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A REVIEW OF MYCELIUM-BASED BIO-COMPOSITES AND THEIR POSSIBLE APPLICATION IN ARCHITECTURE

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ABSTRACT

Construction industry is one of the largest consumers of natural resources, and so faces enormous difficulties in reducing the environmental impact of existing consumption habits. Growing industry demand for biodegradable or alternative materials and products derived from renewable resources, has recently prompted researchers from diverse fields to work in this area. They are working to find sustainable alternatives and develop natural bio-composites to replace various petroleum-based products in the interest of the environment. One such bio-composite derived from mycelium can provide a renewable and biodegradable alternative to conventional building materials. Mycelium, the fibrous root system of fungi, grows on organic substrates under controlled environmental conditions to produce these biomaterials. This article provides a comprehensive analysis of the current research and applications of mycelium-based materials in the field of architecture.

Keywords: Mycelium, Building Materials, Sustainable Architecture, Biodegradable Material, Bio-Composite

1. INTRODUCTION

According to a study conducted by Ghazvinian et al. (505-513), the United Nations has projected that by the year 2050, almost 68% of the global population will reside in urban areas. This significant urbanisation trend is expected to result in a surge in the need for housing. The construction industry, including the building sector, accounts for 38% of all energy-related CO2 emissions Almpani-Lekka et al. (2022). This growth in population and urbanization has led to a need for sustainable, sustainable, and eco-friendly solutions in the construction industry. The focus is now on developing, designing, and using eco-friendly building materials that use low-impact components throughout their life cycle Almpani-Lekka et al. (2022). Bio-design research offers potential solutions to environmental challenges caused by the fast-growing population and discard culture. Bio-design methods involve biology-inspired approaches to design and production, with live organisms playing a significant role Ghazvinian et al. (2019). Current developments in technology, biology, and digital computation capacities have led to the creation of alternative materials and fabrication procedures Attias et al. (2017). Mycelium-based composites are renewable and biodegradable materials that can be used in various design and production processes, including architectural applications Ghazvinian et al. (2019). These materials self-grow, fix themselves, clean up waste, adapt to the environment, have low production and operating costs, and can be returned to nature when no longer needed Adamatzky et al. (2019). Mycelium serves as an organic self-assembling glue when growing into a substrate, creating a dense composite made of biopolymers like cellulose and chitin Sydor et al. (2021)

1.1. MYCELIUM BASED MATERIALS

Mycelium is the living part of a fungus. It is made up of a number of thread-like hyphae that branch out. Most of the time, it is found underground or in other things like wood, soil, or dead organic matter. Mycelium plays a crucial role in the ecosystem as it decomposes dead organic matter, releasing nutrients back into the soil, which supports the growth of other plants and organisms Ghazvinian et al. (2019).

Mycelium-based materials have several advantages over traditional materials such as plastics or wood. They are biodegradable, renewable, and can be produced using low-energy and low-emission methods. Mycelium-based materials can also be moulded into various shapes, making them versatile for different applications. One popular use of mycelium-based materials is in packaging. Mycelium can be grown into various shapes and sizes to create packaging that is both biodegradable and compostable. Mycelium-based materials can also be used in construction, textiles, and even as a leather alternative. Mycelium-based materials are classified into two types: Pure mycelium is the result of complete substrate degradation. Mycelium-based bio-composites, on the other hand, are the result of mycelium hibernating or being killed during its growth process. Fungal growth can be stopped during substrate colonisation by drying or heating the material. Drying the mycelium causes it to hibernate, which means the fungus is ready to resume growth when environmental conditions allow it, whereas heating permanently stops the fungi's growth Ghazvinian et al. (2019). Overall, mycelium-based materials are a promising alternative to traditional materials that have negative environmental impacts.

