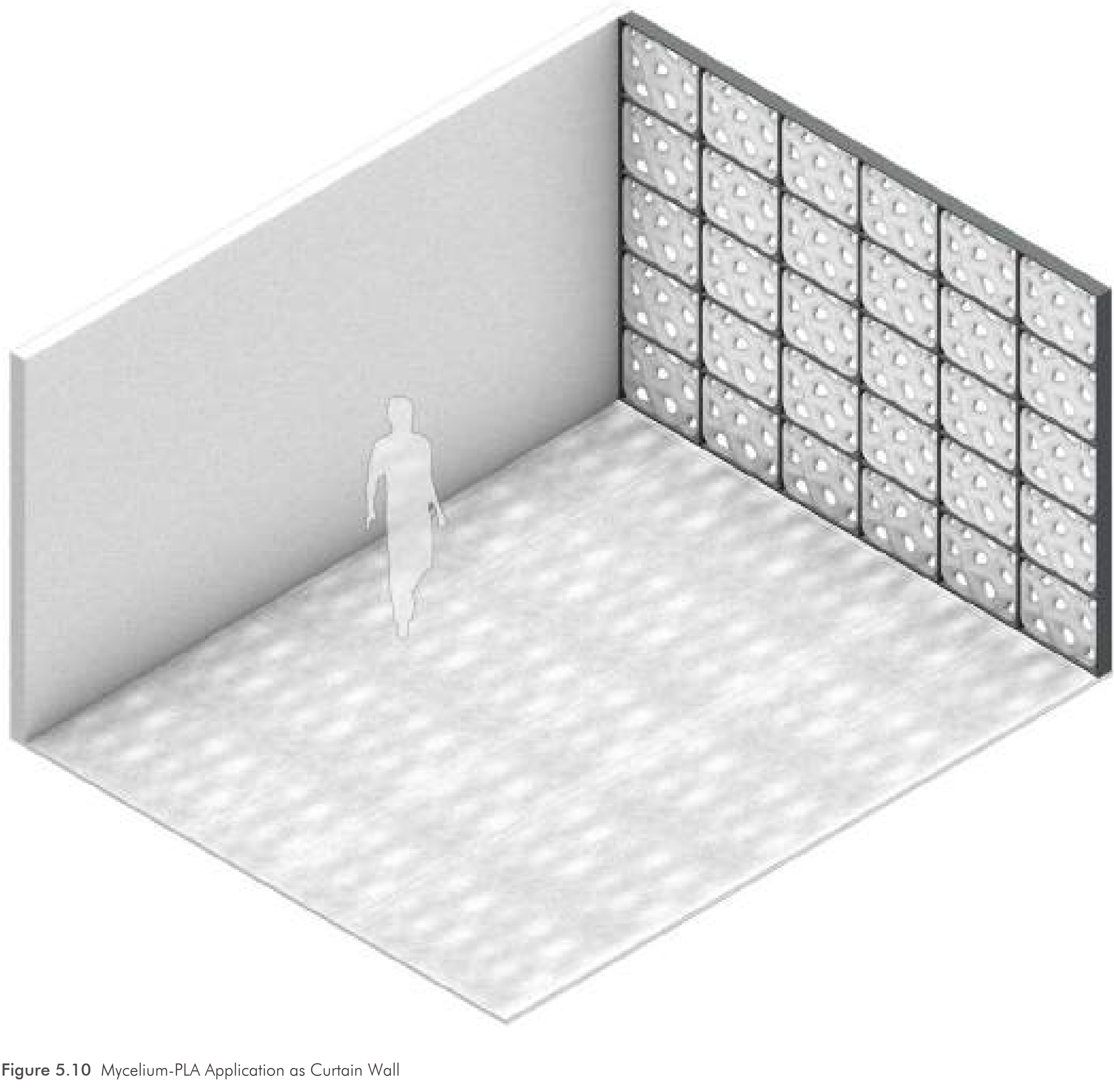


Figure 5.10 Mycelium-PLA Application as Curtain Wall

MATERIAL CATALOG

❸ Mycelium-Wood PLA

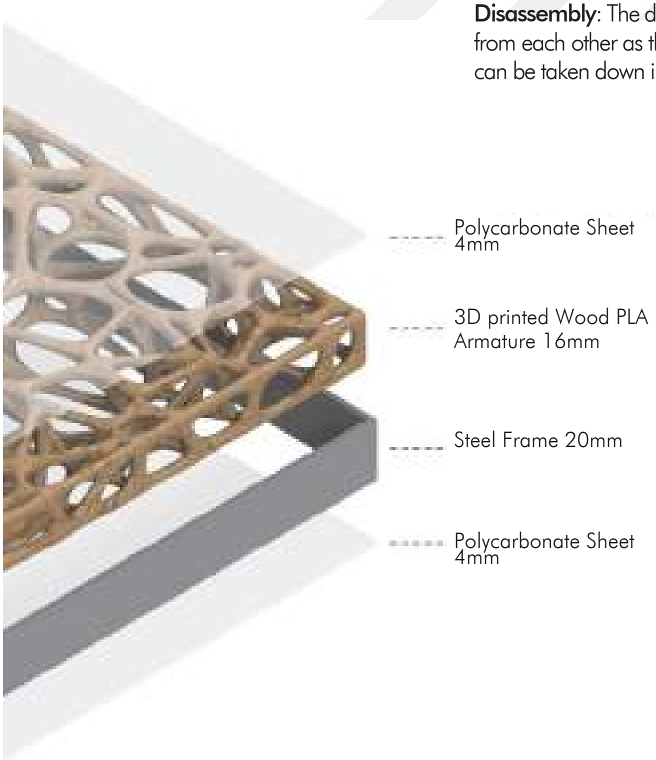
3.B Mycelium Growth on 3D printed Wood-PLA Armature

Figure 5.11 Mycelium-PLA Curtian Wall

This structure offers shading and insulative properties depending on the design of the armature porosity, density of the mycelium colonization and the thickness of the panel. Through changing these factors, the design can be applied to various scenarios.

Assembly: The armature is designed according to wanted porosity level and 3D printed. Later mycelium grains are put to grow inside pores, binding PLA-Wood Armature. After the density is maintained the structure is sealed inside the polycarbonate sheet and steel frame for waterproofing. This way oxygen for mycelium growth is cut and material is stabilized. The panels are integrated to each other from joints and placed on the facade.

Disassembly: The design considers the end of life of the structure or building, as each frame can separate from each other as the components; polycarbonate , mycelium, wood PLA armature and the steel frame can be taken down into pieces and recycled or reused according to their life cycle.



ⓐ Material Components:
Mycelium grain+ Wood-PLA Armature(16mm) + Polycarbonate (4mm) + Steel Frame(20mm)

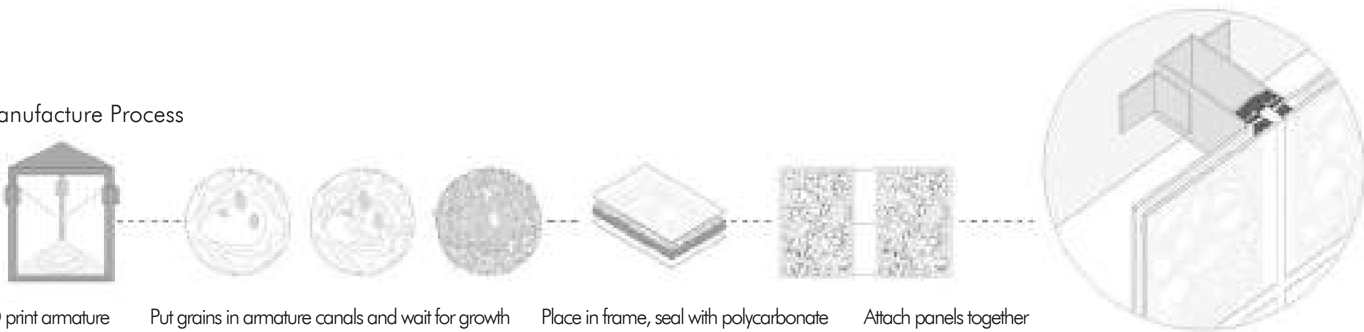
ⓑ Place of Use:
Exterior

ⓒ Architectural Application:
Outer Facade Applications

ⓓ Typology:
Public Buildings

ⓔ Lux Ratio:
Lower %50-70

Manufacture Process



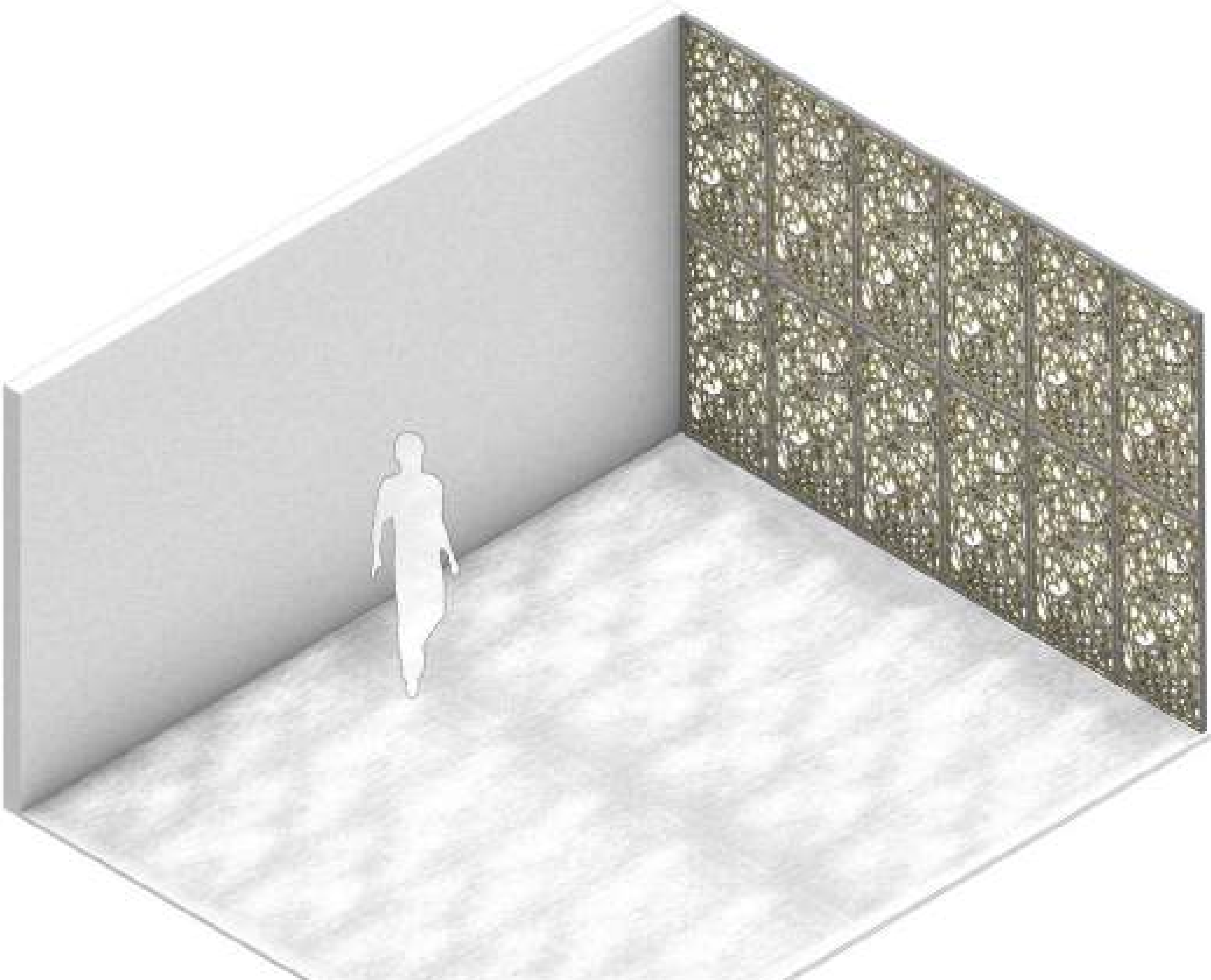
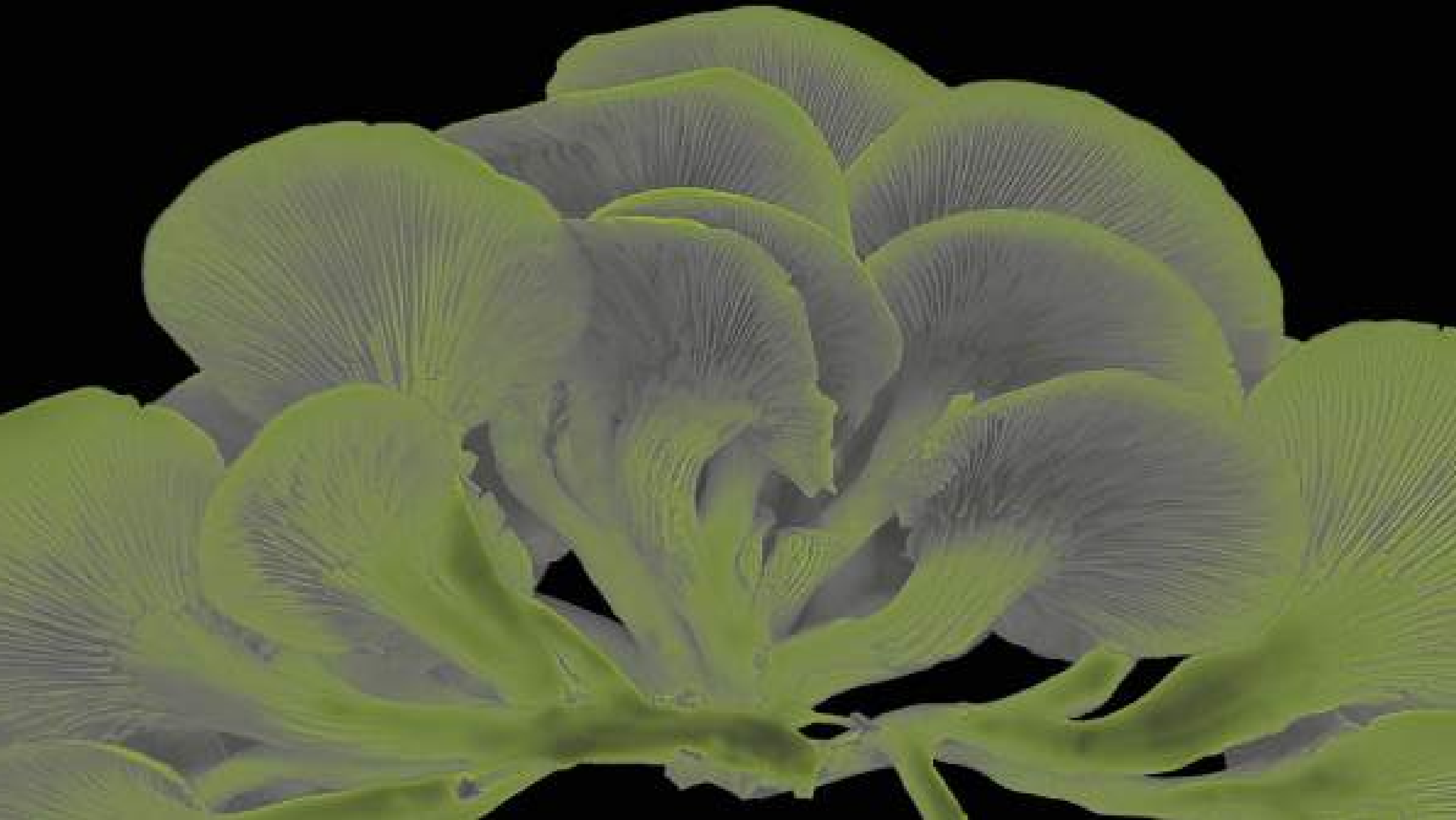


Figure 5.12 Mycelium-PLA Application as Curtain Wall

06



06 DESIGN APPLICATION

6 DESIGN APPLICATION

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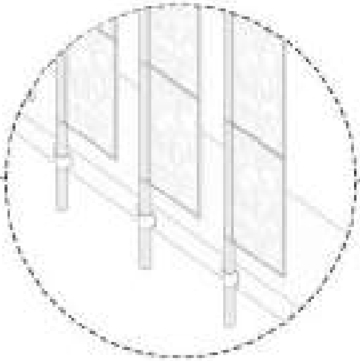
The research aimed for developing a mycelium-based panel which offers light transmittance and insulation in its use as an infill or sandwich structure which can be later used as an alternative architectural element to enhance circular design. As an outcome of the theoretical research and material practices regarding the project of a “Bio-skin: Mycelium based facade panel system for circularity in architecture” 3 typologies of applications were constructed. From the material practice and catalog the design of the panel “3.B Mycelium Growth on 3D printed PLA Armature” is chosen to be further developed in terms of the application and its construction details.

