RESEARCH ARTICLE

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Frontiers in Advanced Materials Research

Harnessing Mycelium Bio-composite panels for Improved Acoustic and Flame-Retardant Properties for Architectural Applications: A Comprehensive Review

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Abstract: This article examines the development and characterization of mycelium-based composites derived from agricultural waste, with a focus on their acoustic and thermal insulation properties for architectural applications. The review evaluates composites created using various substrates—rice straw, corn husks, and sugarcane bagasse—bound together by *Pleurotus ostreatus* mycelium through a controlled growth and deactivation process. Testing revealed promising acoustic absorption coefficients (0.6-0.8) in the 500-2000 Hz frequency range, with corn husk-based composites demonstrating superior performance. Thermal conductivity values (0.038-0.044 W/mK) were comparable to commercial insulation products. Microstructural analysis showed that the unique integration of the three-dimensional mycelial network with natural fibres creates an optimal hierarchical porous structure for heat resistance and sound absorption. The research highlights how these sustainable bio-composites offer competitive performance to synthetic materials while supporting circular bioeconomy principles through waste utilization and biodegradability. Applications in building construction, acoustic panels, e-waste management, and water pollution remediation demonstrate the versatility and environmental benefits of these innovative materials.

Keywords: Mycelium, Circular Economy, Sustainable Product, Fungi Bio-composite, Building Materials, Lignocellulosic Substrate Techniques, UV-C processing

1. Introduction

The population of the world is surging at a truly staggering rate. The advancement of renewable technologies must take place before any of these needs will causes pollution, waste generation, environmental degradation, and depletion of natural resources. From 2007 to 2050, waste generation is expected to increase globally by 70 billion tonnes annually from 2.01bn tonnes in 2016 to 2.2bn tonnes in 2025 and 3.40bn tonnes in 2050 [1, 2]. In order to keep our world liveable, we must embrace sustainability by using (a) materials that are reusable (b) local materials to minimize our emissions from transportation (c) environmentally friendly materials (d) affordable materials and (d) enhancing the design of the materials! Sustainable materials are those that are both environmentally and economically sustainable and have less pollution and waste generated during the manufacturing, use, transportation, and demolition phases [3].The application of microbes in making biomaterials, especially in the construction and packaging industries is one technology that is on the immediate horizon to achieving environmental sustainability[4]. The concept of mycelium as a material first came about in 2007 by Gavin McIntyre and Eben Bayer, owners of Evocative company [5]. This business develops high-quality packaging material that is non-toxic and 100% recyclable [6] there are two main pathways in which to incorporate microbes into the construction industry [1]. Indirectly using of enzymes that are derived from bacteria to develop building materials and [2]. directly using microbes such a cell wall, mycelium, and spores directly[7]. These most common species are *Pleurotus ostreatus& Ganoderma lucidum* which Filum Basidiomycota [8 – 11]. Thus, the current species is favoured because of its superior quality of biomaterial since researchers are projecting most of their research towards these species.

Broadly speaking, acoustic panels are oversized, soft-furnished panels that can be strategically located across spaces that can improve sound quality by capturing echo or reflected sound. They can be made from a variety of materials, including wood wool, PET Eco Felt, foam and fabric, biophilic materials like moss and cork. An acoustic panel is generally a type of sound-absorbing panel, which aims to decrease reverberation and sound levels in a room. Sound absorbing materials are frequently used for noise control in industry. The two most popular classes of materials are foams and fibres. This member is “sound-absorbed” because the sound energy is converted to heat in the material and the sound pressure is decreased.

This research ventured into a new method of using sound absorption panels with these new, innovative composition materials. In 2013, a US-based firm was interested in mycelium based materials and began investigating and developing them, such as acoustic panels. In the last few years, mycelium sound-proofing panels have been explored and developed. The investigation revealed that there were acoustic model tiles, acoustic ceiling, and architectural preparatory. Mycelium panels were shown to have low thermal conductivity and high sound absorption insulation, making them a possible candidate for thermal insulation. The ultimate characteristics of the materials produced are determined by growth parameters - the type of substrate being used by the mushroom species, the growth environment (temperature, humidity and carbon dioxide concentration), and the forming and processing methods [12]. Mycelium architecture is based on renewable resources, such as sawdust, sorghum stalk, flax shive, hemp and paddy straw. These are low-cost by-products of agriculture. Mycelium is the material that filamentous fungus used for vegetative growth, and they bind organic matter by a natural biological process consisting of a network of hyphae microfilaments [13]. The lignocellulosic materials in mycelium composites (or myco-materials), are held together by a fungal biopolymer. Mycelium panels can either be disposed of biologically or recycled, it is considered a composite. There is no waste in biologically based products, specifically, the material is processed and recycled back into agriculture. Relative to other traditional synthetic composites, mycelium-bound composites have many advantages, including lower cost, density and energy inputs. Moreover, they have shown a lower carbon footprint and consequence than composites that claim to be sustainable, such as bioplastics and wood-based composites [14] .We have highlighted some uses for environmental building products, with the potential for them to become alternative sustainable building materials to replace traditional ones, among them, conventional plastic films and sheets, panels, furniture, decking and synthetic boards, foams and plastics. The materials made from mycelium are completely natural and compostable, and can assist in the transition to a circular bioeconomy where waste is produced as by-products rather than waste itself, and the material's value continues throughout the economy. It should be stated that particle size counts too as finer grinds limit the amount of oxygen for the mycelium, making that board denser, and that limits the ability to penetrate core of the board with mycelium fibres as well. Since porousness, tortuosity, flow resistance, and characteristic length are known to influence the acoustic properties, the grind of the material can be expected to generally affect that as well [15, 16].

