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Mycelium-grown composites as a multidisciplinary way for the development of innovative materials for design and architecture

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Abstract: Mycelium-grown composites, also referred to as "myco-composites", have raised a large attention in recent years, for their ongoing transformation into technical materials, in search of an adequate positioning and role in the field of architecture and design. This review collects the principal developments, trying to elucidate the difficulties that hinder this process, and on the other side, the possible contribution of these materials to the sustainable development, as regards in particular the selection of substrates and the control of properties and the adoption of more flexible geometries.

Keywords: Mycelium-grown materials - Myco-composites - Agrowaste - Biomass - Straw - Bamboo

[Resúmenes en castellano y en portugués en las páginas 178-179]

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Introduction

The diffusion and germination of spores coming from mushrooms (basidiomycetes) or molds (ascomycetes) in a respectively sexual or asexual process leads to the formation of mycelium with a mechanism of cell factory, which through the diffusion and germination of spores, generated a complex network of hyphae. It is suggested that the development of this biotechnology can bring to materials production according to a circular economy concept in that they are totally self-grown and can be reproduced and disposed of according to requirements (Meyer *et al.*, 2020). More specifically, it is implied that engineered living materials (ELMs) can be specifically designed for construction applications, as it will be more specifically exposed in the following parts of this work, dealing in a more focused with the applications of natural fibers. Some aspects, which are inherent generally to the development of materials from natural organisms, are the uncertainty of the tailoring process, which involves scaling-up, and the long-term viability, hence the factual and reasonably constant presence of micro-organisms in the samples for the time required for the self-growth process (Jones *et al.*, 2022).
In practice, mycelium acts as a connector for loose ligno-cellulosic products, such as natural fibers on non-woven structures, most recently originated from waste, but which would be otherwise only possibly used into a polymer or cementitious matrices that cover yet not really link the materials among them by penetrating, posing the problem of the interfacial strength between fiber and matrix. The difference is made into myco-composites by the expansion through an intricate network of hyphae, capable of really connecting fibers and other lignocellulosic materials, even in loose and disorganized, or randomic form (Pollini 2021). In this sense, it is recognized that the mycelium-grown materials can take the most different forms, such as light and porous materials, suitable for the packaging sector (*e.g.* MycoComposite™ by Ecovative), This served as a reference for the development of myco-composites using different substrates, such as hemp shives or wood chips (Zimele *et al.*, 2020). Another possibility is offered by MycoBoard™ by Ecovative, which on the other hand allowed suggesting a glue-replacement process for plywood panels that goes beyond the formaldehyde-free resins or even bio-based resins synthesized *e.g.*, from vegetable oils, to serve also as a pre-treatment for wood-like materials (Sun *et al.*, 2022a). A further possibility is offered by the fact not to give up the concept of layer-development, which is archetypal for composites, such as in the case of Reishi™ by Mikoworks, leading to a leather-like material. It is of interest for further exploration on whether the same concept would be able to be applied to connect real leather scraps, especially vegetable-tanned ones, which have been in a recent work inserted in a thermoplastic starch (TPS) matrix (Pompei *et al.*, 2020).

The process of incubation of mycelium and self-growth of materials

Through the process of incubation of the fungal mycelium obtained from some strains in adapted conditions of temperature and humidity on a suitable substrate at controlled pH, it is possible to obtain foam-like materials, possibly with controlled porosity. The initial considerations for the development of mycelium-grown materials were based on the possibility to replace polystyrene foam (also known as Styrofoam) with a more sustainable material, inherently compostable at end-of-life (Elsacker *et al*., 2020). This led to some well-known products, such as the panel for acoustic insulation, commercialized as Mogu (Mogu-bio 2019): however, the perspective of mycelium-based materials is nowadays much more extended than a single application with defined performance. The process of material production consists into three phases: substrate, its colonization (inoculation and growth) by appropriate fungal strains, and dehydration: obviously, the material needs to be then characterized for its suitability for use (Manan *et al*. 2021). In practice, theoretically infinite possibilities have arisen from the selection of the substrate to the control of the dehydration process, which opens the field to semi-structural materials, such as also furniture and decking (Jiang *et al*., 2017). Ligno-cellulosic materials, bound together by the mycelium-grown matrix, form the substrate the mycelium is feeding upon: it is reasonable therefore suggesting that these materials are constituting a new class of composites, of large interest in the construction industry, defined as myco-composites (Javadian *et al*., 2020).