In this chapter construction details of panel “3.B” and its application, as a facade element, are displayed in 3 types of proposals; as fixed angle sun blocker/rotating sun blocker, infill panel for curtain wall, free-standing facade element. Each application is designed to measure up DfD stands for preserving resources and reducing consumption through building for recovery, as the materials and components are designed in a layered way making it simple to deconstruct and reuse. The panel construction is formed of the layers; polycarbonate sheet(4mm), mycelium grown 3D printed armature(20mm), polycarbonate sheet(4mm) or glass(2mm), aluminum frame(30mm); all having a different end of life period. The mycelium-based infill panel is sealed inside the glass-aluminum sandwich structure and connected through bracket and screw to the mullions. Therefore, these layers could be dismantled and replaced or reused in later stages of material lifecycle. Later, these applications are displayed on a case study proposal to further display how the design can be adjusted for site-specific requirements using the climate studio LUX analysis, ladybug light illumination and radiation analysis.

"BIO-SKIN: MYCELIUM BASED FACADE PANEL SYSTEM FOR CIRCULARITY IN ARCHITECTURE"

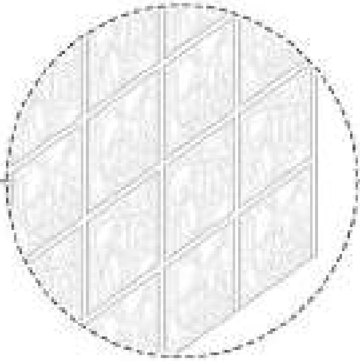
FIXED ANGLE SUN BLOCKER
ROTATING SUN BLOCKER



Components:

+aluminum bracket
+mullion
+aluminum frame
+mycelium based infill panel
+polycarbonate sheet
+rotation hinge
+roller shutter control system

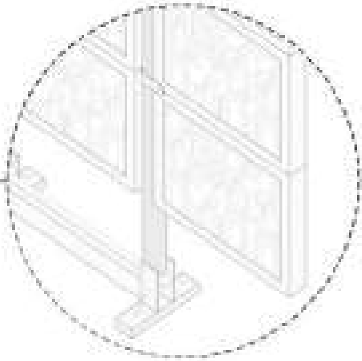
INFILL PANEL FOR
CURTAIN WALL



Components:

+aluminum bracket
+mullion
+aluminum frame
+mycelium based infill panel
+weather sealant
+polycarbonate sheet

FREE-STANDING FACADE



Components:

+aluminum bracket
+mullion
+aluminum frame
+mycelium based infill panel
+polycarbonate sheet
+rotation hinge
+aluminum support leg

6.1 Application Typology Construction Details

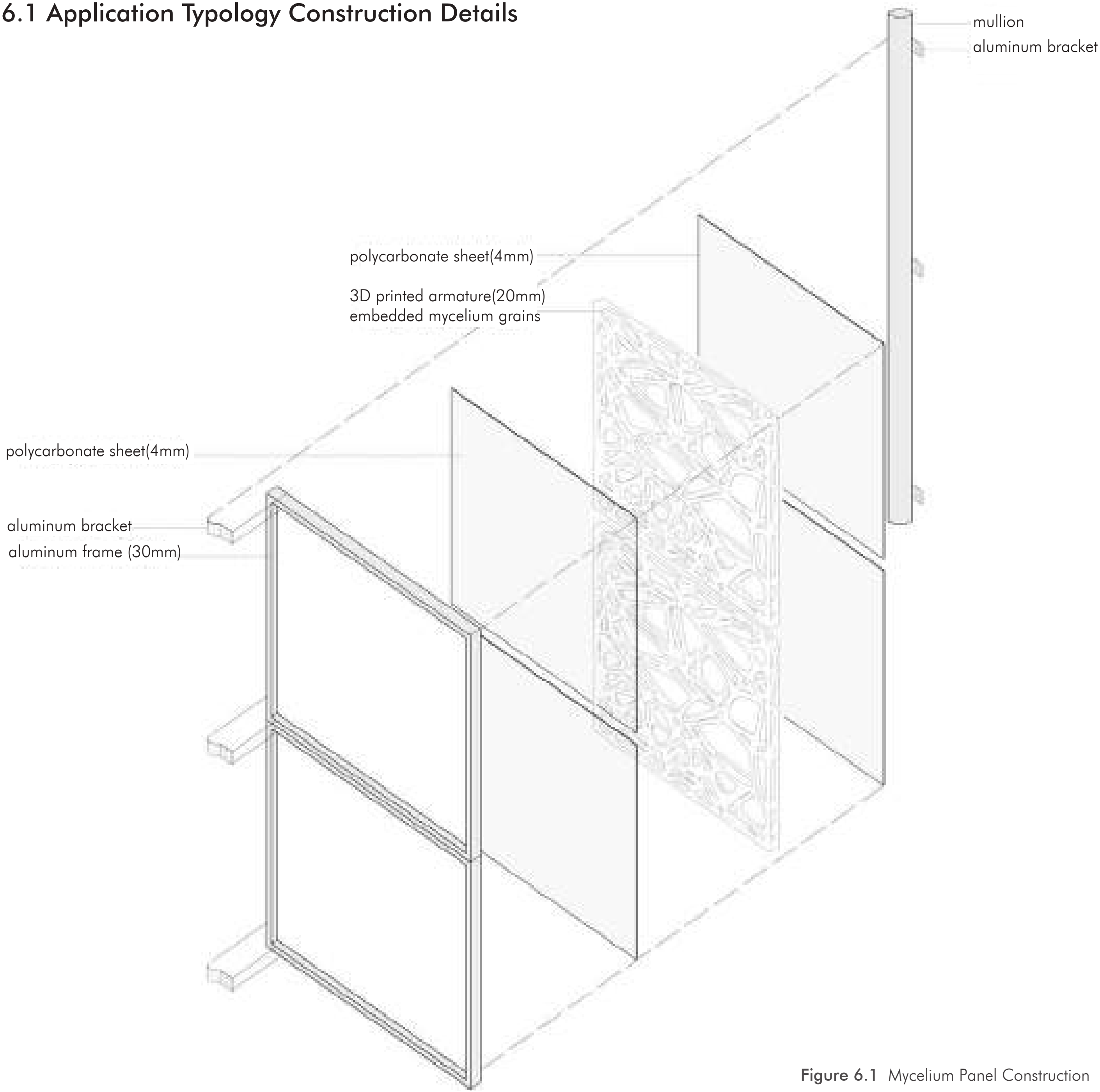
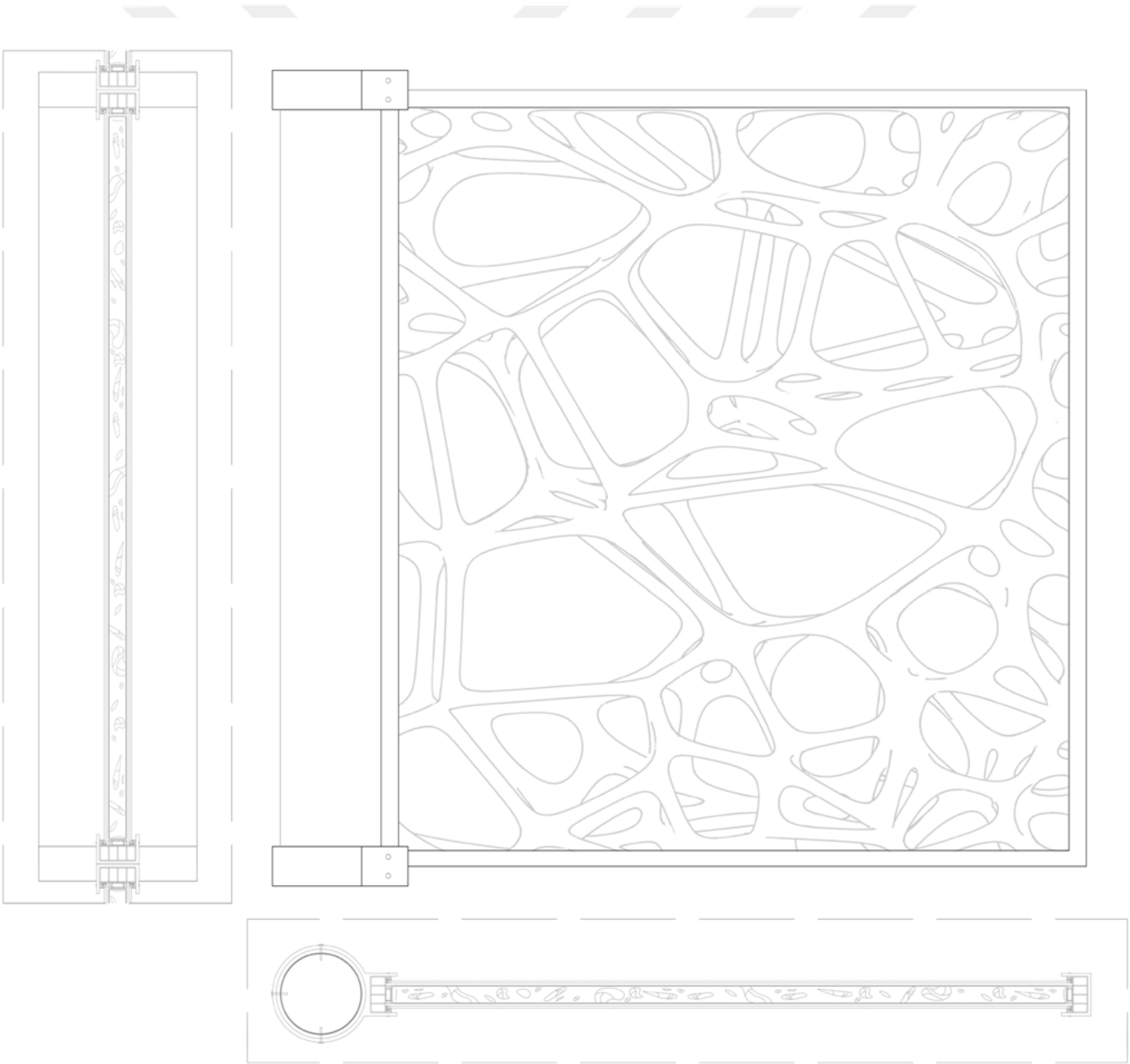


Figure 6.1 Mycelium Panel Construction



Scale: 1/10

0 5 10 cm

Figure 6.2 Mycelium Panel Drawing Set

PANEL APPLICATION

❶ Proposal A

Facade Rotating Sun Blocker

This application of the mycelium 3D printed armature panel can be used as sun-blocker for the façade. These panels can be attached to the slab through mullions which attach to the roller shutter control system. The panels are connected on to a cylinder mullion that can rotate through the rotation hinge and be adjusted to the sun angle.

Scale: 1/10

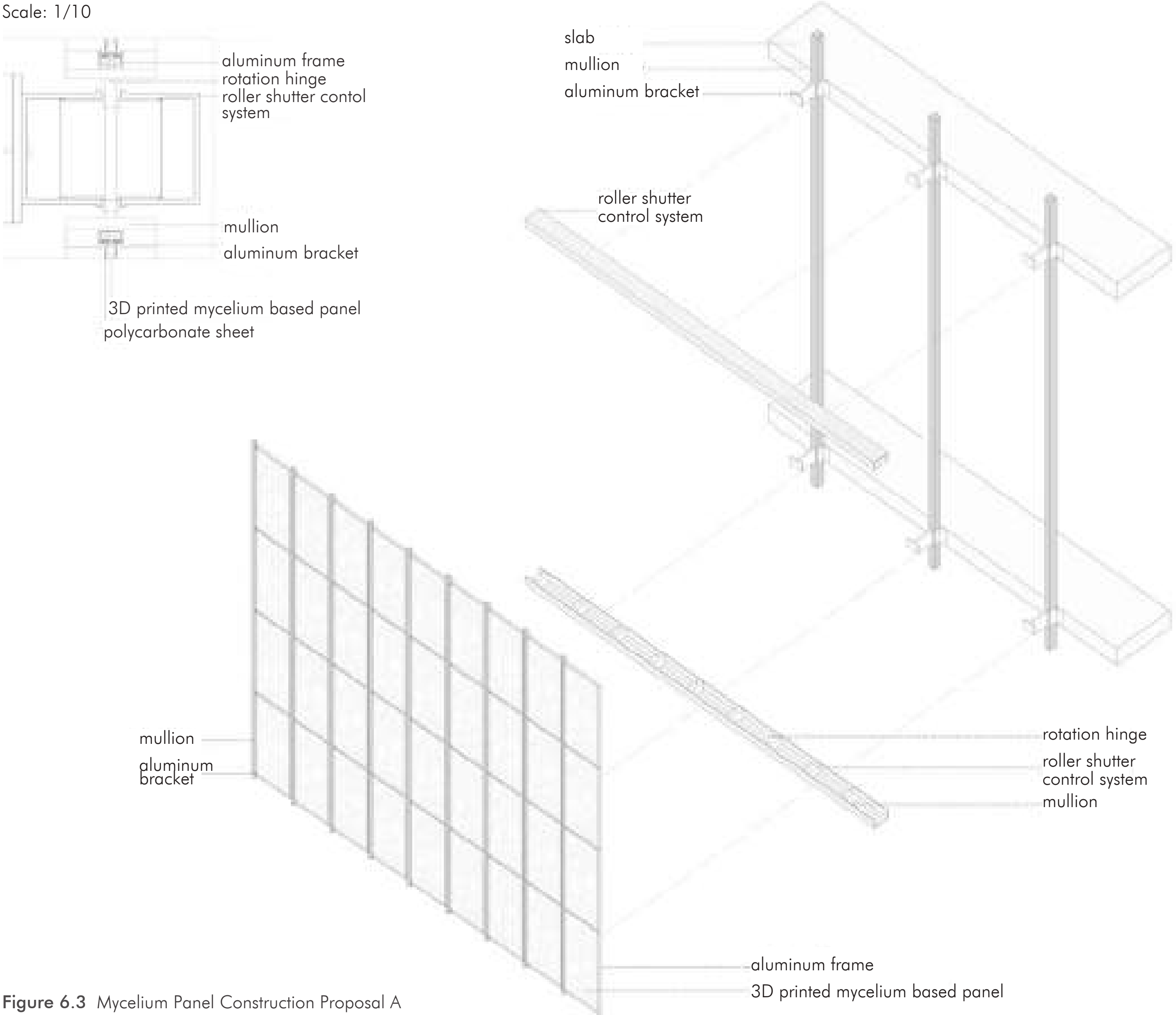
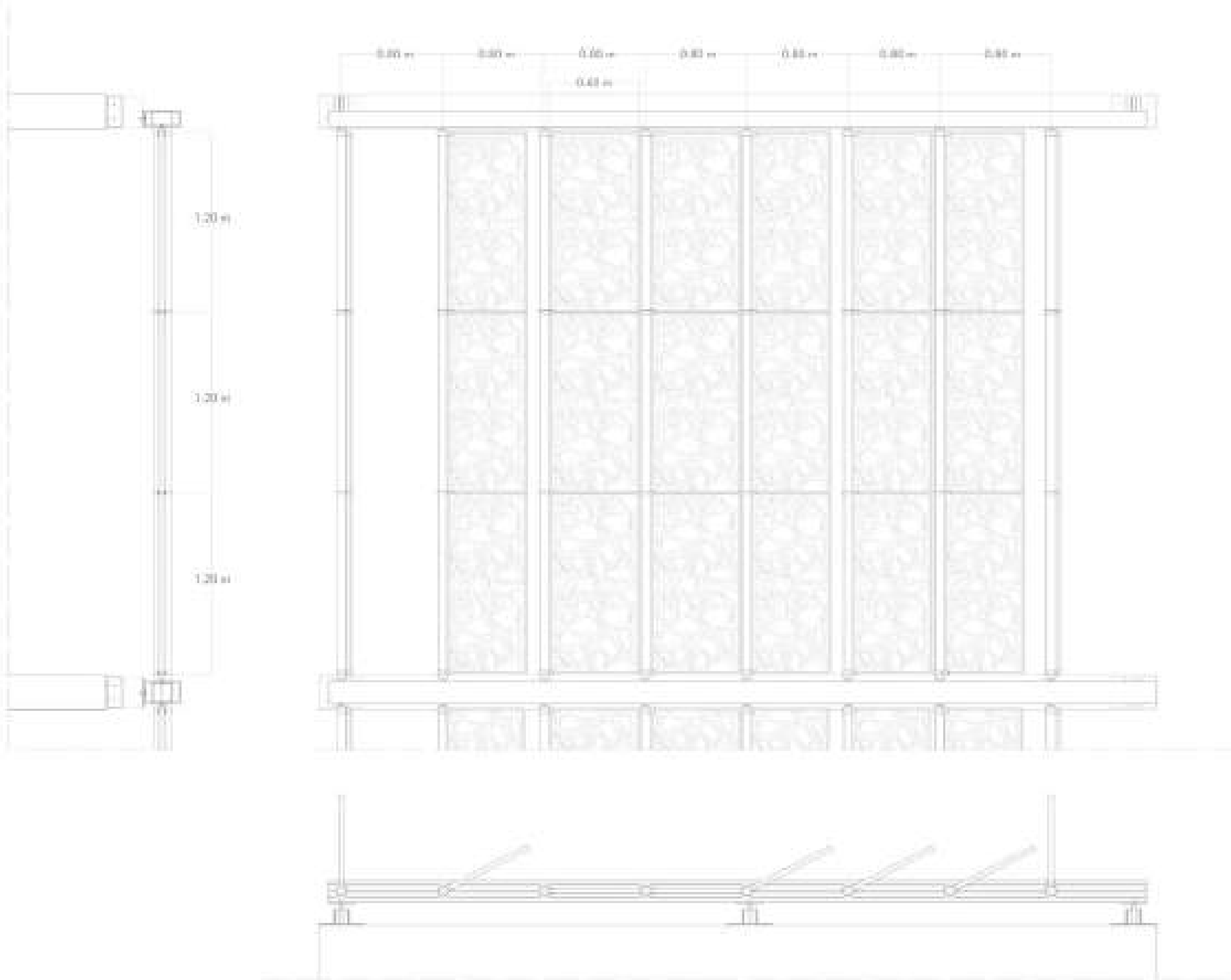