1.2. FABRICATION METHODS USED IN MYCELIUM-BASED COMPOSITES

Growing mycelium in a mould with a predetermined geometry is the most basic way for producing mycelium-based materials. Additive and subtractive manufacturing are the two main ways that mycelium-based materials are made. Subtractive processes can be used on both living and dead mycelium. Additive manufacturing, on the other hand, is used to make low-density products or large building parts that are already in place. The following are some of the common fabrication methods used in mycelium-based composites:

Figure 1

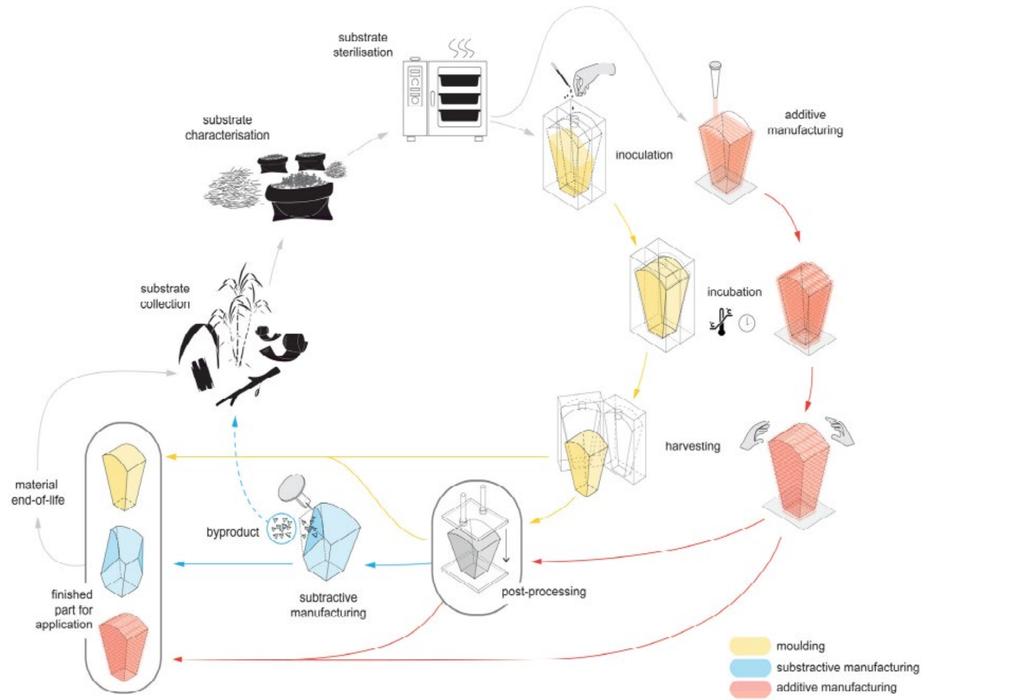

Figure 1 "Types of Manufacturing"
Source Bitting et al. (2022)

Recent advancements in the field of mycelium-based renewable composites have demonstrated the potential to convert industrial waste streams into valuable resources, hence facilitating the production of materials that are both more sustainable and conducive to circularity Figure 1.

Figure 2

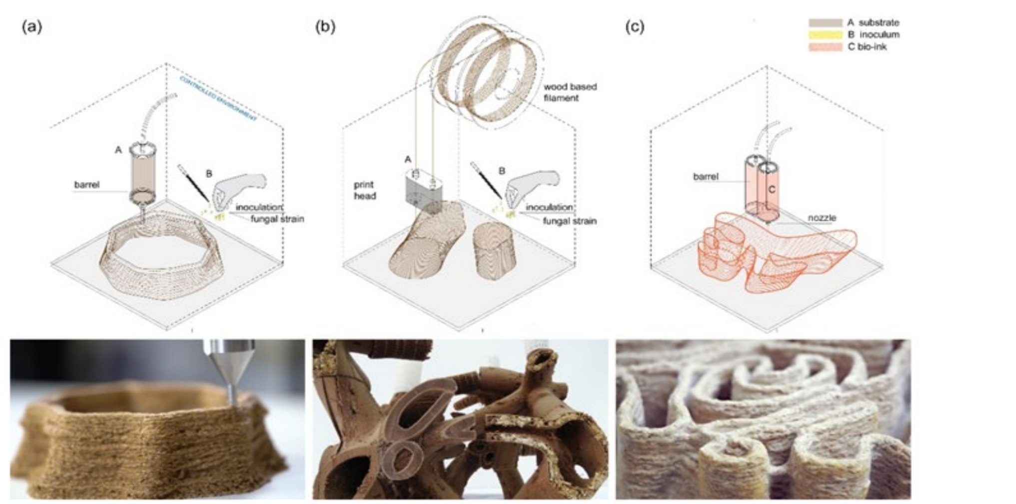

Figure 2 "Additive Manufacturing Methods"
Source Bitting et al. (2022)