2. State Of Arts

The living partners are the co-creators of art. The wind, stone, grass, plant, and sun are all examples of wild partners that have the ability to create art, or to inspire creativity, and become collaborators in the creation of art. Several companies have started to develop and sell mycelium bonded composites all over the world including Myco-Works, MOGU[17], Thermal insulation (Mushroom tiny House, 2023) [18] Mycelium based products such as synthetic leather [19], kitchen utensils [20], packaging materials [21], a varying range of furniture, wall and ceiling panels [22], bio-cement [23-25], blocks and [26,10,11,27], and a range of other

The strains of the fungus are mainly pleurotus ostreatus and Ganoderma lucidum which are then bound to the various agro wastes to end up with a bio-composite which is the final product. Depending on the type of bio composite, each product will have different characteristics, such as density, life-span, conductivity, moisture resistance, structural performance, and aesthetic quality.

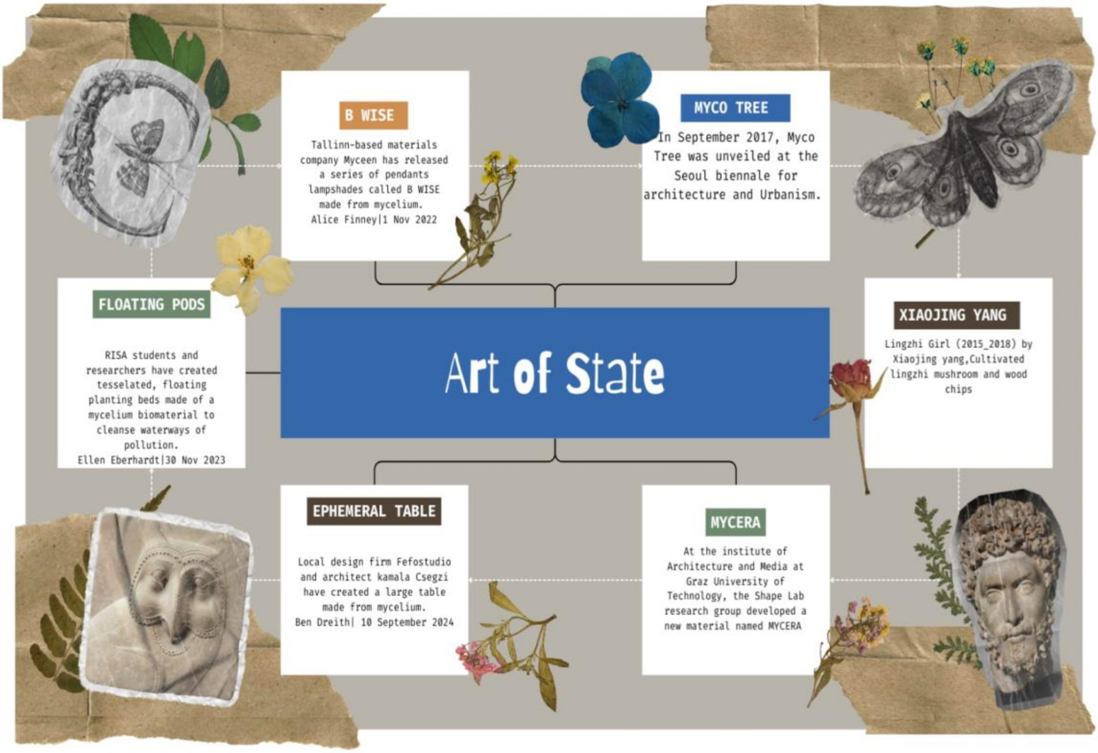

Figure. 1 Art of the State

2.1 Hyphal Architecture

Minimal is known about the proliferation of fungal hyphae. One reason for this is that the molecular architectures of hyphal walls have not garnered sufficient attention. Recently, studies in chemistry have begun to disclose how complex the molecular components of the hyphal wall [28] . The chemical composition of nutrients also determines the mycelial density in hyphal networks. Increases in the carbon content can affect the rate of hyphal extension, as well as increased branching type [29]. Thus, uptake of oxygen is increased [30]. An increase in nitrogen and sulphur amounts results in more branches per millimetre of hypha Mycelial density is also stochastic with respect to biological traits; the basidiomycota [31] in particular there are three types of basidiomycota hyphae; generative, binding, and skeletal. To date, only these types of hyphae have been identified [32, 33] however, many of these fulfil a similar role or are intermediates between the three main types noted above. They are defined as; arboriform, gloeoplerous, sacro-, and skeleto-ligative hyphae [34]. Branching is a feature of septate hyphae controlled by cytoplasmic vesicles; the formation of lateral branches is due to a vesicle being built up behind the septa [34]. When the distal hyphal regions of vesicles are transported to the tip of the hypha during growth and merged with existing walls and membranes, it can promote hyphal extension [36, 29].