This approach has also interest for the transition towards circular economy, as a large variety of lignocellulosic waste has been proven to be adapted for the purpose of this production: examples are *e.g.*, sawdust, corn husk, and rice straw, whose performance is compared in Aiduang *et al*., 2022.

These materials for their lightweight nature and moldability can be used in a number of applications, including design and architecture, as the replacement for less sustainable materials (Attias *et al*., 2020). In practice, the substitution of widely used materials, yet not very flexible and oil-based, such as polystyrene foams, has been the first objective of the production of mycelium-based materials (Abhijith *et al*., 2018). In this case, the appearance of the multidisciplinary content might be concealed, in the sense that involvement of biologists, or mycologists, is minimal, the structural characteristics are obtained by bare geometrical characteristics (increase of thickness, brick-like shapes), and the design value is not considered at all. More recently, the potential for other applications not confined to those of packaging and insulation, the typical sectors in which mainly polystyrene foams are employed, is increasingly explored (Yang *et al*., 2017). As pointed out in Karana *et al*., 2018, designing with mycelium implies that the material is allowed growing, starting from a substrate and developing around a template and a shape: it can therefore be defined as "growing design" starting therefore from the material. In this respect, multidisciplinary approach enables to correlate the selection of specific technical aspects, such as the substrate and the template, with the ultimate result obtained in terms of functional and expressive properties of the design. In other words, fungal growth is able to opportunely tailor the binding process for the lignocellulosic material, provided the template and the substrate are accurately selected (Jones *et al*., 2020). Of course, the latter aspect would need to involve the application of structural engineering concepts, in some cases exploiting the availability of performing natural materials, such as bamboo or other natural fibers, to couple them with mycelium-based material (Heisel *et al*., 2017). This process is also of interest, in a context in which waste lignocellulosic materials are increasingly used for

the extraction of components such as lignin or cellulose or for the incorporation in polymer composites: see *e.g.*, Gabrielli *et al.*, 2022. A comprehensive review on the application of mycelium-based composites (MBC) in art, architecture and interior design is offered in Sydor *et al.*, 2022, which observes that the main difficulties are raised into the idea of increasing strength together with varying geometries, while defining a suitable protocol for the purpose.
As from the above considerations, the present work aims at clarifying whether and at which point a multidisciplinary approach can lead to the development of new materials based on the fungal lifecycle. The considerations will be extended from the myco-composites even to a broader design philosophy, which will include mold (not necessarily purposely produced for materials self-growing, but the result of biological processes normally occurring *e.g.*, on waste) as a structural principle for development. In this sense, it is important to summarize what are the properties that can be obtained from the material. A number of factors and parameters are necessarily to be controlled (Sydor *et al.*, 2022). These include:

- The fungus species, which need to be sufficiently available, not difficult to grow and with controlled growth factor, proficient in providing the hyphae's network, and adapted to the substrate
- The substrate itself, which need to be exempt from contamination, homogeneous, nutritious enough, and able to provide cohesion with the mycelium-grown material
- The technology that would encompass optimal pre-growing, substrate preparation, and post-processing, including deactivation, hence heat suppression of the mycelial action
- Finally, the use of the material needs to be identified and the design appropriate.

The influence of curing time, crucial for other materials, such as thermosetting resins, concrete, but also DIY materials (self-produced "bioplastics"), though neglected initially, has been more recently also put into a relation with the material performance also in mycomposites (Ghazvinian & Gürsoy 2022). On the other hand, incubation period, in which the mycelium is still active, has an effect of paramount importance on the density of hyphae and shape retention (Kuribayashi *et al.*, 2022). The separate and thorough control of these factors is essential in myco-composites to upgrade the material from a generic panel or bio-brick, replacement for wood-plastic or Styrofoam, to a material able to be certified in terms of thermal or acoustic insulation, as recognized in Sun *et al.*, 2022b. The influence of curing time, crucial for other materials, such as thermosetting resins, concrete, but also DIY materials (self-produced "bioplastics"), though neglected initially, has been more recently also put into a relation with the material performance also in mycomposites (Ghazvinian & Gürsoy 2022).
Ideally, a successful biofoam does include short and highly entangled tube-like structures, while the filaments are globally compact: coupling of these two characteristics is ultimately responsible for the lightweight, essential characteristic of the material (Nashiruddin *et al.*, 2022).

