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Prospect of Mycelium in Construction Industry

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ABSTRACT

Fungi are the longest-living eukaryotes on this planet earth. We can trace back their existence more than a billion years ago. They are the primary decomposer of dead organic matter and their byproducts, e.g., trees, woods, plants, vegetables, fruits, bakery products, etc. and we see their abundance in our gardens, farms, and forest. Recent findings also suggest their ability to degrade some inorganic matters like plastic, and asphalt. Our building and construction industry produces a good amount of wood, plastic, and asphalt wastes and from the environmental concern, we need to look for alternative degradation possibilities of these materials. Recent studies in the microbiology sector suggest possibilities of biodegradation of these wastes with the use of fungi. Parallel to degradation, mycelial fungi also show the possibility to shape new products that can be used as construction material. In this paper, we investigate the present state of mycelial fungi in both material degradation and construction arena.

1. Introduction

Any life form that has evolved and thrived on this planet earth completely depends on carbon. Without the supply of it, the growth of life will halt, and eventually, life will end here. It is the exquisite balance of give, take, and store of this fundamental yet sophisticated matter from ground to air and air to water and ground. This process is known as the carbon cycle and is the basic means of sustaining flora and fauna on this planet earth. Living organisms need protein to grow and function, they need energy in the form of sugar or fat to sustain, and the body cells utilize these molecules according to the code written in their DNA (deoxyribonucleic acid) and RNA (ribonucleic acid); and each of these complex molecules needs carbon atom to form.

By weight, 18% of our body mass is carbon. We consume food from other animal and plant sources and our bodies convert it to produce protein, sugar, and fat. As a byproduct of this conversion process, our cells produce carbon dioxide. We inhale air that is rich with oxygen and little amount of carbon dioxide (21% and 0.04% respectively), and our body releases the carbon dioxide produced in our cells with the exhaled air (4%~5% CO_2). This process is called respiration. Our body has a built-in auto-destruction sequence or self-digestion process which is called autolysis, and the decomposition is initiated by the bacteria we host inside our body parts. When we die, our body starts decomposing within some minutes after death. Through the decomposition process, it returns the carbon that we had in our body to the soil and air in various forms.

More interesting and sophisticated carbon cycles take place within plants and trees (Kingdom Plantae) because carbon is one of their main food ingredients. Trees and plants inhale carbon as carbon dioxide from the surrounding air through their leaves; water and other minerals through their roots from the soil or surrounding environment. With the help of sunlight, they then cook these ingredients in their leaves to produce sugar as their energy; the process we know as photosynthesis; and exhale oxygen through their leaves as a byproduct of this process into the air. Trees and plants use this produced sugar for their growth of roots, trunks, branches, leaves, seeds, and fruits. They convert the extra sugar into starch and can store them in their trunks or roots as a source of food for future use.

Trees and plants are the biggest natural source of carbon sequestration in our lithosphere with a unique capability of capturing and storing carbon dioxide directly from the air to its body for a good amount of time. Though their carbon capture efficiency depends upon their

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physical settings, e.g., trees are in a group like a forest or single tree, which climate zone they are in, etc.; how much carbon a tree holds in its body can easily be perceivable. By volume on average 50% of their body is carbon content and the rest 50% is water.

Branches and leaves from trees frequently fell to forest ground and disappear in a few days or months. Even when the tree or plant dies, they continue to decay and also disappear after some months or years. This is the recycling process of nature by which trees, plants, their dead leaves, and branches decompose to break down to their original organic forms so they can add up to the soil. Nature has a whole army of decomposers whose primary task is to break down these fallen liters and logs and transform them into usable nutrients for others.

Plant tissues are much tougher than other organic molecules. They are naturally evolved to protect the plant and its cell walls from the weather effect. Plant cells contain cellulose, lignin, and xylan, whose primary task is to take resistance, and as plant body does not host any bacteria within them or have no self-digestion code written in their DNA, they can sustain in nature much longer and this is why we can use them as a building product. Nevertheless, dead trees, their logs, leaves, and plants decompose with time, or else we might be seeing a huge pile of this organic matter around us. In a moist environment with fallen leaves, plants, or trunks; fungi come into the scene as the first and primary decomposers. They infest the dead litter and logs with their microscopic hairlike tentacles which are called hyphae, collect the cellulose and lignin from the trunks and leaves to make their tissues, and suck out the water and minerals from the inside out. Depending on the toughness of the job, several types of fungi come into action, one after another or even one over another, and they keep continue to invade till the end. They spread their hyphae all over the food source and from all sides and eventually succeed in breaking down the structure. At this stage, bacteria and various other invertebrates (animals with no backbone or spine) e.g., slugs, snails, springtails, beetles, earthworms, etc. also come in gradually to join the feast. As the decomposition continues, mushrooms pop up from the hyphae to spray spores into the air to continue regeneration. In the end, the organic matter converts to humus and becomes part of the topsoil. Fungi keep on traveling through the air with their spores and inside the topsoil with the help of their hyphae in search of a new food source to decompose.