Figure 6.3 Mycelium Panel Construction Proposal A



Scale: 1/50

0 1 3m

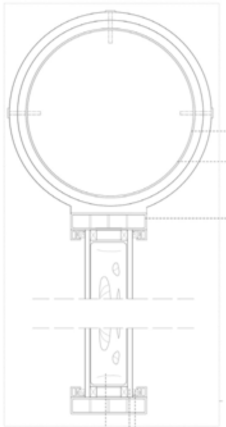
Figure 6.4 Mycelium Panel Drawing Set Proposal A

PANEL APPLICATION

❶ Proposal A
Facade Fixed Angle Sun Blocker

This application of the mycelium 3D printed armature panel can be used as sun-blocker for the façade. The panels are connected on to a cylinder mullion that has fixed angle set with sun intake and radiation analysis optimization according to the specific site.

Scale: 1/10



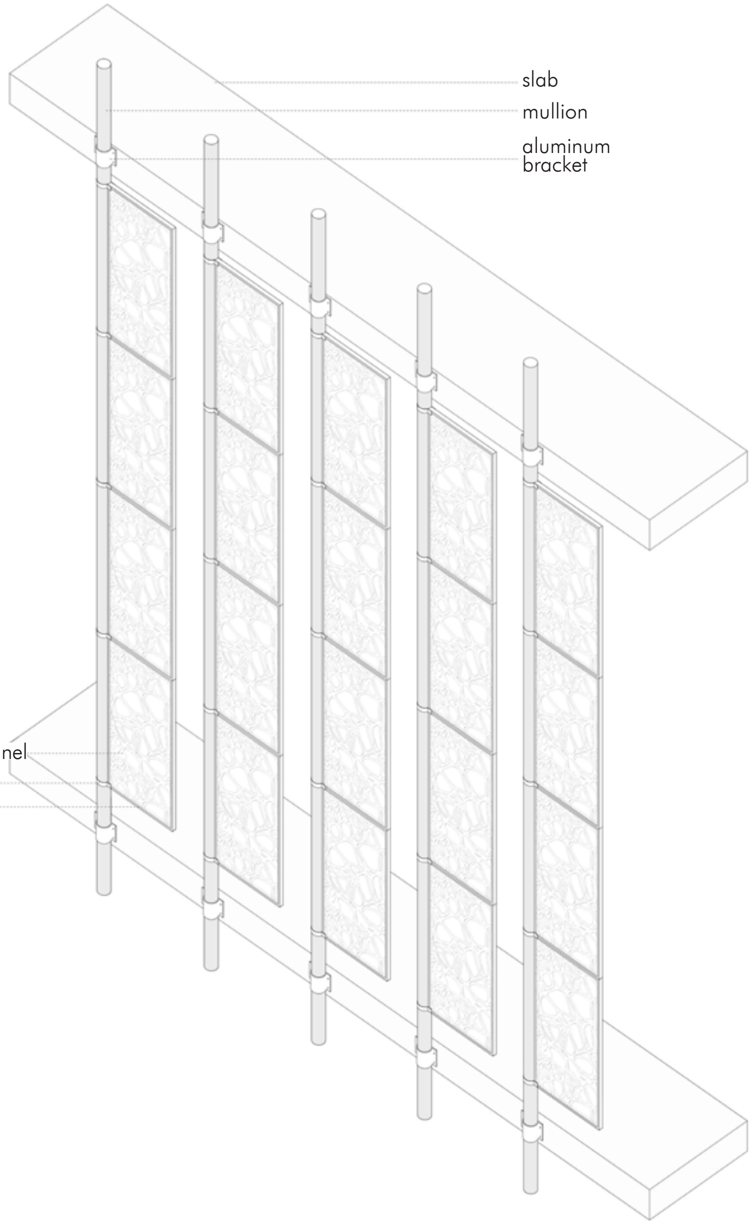
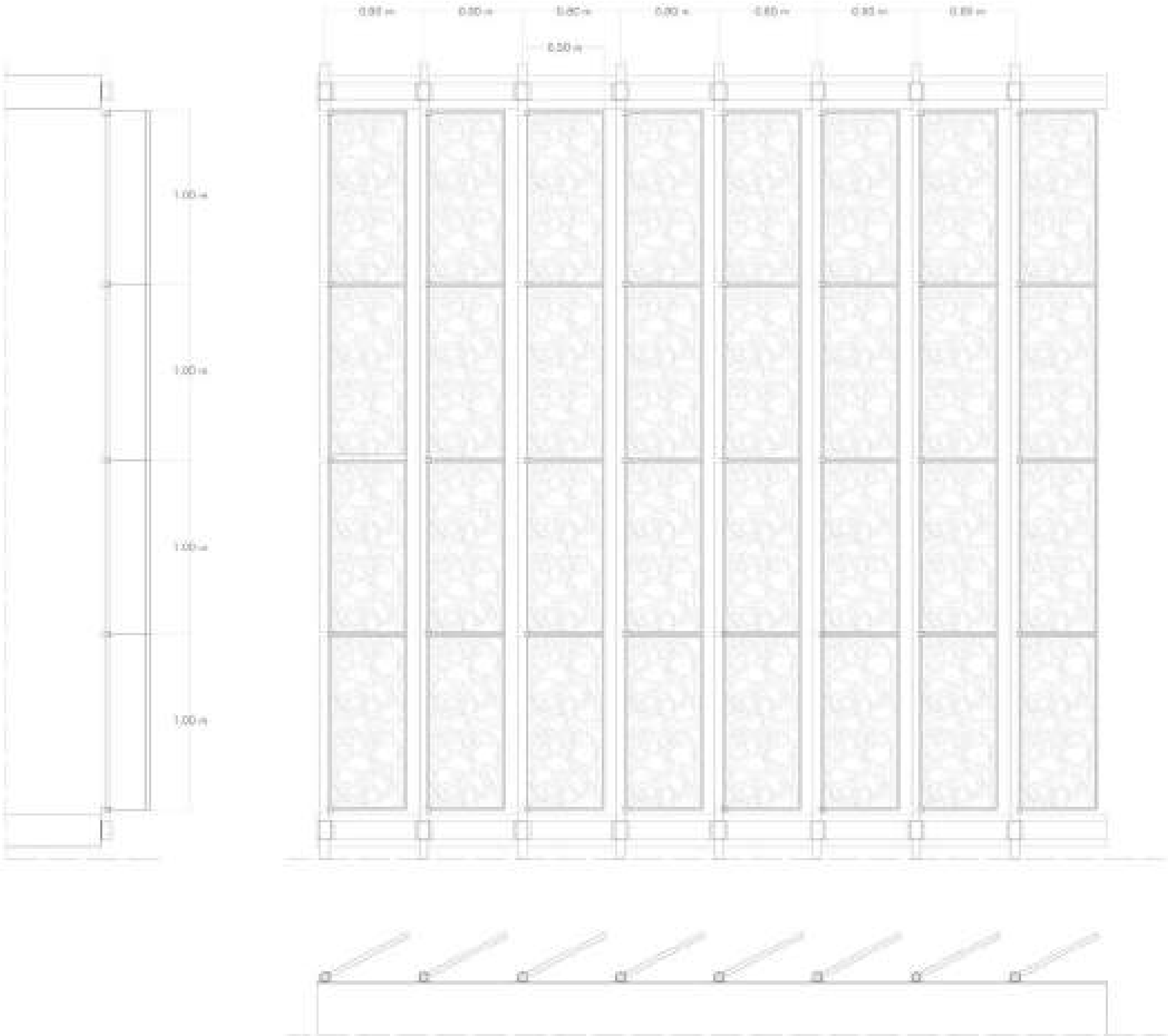


Figure 6.5 Mycelium Panel Construction Proposal A



Scale: 1/50

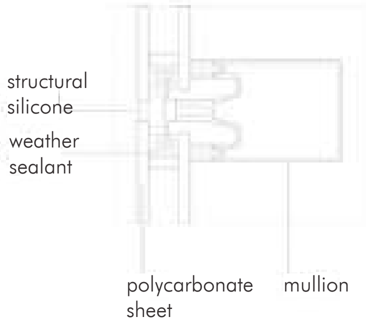
0 1 3m

Figure 6.6 Mycelium Panel Drawing Set Proposal A

PANEL APPLICATION

❷ Proposal B
Cutain Wall

This application of the mycelium-based 3D printed armature panel can be used as an infill of a curtain wall. These panels can be sealed by polycarbonate sheet with a hidden frame structure.



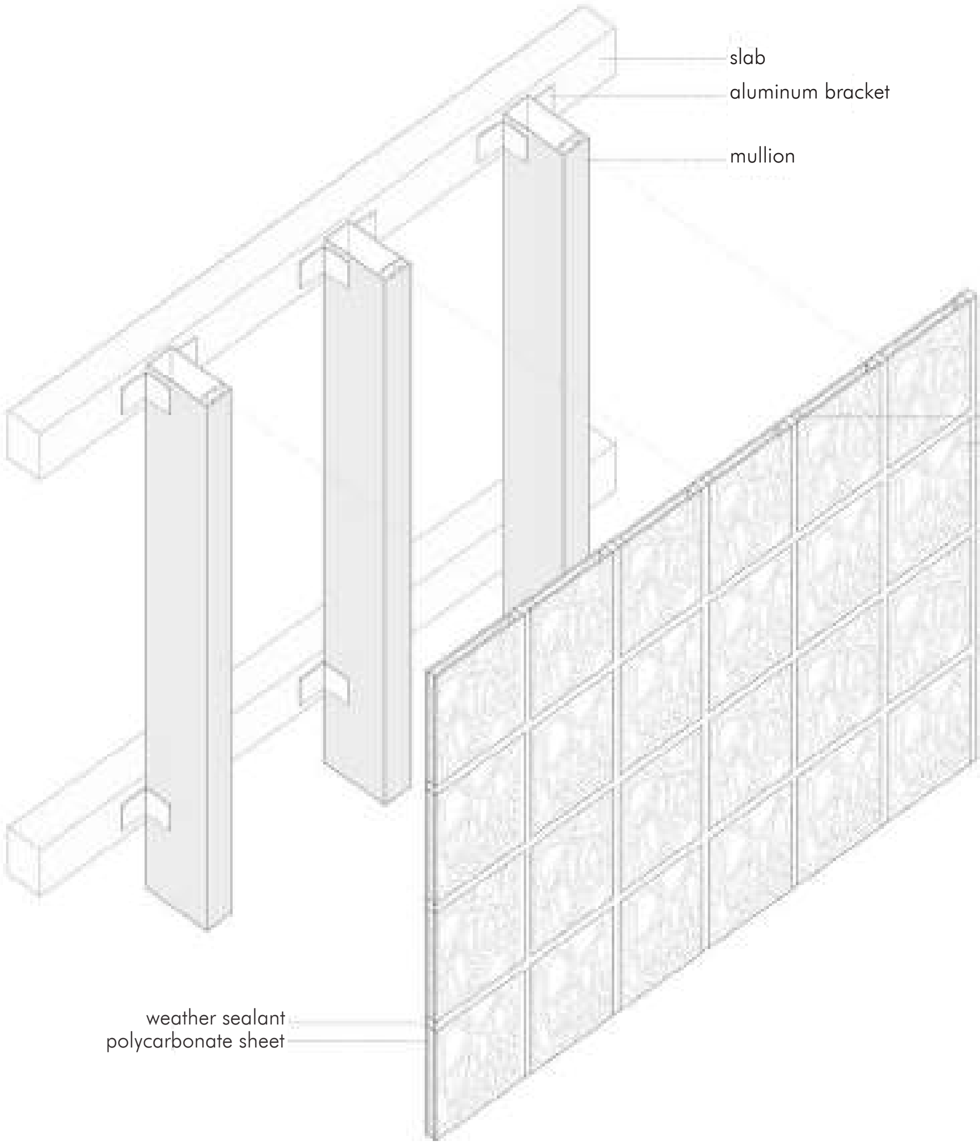
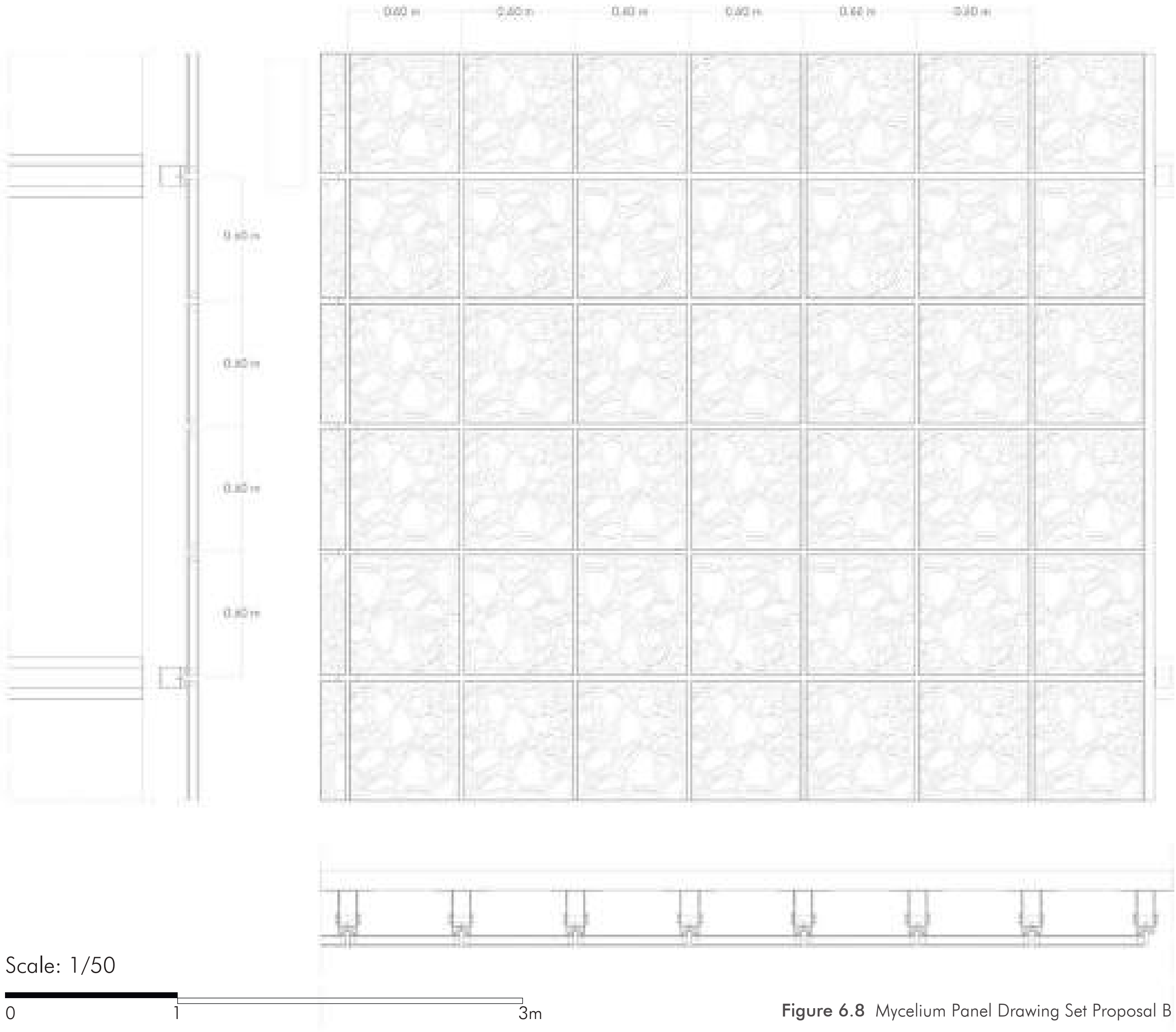


Figure 6.7 Mycelium Panel Construction Proposal B



Scale: 1/50

0 1 3m

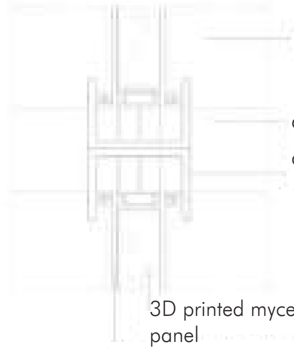
Figure 6.8 Mycelium Panel Drawing Set Proposal B

PANEL APPLICATION

❸ Proposal C
Free Standing Facade

This application of the mycelium 3D printed armature panel can be used as a free standing sun- blocker structure. The panels are connected on cylinder mullion that can rotate through the roller shutter control system hinge. The system is supported by aluminum extension support leg.