The problem of selection of substrate into mycocomposites

To try to perform sensible choices in the selection of substrate for the production of myco-composites, a number of tests have been developed, namely mechanical, thermal, and physical ones: some of the results obtained are exposed, as from the relevant literature.
One problem that has been evident in the development of mycelium composites is the need to reduce the amount of water absorption. This is an initial consideration for the choice of the substrate and allow making considerations on the material design. In the case of a study on different lignocellulosic substrates mixed with *Trametes Versicolor* rot fungi, substrates were carefully controlled not only as for type and species, but also in the form they were introduced in the matrix (Elsacker *et al.*, 2019). In particular, five different substrates were compared, namely hemp, flax, flax waste, softwood, and straw, and, were furthermore processed in different ways, in particular, as defined in the work, in the loose, chopped, dust, pre-compressed and tow format. A number of properties of the different series of samples were compared, in particular the dry density, tensile and compressive stiffness, stress-strain curves, thermal conductivity, and water absorption rate.
In practice, the triggering point on studies about mycelium was the obtainment and the measurement of compression strength, since the uses envisaged involved basically the design of large thickness objects, therefore mainly resistant because of their geometry: therefore, even cyclic compression studies of mycelium structure were investigated (Islam *et al.*, 2017). In the case of substrates, such as hemp shives (Loris *et al.*, 2022), compression properties were sufficient, indicating a strength of 235 kPa, hence compatible with what obtained with expanded polystyrene foam, depending on the density (Krundaeva *et al.*, 2016). On the other side, hemp shives demonstrated to be a particularly flexible material, still abundant in cellulose (ca. 47%) (Bradzauks *et al.*, 2016), as a by-product, for the production of wood-replacement composites. In particular, the combination of hemp shives with non-water absorbing materials, such as pottery clay, which are inert as a substrate, proved successful (Scardecchia *et al.*, 2020). This could be applied also to mycelium matrix ones: as a matter of fact, hemp shives were among the first substrates to be applied in myco-composites (Siwulski *et al.*, 2010). Another open question on hemp shives, which might be relevant for their use as a substrate in myco-composites is that complete biodegradability was ensured after 12 weeks of exposition to composting conditions, yet water uptake ascended to up to 1000%. This suggests possible uses for water absorption-desorption cycles, at a lower, yet considerable level. Further developments with hemp shives were achieved by adding birch by-products (sawdust and bark) and wheat bran (WB), using the *Trametes versicolor* mycelium, obtaining a lower mycelial increment, with improved stability. The fabrication process involving thorough control of temperature (22 °C), moisture (70% relative humidity), curing time (14 days) in the absolute absence of sunlight (Irbe *et al.*, 2022).
In this sense, wheat bran has been often proposed as an upgrading filler for the use of other natural fibers, such as cotton or hemp, in mycelium-based composites. Here, it can compensate to the high deformation imparted by other natural fibers by reducing the amount of porosity in the material, therefore synergistically increasing its strength and hardness (Sisti *et al.*, 2021). As concerns compression strength, the properties of cotton

fiber reinforced myco-composites are consistently higher than those of the corresponding hemp reinforced composites in the case no wheat bran is added. This is of interest, since it can be suggested that the properties are other than those observed for the same fibers when inserted into polymer or cementitious composites for construction applications (Mohanavel *et al.*, 2021). In other words, using mycelium matrices can lead to modifications of the properties of the single fibers. In the same way, although with even less repeatability, after wheat bran addition the performance does depend in non-predictable way from wheat bran amount and degree of compression. It might be proposed that this might be a side effect of wheat bran introduction, which normally improves the stiffness of the material, but not necessarily the strength, especially due to the variable aspect ratio of the particles (Rahman *et al.*, 2021). This difficult predictability also suggests the possibility to tailor the properties of myco-composites in a way that is not possible in the case of natural fiber composites. This broadens the possible fields of application for mycelium-grown materials, for example a surfboard prototype has been prototyped, based on the potential to limit water absorption via a suited fabrication process, as the part of the Mycological Innovations Challenge Grant (Dias *et al.*, 2022). It is possible to control the cushion properties of these materials by offering different combinations of mycelia *e.g.*, with various fabrics, therefore entering some fields, which have not been considered so far, such as footwear design (Silverman *et al.*, 2020).
Other fibers pertaining to large production systems, such as bamboo, have also been proposed for mycelium-grown composites, and the process of improving their manufacturing process has been undertaken, for example by allowing an easy extrusion from the obtained paste, by adding chitosan. This is a process that is often considered for myco-composites, to partially compensate for the limited tensile performance of mycelium-grown materials (Soh *et al.*, 2020). Chitosan, such as alginate, is well renowned for its potential in improving the plasticity of bioplastics, which has been often experimented also in the case of DIY materials, often used for expressive and demonstrative reasons *e.g.*, to include waste or by-products, which is relevant also for myco-composites (Cecchini 2017). To ensure an even enhanced compatibility, the extraction of chitosan from fungal mycelium is also possible in place of employing the one traditionally obtained from crustacean shells (Dhillon *et al.*, 2013).

