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A Review of Mycelium-Based Composites

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ABSTRACT

Concrete production contributes substantially to global carbon emissions, mineral extraction, and construction waste. This narrative literature review evaluates mycelium-based composites (MBCs) as lower-carbon materials for selected non-structural construction applications. It examines their biological basis, production methods, material properties, environmental performance, commercial development, and current technical limitations. MBCs are produced by growing fungal mycelium through agricultural residues, forming lightweight composites without the high-temperature processing required for cement or mineral insulation. Published studies indicate that standard MBCs can achieve thermal conductivity values of approximately 0.038–0.058 W/m·K, overlapping the ranges reported for several conventional insulation materials (Babenko et al., 2024; Lewandowska et al., 2025). However, reported results vary according to fungal species, substrate, density, processing method, electricity source, transportation distance, production scale, treatment of biogenic carbon, and life-cycle assessment (LCA) boundaries. MBCs also remain limited by low structural strength, moisture sensitivity, uncertain fire performance, variable feedstocks, uncertain industrial-scale production costs, and the absence of harmonized construction standards. Commercial products and architectural demonstrations show that production beyond the laboratory is possible, although long-term durability and industrial-scale economic data remain limited. MBCs are thus not replacements for structural concrete, but they may reduce the unnecessary use of high-carbon materials in insulation, interior panels, acoustic products, and packaging.

1. INTRODUCTION

Concrete is the foundation of modern infrastructure and a major component of the built environment. Its production, however, carries substantial environmental costs. Cement production accounts for approximately 7% of global CO_2 emissions (Global Cement and Concrete Association [GCCA], 2021). In 2022, the average thermal-energy intensity of clinker production was approximately 3.6 GJ per tonne of clinker, whilst low-emissions fuels supplied only 5% of the sector's thermal energy (IEA, 2023).

Energy use is only one source of cement emissions. Calcination—the high-temperature chemical decomposition of calcium carbonate ($CaCO_3$) into calcium oxide (CaO) and carbon dioxide (CO_2)—releases approximately 0.50–0.55 tonnes of process CO_2 per tonne of clinker (Andrew, 2019; IPCC NGGIP, 2019). When fuel combustion and the composition of finished cement are considered, total emissions are approximately 0.80–0.95 tonnes of CO_2 per tonne of clinker and 0.60–0.80 tonnes of CO_2 per tonne of cement

(Andrew, 2019; IPCC NGGIP, 2019). Because calcination emissions result directly from the chemical reaction used to produce clinker, they cannot be eliminated through efficiency improvements or alternative fuels alone.

Concrete production also requires extremely large quantities of mineral resources. Construction consumes an estimated 40–50 billion tonnes of sand and gravel annually, contributing to riverbed disturbance, coastal erosion, habitat degradation, and illegal extraction (UNEP, 2019). These pressures are expected to grow as urbanization and construction demand increase (UN DESA, 2025). Researchers are thus investigating materials that reduce limestone calcination, virgin aggregate extraction, or the use of high-impact insulation products. These approaches include recycled aggregates, geopolymer binders, lower-clinker cement formulations, and bio-based composites (Monteiro et al., 2017).

One such material is mycelium, a network of microscopic fungal filaments known as hyphae. When cultivated through agricultural residues, mycelium can bind loose particles into lightweight composites without requiring mined aggregates or cement-kiln temperatures (Alaneme et al., 2023; Ghazvinian & Gürsoy, 2022). MBCs may provide useful thermal insulation, geometric adaptability, and end-of-life biodegradability. However, their low mechanical strength, sensitivity to moisture, variable biological feedstocks, and uncertain long-term durability limit their current use primarily to non-structural applications.

Mycelium is only one of several materials being investigated to reduce the environmental impacts of construction. Other approaches include geopolymer concrete, recycled aggregate concrete, hempcrete, and lower-carbon cement formulations. These alternatives address different parts of the problem; some reduce clinker use, some reduce aggregate extraction, and some replace high-impact insulation or non-structural materials (Monteiro et al., 2017; Amran et al., 2020; Xing et al., 2022; Asghari & Memari, 2024). MBCs should thus be evaluated within this broader field rather than presented as a single replacement for concrete.