Table.1 Basidiomycota's hyphal kinds; Compiled from literature: [34,35]

Parameter	Generative	Binding	Skeletal
Wall-Thickness	Thin Wall	Thick	Thick
Internal Structure	Hollow	Often solid	Often Solid
Growth	Plate form of growth for more hyphae	Restricted development and Inter-weaving with other hyphae	Disperse laterally
Septa	Yes	No	No
Origin	Always present	Generative Hyphae	Generative Hyphae
Branching	They are Branched	Branched Strongly	Unbranched

Mycelial density is also influenced by intrinsic biological characteristics; for example, on the basis of distinct hyphal networks, the fungi of phylum Basidiomycota can be grouped into mono-, di-, and tri-mitic forms [32]. The term mitic is used to classify species by the number of distinct hyphal types that are present in a species. In mono-mitic species, only generative hyphae are present; in dimictic species each species has two hyphal types that are typically generative and skeletal hyphae; and in trimitic species the three major hyphal types. [34]. the ability of fungi to generate polarized cell types of a variety of forms further illustrates their remarkable temporal and spatial control over establishing polarity axes.

The development of hyphae involves the establishment and maintenance of one or more stable axis of polarization during the germination of the spore and the extension of the tip [37].

2.2 Technique in Contemporary Bio Technology to Enhance Mycelial Characteristics

Mycelium-based material design and development has recently explored, tested, and/or utilized a number of biotechnological technologies, like industrial fermentation, strain improvement, recombinant DNA technology, gene editing, and gene silencing. For example, if two or more fungal species inside either the Ascomycota or Basidiomycota groups are cultivated to grow mycelium in high volumes for material applications, there are no restrictions on the fermentation process or intended applications [38]. The strains that used for the biotechnological applications described here have previously and will continue to be able to be genetically modified [39]

2.3 Genetic Alterations of Fungi to Enhance Mycelial Characteristic

The implications of using living systems for various uses in environmental technology, food, agriculture, and medicine has shifted due to the biological alteration of living organisms [40,41]. Targeted biological alteration has improved recently with genetic editing technologies such as CRISPR-Cas9 [42]. CRISPR-Cas9 has many applications and is seen as a versatile and powerful form of biological alteration. As a result, CRISPR-Cas9 is more precise, cheaper, faster, and more effective related to other genome editing methods [43]. The CRISPR-Cas9 system has been used to modify the production of ligninolytic enzymes in white-rot fungi [44] and to interfere with the secondary metabolism of filamentous fungi [45] the former may also be applied to mycelium-based products to modify their fungal characteristics, and growth patterns.

3. Mycelium – Based Composites

The test specimens were shaped by growing basidiomycete's type fungus. When the fungal growth is stopped after colonizing the substrate, a composite substance is formed that follows mycelium-based composites. [46] As a natural composite material, the substrate determines the mechanical and physical properties of the as-grown mycelium composites. Lignocellulosic substrate-Roughly speaking, all living plants on the planet are lignocellulosic biomass, including roots, leaves, stems, fruit and flowers. The substrate for lignocellulosic biomass will be cornstalk, corncobs, sugarcane bagasse, wheat straw, rice straw, and sugarcane waste. Biodegradation of the waste substrates by fungus - the agro-waste substrates give fungi the lignin and cellulose to digest.

Fungi produce powerful enzymes which can degrade the three biopolymers that make up plant cell walls. The enzymes can be classified as hydrolytic, or non-hydrolytic, and will digest both cellulose and lignin. [47] Composite or reinforced materials are the majority of mycelium-based materials, because most of them do not use a pure mycelial sheet, and even in those instances mycelial sheets are often plasticized to provide additional flexibility [48, 49]. Composites are interesting because while they do have a general composite material property, they are totally unique since they combine at least a couple of distinct constitutive material behaviours. To include distinct aspects of a material's property potential such as stiffness, tensile or compressive strength, weight, high-Temperature performance, rigidity, hardness, and conductivity is not achievable with any one of those aspects alone [50].

Further-more the compressive or flexural behaviour of composites varies or will depend greatly on their constituents. For Example; the mycelium composites collected from the *Ganoderma* genus displayed a totally different compressive property from those of the other genus of mycelium. It should also be noted that a mycelium composite made from Red Oak wood was able to achieve a maximum compressive strength of 490 kPa. [51]The growth medium also impacts tensile mechanism performance; when grown on cellulose instead of potato dextrose, *Ganoderma lucidum* and *pleurotus ostreatus* had a greater young's modulus ([12-28MPa vs 4-17MPa]) and lower elongation ([4-14% vs 9-33%]), but their tensile strengths were still comparable (~0.7-1.1MPa) and not significantly different from each other [14].