The cases of typical supports: Bamboo, and various straw

In the case of the application with bamboo, investigations have been performed over the possibility of making wood-like boards, using mycelium as a binder, and evaluating which will be the geometry of bamboo, namely of the *Gigantochloa apus* species, to be most compatible with mycelium grown matrix, powder, short fibers, and long fibers. Quite contrarily to expectations, the most compact boards were obtained using the bamboo powder, with the significant advantage of having a density of the board as low as 0.18-0.23 (Ridzqo *et al.*, 2020). Always using bamboo, this time short fibers of 200 microns length from the *Dendrocalamus asper,* a considerable improvement of compressive strength up to

approximately 270 kPa, corresponding to a strain in the order of 40% by using a beeswax coating to allow more uniform properties during loading (Gan *et al.*, 2022). The role of beeswax has been recognised also in works with mycelium-grown materials to control the penetration of concrete in the myco-composites, therefore to control the scaling up of the material in order to prepare it for architectural applications (Bitting *et al.*, 2022).
Another typical support is offered by the application of straw: a number of examples of this practice for the production of mycelium-bound composites are reported. A study on the potential as a substrate of soybean straw on *Ceriporia lacerata* mycelium comprised the measurement of thermal properties, acoustic insulation, and compression performance (Shao *et al.*, 2016). In this case, soybean straws with 2-8 mm length were used, which offered compression strength of up to 800 kPa, a thermal conductivity of 0.054 W/(m·K), with coefficients of sound absorption higher than 0.6 above 800 Hz, yet much lower below that frequency. It needs to be noticed that the measured thermal conductivity value does not differ much from what revealed on expanded polystyrene (EPS) foams at temperature intervals between 0 and 50 °C (Gnip *et al.*, 2012). The comparison of rice straw substrate with the one obtained using bagasse, a typical sugarcane residue of frequent interest into composite production lately (Kumar *et al.*, 2021), and the latter offered a much denser structure of the hypha network, which resulted in a flexural strength of 540 kPa against 160 kPa, when using rice straw (Peng *et al.*, 2023). In particular, with the idea to use the mycelium-based composites in the field of architecture, it is very important to assess the maximum level of compression strength achievable and the tolerance to humid conditions of the material. In this sense, hybrid compositions of the substrate, including sawdust, wheat bran and straw, inoculated with *Pleurotus Ostreatus* fungus, have been produced (Ghazvinian *et al.*, 2019). Despite the compression strength measured is much lower for the hybrids than for pure sawdust substrate, it has been revealed that a 50% sawdust/50% straw hybrid has not evidently higher properties over a 90% straw/10% wheat bran hybrid: in other words, the effect of wheat bran is more significant. This led to other investigations that made wheat bran, also due to the aforementioned limitations in terms of fibrous structure arrangement i.e., variable aspect ratio, a typical additive to a sawdust substrate, in the specific case using *Lentinus velutinus*, *Pleurotus albidus*, and *Pycnoporus sanguineus* (Bruscato *et al.*, 2019).

The use of chemically extracted biomass, or waste biomass

In the view to improve the performance of mycelium-grown composites, it has also been attempted to start from a chemically extracted biomass. A specific study used hexane extracted rose flowers (HERF) and steam-distilled lavender straw (SDLS) inoculated on *Ganoderma resinaceum,* offering compression strength equal to 1029 kPa for the HERF-based mycelium composite and to only 718 kPa for the SDLS one (Angelova *et al.*, 2021). This was attributed to the larger presence of open pores in the latter, which absorbed about twice the water weight per unit area than the former (6.5 vs. 3.4 kg/m^2). These values of water absorption exceed the range (2-3.5 kg/m^2) that was reported in Elsacket *et al.*, 2019, for substrates constituted in flax, hemp or straw.