Through the use of narrative literature review, MBCs are evaluated as lower-carbon materials for selected non-structural construction applications. It first examines the environmental burden of conventional concrete and situates MBCs among other sustainable construction alternatives. It then reviews MBC production, material properties, environmental performance, commercial applications, evidence limitations, and future research priorities. The analysis does not treat MBCs as a universal substitute for concrete, but instead evaluates the narrower applications in which their low weight, insulation performance, and biodegradability may offer practical advantages.

2. REVIEW METHODOLOGY

This study used a narrative literature-review approach to evaluate the environmental and material performance of mycelium-based composites (MBCs) in selected construction applications. A narrative review was chosen because the relevant evidence spans several distinct fields, including fungal biology, materials science, construction engineering, LCA, architecture, environmental policy, and commercial product development. The purpose was not to calculate a pooled effect size, but rather to identify recurring findings, compare reported performance ranges, evaluate inconsistencies among studies, and determine where evidence remains insufficient.

Literature searches were conducted between August 2025 and June 2026 using Google Scholar, ScienceDirect, JSTOR, Academia.edu, and Google Search with advanced search operators. Publications dated from January 2000 through December 2025 were considered. Search terms included combinations of “mycelium-based composites,” “mycelium construction materials,” “fungal composites,” “mycelium insulation,” “mycelium thermal conductivity,” “mycelium compressive strength,” “mycelium LCA,” “mycelium biodegradation,” “mycelium moisture resistance,” “mycelium fire performance,” and “mycelium commercial construction.” Additional searches examined the environmental effects of conventional concrete using terms such as “cement process emissions,” “cement calcination emissions,” “construction aggregate extraction,” “concrete LCA,” and “concrete demolition waste.” Searches concerning competing sustainable materials included “geopolymer concrete,” “recycled aggregate concrete,” “low-clinker cement,” and “hempcrete.”

Sources were included when they provided evidence relevant to at least one of the following categories: MBC production methods; fungal species or substrate selection; mechanical performance; density; thermal and acoustic performance; moisture absorption; dimensional stability; fire performance; life-cycle environmental impacts; biodegradation and durability; industrial scalability; construction regulation; economic feasibility; or documented commercial and architectural applications. Peer-reviewed journal articles, review papers, conference proceedings, government and intergovernmental reports, technical standards, and official product documentation were considered. Sources were excluded when they lacked identifiable authorship or publication information, repeated claims without traceable evidence, focused primarily on fungal products unrelated to construction materials, or discussed speculative construction applications without supporting material-performance data.

Peer-reviewed primary studies were used for quantitative values where they could be identified and accessed. Review articles were used to identify broader trends, compare heterogeneous findings, and locate relevant primary research. Governmental and intergovernmental reports were used for cement emissions, aggregate extraction, urbanization, and construction-sector trends. Official technical documentation was used cautiously for commercial products and regulatory claims because company-reported performance may not have undergone independent review. Reference lists of relevant reviews and primary studies were also examined to identify additional sources not retrieved through the initial searches.

Data were extracted into the following comparison categories: production conditions, substrate type, density, compressive strength, thermal conductivity, moisture absorption, dimensional stability, biodegradation, embodied greenhouse gas emissions, production scale, and reported commercial use. Numerical values were retained as ranges when studies reported heterogeneous formulations or test conditions. Exceptional values from specialized experimental materials were distinguished from values reported for standard MBC formulations.

The evidence was synthesized qualitatively rather than statistically because the studies differed substantially in fungal species, substrate composition, specimen density, production methods, treatment, testing standard, functional unit, and life-cycle boundary. Direct numerical comparisons were made only where the materials served comparable functions. For example, MBC thermal and environmental performance was compared primarily with insulation materials rather than with structural concrete. Concrete remained a reference material for strength, density, emissions, resource extraction, and end-of-life behavior, but the review did not assume that MBCs could provide equivalent structural performance.

Critical evaluation focused on the repeatability and applicability of reported findings. Particular attention was given to laboratory-scale production, standardized substrates, short testing periods, inconsistent fire and moisture methods, electricity-generation assumptions, transportation distances, life-cycle system boundaries, treatment of biogenic carbon, fungal respiration, production scale, and service-life assumptions. Commercial demonstrations were treated as evidence of technical feasibility, but not as proof of long-term durability, regulatory compliance, industrial-scale environmental performance, or economic competitiveness.

Because this was a narrative rather than a systematic review, it did not aim to identify every publication in the field or conduct a formal meta-analysis. The findings should thus be interpreted as a structured synthesis of the available evidence rather than an exhaustive quantitative assessment.