The mold method involves three steps: inoculation, incubation, and moving the mycelium material out of a controlled environment. Custom molds can be made and sealed to prevent fungi growth Bitting et al. (2022). A subtractive process uses pre-made mycelium-bound composites, which can be machined, wire-cut, or other processes. Additive manufacturing (AM) has gained popularity due to rapid prototyping and the ability to create geometrically complicated items at no additional cost. The primary use of this technique is within the fields of tissue engineering and regenerative medicine. Research areas encompass bio-inks, filament-based, and substrate core deposition, as depicted in Figure 2 Bitting et al. (2022).

2. SELECTION OF THE PRESENTED STUDIES

Researchers examined the frequency of mycelium-based biocomposites as primary building materials in architectural projects, revealing new ideas in fungal architecture. The study analyzed data from major architecture and engineering journals, peer-reviewed studies, and articles. The classification system categorized projects by location, mycelium type, size, fungus, base, support structure, and post-project outcomes. The objective of this study was to gain insight into the typical applications of mycelium-based construction materials in terms of their sizes.

2.1. USE OF MYCELIUM IN ARCHITECTURE

Mycelium hybrid materials are useful because they are found in nature, don't take much energy to make, and break down naturally. Compared to most building materials, mycelium composites can only handle a very small amount of stress. When architects and builders tried to build with mycelium on an architectural scale, they had to use strict structurally informed design methods Dessi-Olive (2019).

Table 1

Table 1 Reviewed Projects

Project	**Year**	**Location (Country)**	**Type**	**Structure**	**Size**	**Fungi**	**Crop residue**	**Post-treatment**	**Creators**
Inhabiting Ecologies	2022	Exterior (Denmark)	Panel	Wood	Information not available	Information not available	Kvadrat textiles, sawdust and coffee grounds	Information not available	Nikolaj Emil Svenningsen and Sean Lyon and designer Søs Christine Hejselbæk (“Chart Art”)
Me-co Space	2021	Exterior (Germany)	Panel	Wood, Steel	5.2 × 6.0 × 3.0 m.	Fomes fomentarius	Hemp	Heat treated, Weather resistant coating	MY-CO-X Collective ("My-co Space")
Monolito Micelio	2020	Exterior (United States)	Monolith	Wood, Steel	2.5 x 2.5 x 2.5 M	Ganoderma lucidum	Hemp	Naturally dried	Georgia Institute of Technology School of Architecture (Almpani-Lekka et al. 1–8)
Growing Pavilion	2020	Exterior (Netherland)	Panel	Wood	200×70 cm panel size	Ganoderma lingzhi	Hemp, Cattail, Mace	Heat treated, Weather	Company New E. Klarenbeek ("Pavilion

								resistant biocoating	Grown From")
Circular Garden	2019	Exterior (Italy)	Monolith	Information not available	4 M high, 60 arches, 1 km long approx.	Information not available	Information not available	Information not available	Carlo Ratti Associati ("The Circular Garden")
Shell Myceliun	2017	Exterior (India)	Panel	Wood, Steel	Information not available	Information not available	Coir pith	Naturally dried	Studio Beetles 3.3, Yassin Arredia Design ("Shell Mycelium: Exploring")
Mycotree	2017	Interior (Germany)	Block	Bamboo, Steel	Information not available	Pleurotus ostreatus	Sugar Cane, Cassava root	Heat treated	Sustainable Construction, KIT Karlsruhe, Block Research Group, ETH Zurich ("Structure Shows How")
Mycelium Mockup	2015	Exterior (Canada)	Block/ Monolith	Information not available	1.75 x 1.75 x one brick thk. Wall approx.	Pleurotus ostreatus	Sawdust	Information not available	AFJD Studio ("Mycelium Mock- up")
HY-FI	2014	Exterior (United States)	Brick	Wood, Steel	12 M tall	Ganoderma lucidum	Corn stalks	Heat treated	The Living Studio ("HyFi Reinvents")

Source Compiled from Almpani-Lekka et al. (2022) and various other sources.