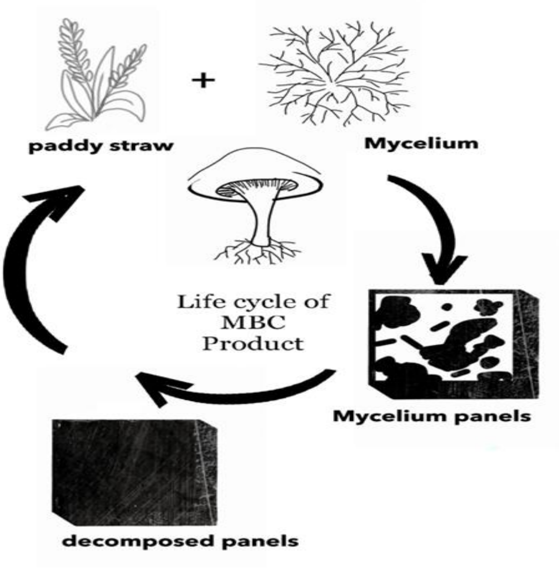

Figure 2. Life Cycle of Mycelium-Based Composites

Overall, the mechanical properties of the substrates, themselves, correspond to the tensile properties of the mycelium composites made from sawdust as they were produced. Sections of clear, straight-grained Beech wood have a tension perpendicular to grain strength of 5-7 MPa that is roughly equal to, or exceeds that of, red oak (5.5 MPa) [52,53].

3.1 Collection of the Substrates

The factors involved in production techniques, substrate type, and species type all influence the end quality of products created from mycelium. [54-56] However, fungal species are more effective at influencing the final character of the finished material than the type of substrate used. [19] This occurs because the fungal mycelium contains chitin, which is key for adhering to food conditions for the substrate. When choosing a substrate the following factors should be considered: [1] nutritional value, [2] quantity and accessibility, [3] biodegradability, [4] cost, [5] structural and texture properties, and [6] compatibility [55]. Some groups of plants, such as hemp, produce a toxic substance that inhibits fungi growth. [57] The most recognized substrates to produce mycelium-based materials include wood chips [58, 8, 59], sawdust, straw [60, 20, 61, 19, 62], coconut powder [63], garden waste [4], and bagasse [22]. The mycelium grew faster in the straw substrate compared to sawdust [20]. Bagasse had a faster growth rate compared to sawdust and mix of sawdust [22]. Also,[8] noted that fungi could access nutrients from soft substrates easily than hard substrates, straw or bagasse are less abrasive, so the substrate is softer than sawdust.

3.2 Selecting Species

Selecting the proper species is one of the most challenging and important elements of making biomaterials effectively, according to several researchers. Species selection is based on several factors including mycelium density, speed of growth, level of toxicity [8], cost of growth media (substrate), method of growing difficulty, and mycelium ramifications [55]. Choosing only two vital attributes- septa and anastomosis- has led us to the phylum [59].

Table 2. Mycelium-Dervied Materials Utilizing Various Strain And Substrate

kingdom	Species name	Substrate Type	Moisture Content (%)	Temperature	Incubation Time(day)	Dry	reference
Fungi	Pleurotus ostreatus	Sawdust, Straw, And mixture	67.5	24	14a+3b	90c	20
Fungi	Ganoderma lucidum	Cotton stalk	65	25	7b	65c	64
Fungi	p.ostreatus, Pleurotus Eryngii & Pycnoporus sanguineus	Coconut powder	60-70	25	(15,30,45)b	-	65
Fungi	Trametes versicolor	Yellow Birch Wood veneers	80	28	18b	-	66
Fungi	Pleurotus ostreatus	Soil, Xanthan gum,and Guar gum	60-70	27	20a+30b	-	67
Fungi	G.lucidum	Rapeseed straw	58	30	21b	65c	54
Fungi	Trametes versicolor, Trametes multicolor, G.sessile	sawdust	50	23	6a+6b	60c	19

(A-Incubation period before mold; b-Incubation period after mold)

1. Septa are peculiar transverse fungal cell walls with a reversible opening valve, which aids the cell in closing the opening by reducing damage to the colony from ruptures and then boosts the resilience of mycelium considerably [59].

2. Anastomosis has the unique trait of being able to join two different hyphae together when the two come in contact [8, 55]. Mycelium can grow and expand quickly, densely, and resiliently by fusing two or more hyphae together to form an extensive biomass that is able to provide nutrients between the substrate much faster.

The mechanical performance of the mycelium bio-composite is primarily determined by the species of fungus, and this characteristic can be manipulated by using different types of spores in the first step of the mycelium's incubation. *Ganoderma lucidum* (25%, by the number of studies) *and Pleurotus ostreatus* (12%) were identified as the most common [8]. These fungi include trimitic and monomitic species.

The directive is to reduce waste production and environmental pollution. Lower-value agricultural waste may be converted into high-value products via mycelium-based materials, this creates opportunities for new businesses.

Both the farmer and the manufacturer of the MBC's (Mycelium-based composites) products may take advantage of this scenario, whereby the farmer can collect its agricultural waste for re-use, throwing it out or burning it rather than the Manufacturer would have raw materials of retained quality and lower-cost raw materials.