As concerns the use of waste biomass for inoculation of mycelium and production of composites, one of the most diffuse agricultural systems is the one based on palms. In particular, not all types of palm biomass lead to a significant effectiveness in terms of composting: a study undertaken in the case of peach palm residue highlighted some decrease in plant growth by blending it in compost (Bellettini *et al.*, 2017). In this context, using peach palm sheaths, in combination with cassava bran and with further nitrogen provided by cooked soy flour, together with ammonium sulphate and potassium nitrate, while ensuring the best conditions for pH, moisture, and water activity, allowed reporting compression strength values in the order of polystyrene [36]. On the other side, longer period of cultivation improved the mechanical properties, enhancing the level of hyphae aggregation. In addition, the possible mixture between sugar palm biomass and cassava bagasse in different ratios (65:35, 50:50, and 35:65) with inoculation of *Ganoderma lucidum* led to the best results for the last one, which gave an average value for compression strength as high as 3.08 MPa [37]. Most recently, also another type of bagasse has been proposed to act as a substrate for the production of mycelium-grown materials, which is guayule (*Parthenium argentatum*) bagasse (César *et al.*, 2023). The sense of this operation is aimed at increasing the value of this cultivation, presently used only for biofuels and as the complement to refractory bio-bricks, although it has been historically used also as an alternative to rubber to be adapted also to the European climate (Sfeir *et al.*, 2014).
In general terms, it can be highlighted that mycelium is able to represent a biological binder for offering a suitable process for fabrication of material boards using different types of agrowaste, despite the fact that only few of these have been used so far, especially in fibrous form, while availability of biomass is growing. In recent years, the multifunctionality issue and the control of the effects obtained with the self-growing process appear to be more and more developing. Some examples can be reported, such as the possible modelling of the effect of particulate agrowaste on the mechanical properties of mycelium-based composites (Islam *et al.*, 2018). Moreover, as regards multifunctional approach, the coupling of other effects *e.g.*, creating composites able to absorb heavy metal ions, such as Cu (II), contributing therefore to bioremediation, has been investigated, with particular attention to spontaneous plants (*Aspergillus campestris*) (Saravanan *et al.*, 2020). Moreover, a shift from traditional applications of mycelium-grown materials is also noticed, as can be the proposal for diverse applications than the so-obtained bio-blocks, depending on growth features and baking process (Joshi *et al.*, 2020). In any case, these mycelium-bound composite materials are developed in a concept of 100% degradability, as competitors for biocomposites based *e.g.*, on polylactic acid (PLA), which are rather better conceived with a philosophy of easier recyclability, and as the replacement for polyolefin plastics (Rafiee *et al.*, 2021).

Multifunctional mold-based materials

Further developments can be expected in the case of suitable modification of mold and fungi, leading to multifunctional materials, such as it case for biosensors. In this sense,

there is correlation with biomimetics, since fungi showing natural bioluminescent properties make them suitable candidate for preparing fungal-based biosensors (Singh *et al.*, 2020). A number of fungal-based biosensors are for electrical properties, colorimetry, luminescence, fluorescence, etc., and it is obvious that those fungi that show bioluminescent properties offer the best candidates. This is also in view of the selection for substrate for mycelial growth of the material: a recent review recognizes that mostly the development of fungal luciferin is due to the presence of caffeic acid, common to all plants, as a way to attract insect then diffuse spores (Ke and Tsai 2022). This might imply some sort of independence of the bioluminescence mechanism from the substrate used, which is ultimately the reason why the application of bioluminescent fungi to the production of mycelium-grown materials may be highly advisable. Another possible consequence of the self-growth is the possibility to create multifunctional blocks in adapted shapes, which after being rectified *e.g.*, by Laser cutting, are able to self-heal their possible fractures, therefore protracting their service life, with obvious advantages for sustainability (Elsacker *et al.*, 2021). This possibility adds to the vast literature on self-healing composites, which are mainly based on the release of hydrogels, or in some cases of polyurethane, sometimes filled with graphene or graphene oxide, into the material, their diffusion being the consequence of internal damage (Kanu *et al.*, 2019).
An important and last consequence of multifunctionality due to appropriate mycelium growth in a suitable support with added geometrical constraints *e.g.*, by applying different positions of the fibers, is that mycelial composites do occupy a very large area in the most classical Ashby diagrams, those based on strength vs. stiffness. The typical loading mode applying is the flexural or the compressive ones, as dictated by the geometrical characteristics of the obtained materials (Rigobello *et al.*, 2022). Of course, to obtain this unprecedented potential, it is important to set-up accurately the fabrication method *e.g.*, extrusion can be tentatively applied, in view of implementing an additive manufacturing procedure, which is capable of being coupled to the spontaneous growth of the material to provide an improved geometrical control (Elsacker *et al.*, 2022). In other cases, coupling *e.g.*, of wood veneer with mycelium-grown material would provide an alternative way of 3-D modelling of the material by using fused deposition mode (FDM) with properties comparable to common wood-plastic composites (WPC) based on wood powder (Özdemir *et al.*, 2022).