2.2. INHABITING ECOLOGIES (2022)

Figure 3

Figure 3 "Inhabiting Ecologies"

Source https://shorturl.at/blO39

The temporary pavilion for the 10th annual Chart Art Fair in Copenhagen was designed by architects Nikolaj Emil Svenningsen and Sean Lyon, in collaboration with artist Christine Hejselbaek. The pavilion, referred to as "Mycelium Textile Pavilions," was constructed utilising organic Kvadrat fabrics and hardwood frames derived from Super-wood. Mycelium spores were sewn into the fabric, which grew and spread through the fabric. A biopolymer made from algae connected the cloths to the frames, creating an abstract structure inspired by Charlottenborg's neoclassical architecture Figure 3. The tent was a restaurant serving mushroom pizza, intended to be disassembled and repurposed at the end of the show. The pavilion was developed as part of Chart Art Fair's annual architectural competition, aiming to spark a conversation about the symbiotic link between architecture and nature ("Chart Art").

2.2.1. MYCO-SPACE (2021)

Figure 4

Figure 4 "Myco-Space"
Source https://www.v-meer.de/my-co-space

The convergence of fungal biology, builders, and artists has the potential to engender novel modalities for perceiving spatial dimensions and forms. The researchers from Technische Universität Berlin, Universitat der Künste Berlin, Hochschule Bochum, and Hochschule für Nachhaltige Entwicklung Eberswalde have together developed a fungal-based artwork that offers habitable spaces for individuals. The primary objective of the pavilion is to establish a structure that is both sustainable and cost-effective, with the added benefit of being able to be constructed off-site and subsequently assembled on-site. The outer surface of the structure consists of a total of 330 fungal composite panels that have been coated. These panels are affixed to a wooden foundation, serving the dual purpose of providing insulation against heat fluctuations and acting as soundproofing elements. The wood frames in the panel structure of "My-co Space" were reinforced by the utilisation of box joints and arc-shaped connectors.

2.2.2. MONOLITO MICELIO (2020)

Figure 5

Figure 5 "Monolito Micelio"

Source https://jdovaults.com/El-Monolito-Micelio

The Monolito Micelio vault is a self-supporting building made of a single piece of mycelium, using a computational design method to ensure functionality and imprecision in flexible formwork systems Almpani-Lekka et al. (2022). The building has a volume of 2.75 m3, containing around 800 kg of living mycelium Figure 5. It features a hard internal "lost-work" reinforcing skeleton and a hybrid removable formwork system, combining a highly regulated plywood exterior with a flexible geotextile interior Dessi-Olive (2022).

2.3.4 THE GROWING PAVILION (2020)

Figure 6

Figure 6 "Growing Pavilion"

Source https://shorturl.at/qCPQ3

The Growing Pavilion serves as a temporary venue for hosting events throughout the duration of Dutch Design Week. The structure consists of panels composed of mushroom mycelium, which are supported by a wooden frame. The outside walls were made of mushrooms, and the roots' mycelium provided support. They are covered with a bio-based material that the Maya people of Mexico came up with Figure 6. The pieces are attached to a wooden frame, but they can be taken off and used again if needed. The floors are made of cattail reed, and the chairs inside and outside are made of leftover materials from farming ("Pavilion Grown From"). It is a study of bio-based building that employs a variety of biomaterials and bio-manufacturing technologies. The pavilion served as an exhibition and performance area, with musical concerts given on a regular basis to illustrate the sound absorption performance of mycelial materials ("The Growing Pavilion").