Scale: 1/10



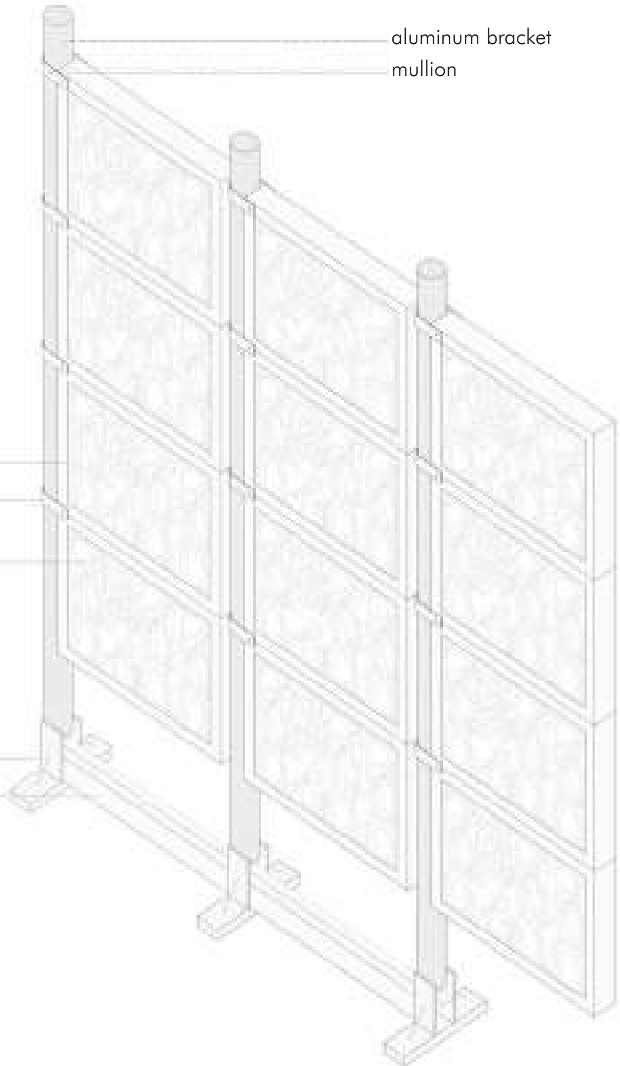
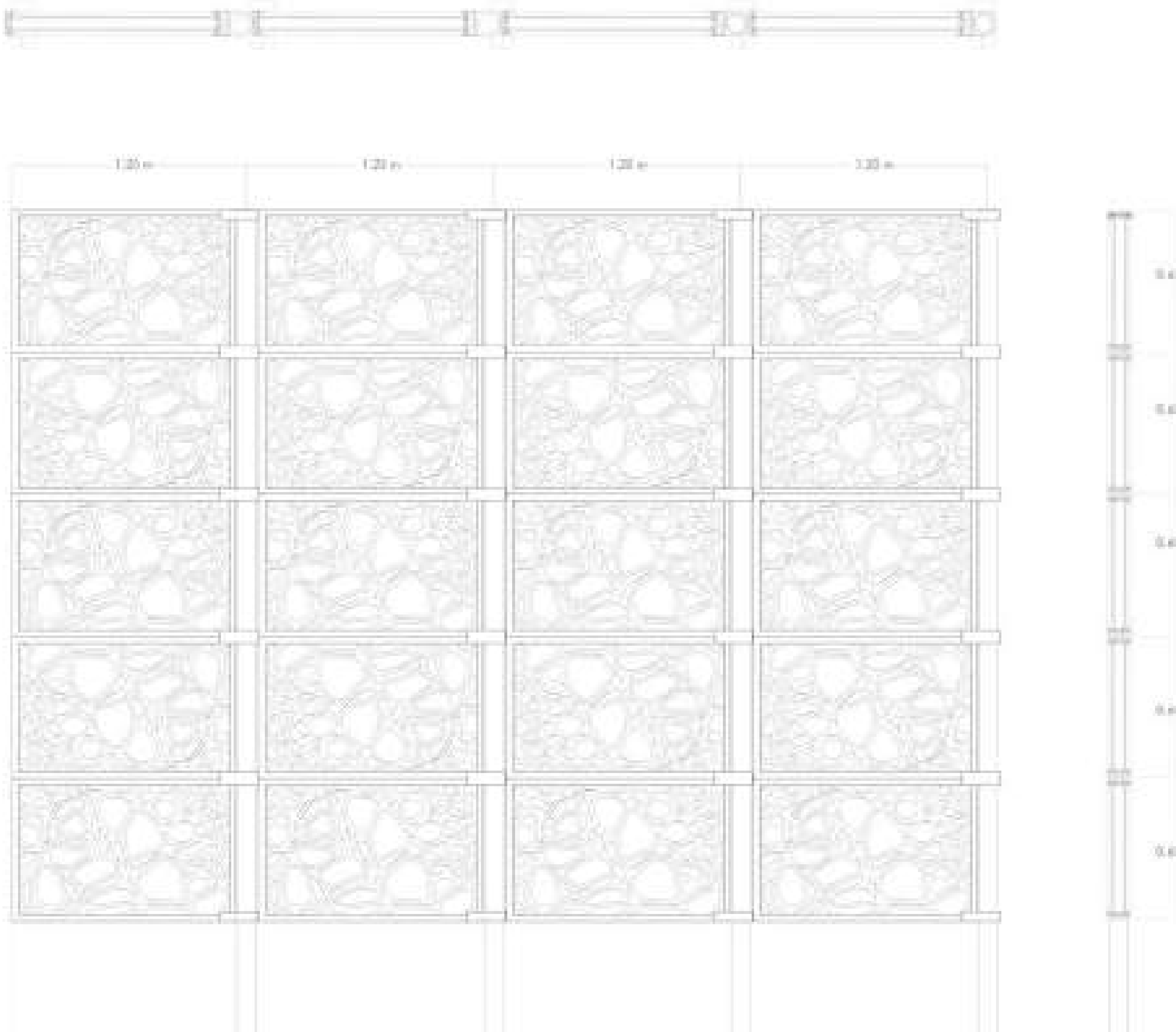


Figure 6.9 Mycelium Panel Construction Proposal C



Scale: 1/50

0 1 3m

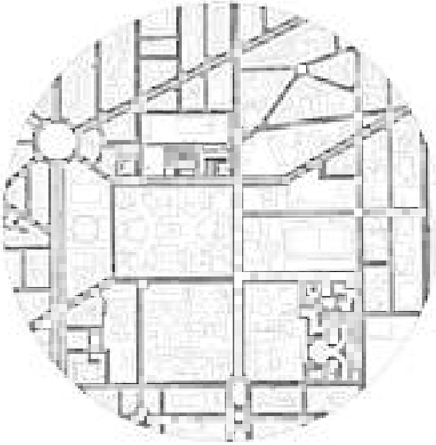
Figure 6.10 Mycelium Panel Drawing Set Proposal C

07

07 CASE STUDY PROPOSAL

7 CASE STUDY PROPOSAL

The proposed location for application of "Bio-skin: Mycelium based facade panel system" is set as the Polictecnico di Milano campus in Via Bonardi, Citta Studi, Milano. The panel design is applied to the buildings "Edificio 16B" and "Edificio 13-Trifoglio" facade. In order to select the application typology; fixed angle sun blocker/rotating sun blocker, infill panel for curtain wall, free standing facade element; sun illuminance analysis is done on the buildings.



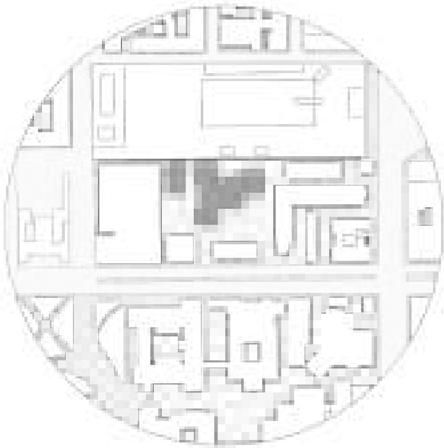


Figure 7.1 Case Study Proposed Site Plan

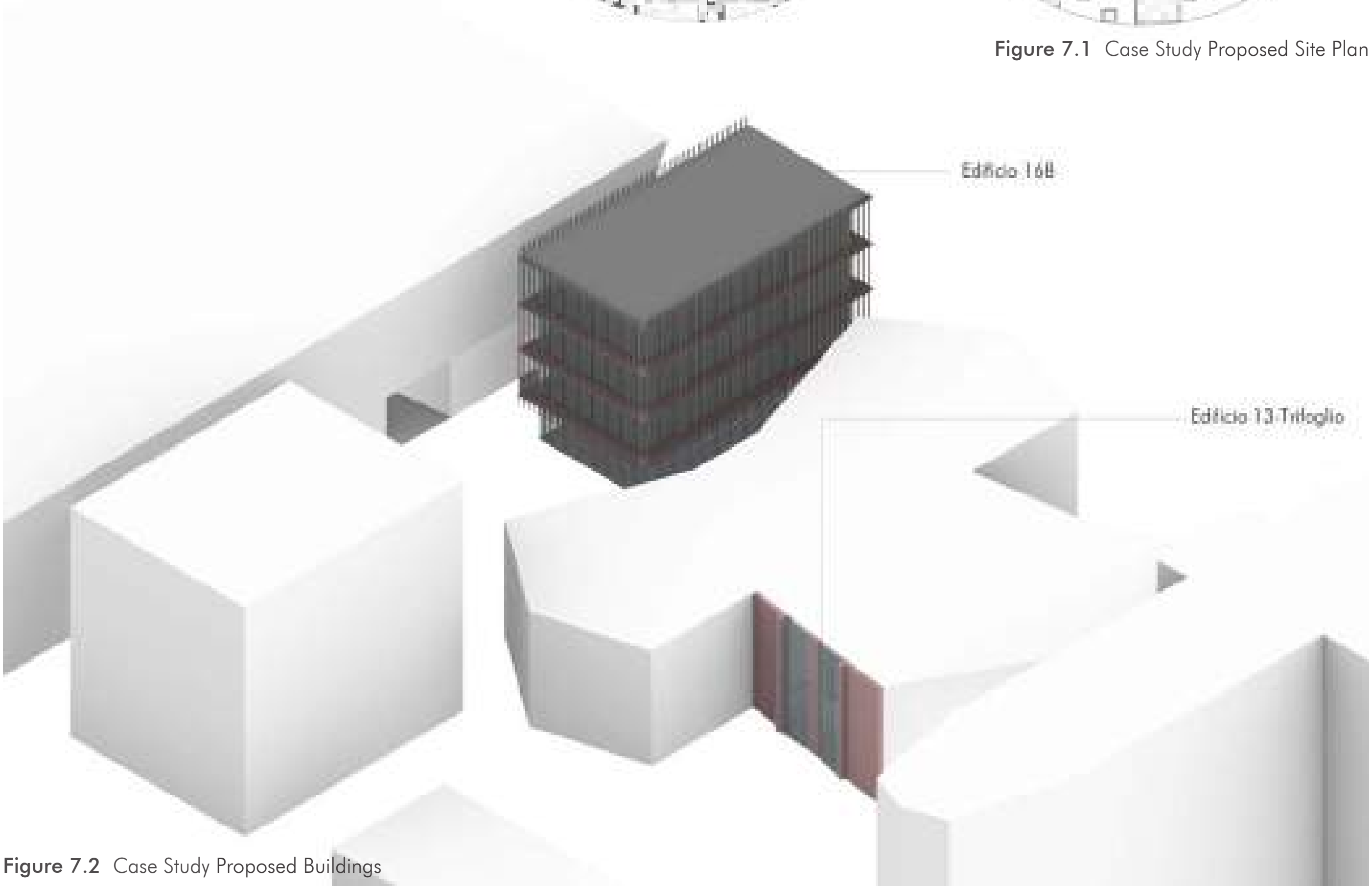


Figure 7.2 Case Study Proposed Buildings

The daylight analysis calculates the number of hours of direct sunlight received by the geometry using sun vectors. By optimization the geometry that intakes most daylight can be obtained for shadow studies or to estimate glare potential from direct sunlight. The solar radiation analysis calculates the radiation falling on geometry using sky matrix. This can be used for building envelopes to gain information on zone of solar heat gain and radiation levels that could affect thermal comfort.