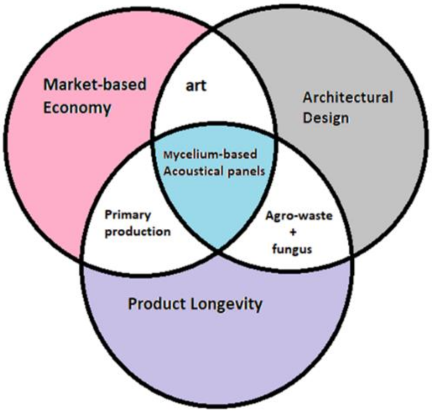

Figure 3. The Concept of Tri-Circular Economy

Cold-compostable products may result from the creation of biomaterials derived from natural waste as a resource. MBCs follow the circular economies principles of waste reduction and environmental sustainability for two chief reasons. First; agricultural waste can be used to produce them locally [68]. Secondly; they can biodegrade rapidly in accepted composting means, thereby reducing carbon emissions from waste management and also avoiding landfill accumulation [69].

Research into the application of mycelium-based composites as a viable material solution in industrial and architectural design is being seen globally [8].

5. Acoustic Absorption Panel

One method of acoustic treatment is sound absorption. In general, acoustic absorbers can be categorized as fibrous, porous, or reactive resonators. Nonwovens, fibrous glass, mineral wools, felt and foams are a few examples [70, 71]. Absorbers diminish the intensity of reflected sound while preventing sound from accumulating in closed spaces, by turning the mechanical oscillation of air molecules carrying sound waves into low grade heat. [70-73] there are a variety of applications of sound absorbing materials including industrial, studio, automotive, and architectural acoustics. Sound absorbers can be considered for use as inner lining for buildings and interiors, ducts, automobiles, airplane, and industrial machinery. The sound absorption coefficient, or E/a, is the ratio of the energy absorbed to the incident energy (redirected towards a structure owner): the coefficient of a material can tell you the ability of a material to absorb sound - the higher the coefficient, the better the absorbent material [73]. The improved acoustic absorption efficiencies of mycelium composites is linked to their porous, fibrous structure. As a material's airflow resistance will greatly influence the impedance and propagation constants it uses to describe its acoustic properties [72]; a material with greater airflow resistance will result in greater acoustic absorption. The fibres in mycelium composites serve as frictional elements when sound waves attempt to pass through and navigate the convoluted paths of the material, thereby inhibiting their motion and reducing amplitude. The energy absorbed and converted into heat. [75]. Thin fibres are capable of greater movement and navigate more convoluted pathways and airflow resistance due to greater density per unit volume, thus are more efficient in contributing to acoustic absorption [76-77]. Hot or cold pressing (the most common methods used to compress agricultural waste into mycelium composites) is not recommended when used as acoustic absorbers, as the compressive process reduces acoustic absorption, primarily due to reduced thickness [74].

5.1 Noise Mitigation through Acoustic Absorption

Social disabilities, lost productivity, and severed student-teacher communication are several secondary impacts associated with these effects. In architectural design and environmental sustainability, the impacts of noise pollution—especially for citizens who live and work in urban metro areas—are receiving a lot of attention [78]. It is important to find sustainable alternatives to conventional synthetic sound-absorbing materials (polystyrene, stone wool, and glass wool). The environmental impacts of traditional sound-absorbing material were explored in their 2020 article by Arenas and Sakagami and Desarnaulds et al.. In their article, Arenas and Sakagami explained that asbestos-based sound-absorbing material originally was used, but when the health risks to humans from asbestos were becoming evident, it made sense that the mineral-based fibrous materials took its place. The fibres were mainly glass and rock wool, being used, however, there continues to be evidence of negative environmental impact from using them. A recommendation for eco-material made from residues or various other sustainable substitutes was suggested by the research [80, 79]. built upon this by evaluating and researching sustainable acoustic materials and its environmental performance. The main assertion in this article was that glass and rock wool are unsustainable because they go to a landfill that does not deal with inert waste. On top of this, they release fibres known to be harmful to workers, contractors and future inhabitants into the atmosphere. The acoustic effect of road noise, namely, was demonstrated to be between 45.5 and 47.0 dB based in mycelium-bound composites with fillers for example rice straw-sorghum fibre, rice straw-cotton bur fibre, sorghum fiber-switchgrass [81-83].The fibrous and porous nature of the materials led to this performance. Since they have the ability to move, the very thin filaments of mycelium bio composites actually act like frictional mediums. The movement reduces the dampness of the wave motion and was able to provide good sound absorption performance [83].

5.2 Sound absorption of the Mycelium based composites

Most sound-absorbing materials are fibrous or porous. The following physical properties of the material determine their absorption behaviour: Material density, thickness, porosity, and fibre size [71].As unique acoustic absorbers, the mycelia by themselves have significant absorption ability in the low frequency range (<1500Hz). They are more effective in terms of road noise than commercial ceiling tiles or cork made from oak trees [83]. The presence of such a unique property implies that, when bundled with other material, mycelium-based foam or insulating board could provide increased resonance absorption capacity. Furthermore, a mycelium-related composite consisting of an agricultural residue adhered to mycelia can provide additional accessibility for perceived road noise or a wider range of acoustic absorption with 70-75% absorption [82]. Sound absorption testing was conducted in accordance with the SR EN ISO 10534-2 standard, which employed materials tested with an impedance tube using the transfer function method (ISO: Geneva, Switzerland, 10-20230).