2.2.3. CIRCULAR GARDEN (2019)

Figure 7

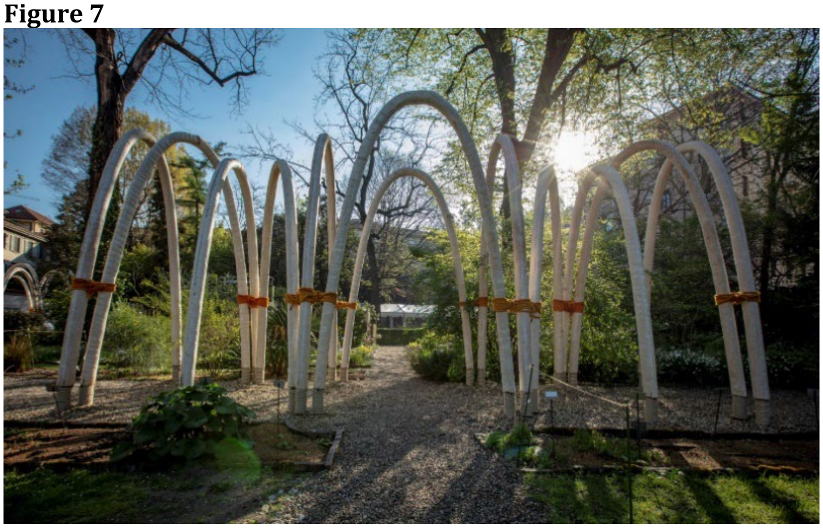

Figure 7 "The Circular Garden."
Source https://carloratti.com/project/the-circular-garden/

Carlo Ratti Associati collaborated with Eni, a multinational energy corporation, to construct an architectural edifice utilising mushrooms as a primary material. The exhibition was showcased at Milan Design Week in 2019. The experiment involves the examination of sustainable constructions that possess the ability to autonomously grow and ultimately return to the natural environment in a complete cycle manner (see Figure 7). The concept was exhibited at the Orto Botanico, often known as "The Circular Garden," located in Brera during Milan's Fuorisalone. The Orto Botanico features a distribution of 60 arches constructed from mycelium, each measuring 4 metres in height. Collectively, these arches constitute a distance of one kilometre of fungus ("Carlo Ratti Grows"). In a comparable vein, subsequent to the conclusion of Milan Design Week, the entirety of the mycelium material will be subjected to shredding and afterwards reintegrated into the soil in a manner that adheres to circular principles, as exemplified by the "Carlo Ratti Circular Garden" initiative. Many of the pavilions constructed for temporary exhibitions and fairs, such as Milan Design Week, generate a significant amount of waste. The Circular Garden project will employ a circular recycling process for its components. Specifically, mushrooms, ropes, and wood chips will be reintegrated into the soil, while small metal fragments will be repurposed for alternative applications ("The Circular Garden").

2.2.4. SHELL MYCELIUM (2017)

Figure 8

Figure 8 "Shell Mycelium"
Source https://shorturl.at/goGY3

The installation known as the 'shell mycelium' was collaboratively created by Asif Rahman, an architect based in Kochi and affiliated with beetles 3.3 (B3.3), Giombattista Areddia, an Italian architect, and Mohamad Yassin, a Lebanese architect associated with Yassin Areddi design. It was shown at the Dutch warehouse during the MAP project space festival as a Kochi muziris biennale collateral (YAD) ("Shell Mycelium: Exploring"). The thing that makes the material stand out is that it can blend in with the building it is added to. In the case of the Shell Mycelium gazebo ("Beetles 3.3"), the material was mixed with a triangulated wood frame. Modern architecture needs to be able to degrade, last for a long time, and be responsible for what it does. The degradation movement in building supports the biological, that is, the argument for a degradable necessity ("Shell Mycelium").