Conclusions

Most applications of biomimetics have been developed by the use of materials that are not of natural origin: this is principally due to the difficulty to apply natural materials in a way capable of exalting their intrinsic possibilities, rather than reductionist in terms of geometry and properties. Some potential is offered by the development of mycelial hyphae networks, whenever produced in adapted conditions with accurate control of incubation and then curing time, temperature, humidity, and subsequently growth and moment for suppression. This depends also on the substrate employed, which can represent a reinforcement solidly bonded and interpenetrated with the mycelium-grown structure. As such, myco-composites can represent an alternative to the development of bioresins or as wood replacement materials, especially as far as they are able to include a large variety of substrates, also originated by agrowaste or generally bio-products. This would therefore contribute to a sustainable use of refuse by effective introduction in other materials, and in some other cases also to offering ideas to increase the profitability of a production system with limited interest so far (this is for example the case for different types of straw, or for guayule).

On the other hand, it is still difficult presently to move farther than it was the case for packaging substitute for Styrofoam or bio-blocks, concentrating especially on the compression strength and on the lightweight of myco-composites. Some examples can be found in trying to appropriately mold these materials into different shapes, by working either on their curvature or on their possible mechanical rectification by cutting. Other potential is offered in trying to optimize the thermal and acoustic properties of these materials, which needs to be achieved by integration of environmental factors for growth and accurate selection of the substrate. Other possibility may arise by cross-contamination with other sectors that are under development, yet still lacking development of end- products, able to be effectively marketed, such as that of self-healing composites, which currently involve expensive and not very effective and practicable solutions.

One final consideration, which is essential to understand the value of myco-composites, is that in polymer or cementitious composites: here, the two phases are bonded together, yet very conditioned by the degree of interfacial strength. In contrast, myco-composites do present a higher degree of integration and interpenetration between the mycelium matrix and the substrate reinforcement, which are both hierarchically arranged, and continuously evolve and modify during the life of the material, to a level unprecedented in natural fiber composites, even when bio-based matrices are used.

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Resumen: Los composites cultivados a partir de micelio, también denominados "mico-composites", han suscitado una gran atención en los últimos años, por su continua transformación en materiales técnicos, en busca de un posicionamiento y papel adecuados en el campo de la arquitectura y el diseño. Esta revisión recoge los principales desarrollos, tratando de dilucidar las dificultades que dificultan este proceso, y por otro lado, la posible contribución de estos materiales al desarrollo sostenible, en lo que se refiere en particular a la selección de sustratos y el control de propiedades y la adopción de geometrías más flexibles.

Palabras clave: Materiales cultivados a partir de micelio - Micocompuestos - Residuos agrícolas - Biomasa - Paja - Bambú

Resumo: Os compósitos produzidos em micélio, também chamados de "micos-compósitos", têm suscitado grande atenção nos últimos anos, por sua contínua transformação em materiais técnicos, em busca de um posicionamento e papel adequados no campo da arquitetura e do design. Esta revisão reúne os principais desenvolvimentos, tentando elucidar as dificuldades que dificultam este processo e, por outro lado, a possível contribuição destes materiais para o desenvolvimento sustentável, no que diz respeito em particular à seleção de substratos e ao controle de propriedades e à adoção de geometrias mais flexíveis.

Palavras-chave: Materiais produzidos a partir de micélio - Myco-compósitos - Agrowaste - Biomassa - Palha - Bambu