The loudness of sounds in air as heard by the human ear is expressed in A-weighted decibels, where sounds in the higher frequency range are not corrected and the perception of lower frequency sounds is corrected for the human ear's reduced sensitivity in this range (<1000 Hz) [84]. This gives people and idea of how they perceive the loudness of certain household sounds, such as dogs barking (500-1500 Hz), human speech (85-255 Hz), or noise from traffic (700-1300 Hz) [85-88].

6. Thermal Insulation and fire safety properties of Mycelium

Mycelium insulation, a new biomaterial, is created by growing fungal hyphae on organic substrates, especially waste from forestry and agricultural procedures. Mycelium insulation's complete biodegradability is different from the established characteristics of insulation materials, such as mineral wool, expanded polystyrene, and polyurethane foam, which are derived from non-renewable resources and are resistant to biodegradation. Mycelium's physical deterioration and thermal response characteristics are representative of other cellulosic and biologically produced materials and generally comprise a three-stage thermal degradation. Mycelium does not have any appreciable or practical fire-retardant properties. [14, 89, 90] First, between 25 and 200°C (~5 weight percent), free and chemically bound water evaporates.

[91] After this, there is a considerable mass loss between 200 and 375°C with degradation commencing at approximately 280 to 290°C [14, 92] .The larger mass loss is due to the emission of water vapour or due to the breakage of organic compounds such as proteins and polysaccharides (~70 weight percent) (81). Reports state that especially hydrophobins tend to promote drying rather than depolymerization of polysaccharides, which leads to char [93]. Mycelium composites containing substrates or fillers that are rich in naturally occurring phenolic polymer(s) like lignin, and naturally occurring or synthetic silica (SiO_2) can show noticeably improved thermal degradation, fire reaction and safety components even though mycelium alone has no distinct fire-retardant feature(s) of itself [81]. The mycelium composites fire-retardant performance can be attributed to its char production, which is influenced by the phosphorus and aromatic compounds associated with the mycelium as well as high silica content from the agricultural waste used to grow it.

The overall conclusions of the review suggest mycelium biocomposites has great potential as a sustainable alternative for insulation materials. The use of agricultural waste, which is easily available, enhances their market cost, while their biodegradable nature is consistent with circular economy ideals. Carbon dioxide is one significant greenhouse gas that contributes to global warming, however, mycelium can hold and sequester atmospheric carbon dioxide. The process of carbon sequestration, which is a process of incorporating carbon into materials without releasing it back into the atmosphere, is akin to how plants and other species use the process of photosynthesis. In addition to carbon sequestration properties, living materials have the added benefit of reducing energy consumption of buildings.

Using mycelium derived insulation, for example, has shown to have superior thermal insulation, which has decreased the uses of heating and cooling systems, reducing the amount of energy we consume. Another benefit of utilizing mycelium to replace materials in buildings is there is less waste, and supports a circular economy. Many living materials can be produced and then grown into a specific shape and size so that there are no excess materials required in construction i.e. you don't have to cut anything out of place. Also, many of these materials can also be composted or recycled at the end of their life cycle, reducing the amount of waste that enters the landfills. The argument that mycelium can be used for building materials still requires more rigorous scientific evidence, as there is instead only subjective evidence during experimentation, although another study suggested 20 years of lifespan is possible in stable conditions [94].

6.1 Recycle Insulation Panels

Due to the frenzy to find the next sustainable technology or new materials science research variable that is going to significantly decreased ecological footprint and increase the betterment of our natural environment, several new materials--that might help achieve this generations sustainability--have been developed. The Mycelium Brick is among the newest and most exciting. A mycelium brick is an organic brick comprised of fungal mycelium and organic waste. The health/environmental benefits include improved indoor air quality, less energy used, less carbon emissions, improved acoustic and thermal performance. However, they also have cons; they may have costs that are higher, rarer supply, require treatments or additives, and may have lower R-values or greater densities than conventional insulations [95].

6.2 Renewable Insulation Material

Insulation products take many forms from rigid foam boards, foil, to bulk fibres such as fiberglass, rock and slag wool, cellulose, and natural fibres. When used as a bulk material in a building cavity, they effectively slow convective and somewhat conductive heat flow. The renewable and sustainable Insulation materials include; Mineral wool, Cellulose, Natural fibres, etc.., Sustainable insulation materials provide thermal and acoustic insulation and/or can lessen a building's energy demand and environmental impact. Often made using natural, recycled, or renewable resources, they are naturally low in embodied energy and greenhouse gas emissions.