3. THE ENVIRONMENTAL BURDEN OF CONVENTIONAL CONCRETE

Portland cement production generates emissions through both chemical reactions and energy use. The largest source is calcination, which releases CO_2 directly from limestone during clinker production and accounts for approximately 53% of cement-production emissions. Fuel combustion contributes about 35%, whilst electricity use accounts for the remaining 12% (IRENA, n.d.). Unlike fuel- and electricity-related emissions, calcination emissions cannot be eliminated through renewable energy or efficiency improvements alone because they arise directly from the chemistry of cement manufacture. Deep reductions thus require lower-clinker formulations, alternative binder chemistries, or carbon capture, utilization, and storage (CCUS). CCUS can address process emissions, but its operation requires additional energy and substantial transport and storage infrastructure. For post-combustion chemical absorption, the IEA reports an additional energy demand of approximately 50–90 kWh per tonne of clinker and an additional thermal-energy demand of approximately 1–3.5 GJ per tonne of clinker (IEA, 2019). The IEA's Net Zero Emissions by 2050 Scenario requires the cement sector to achieve annual CO_2 intensity reductions of 4%, yet the average thermal energy intensity of clinker declined by only 0.2% annually between 2010 and 2020 (IEA, 2023). This gap between the rate of incremental improvement and the rate required for climate alignment is a central challenge for the industry.

3.1 The Limits of Fuel Substitution

Table 1. Selected Indicators of Fuel Substitution in Cement Production

Indicator	2022	IEA 2030 Milestone	Source
Kiln thermal-energy intensity	3.6 GJ/t clinker	3.4 GJ/t clinker	IEA, 2023
Share of low-emissions fuels in thermal energy	5%	30%	IEA, 2023
Bioenergy without CCUS	5%	15%	IEA, 2023
Share of near-zero-emission clinker production	0%	8%	IEA, 2023
Carbon dioxide captured	0 Mt	170 Mt	IEA, 2023

These values show that fuel substitution and energy-efficiency measures must accelerate substantially to meet the IEA's 2030 milestones. However, even complete decarbonization of kiln energy would not eliminate the process emissions released during calcination. Lower-clinker binders, alternative chemistries, material efficiency, and CCUS thus remain necessary for deeper reductions (Monteiro et al., 2017; IEA, 2023; IRENA, n.d.).

3.2 Aggregate Extraction and Resource Depletion

Concrete production depends on large quantities of sand and gravel; aggregates typically occupy approximately 60–75% of concrete's total volume (American Cement Association, n.d.). Construction-material demand is expected to rise as urbanization and infrastructure development continue, increasing pressure on aggregate resources (UNEP, 2019).

Not all sand is suitable for concrete. Desert sand particles are often too rounded and smooth to provide the interlocking and bonding characteristics required in conventional concrete mixtures. Construction thus relies heavily on river, coastal, and lake-derived aggregates, which are already subject to extensive extraction pressure (UNEP, 2019).

Aggregate mining can alter river flow, reduce sediment transport, destabilize banks, damage aquatic habitat, accelerate coastal erosion, and increase flood vulnerability (UNEP, 2019). These pressures may intensify as annual concrete production rises. In regions where construction-grade aggregate is most acutely scarce—including parts of South and Southeast Asia and sub-Saharan Africa—informal extraction operations have already expanded significantly, producing associated ecological degradation and governance failures (UNEP, 2019). IRENA states that demand for cement and concrete is expected to rise substantially through 2050 as urbanization and infrastructure demand grow (IRENA, n.d.). Without changes in material composition, reuse, or construction demand, aggregate consumption would be expected to rise correspondingly.

3.3 Life-Cycle Burden and End-of-Life Waste

Table 2 summarizes the primary environmental contributions by life-cycle stage.

Table 2. Principal Environmental Effects of Portland Cement Concrete by Life-Cycle Stage

Life-Cycle Stage	Primary Environmental Impact	Principal Effect	Key Sources
Limestone and aggregate extraction	Aggregates occupy approximately 60–75% of concrete by volume; global sand and gravel extraction is estimated at 40–50 billion tonnes per year (American Cement Association, n.d.; UNEP, 2019).	River, coastal, and habitat disturbance; depletion of suitable aggregate sources	UNEP, 2019
Clinker production	Cement production accounts for approximately 7% of global CO_2 emissions; calcination contributes approximately 53% of cement-production emissions	Process CO_2 and kiln-fuel emissions	GCCA, 2021; IRENA, n.d.
Cement grinding, transport, and concrete mixing	Impact varies with energy mix and transport distance	Electricity use, fuel combustion, particulate emissions	Monteiro et al., 2017
Use phase	Carbonation may reabsorb a portion of previously emitted CO_2 over time	Partial carbon uptake, but not full compensation for production emissions	Xi et al., 2016
Demolition and disposal	Most recovered concrete is downcycled rather than reused as equivalent structural concrete	Large-volume C&D waste and continued demand for virgin materials	Cerchione et al., 2023