Fungi hold the topsoil with their microscopic threadlike web of hyphae which is collectively known as mycelium. That is to say, they have a binding capability. When they infest a food source, they spread their hyphae all over it. They are abandoned in nature, digest organic matter, and are a vital part of the carbon cycle. These are the few characteristics of fungi that draw our attention to their possible utilization in the AEC (Architecture, Engineering, and Construction) industry. In this investigation, we follow a descriptive methodology to address the present relationship of fungi with the AEC industry in the area of waste recycling and utilization of their binding capability in building material production.

2. Literature Review

A study of "early land plant evolution" suggests that plants evolved on earth around 500 million years ago (Morris et al., 2018), and the presence of fungi can be traced back more than a billion years ago (Loron et al., 2019). The latest number of known fungal species is around 150K and the actual figure of the fungal species is believed to be much larger (Hyde, 2022).

Depending on genetic sequencing, the taxonomy of all living things falls under three domains, viz., the Bacteria, the Archaea, and the Eucarya (Woese et al., 1990). Fungi are living things and along with animals and plants, they share the common tree of life which is known as Eucarya. Like animals and plants, fungi also respire. Most of the fungi types intake oxygen and respire carbon dioxide, a similar activity to animals. Other types can thrive in conditions where there is no oxygen (anaerobic), e.g., phylum Neocallimastigomycota. Even some types of fungi can sustain in both aerobic and anaerobic conditions, e.g., Yeast. There are about 1500 known yeast fungi species and for their dual-surviving mode, they are known as facultative anaerobes.

Fungi do not need sunlight for food production, nonetheless, sunlight affects their growth and reproduction. Fungi like to grow in a shaded and dark place with moist and acidic conditions. Digestion is the primary step to take part in the decomposition process. Animals consume foods and digest them inside their body. Plants process their food inside their leaves, with exception of some carnivorous plants that trap some organisms and consume nutrients through absorption and digestion. In the case of fungi, they land over their food source, surround it with their hyphae, and digest the food externally. They discharge necessary enzymes through their hyphae over the food source for digestion, and again they use the hyphae to collect the digested nutrients inside their fungal body. With the mass of hyphae or mycelium, fungi infest their surrounding soil and its food source. With the right conditions, like moist soil, favorable temperature, and an abundance of food sources, a single mycelium can spread through thousands of acres of land, e.g., in Oregon's Blue Mountains, USA, scientists found the largest and long living fungus on the earth which sprawl from a single mycelium. It covers about 2384 acres of land and is estimated to be about 2400 years old.

3. Discussion

Construction waste biodegradation by using mycelium:

A study on the biodegradation possibility of plastic materials by fungi suggests that some of the common leaf spots causing fungus in the genus Pestalotiopsis are capable of efficiently degrading polymer polyester polyurethane (PUR) in both solid and liquid states (Russell et al., 2011). The study also founds that these fungi can perform in both aerobic and anaerobic conditions. We use an enormous amount of polyurethane-based materials in our building and construction industry, viz., as a polyurethane foam in furniture, wall insulation, and material safety packaging; in paint coatings, adhesives, and Sealant industries; thermoplastic, as a binder in the wooden board, panel, and composite wood manufacturing, roof insulation coating, etc., are few examples. Without HVAC electrical items, conduit cables, kitchen, and toilet electrical equipment, our buildings would not become usable, and we use polyurethane for all these electrical items. We use polyurethane fabrics for furniture, curtain, and interior decoration purpose. This discovery opens the opportunity to naturally degrade our plastic-based building and construction wastes, and save the environment from their release of carbon content into the atmosphere by burning.A large number of fungi species are involved in the wood and plant decomposition process. However, they considerably differ from one another in their working procedure and specialty. Trees and plants need both carbon and nitrogen for their growth (Zheng, 2009). They receive carbon by the carbon dioxide they intake from the atmosphere and nitrogen from the soil through their roots. More nitrogen availability yields more intake of carbon dioxide by trees; resulting in healthier plants, and increased crop growth (Wang et al., 2019); the inherent reason for using nitrate fertilizers in crop fields. However, in an environment, where nitrogen availability to plants and trees solely depends on natural processes, mycorrhizal fungi come into the scene. These are the special types of fungi that live on plant roots, take carbon as food from trees and plants, and in exchange provide precious nitrogen to the trees. Notably, two distinct types of mycorrhizae are involved in this operation: ectomycorrhizae and arbuscular mycorrhizae, where the first one outperforms the second. Ectomycorrhizal fungi can easily exchange nitrogen with trees and even can keep a continuous supply in low-nitrogen environments (Terrer et al., 2016).