6.3 Utilizing Spent Mushroom Substrate

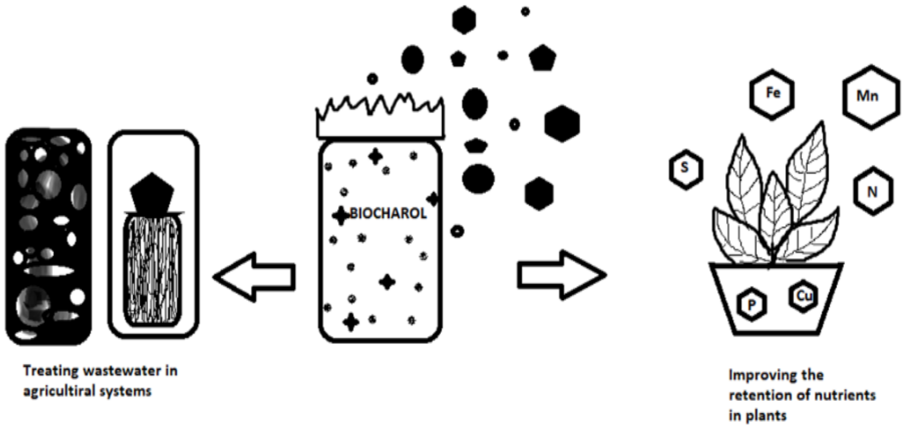

Figure 4. SMS-Spent Mushroom Substrate

7. Application of Myceilum – Based Composites

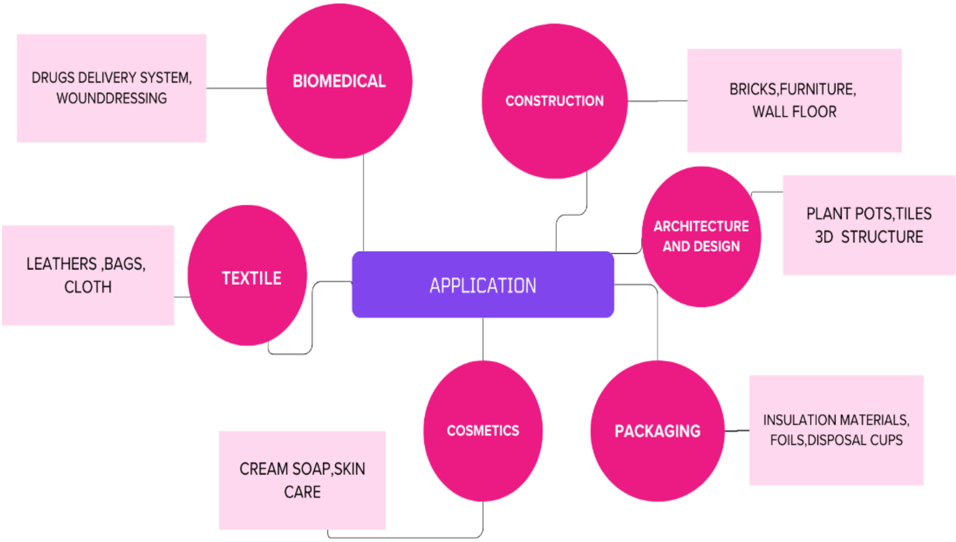

Figure 5. Mycelium-based Composite products

7.1 Building and Construction

Mycelium-based materials are presently being applied in the construction industry mainly due to its special properties, including acoustics absorption, thermal insulation, and fire protection [96]. Microbes can also be used in the production of building products such as bioconcrete, bioblock, biocement, and biopolymer with their ability to biosynthesize calcium carbonate through precipitation, secrete soil stabilizing enzymes, and benefit from their mycelium's unique inherent bonding agent [8,55]. Bio-based materials can be readily incorporated with the prefabricated constructive system since they employed a number of mitigation strategies, such as low embodied energy and carbon, low cost, recyclable, use locally-sourced materials, and utilize waste and by-product [46]. The previous advantage of the mycelium-based block (MBB) in contrast to traditional materials was the low cost of mycelium-based blocks.

Several studies that were reviewed have shown improvements in material characteristics of mycelium-based composites that could be used for construction or building purposes [11, 21]. It has also been widely established that mycelium-based composites offer improved fire safety characteristics compared to traditional building materials such as particle board and polystyrene insulation [100]. MBC has improved termite resistance characteristics as compared to traditional building products [49].

Table 3. Mycelium blocks

Product	Species Name	Application	Reference
BLOCKS	*Ganoderma lucidum *Agrocybe aegerita *Trametes versicolor *G.sessile	Insulation, Design and architecture, And packaging	97, 98,58,8
BIOCONCRETE	*Aspergillus nidulans	Construction	99

7.2 Myceilum Walls, Floor, and Ceiling Tiles

Mycelium-based materials are very cheap and have been proven to have superior fire performance characteristics over traditional building materials such as particleboard and extruded polystyrene foam. MBC acoustic tiles have similar properties to commercial acoustic tiles per. [101], for instance, the mycelium tiles harvested on agricultural waste had density and acoustic damping properties of 0.42 g/cm3 and 7.1, respectively; these are comparable to 0.71 g/cm3 and 7.6 for a commercial acoustic tile.

The global sustainable development agenda aims to shift from a linear economy to a sustainable bio-economy by substituting non-renewable raw materials with bio-based ones [102]. This assertion is based on their numerous benefits for the construction industry, such as lightness, low construction energy, thermal insulation, and sound absorbing qualities, specifically due to the ability to dampen sound through the absorbed sound by the core layer of mycelial material. MBC tiles are likely to replace traditional ceramic and plastic tiles in the very near future based on their sustainability, biodegradability, and affordability [103]. Mycelium based composites, or MBCs, add aesthetic value, have ecological benefits, and lessen their production cost. In addition to scientific investigation, engineering innovation is on this path supported through patent documents, and will be engaged in this supporting process, because the scientific and engineering innovations do not yet have strong design characteristics and reliability (quality in use).