The environmental costs of concrete extend across its full life-cycle beyond the production phase. At end-of-life, concrete structures generate substantial volumes of construction and demolition (C&D) waste—one of the highest-volume sources of waste globally (Cerchione et al., 2023). Whilst concrete is frequently described as a recyclable material, the reality is more limited: most demolished concrete is processed into low-grade fill material or road sub-base aggregate, applications that do not displace demand for new concrete in structural or architectural use (Cerchione et al., 2023). True closed-loop recycling, in which demolition waste is reprocessed into structural-grade concrete, remains technically constrained and commercially limited. New construction commonly continues to require substantial inputs of virgin limestone and aggregates, even when recycled material is incorporated, reinforcing the resource demand discussed in Section 3.2. Furthermore, concrete is not biodegradable; demolished material that is not recycled or downcycled remains as persistent mineral waste in landfills unless recovered for another use (Cerchione et al., 2023).

3.4 Relationship to Other Low-Carbon Construction Materials

MBCs are one component of a broader transition towards lower-impact construction. Alternative materials address different sources of environmental burden and should not be treated as directly interchangeable substitutes. Some primarily reduce clinker-related emissions, whilst others reduce aggregate extraction or replace high-impact non-structural products.

Table 3. Functional Comparison of Selected Sustainable Construction Materials

Material	**Functional Role**	**Environmental Value and Advantages**	**Main Limitation**
Geopolymer or alkali-activated concrete	Potentially structural	Reduces or replaces Portland cement; some formulations achieve performance suitable for structural applications (Amran et al., 2020; Singh et al., 2023)	Impacts depend on precursor availability, activators, curing, and formulation
Recycled aggregate concrete	Potentially structural	Replaces some virgin aggregate and reduces demolition waste (Xing et al., 2022; Wang et al., 2023)	Often retains substantial Portland cement
Lower-clinker cement blends	Structural	Reduce clinker content whilst remaining compatible with established concrete systems (Monteiro et al., 2017; IEA, 2023)	Remaining process emissions and regional availability of supplementary materials
Hempcrete	Generally non-load-beari ng	Bio-based, low-density, and insulating (Asghari & Memari, 2024)	Moisture, strength, and regulatory limitations
MBCs	Non-structural	Lightweight, insulating, and potentially biodegradable (Alaneme et al., 2023; Ghazvinian & Gürsoy, 2022)	Durability, fire performance, production consistency, and cost uncertainty

MBCs thus occupy a different functional category from structural concrete and lower-clinker binders. Their closest comparisons are insulation products, non-load-bearing bio-composites, acoustic panels, and lightweight interior materials. Geopolymer concrete, recycled aggregate concrete, and lower-clinker cement are most relevant where structural capacity must be retained (Amran et al., 2020; Wang et al., 2023; Monteiro et al., 2017). MBCs are most relevant where the required function can be achieved without the strength and mass of concrete (Amran et al., 2020; Xing et al., 2022; Asghari & Memari, 2024; Alaneme et al., 2023).

4. DEFINING MYCELIUM MATERIALS

Most construction-oriented MBCs are manufactured biocomposites in which fungal growth acts as the binding mechanism and is subsequently stopped by drying or heat treatment. Living mycelium systems also exist experimentally but are outside this review's principal scope.

4.1 Fungal Biology Basics

Mycelium is the vegetative network of fungi, made up of microscopic filaments known as hyphae. These hyphae grow in an outward, branching, and interlocking way as they search for nutrients. Individual hyphae typically have diameters of approximately 2–10 µm, which allows dense interweaving through porous substrates (Alaneme et al., 2023). Under favorable conditions, hyphal extension rates commonly reach several millimeters per day, depending on the species and nutrients available (Karana et al., 2018; Alaneme et al., 2023).