Figure 7.3 Daylight Analysis Script

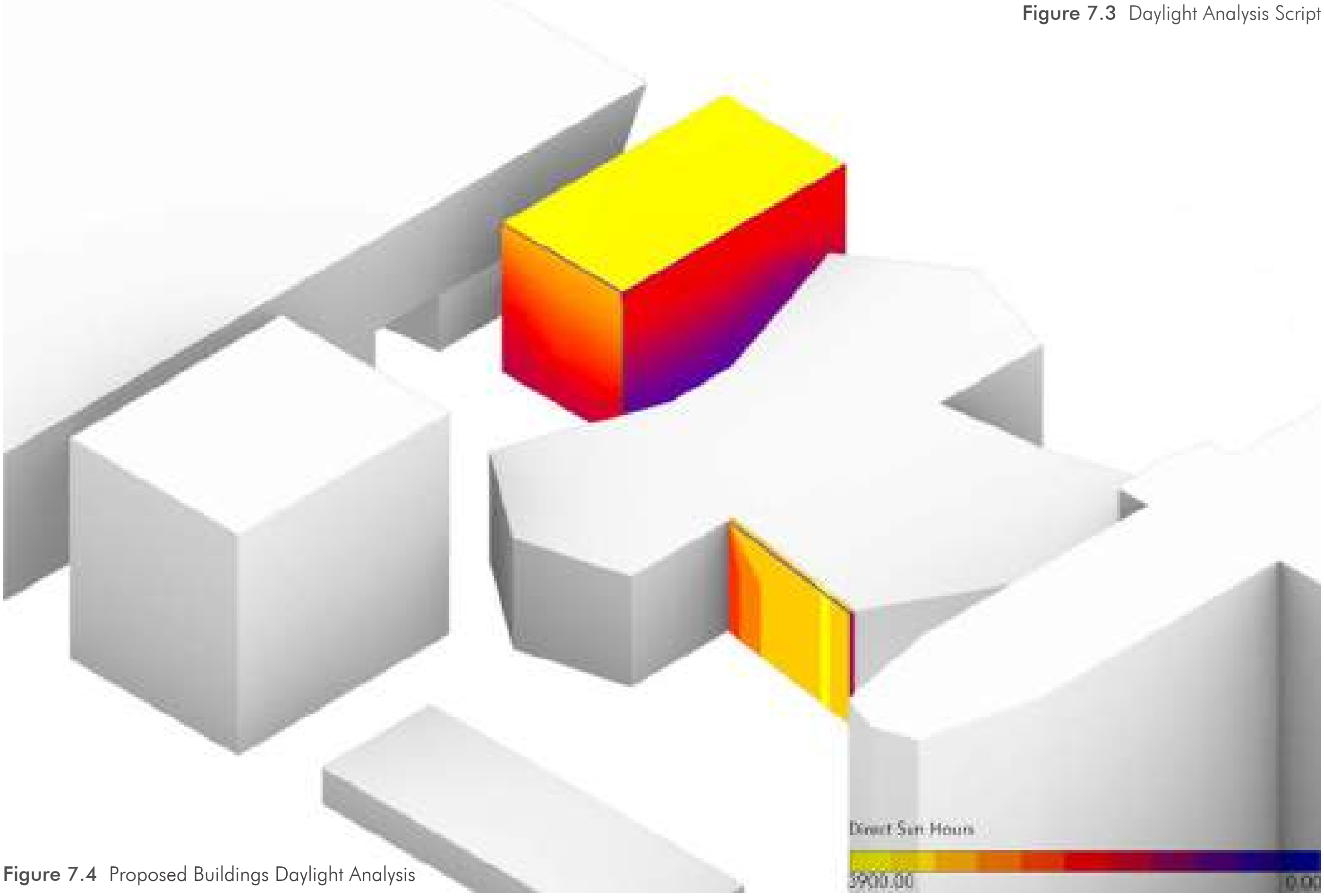


Figure 7.4 Proposed Buildings Daylight Analysis

7.1 Building Analysis Edificio 16B

The Building Edificio 16B is part of the transformation project of via Bonardi complex designed by Renzo Piano and ODB&Partners developing the original design idea of Renzo Piano. The building is formed of 4 floors designed to function as teaching classrooms.

BUILDING ANALYSIS

❶ Edificio 16B

Figure 7.5 Photograph Edificio 16B

Figure 7.6 Photograph Edificio 16B

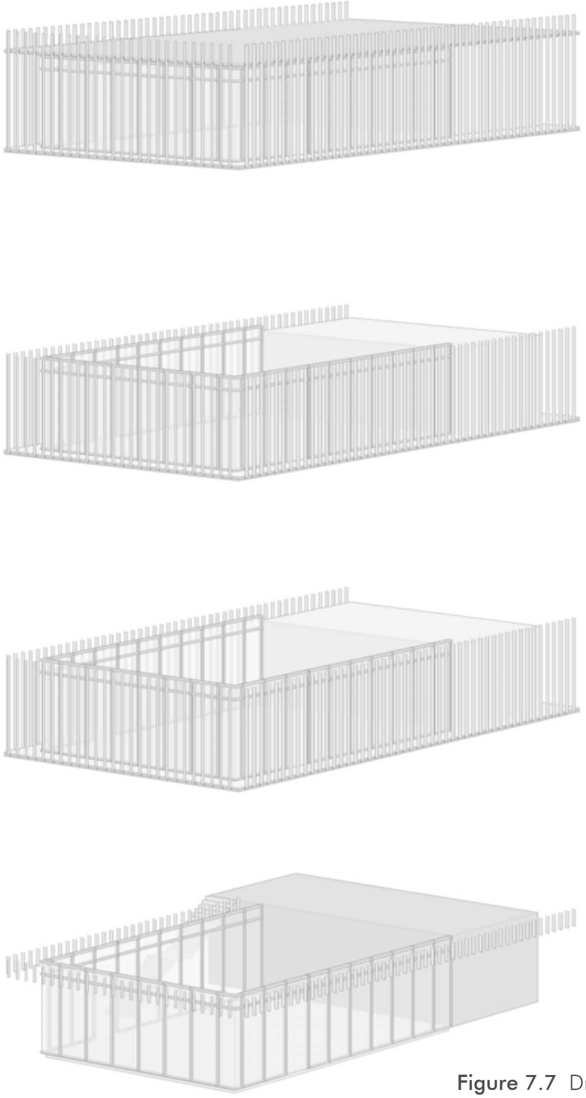
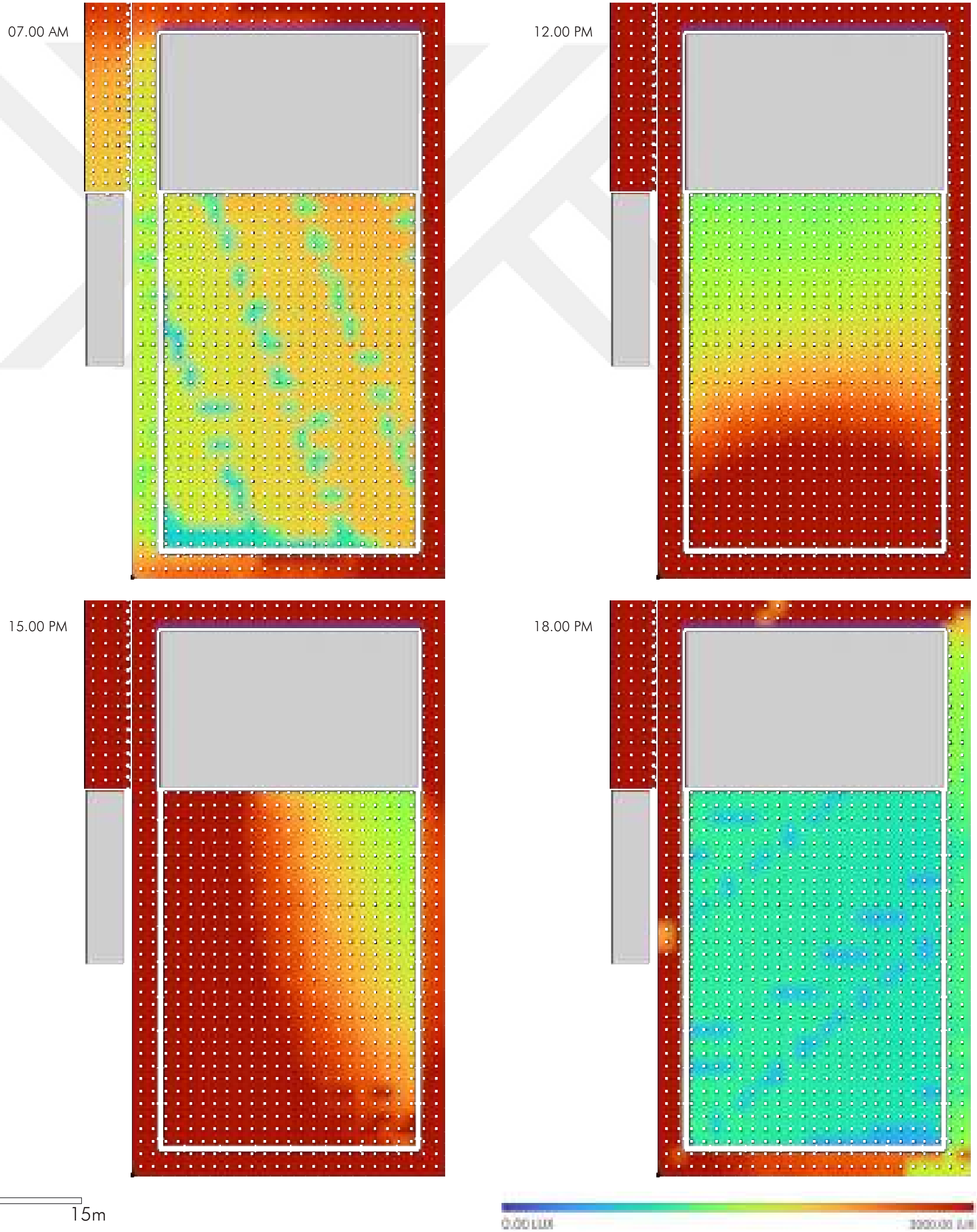


Figure 7.7 Drawing Edificio 16B

As all new buildings Edificio 16B is built with Schüco aluminum systems; FWS curtain wall with horizontal strips-42 mm mullions. The structure is designed with micro louvre blades inserted in the glazing to prevent excesse daylight. This facade provides for design for disassembly.

Direct Sun Hours

Figure 7.8 Edificio 16B
Plan Daylight Analysis



Scale: 1/300

0 5 15m

7.1.1 Edificio 16B Proposal

Facade Rotating Sun Blocker

The Light Illuminance analysis displays that without the micro louvre blades integrated glazing, the facade cannot prevent excessive daylight into the teaching rooms. Therefore, the application of “Bio-skin: Mycelium based facade panel system” is proposed for the facade of Edificio 16B.

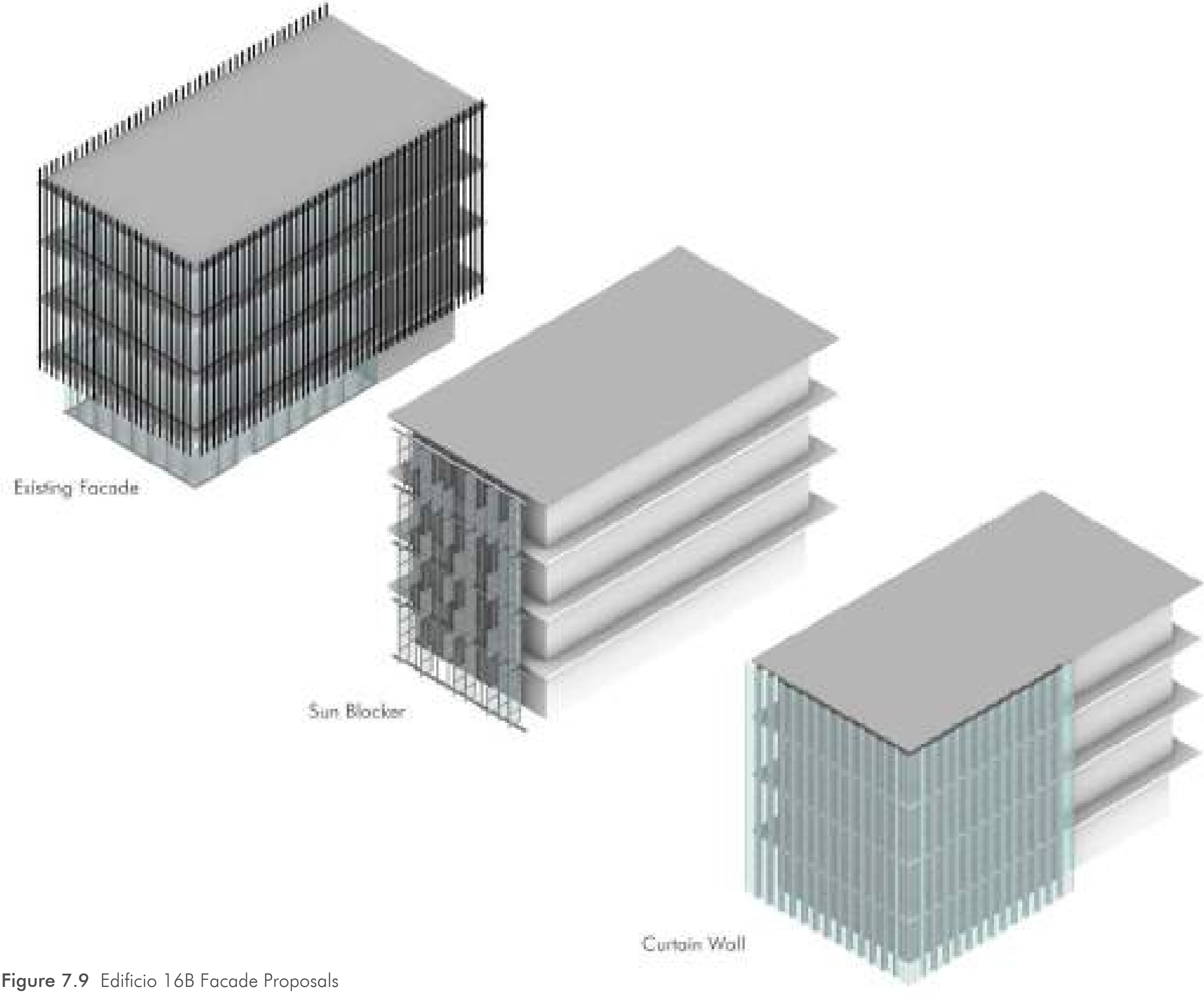


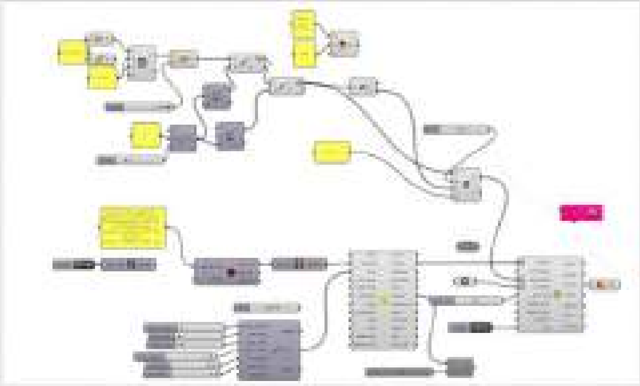
Figure 7.9 Edificio 16B Facade Proposals

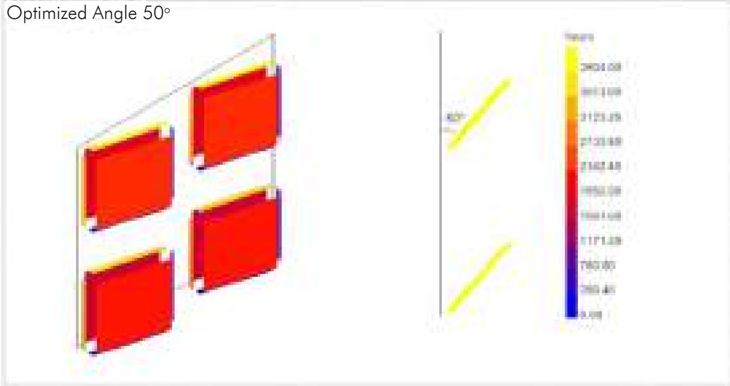
To select the application typology; fixed angle sun blocker/rotating sun blocker, infill panel for curtain wall; the design of the floor plan, function and façade elements are put in consideration to readapt the existing facade.

Edificio 16B Annual Optimization of Direct Sun Hours

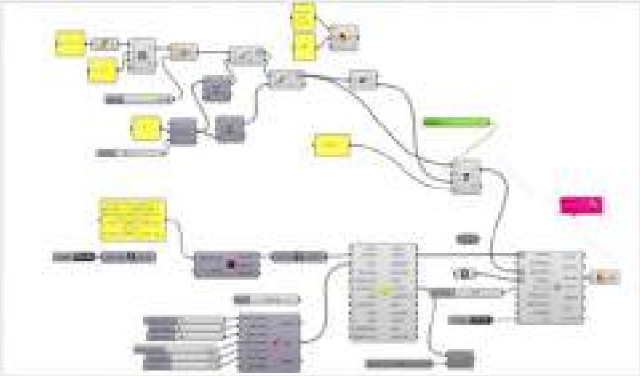
To adapt the existing outer balcony, horizontal strip mullions, and provide for the differences in Light Illuminance analysis the application typology of rotating sun blocker system with integrated mycelium-based infill panels are selected. To set the rotation, annual optimization tests of direct sun hours on each facade are done. The rotation of panels attached to mullions follow these angles for most efficient angle of illuminance.