7.3 Building a Living House with Myceilum

Living architecture can be used to build a living house. This study had the objective of promoting sustainable development to the extent that people could build worthwhile, environmentally sensitive, affordable homes without destroying the environment and creating waste.

Living architecture is harnessing the forces and opportunities of living organisms to help create sustainable and affordable buildings; it is not a novel idea. Living architecture has been practiced for thousands of years.

7.3.1 Natural Living Building

In most cases, a family dwelling will consist of two areas or realms. The first is the structure, which allows the house to hold its own dead load and withstand environmental demand, and the second is the envelope, which serves essentially as a closed cover, mostly to protect its inhabitants from the elements, such as wind, cold, and wild things. I think the two arenas can be created in many fascinating ways in nature

8. Potential Uses in Africa

8.1 E-Waste Management

E-waste is made up of electrical and electronic equipment (which includes consumer electronics, IT equipment, and household appliances) and components for which the owner has intended to discard or no longer useful (end of life) (E-Waste as the new Gold and the New Plastic, [104]. E-waste pollution has reached notorious proportions in Egypt, South Africa, Nigeria, Libya, Algeria, Botswana, Gabon, and Namibia [105-107].

Mycelium composites are being investigated for more advanced electrical and electronic applications, also. Fungi can sense light, chemicals, gasses, gravity, electric fields, and mechanical signals and adjust to changing environments. [108,109] Mycelium composites exhibit some properties such as low electrical conductivity and better than average fire resistance ratings that make them suitable in several situations. [103]

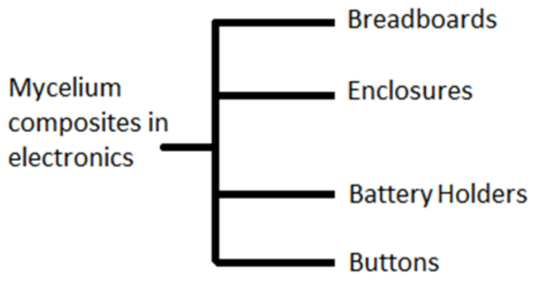

Figure 6. Electronic mycelium composite

8.2 Management of Waste Water

Water pollution is a widespread issue across Africa. The main sources of water pollution include biological and chemical loading due to dumping of untreated municipal and industrial effluents into lakes, rivers, dams, and lake shores [110,111]. The main sources of pollution are agricultural effluents, [112] untreated sewage, [113] waste plastics, and ASM effluents [114,115].

There are some fungi that can absorb, adsorb and sequester pathogenic organisms (e.g., E. coli) and heavy metals like lead, mercury, and selenium. Fungi are also strong antimicrobials, and act as natural decomposers of organic materials. [116-118]. Prior studies have examined the bio-remediation abilities of mycelium on soils and waters contaminated with pesticides, fertilizer runoffs, chlorine, and dioxins, showing the ability to detoxify anthropogenic pollutants [119-121].

8.3 Plastic Pollution Management

In Africa, agricultural, plastic, and electronic waste ("e-waste") is a significant problem and a threat to the environment and public health. [122-124] Plastics (about 13 % by mass) are the major part of municipal solid waste (MSW) produced in Africa, with solid organic waste (nearly 70%, includes food waste and waste from forestry, agro-industrial, and agricultural sectors) also being significant. [106] Plastics and microplastic particles have also been found to be major pollutant materials to the aquatic environments and its biota. [125] unfortunately, regardless of pollution source, remediation of contaminated soil and water is expensive, difficult, or even impossible. Because fungi naturally degrading plastics, this could provide opportunity for innovation such as incorporating plastics as substrates or additives in mycelium composites, which would also provide an environmentally friendly method to manage plastic waste.

The reason the filtering efficiency increased as mycelium network density increased is due to the greater microchannel density for the physical capture of pollutants.

9. Conclusion

Mycelium composites can grow to fill complex geometries, use only inexpensive organic waste as fuel, and are naturally biodegradable, eliminating the need for costly, energy-intensive production procedures in favor of biological growth. They are therefore feasible substitutes for many synthetic materials in terms of both cost and environmental impact. Mycelium composites are particularly well suited for thermal and acoustic insulation applications, exhibiting similar or lower thermal conductivities than commercial thermal insulation materials and 70-75% acoustic absorption or better, outperforming traditional ceiling tiles, urethane foam and plywood. They also exhibit better fire reaction and fire safety properties than traditional construction materials such as extruded polystyrene and particleboard and good termite resistance utilising natural termiticides. However, their typically foam-like mechanical properties, high water absorption and many gaps in material property documentation currently limit the application and usage of mycelium materials with further research and development of these materials necessary, in addition to targeted usage in specific, suitable applications. Nonetheless, the growing trends in the research and commercialisation of mycelium composite materials and their useful material properties makes them an effective, cheap and environmentally sustainable technology emerging with the potential to significantly contribute to the future of green construction.

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