Most of the wood-decomposing fungi reside in the Basidiomycota and few in the Ascomycota phylum and they are especially capable to degrade xylem cell wall components or polymeric materials of wood structure, viz., cellulose, hemicellulose, lignin, and other extractives (Lundell et al., 2010). However, there are very few fungal species that are capable to decompose all these three primary cell wall components. Most of the fungi specie of Basidiomycota phylum are filamentous, that is to say, they form a huge network of mycelium around the wood component and in the soil to exchange and transport the food extracts. According to their polymeric material decomposition capability, these wood-decomposing fungi are described in three common terms: white rot, brown rot, and soft rot (Goodell et al., 2020). Some other environmental conditions, viz., adequate moisture content (about 30%), air movement, favorable temperature (24~34 degree Centigrade), and presence of nitrogen in the environment (ground contact), must also be satisfied for rapid and successful fungal colonization on wood substrates (Goodell et al., 2020).

Both white rot and brown rot fungi are capable to depolymerize all three primary cell wall components. Still, they have some notable differences in the work procedure. While white rot decomposes all the cell wall components including lignin, brown rot cannot decompose but modify the lignin structure (Krah et al., 2018). Degradation of brown rot fungi is much faster than white rot even before any visual appearance of decay in the timber body which results in a rapid loss of timber tensile properties. Brown rot prefers to colonize softwoods while white rot prefers to attack hardwoods. Yet favorable conditions can influence their preferences for choice of wood types. Structural loss of timber due to the attack of white rot fungi is much slower compared to brown rot (Goodell et al., 2020).

Fungi that are responsible for the soft rot decomposition of wood are taxonomically classified in the Ascomycota phylum. Their decay pattern can easily be identified by a chain of biconical and cylindrical cavity marks in the wood cell walls (Blanchette et al., 2004). These fungi species have the exceptional capability to manage nitrogen from the surrounding environment. They commonly affect woods that are exposed to extreme weather conditions (too hot, cold, or moist environment) where deterioration by white or brown rot types of fungi is impossible; even with woods that are treated with preservatives. In spite of their exceptional attacking behavior, their damage limits only a few millimeters of the affected wood surface (Goodell et al., 2020).

Which type of fungi would be suitable for our biodegradation purpose of wooden wastes could be answered by the research of Kameshwar and Qin. They have conducted a comparative genetic study on white, brown, and soft rot fungi enzymes on their biomass degradation capability. White rot fungi can break down lignin more efficiently than the other two, whereas soft rot fungi are more efficient in cellulose, hemicellulose, and pectin degradation (Kameshwar et al., 2017). That is to say, the choice of fungi for biodegradation purposes should be made depending on the wood waste biomass structure and white rot would be a safe choice as they can degrade all the primary cell wall components with ease.

We use asphalt in our road construction, in building roofs, and green roofs for waterproofing, as a sealant and binder, etc., and are not easily degradable to nature. Due to their long-lasting capability, they became a reliable construction material. Their reliability turns into an environmental hazard when it becomes to construction waste. Research conducted by Ding et al. suggests that Phanerochaetechrysosporium fungus belonging to the white rot fungi class is capable to biodegrade asphalt. As a petroleum byproduct, asphalt contains polycyclic aromatic hydrocarbons (PAHs) which are hazardous to health, and the Phanerochaetechrysosporium white rot fungus enzyme can digest PAHs (Ding et al., 2021).

Mycelium composite material production prospect:

From the above discussion, we already learned that nature has its own program to cultivate and recycle new materials that we use in our architecture and construction purposes. With the advancement in biotechnology, we can now perceive our construction materials on a molecular scale and can understand their use and life cycle impacts on the microscale. With our recent advancement in the field of mycology, the possibility of harvesting modular construction materials by using fungi adds a new dimension to our AEC industry. Cultivating mycelial fungi on starchy agricultural byproducts to shape usable forms gives us the potential to mimic natural carbon sequestration techniques.