Depending on the fungal species, hyphae secrete extracellular enzymes that degrade components of lignocellulosic biomass, including cellulose and hemicellulose and, in ligninolytic fungi, lignin (Sydor, Cofta, et al., 2022).

Once the desired growth and binding have occurred, the composite material is dried or heat-treated. Reported treatment temperatures commonly fall between 80 and 120°C, stopping active fungal growth and reducing moisture content (Alaneme et al., 2023). The resulting product is a manufactured bio-composite rather than a continuously growing organism.

4.2 How Mycelium Composites Are Grown

Table 4. Typical MBC Production Conditions Reported in the Literature

Production Stage	Condition or Range	Function	Key Sources
Substrate preparation	Sterilization or pasteurization	Reduces competing microorganisms	Sydor, Bonenberg, et al., 2022; Sydor, Cofta, et al., 2022
Incubation / Colonization	Approximately 5–42 days in reported protocols	Allows mycelium to colonize and bind the substrate; duration depends on fungal species, substrate volume, geometry, and process conditions	Alaneme et al., 2023; Sydor, Cofta, et al., 2022
Incubation temperature	Approximately 20–30°C	Supports fungal growth	Alaneme et al., 2023
Relative humidity	Commonly above 80%	Prevents premature drying during colonization	Alaneme et al., 2023
Gas conditions	Aerobic	Supplies oxygen for fungal metabolism	Alaneme et al., 2023
Growth termination	Approximately 80–120°C drying or heat treatment	Stops biological activity and stabilizes the composite	Alaneme et al., 2023
Final residual moisture	5.8–9.6% by mass after drying at 80°C for 24 h in one comparative study; formulation- and conditioning-dependent	Provides a measurable post-drying endpoint before testing or use	Appels et al., 2019

Manufacturing begins with selection of a fungal species and compatible lignocellulosic substrate. The substrate—typically agricultural or forestry waste—is prepared to control contamination, inoculated with fungal material, placed into a mould, and incubated until the mycelial network has sufficiently bound the particles. Growth is then stopped through drying or heat treatment. Table 4 presents typical conditions reported in the literature; these values should not be interpreted as universal production requirements because optimal conditions vary by fungal species, substrate, geometry, and manufacturing method.

MBC processing occurs at substantially lower temperatures than clinker formation, which requires approximately 1,450°C (IEA, 2023; Monteiro et al., 2017). However, MBC manufacture is not energy-free. Sterilization or pasteurization, controlled incubation, ventilation, and drying may contribute significantly to life-cycle impacts, particularly at industrial scale (Volk et al., 2024).

4.3 Substrate and Feedstocks

One potential advantage of MBC production is the ability to use low-value agricultural and forestry residues. However, variable waste streams do not automatically produce consistent material properties. Substrate availability is geographically flexible, allowing production to be adapted to regional waste streams rather than relying on globally mined resources (Sydor, Bonenberg, et al., 2022).

Reported particle sizes commonly range from approximately 1 to 10 mm. Finer particles may improve material homogeneity but restrict oxygen movement, whilst coarser or more fibrous substrates can alter density, mechanical strength, and insulation performance (Alaneme et al., 2023). Denser formulations generally favor mechanical strength, whereas lower-density and more porous formulations tend to favor thermal insulation (Alaneme et al., 2023; Appels et al., 2019).

Common MBC substrates include sawdust, wood chips, hemp hurd, corn stalks, rice husks, and other agricultural residues. These feedstocks are lignocellulosic, but their cellulose, hemicellulose, lignin, extractive, ash, and moisture contents vary substantially with plant species, cultivation conditions, processing method, and geographic origin (Alaneme et al., 2023; Sydor, Cofta, et al., 2022). Fungal growth partially decomposes these constituents whilst the developing hyphal network binds the remaining particles. Standardized performance thus requires preprocessing, characterization, and quality control, which may reduce some of the economic and environmental advantages attributed to using untreated local waste streams (Sydor, Bonenberg, et al., 2022; Sydor, Cofta, et al., 2022; Alaneme et al., 2023).

4.4 Physical Properties and Performance

MBC properties vary substantially with fungal species, substrate, density, growth conditions, and post-processing. Standard composites are generally lightweight and non-load-bearing, with reported compressive strengths commonly below 1 MPa and densities substantially below those of concrete (Alaneme et al., 2023; Lewandowska et al., 2025). A detailed comparison is provided in Section 5.1.