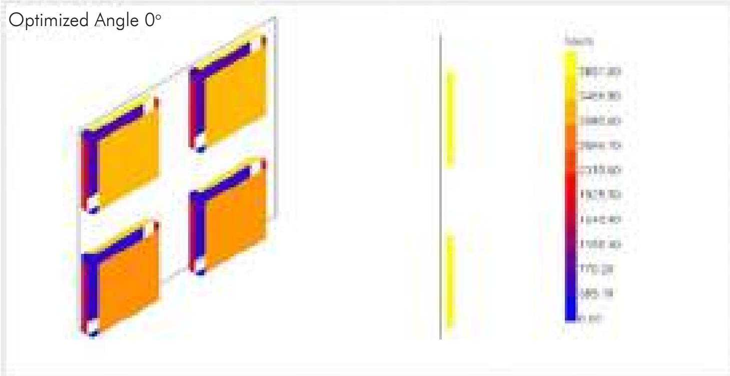
East Facade



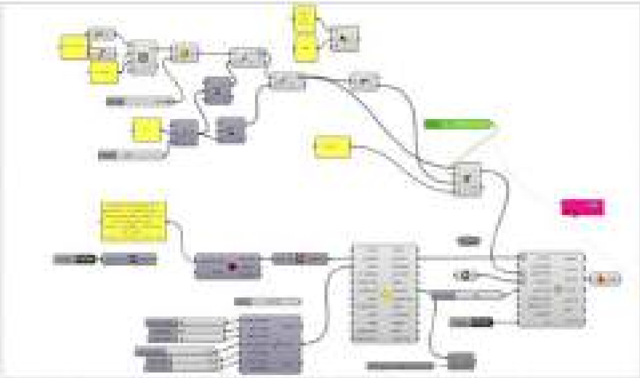


South Facade





West Facade



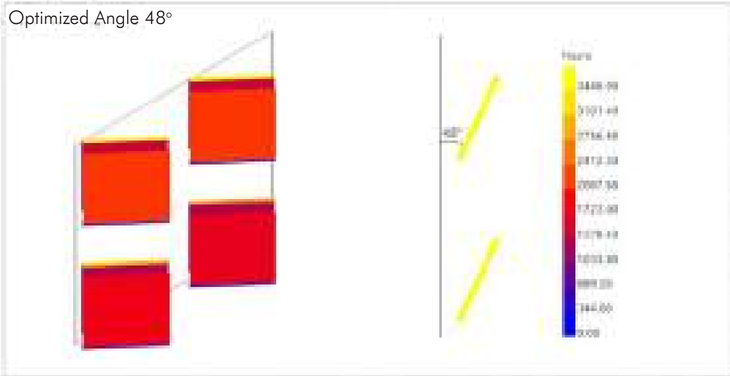


Figure 7.10 Edificio 16B Annual Optimization

Edificio 16B Proposal
Facade Rotating Sun Blocker

This application of the mycelium 3D printed armature panel can be used as sun-blocker for the facade. These panels can be attached to the slab through mullions which attach to the roller shutter control system. The panels are connected on to a cylinder mullion that can rotate through the rotation hinge and be adjusted to the sun angle.

Figure 7.11 Edificio 16B Proposed Facade

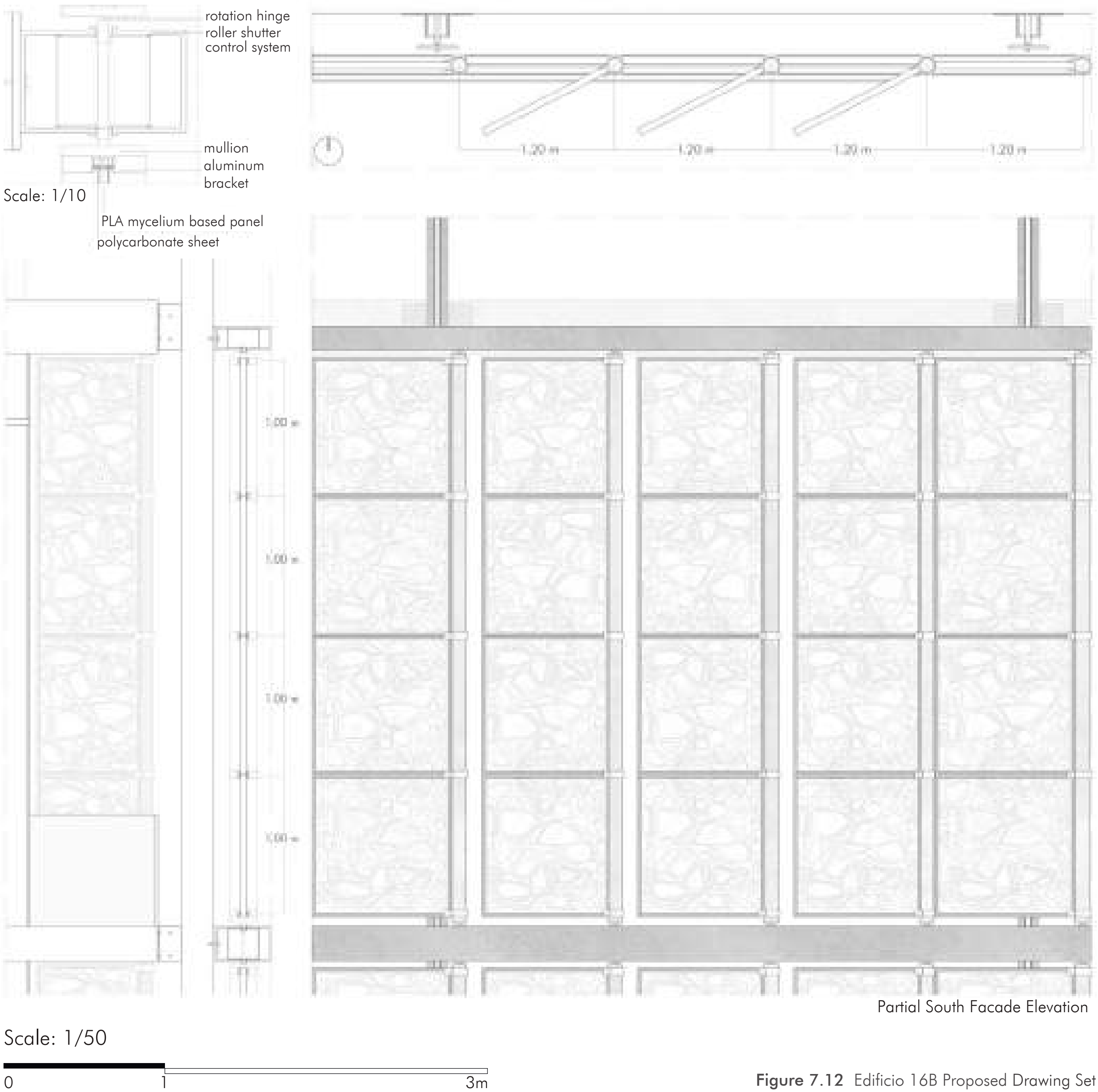


Figure 7.12 Edificio 16B Proposed Drawing Set

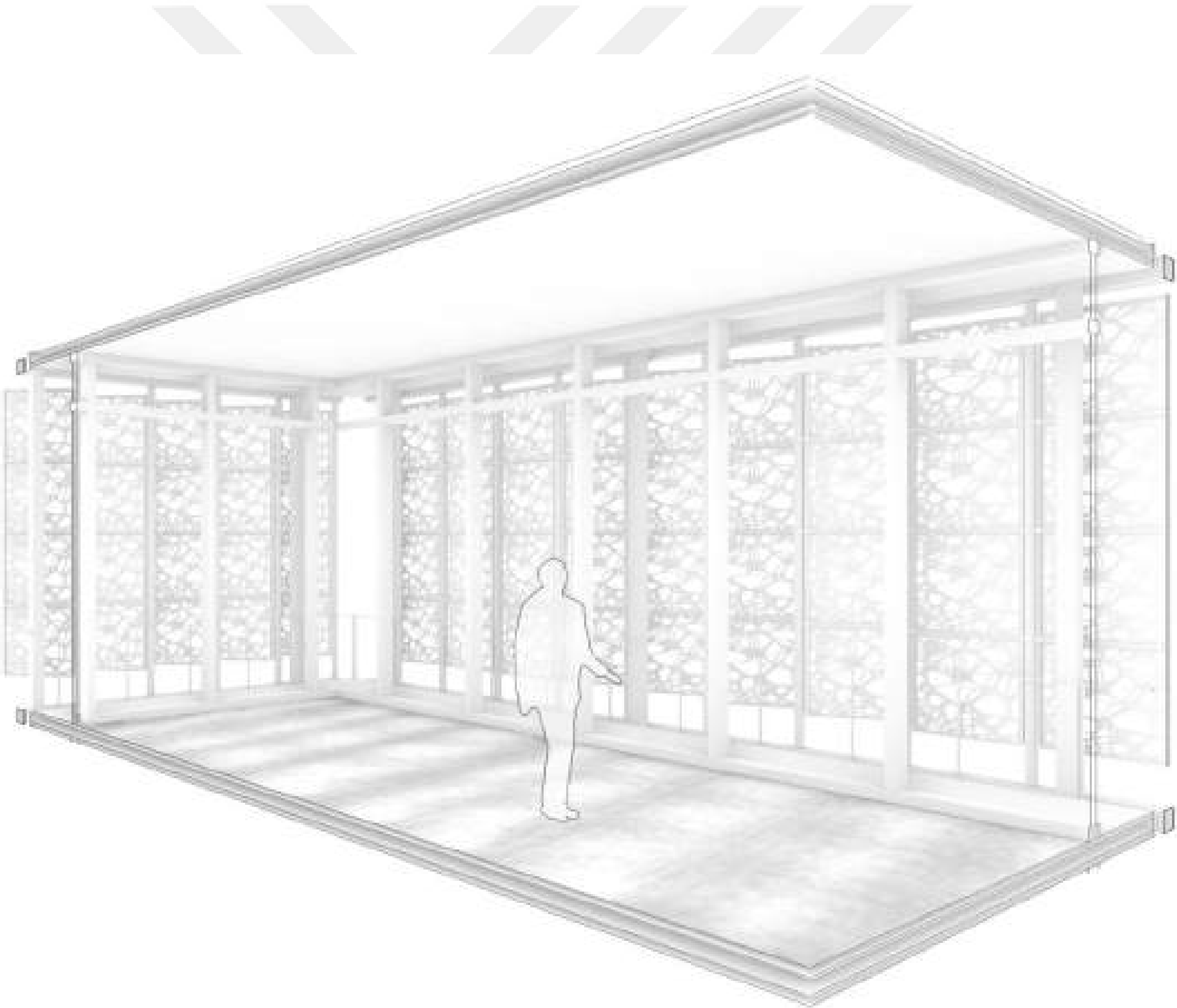


Figure 7.13 Edificio 16B Proposed Interior Drawing

Figure 7.14 Edificio 16B Proposed Facade Detail

7.2 Building Analysis Edificio 13

BUILDING ANALYSIS

❷ Edificio 13-Trifoglio

The building Edificio 13, Trifoglio is part of the transformation project of via Bonardi complex designed by designed by Renzo Piano and ODB & Partners, restoring and developing the original design of Gio Ponti. The building is formed of 3 floors designed to function as teaching classrooms, study areas and auditorium.

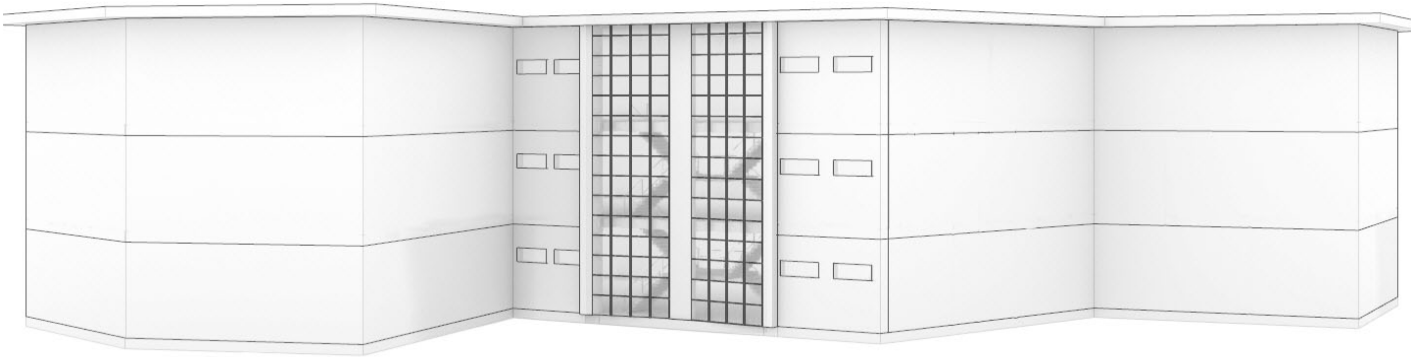


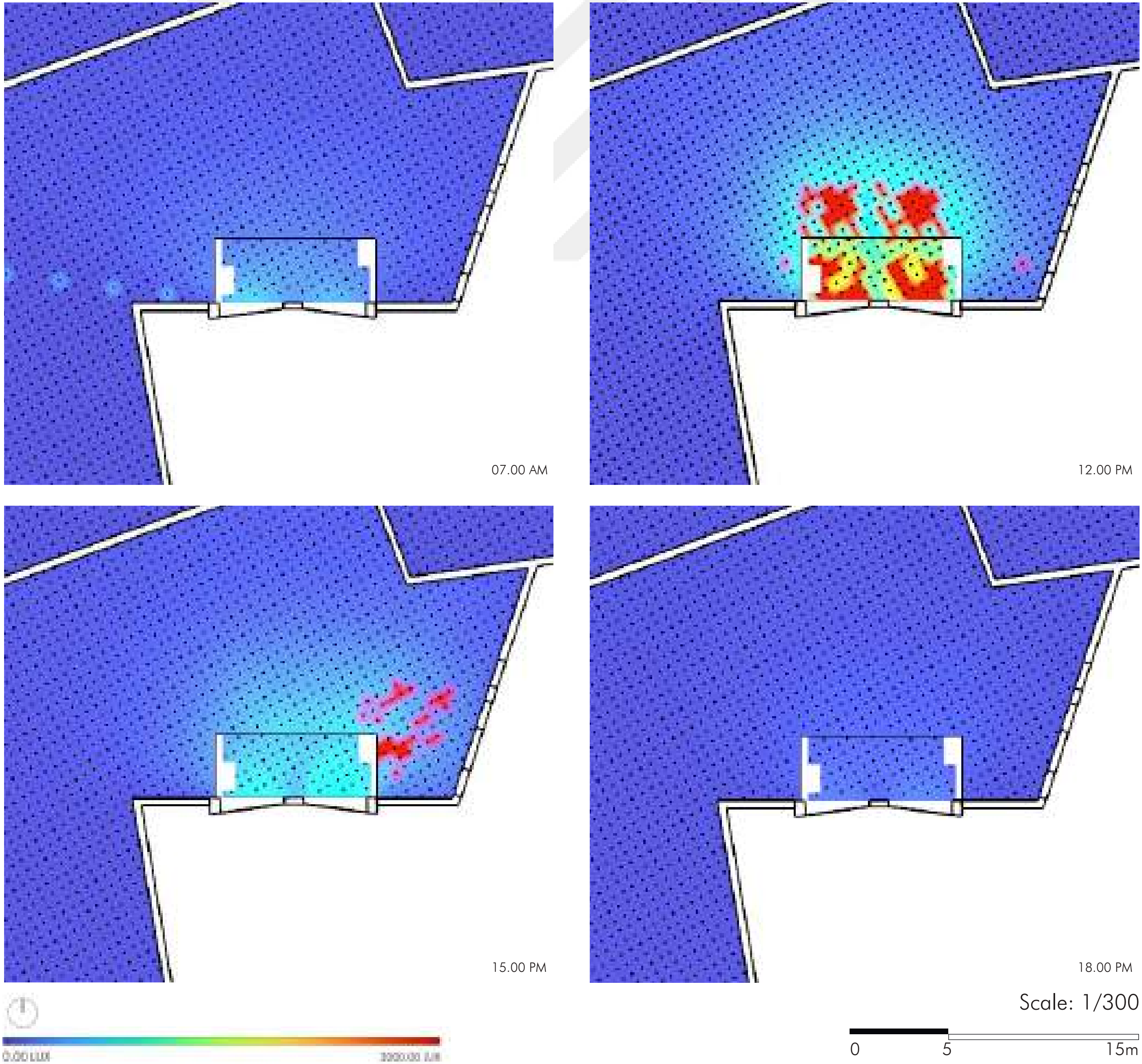
Figure 7.15 Edificio 13 View

Figure 7.16 Photograph Edificio 13-Trifoglio

Figure 7.17 Photograph Edificio 13-Trifoglio

Direct Sun Hours

Figure 7.18 Edificio 13
Plan Daylight Analysis



7.2.1 Edificio 13-Trifoglio Proposal

Curtain Wall system

Edificio 13 is part of the transformation project of via Bonardi complex. The building formed of 3 floors designed to function as study-areas and auditorium. The Light Illuminance analysis displays that the staircase gap receives excessive daylight through the day.