We use polystyrene in our construction as an insulative material. Apart from that, large use of this material and its byproducts take place in the packaging and safety packaging industry, disposable items manufacturing, etc., and due to low cost, its recycling is not profitable, hence it produces a considerable amount of environmental litter (Kik et al., 2020). We can investigate laboratory research conducted by Arifin et al., to produce a substitute material with the same purpose as polystyrene provide by using rise husk and wheat grain and using mycelium as a binder for the end product. Their main goal was to produce a substitute for polystyrene which would be low-cost in terms of raw material and energy use, environment-friendly, and fully biodegradable. in that paper, they explained their test specimen production procedure gradually. In the first stage, they sterilize their raw material which is rice husk and wheat grain in different proportions mixed at 121⁰C by saturated steam with high pressure for about 15 to 20 minutes. After that, they left the sterilized raw material for about 24 hours. In the second stage, they mixed the raw materials with mycelium spore in a polypropylene container and let the mycelium grow and infest for about three weeks. In the third step, they dried the sample at 50⁰C for about two days to stop the mycelium growth. To justify their findings, they conducted some physical tests like density, porosity, and microstructure test (Arifin et al., 2013). Apparently, we could not replace polystyrene from the market yet, nevertheless, mycelium packaging products became a successful biodegradable and environment-friendly alternative to it.

Scientists and design professionals alike understood the potential of this new immerging technology and are investing in R&D to develop new composite building products out of mycelium with agricultural or farming waste. One research reveals that we can manipulate the mycelial growth pattern, their bonding characteristics, mechanical property, and the appearance of the final product by providing different diets to the mycelium and selecting the right type of fungi (Haneef et al., 2017). Two types of edible medicinal fungi, Ganoderma lucidum, and Pleurotusostreatus belonging to the white rot fungi class were used in their experiment. The specimen showed thermal stability and a high value of water-resistant capability in lab conditions and the researchers stated high confidence in their commercial prospects. Research also suggests that mycelium composite made out of rice hulls exhibits better fire reaction properties (Jones et al., 2017). Another research was conducted by the faculties of Poznan University, funded by the Faculty of Architecture, where the researchers proposed 11 features to increase the effectiveness of fungi on Mycelium-Based Composite material production (Sydor et al., 2022). Invaluably, the research also revealed a compilation of fungi species that are related to Mycelium-Based Composites production.

Our contemporary construction industry is highly carbon-intensive. To comply with the construction safety standards and guidelines there is still no alternative to cement, concrete, brick, steel, glass, etc. and all these materials have high embodied carbon. This means, from the birth process till their use in our building to produce the finished building product, these materials are the cause of releasing a huge amount of carbon dioxide and other greenhouse gases into our atmosphere. What's more, a study suggests that our pace of construction material consumption and future floor space requirement on a global scale might become doubled by 2060. This projection indicates a healthy future economy with increased buying power, and in parallel, also indicates possible damage by our construction industry with double the impact on our environment. One possible way of avoiding these consequences is by abating our high embodied carbon material consumption by a considerable amount, and need to look for alternative materials with very low or zero embodied carbon or carbon footprint to fill in the gaps.

With an understanding of the potential of mycelium technology in the architecture and construction industry, many startup companies, and various university faculties are experimenting and exhibiting their design products and construction techniques out of mycelium composite. Review articles are published with in-depth analysis of the challenges they are facing in construction with this new material technology, the procedures they are adopting to overcome those challenges, and their future proposals of construction techniques with hands-on lab samples (Attias et al., 2020, Dessi-Olive, 2022). Some common issues revealed regarding mycelium composites, e.g., low compressive strength, low tensile capacity, unmanageable product scale that prohibits heat treatment which is essential to deactivate mycelium growth, water permeability, prone to moisture, the possibility of contamination and allergic issues through raw materials, etcThe author believes that it would be impractical to expect longevity from a material that was born to be easily biodegradable. In architecture and construction, the application areas of low-cost and short-lifespan materials are well understood. The answer to the low-cost yet long-lifespan building materials production possibility from mycelium composites lies in the selection of the appropriate type of fungi species for the specific job coupled with the raw materials we are using for production (Haneef et al., 2017, Sydor et al., 2022). To meet the production and construction challenges on a global scale, and most importantly to make the material acceptable to the mass population, the author suggests some areas that need our further attention:

- The final product should be in a manageable size for easy processing and handling,
- The product should be in a familiar shape to increase mass acceptance,
- The production and installation process should be simple and with minimum hazards, and
- Choices of raw materials should be easily accessible with simple alternatives.

4. Conclusion

Fungi are a vital element in our carbon cycle. Their existence is evident long before animals and plants appeared on this planet earth. They have survived all the past traceable mass extinctions and yet their existence is quiet and humble. No doubt we have a lot to learn from them, and with growing understanding and interest in this subject, we are doing so. In this research paper, we explored the biodegradation possibilities of waste materials that are generated in our construction industry, viz., timber, plastic, and asphalt. We also explored the prospect of mycelium composite materials in our construction industry and proposed some future development areas.

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