2.2.5. MYCOTREE (2017)

The collaborative efforts of the Sustainable Building Professorship at the Karlsruhe Institute of Technology (KIT), the Future Cities Laboratory (FCL) in Singapore, and the Block Research Group at the Swiss Federal Institute of Technology (ETH) Zürich culminated in the development of MycoTree, as reported in the article "Structure Shows How". The MycoTree structure consists of a scaffolding system that is covered in a mycelium-based composite material. The mycelium acts as a natural glue, binding together organic waste materials such as wood chips, straw, and other agricultural by products. As the mycelium grows, it binds these materials together, creating a strong and lightweight structure (Figure 9). The structure is a thought-provoking example of how we could stop taking building materials from the earth's crust and instead grow them in cities. It also shows how stability can be achieved through geometry instead of material strength, which makes it possible to use weaker materials structurally and safely Heisel et al. (2017).

Figure 9

Figure 9 "Myco Tree"

Source https://shorturl.at/cfDU7

2.2.6. MYCELIUM MOCKUP (2015)

Figure 10

Figure 10 "Mycelium Mockup"

Source https://shorturl.at/IKPX4

The display titled "Mycelium Mock-up" by AFJD Studio delves into the realm of architectural possibilities, specifically focusing on the utilisation of mycelium, the intricate network of fungal roots, in conjunction with cellulosic wood waste. This innovative approach aims to shed light on the potential future advancements in the field of architecture. This compostable bio-composite building material fuses together into a monolithic whole, with edible oyster mushrooms growing on the wall. The exhibition questions the tensions between sustainable ambitions and market forces in architecture. Sustainability requires smart architecture that is biodegradable and edible, planning its own disintegration into the materials ("Mycelium Mock-up"). The artwork challenges the relationship between building materials and rapid destruction, highlighting the need for biodegradable materials designed to break down over time (Dahmen, Joseph, and Amber Frid-Jimenez, 2001). Mycelium Mock-up envisions a future where soft living materials develop over time, adjusting to change and satisfying structural, aesthetic, and sensual needs Dahmen and Frid-Jimenez (2020).

2.2.7. HY-FI (2014)

Figure 11

Figure 11 "Hy-Fi"
Source https://shorturl.at/anpHR

Hy-Fi, a 40-feet-tall tower made of biodegradable mushroom bricks, was built in New York City in 2014. The tower was designed by The Living and Ecovative, a New York-based architecture firm, in collaboration with Ecovative ("HyFi Reinvents"). The tower was built for a summer concert event called "Warm Up" at MoMA PS1 in Queens, New York. Around 10,000 blocks were used in the construction, making it the largest construction project with mycelium composite materials to date (Figure 11). The tower's top was coated with a special coating, and the hempcrete bricks used reusable ground screws for the frame. Arup, the company responsible for the pavilion's structural study, found that the bricks could hold their weight at 13 meters and withstand winds of up to 65 mph Almpani-Lekka et al. (2022). Hy-Fi's unique feature is its natural air-conditioning system, creating a chimney effect that draws hot air out of the structure and brings in cooler air from below. The organic nature of the mushroom bricks also helps regulate humidity and temperature, creating a comfortable environment for visitors Tower of "Grown" Bio-Bricks by the Living Opens at MoMA PS1. (2014).

3. CONCLUSION

Fungi mycelium is increasingly being explored as a sustainable and innovative material in architecture. Mycelium, the vegetative part of the fungus, is capable of growing and forming complex networks that can be used to create a variety of structures and products. One of the main advantages of mycelium is its ability to grow and adapt to different shapes and sizes. This makes it a versatile material that can be used for a wide range of architectural applications, from insulation and structural support to decorative elements and furniture. In addition to its versatility, mycelium is also a highly sustainable material. It can be grown using agricultural waste or other organic matter, reducing the need for energy-intensive manufacturing processes and minimizing waste. Mycelium is also biodegradable and compostable, making it a more environmentally-friendly alternative to traditional building materials.

As research and development in mycelium-based materials continue to advance, we can expect to see more innovative applications of this material in architecture. Overall, the future of mycelium in architecture looks promising, as more architects and designers explore the potential of this sustainable and versatile material.

CONFLICT OF INTERESTS

None.

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