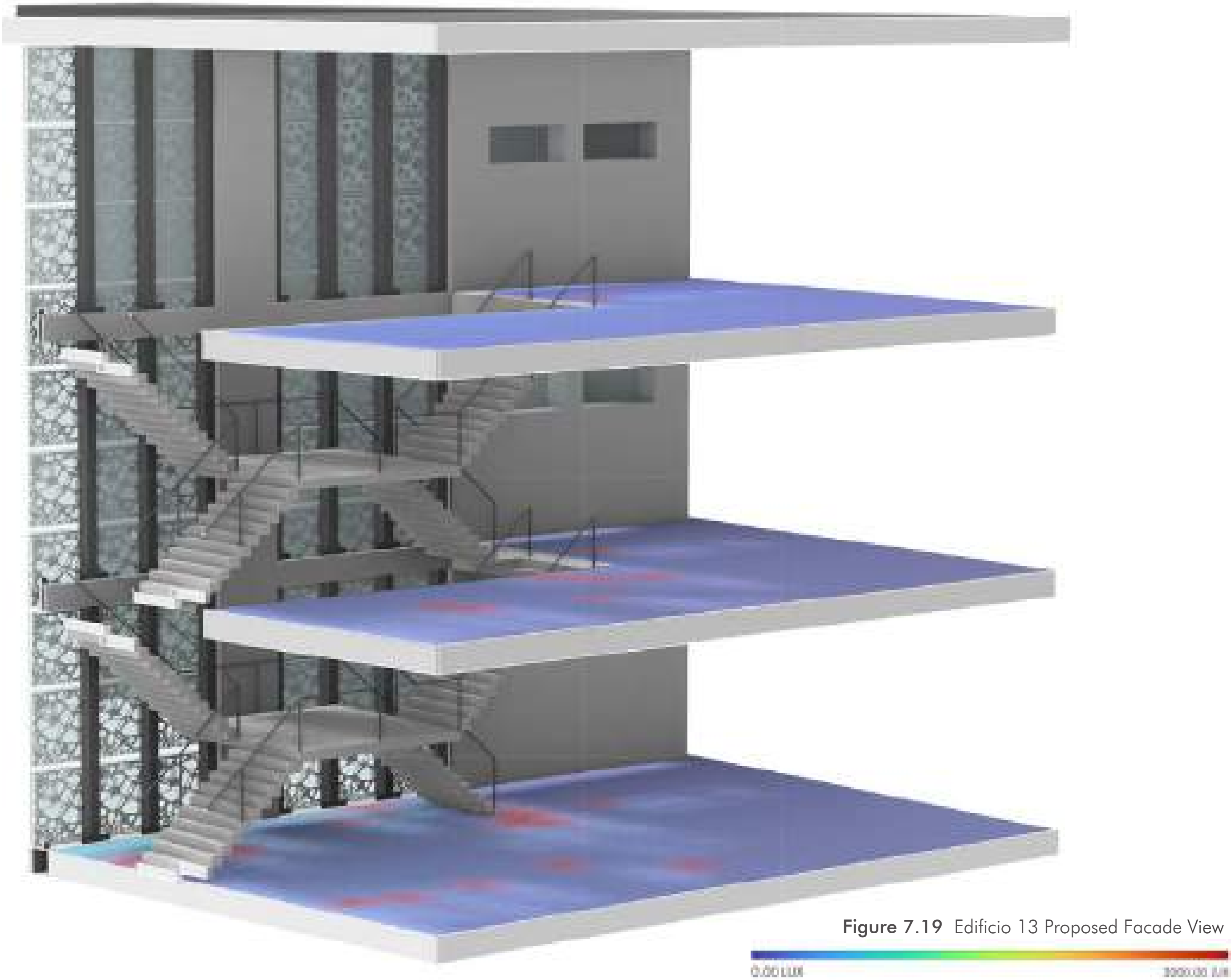
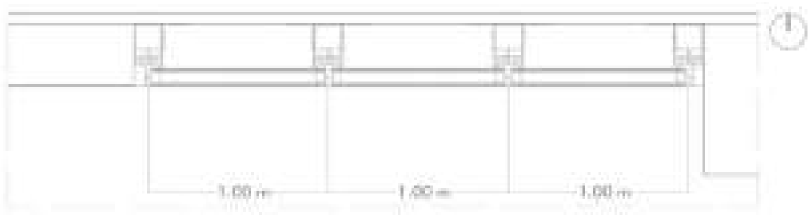
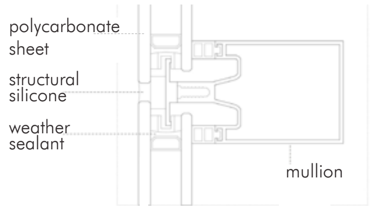


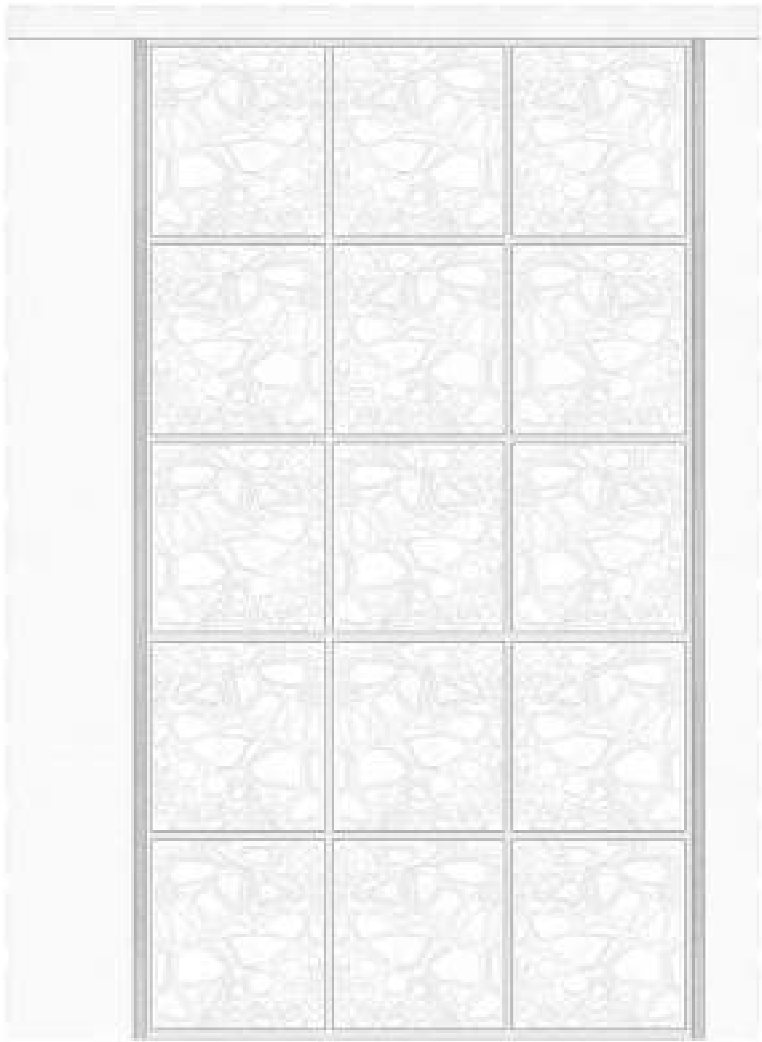
Figure 7.19 Edificio 13 Proposed Facade View

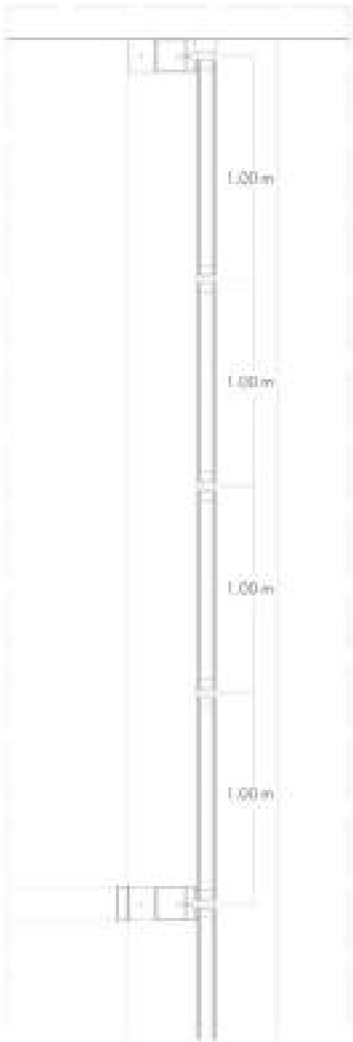
Therefore, the application of "Bio-skin: Mycelium based facade panel system" is proposed for facade of Trifoglio, staircase. To select application typology the design of floor plan, function and facade elements are put in consideration to readapt the existing. To adapt the existing structure and provide for light illumination to the interior, curtain wall system with integrated mycelium infill panel is selected.





Scale: 1/10





Partial South Facade Elevation

Scale: 1/50

0 1 3m

Figure 7.20 Edificio 13 Proposed Drawing Set

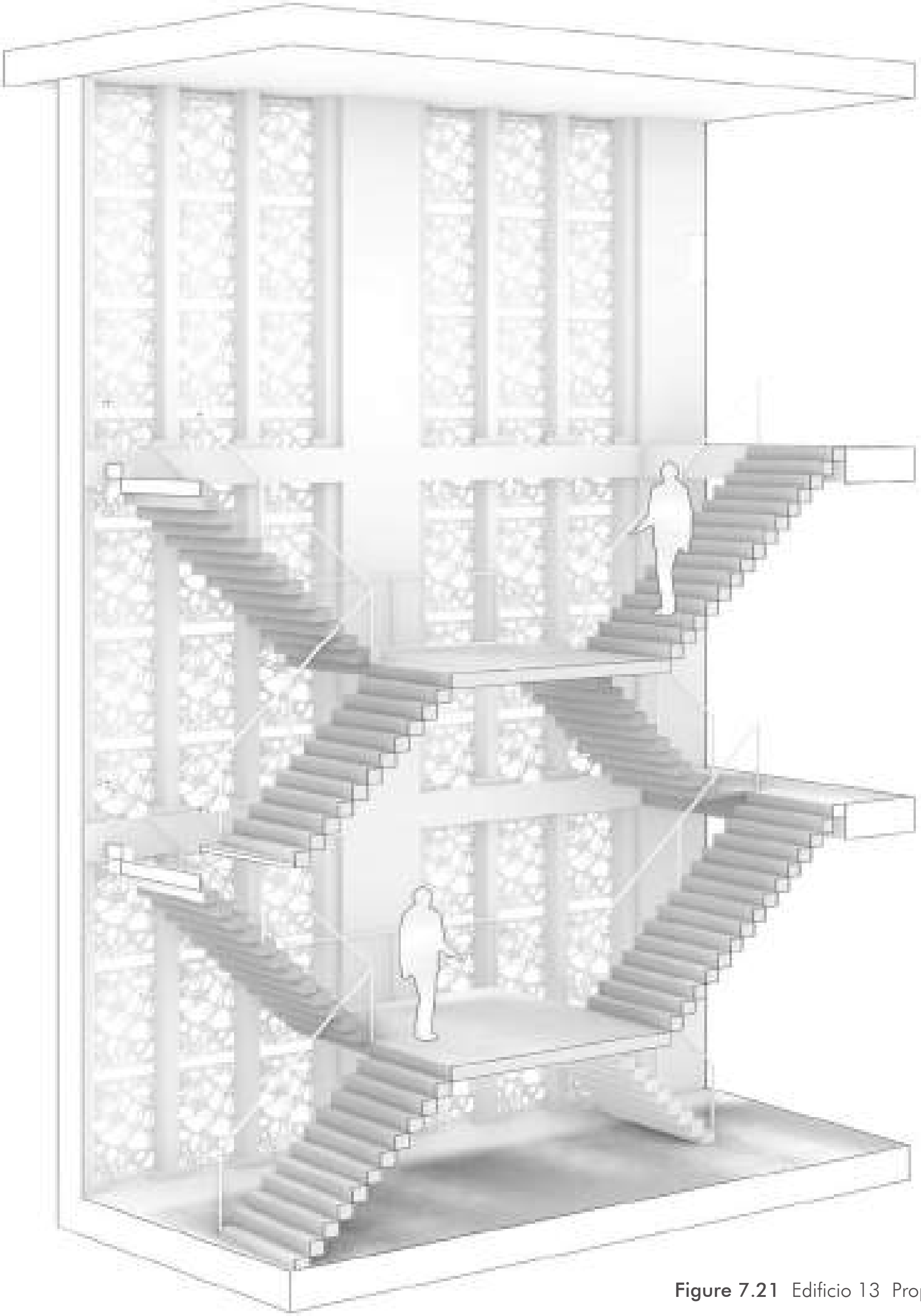


Figure 7.21 Edificio 13 Proposed Interior Drawing

7.3 Building Analysis Edificio 13

SITE ANALYSIS

❸ Urban Furniture

The 3rd application proposal is for the urban furniture that is a part of the transformation project of via Bonardi complex designed by Renzo Piano and ODB&Partners developing the original design idea of Renzo Piano. The concrete benches designed for the landscape of the complex receive excessive daylight throughout the day. Therefore, to provide shading, the application of a free-standing sun- blocker structure with mycelium-based infill panel is selected. This system can be dismantled and constructed according to the principles of design for disassembly providing a flexible design.