The most competitive property of MBCs is their thermal performance. Standard formulations commonly report thermal conductivity between approximately 0.038 and 0.058 W/m·K, overlapping the ranges reported for expanded polystyrene and mineral wool insulation (Alaneme et al., 2023; Volk et al., 2024). Their porous structure may also provide useful acoustic absorption (Sydor, Bonenberg, et al., 2022).

Biodegradability may reduce long-term waste, but it also raises questions about resistance to moisture and microbial degradation. The relationship between end-of-life decomposition and in-service durability is examined in Sections 5.5 and 7.1, with quantitative examples summarized in Table 5B.

4.5 Realistic Use Cases

Due to these properties, mycelium-based composites are not intended as a universal replacement for concrete. Their most realistic applications are areas where concrete is over-engineered or unnecessary.

Demonstrated and proposed uses include:

- Thermal and acoustic insulation panels
- Furniture cores and architectural elements
- Packaging and temporary structures
- Interior partitions and non-structural wall systems

Reported LCAs are evaluated quantitatively in Section 5.2.

In these contexts, mycelium's low weight, low embodied carbon, and possible end-of-life biodegradability may offer advantages over concrete or synthetic insulation materials. In suitable applications, MBCs may provide the required insulating or non-structural function without the strength, mass, and mineral inputs associated with concrete. Nevertheless, large-scale adoption depends on solving challenges around moisture resistance, fire performance, production speed, and regulatory acceptance. Untreated formulations may show inadequate moisture and fire performance, although outcomes vary by substrate, density, treatment, and test method (Alaneme et al., 2023).

5. COMPARATIVE PERFORMANCE

MBCs and Portland cement concrete occupy different functional categories, so direct comparison must distinguish between structural and non-structural applications. This section evaluates the materials using five criteria: mechanical capacity, embodied carbon and production energy, thermal performance, density and transport implications, and end-of-life behavior. Numerical comparisons are interpreted in relation to the function being replaced. For example, MBC life-cycle results are compared primarily with insulation materials rather than with structural concrete because insulation is the application in which MBCs provide equivalent functional performance.

Table 5A. Functional Performance of MBCs

Property	Standard MBCs	Experimental MBCs	Comparator
Compressive Strength	Commonly reported range: 0.05–0.50 MPa	2.409 MPa compressive strength in a hollow-reinforced system; 7.29 ± 0.65 MPa yield strength in a 50%-porosity wood-PLA gyroid-scaffold system; 7.5 ± 0.3 MPa compressive strength in a mixed-substrate bioblock	Structural concrete: 20–80 MPa
Density	50–250 kg/m^3	Formulation-dependent	Normal-weight concrete: 2,320–2,400 kg/m^3
Thermal Conductivity	0.038–0.058 W/m·K	0.012 W/m·K in a 90%-porosity wood-PLA gyroid-scaffold system; 0.0370 W/m·K in a hollow-reinforced system	EPS, mineral wool, cork

Note. Values are study-specific and are not directly comparable because formulations, specimen geometries, test methods, deformation criteria, and reported endpoints differ. Sources: standard MBC ranges—Alaneme et al. (2023), Babenko et al. (2024), and Lewandowska et al. (2025); experimental systems—Joshi et al. (2020), Zhou et al. (2025), and Sharma and Le Ferrand (2025); concrete comparators—ACI Committee 318 (2014) and European Committee for Standardization (2023).

Table 5B. Reported Durability and Environmental Indicators

Indicator	Reported value	Qualification	Sources
Water absorption	Example: 237 ± 10% mass gain after 24 h complete immersion	One mixed sawdust / sugarcane formulation; representative result, not a cross-study maximum	Joshi et al., 2020
Soil-burial mass loss	43% for heat-inactivated specimens and 50.8% for living specimens after 16 weeks	One laboratory potting-soil experiment; not equivalent to service life or certified compostability	Van Wylick et al., 2022
Drying shrinkage	Maximum 53.6 ± 5.6%	Specific fiber-containing Arboloco / Kikuyu-*G. lucidum* formulations	Jiménez-Obando et al., 2025

LCA climate-change result	No single defensible percentage range; see §5.2	Boundaries, functional units, production scale, service life, energy mix, and end-of-life assumptions differ	Volk et al., 2024; Alaux et al., 2024