Direct Sun Hours

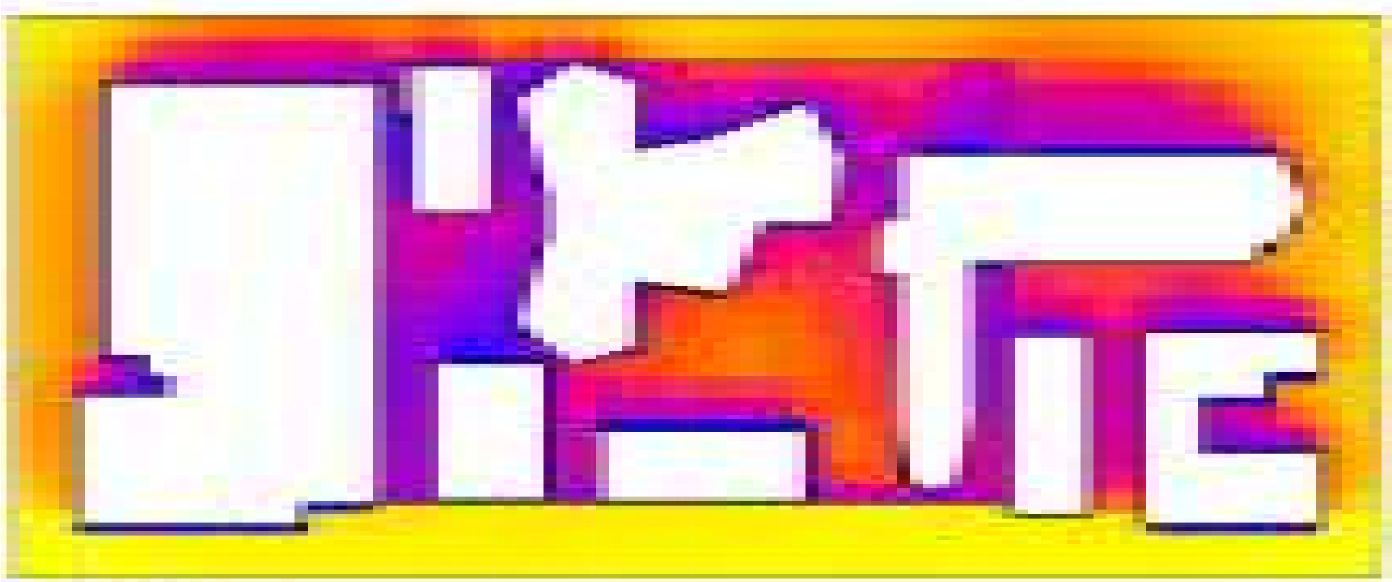
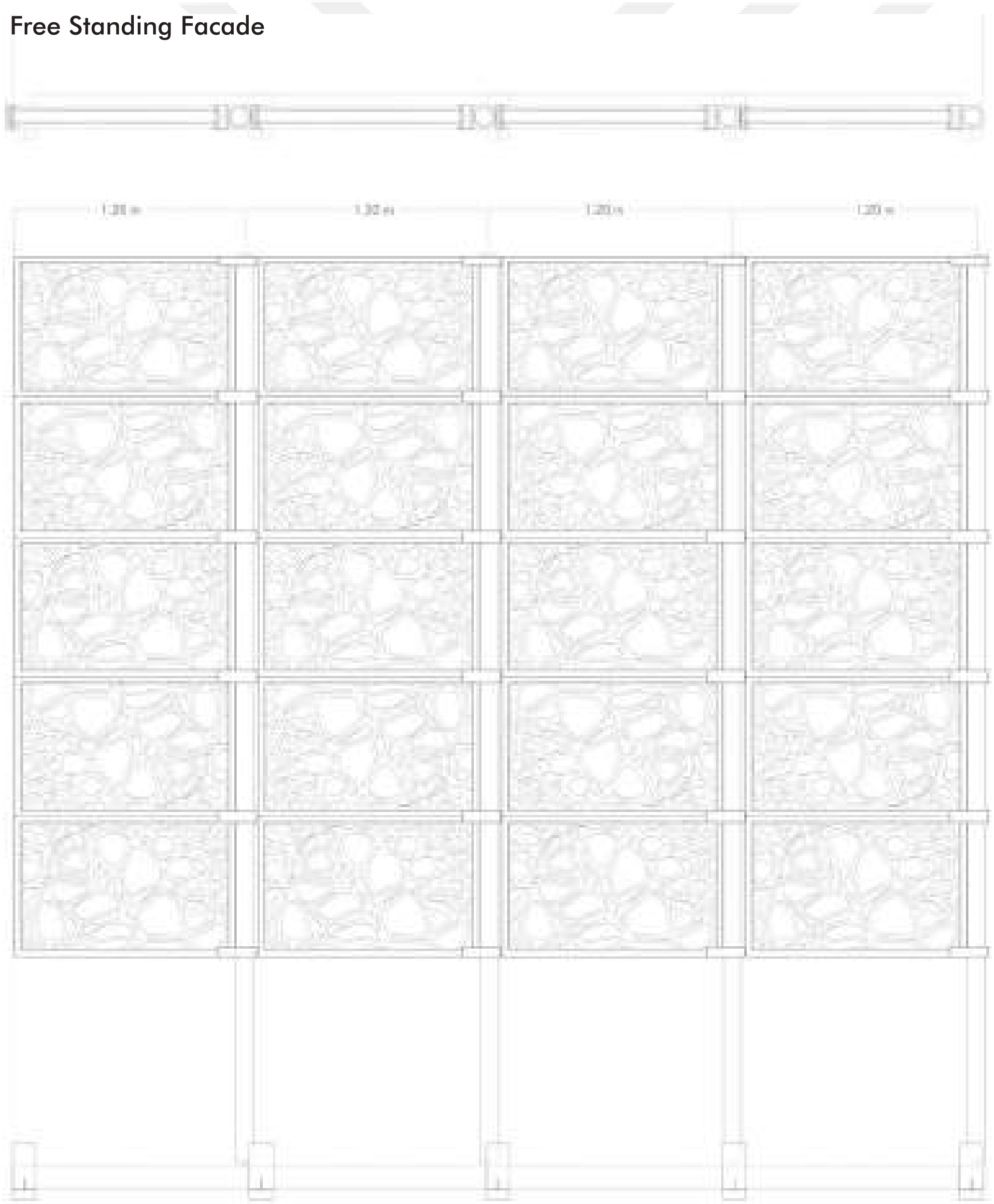
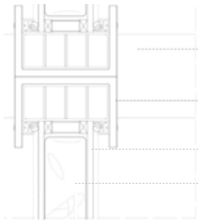


Figure 7.22 Site Plan Daylight Analysis

7.3.1 Urban Furniture Proposal

Free Standing Facade





Scale: 1/10

Scale: 1/50

0 1 3m

Figure 7.23 Proposed Free Standing Facade Drawing Set

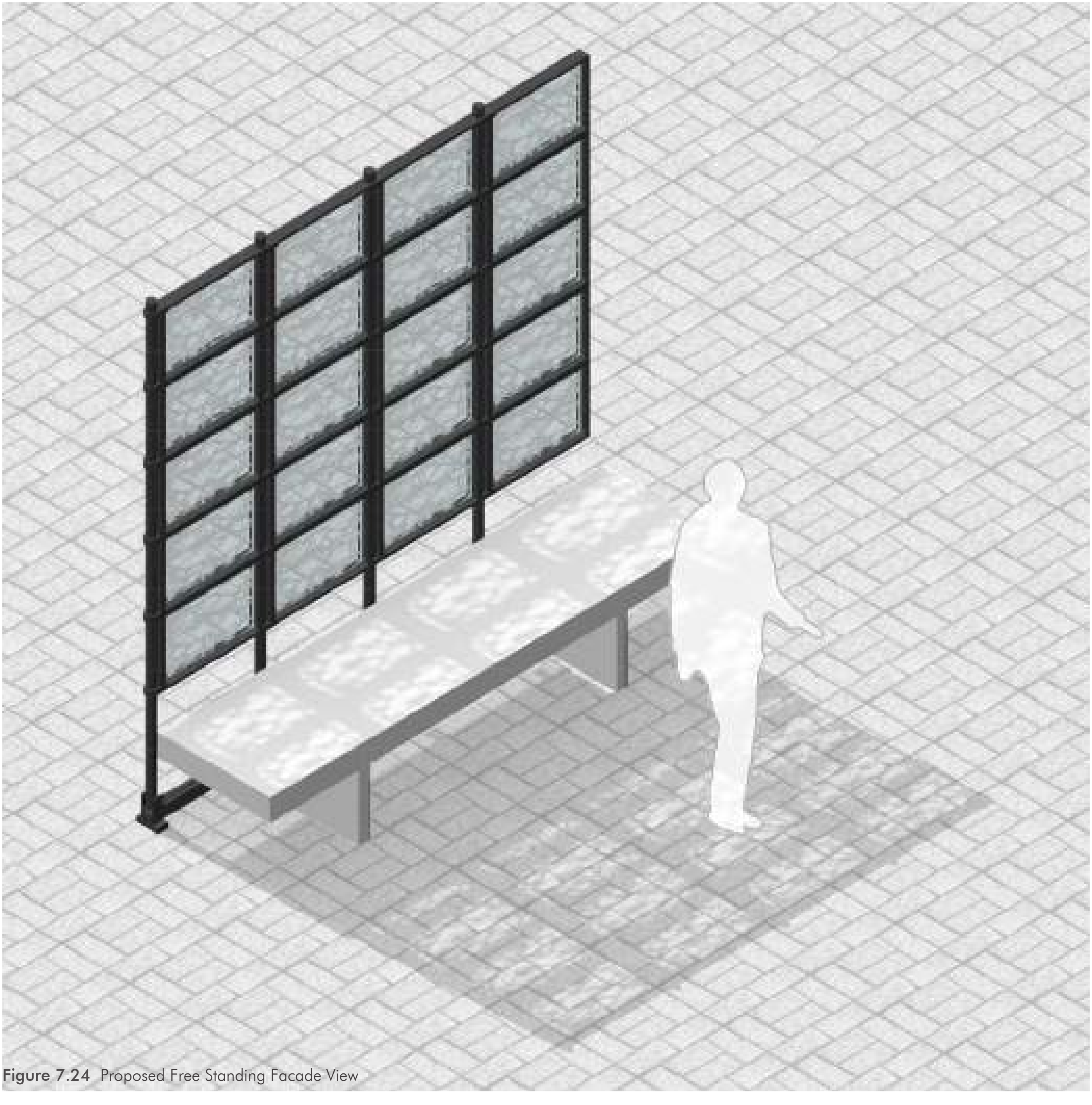
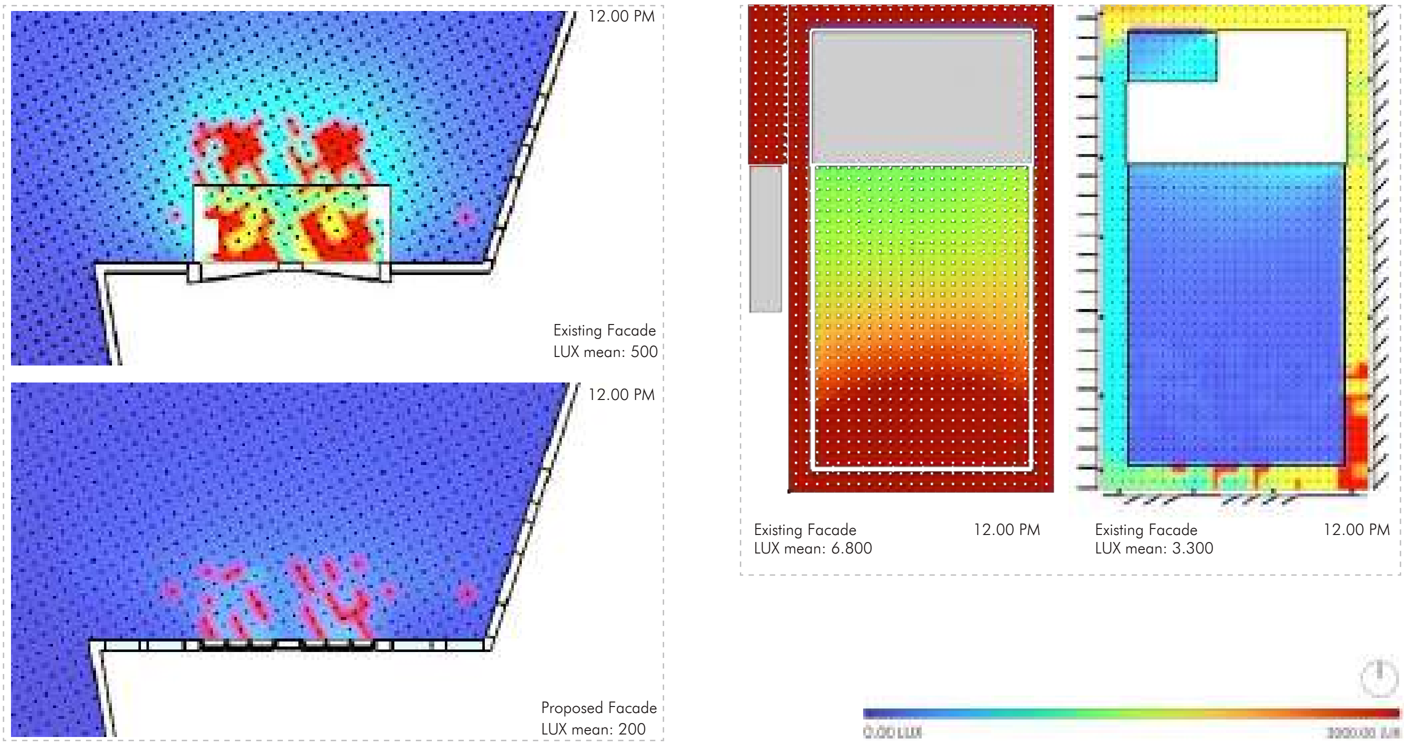


Figure 7.24 Proposed Free Standing Facade View

7.4 Case Study Proposal Outcome

As an outcome of the application of "Bio-skin: Mycelium based facade panel system" to the proposed location, Polictecnico di Milano campus in Via Bonardi, buildings Edificio 16B and Edificio 13-Trifoglio; the climate studio and ladybug light illumination analysis are compared with the existing façade LUX values. The LUX analysis values set on September 12:00 pm, and scheme display that the use of mycelium-based infill panels decreases the floor plan LUX mean value of Edificio 16B from 6.800 to 3.000 and the LUX mean value of the study area of Edificio 13-Trifoglio from 500 to 200. These results state that the different applications of mycelium-based facade panel systems offer both shading and light illuminance. As the design can be adapted for a specific site as the construction gives flexibility to be used in various angles, width and height and different levels of porosity of mycelium-based infill. By optimization of shadow studies or estimate glare potential from direct sunlight according to the geometry, context, and environmental factors the design can be modified.

Figure 7.25 Daylight Analysis Comparison



7.5 Material Life Cycle and Circular Economy System

The design of mycelium-based facade panel systems based on the materials management, manufacturing, consumption, and end of life cycles. It is designed to decrease the negative impact of construction industry on the environment through circular economy. Therefore, guidelines of "butterfly" diagram by the Ellen MacArthur Foundation is followed. The material flow is separated into two cycles as the; biological where materials are renewable and plant-based which then restored back, technical where products are re-used by remanufacturing to avoid waste production. As stated, before in the end of life, the Bio-skin can be dismantled into layers where; the steel components as mullion, frame, bolt and glazing components polycarbonate sheets can be remanufactured, while the mycelium-based armature can dissolve into nature.

3D printed PLA Armature-Mycelium: PLA is a 100% bioplastic: biodegradable and compostable product having three times lower carbon emissions in manufacturing process compared to other plastics. It belongs to the biological cycle as in the end of life the material is composted. As so mycelium being an organic material can directly regenerate into the biosphere within the armature that it binds to.

Polycarbonate Sheets: The polycarbonate sheets can be recycled or reused by improving the energy efficiency and lowering the carbon emissions in manufacturing and transportation stages with its lightweight. It belongs to the technical cycle as in the end of life it can be reused or remanufactured.

Aluminum Components: Aluminum, compared to other metal components requires less energy and time to recycle. It belongs to the technical cycle as in the end of life it can be reused or remanufactured.

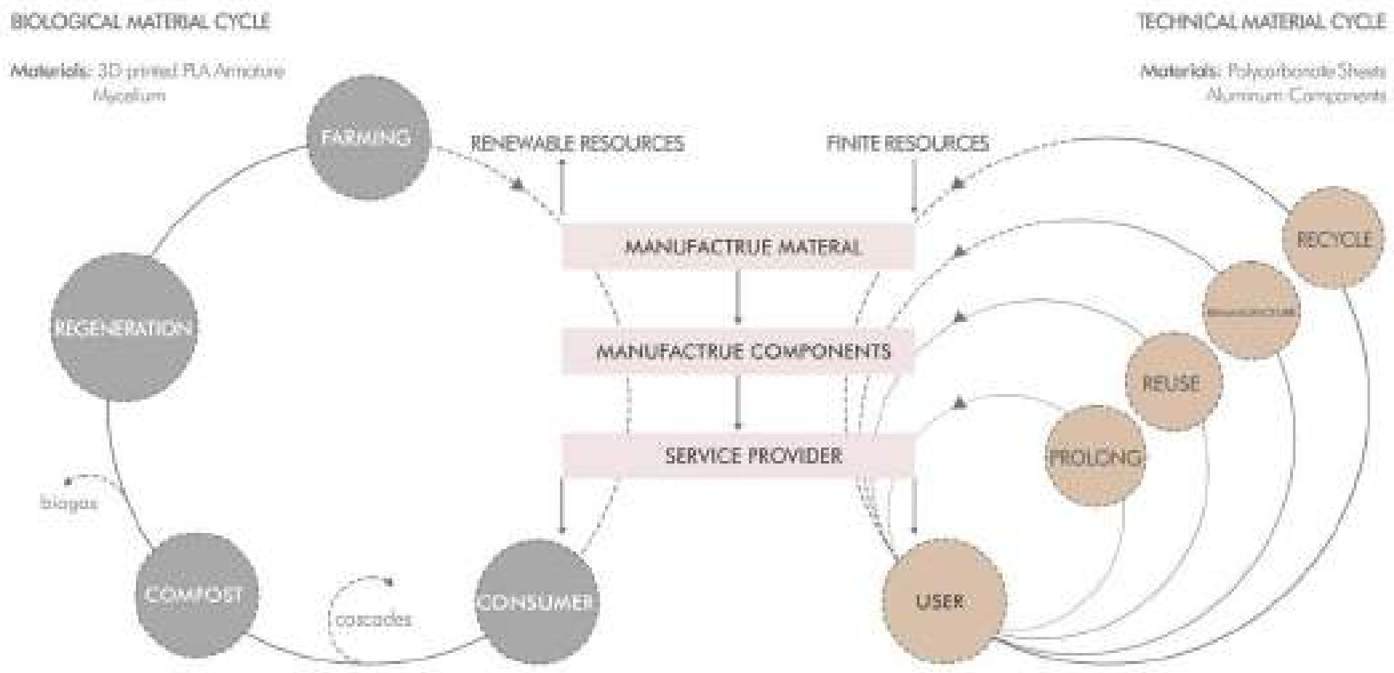


Figure 7.26 Circular economy systems and Material Life Cycle Diagram

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