5.1 Structural Capacity

Common normal-weight structural-concrete classes have characteristic cylinder compressive strengths ranging from approximately 20 to 80 MPa (European Committee for Standardization [CEN], 2023). Standard MBC studies commonly report compressive strengths of approximately 0.05–0.50 MPa. Selected high-performing experiments have reported 2.409 MPa compressive strength for a hollow-structured reinforced material (Zhou et al., 2025), 7.29 ± 0.65 MPa yield strength for a 50%-porosity wood-PLA gyroid-scaffold system (Sharma & Le Ferrand, 2025), and 7.5 ± 0.3 MPa compressive strength for a mixed-substrate bioblock (Joshi et al., 2020). These values should not be ranked as a single material maximum because the formulations, specimen geometries, deformation criteria, and test protocols differ. Even these selected laboratory results remain below the 20–80 MPa structural-concrete comparator range used here and do not establish code-qualified structural use. This difference is not necessarily a failure when MBCs are used for insulation, acoustic baffles, interior partitions, packaging, or other applications in which high compressive strength is unnecessary.

5.2 Embodied Carbon and Energy

The two cited life-cycle assessments use different system boundaries and functional units and should therefore be reported separately. Volk et al. (2024) reported 0.3668 kg CO_2-eq per kilogram of MBC for laboratory-scale hemp MBC production in Germany using a cradle-to-gate model. Relative to the per-kilogram XPS and rock-wool values tabulated in the same study, this is approximately 87.5% and 72.0% lower, respectively; however, the comparison does not demonstrate equivalent thermal function, and end-of-life was not assessed. Alaux et al. (2024), using a prospective cradle-to-grave comparison based on insulation providing 1 $m^2 \cdot K/W$ over 30 years, found MBC greenhouse-gas emissions to be about half of those of PUR and XPS and only slightly below those of rock wool. That study also found less-favorable results for several non-climate indicators and substantial sensitivity to the assumed 15- or 30-year MBC service life. The evidence therefore supports conditional climate-change advantages under particular scenarios, not a universal 70–90% reduction.

Table 6. Sources of Uncertainty in MBC LCAs

LCA Variable	**Effect on Reported Results**	**Required Reporting**
Electricity Generation	Sterilization, incubation, ventilation, and drying produce different emissions under fossil-intensive and renewable grids	Grid mix, facility location, electricity consumption by production stage

LCA Variable	**Effect on Reported Results**	**Required Reporting**
Transportation Distance	Local substrates may reduce transport impacts; centralized production may increase them	Distances and transport modes for substrates, cultures, treatments, and products
System Boundary	Results differ depending on whether cultivation, buildings, equipment, coatings, installation, use, and disposal are included	Explicit cradle-to-gate or cradle-to-grave boundary
Functional Unit	Per-kilogram comparison can favor lightweight materials but may not represent equivalent thermal or service performance	Compare equivalent insulation resistance, area, thickness, or service delivered
Biogenic Carbon	Results change depending on whether stored biomass carbon is counted as temporary storage, neutrality, or sequestration	Carbon-accounting method and expected storage duration
Fungal Respiration	Excluding metabolic CO_2 may understate production emissions	Whether respiration is measured, estimated, or excluded
End-of-life Scenario	Composting, landfill, incineration, reuse, and uncontrolled decay have different emissions	Disposal pathway and methane and CO_2 assumptions
Production Scale	Laboratory systems may not reproduce industrial energy use, contamination losses, or transport	Scale, yield, rejected batches, and facility energy
Service Life	A lower-carbon product may not provide an advantage if it requires more frequent replacement	Assumed lifespan and maintenance requirements

Note. Uncertainty categories synthesized from Volk et al. (2024) and Alaux et al. (2024).

The studies reviewed do not use a harmonized LCA boundary for MBCs, making cross-study comparisons approximate. Available evidence supports the possibility of lower climate-change impacts than selected synthetic insulation systems under favorable conditions, but it does not support a universal percentage-reduction range. Industrial-scale data, harmonized functional units, transparent biogenic-carbon accounting, and realistic service-life assumptions are required before these values can support procurement or building-policy decisions.

5.3 Thermal Performance Comparison

Table 7 presents thermal conductivity values for MBCs and selected comparator insulation materials reported in peer-reviewed literature.

Table 7. Reported Thermal Conductivity of MBCs and Selected Comparator Materials

Material	**Thermal Conductivity (W/m·K)**	**Evidence Note**	**Source**
Standard MBC	0.038–0.058	Range varies with density, moisture, substrate, and testing method	Lewandowska et al., 2025; Babenko et al., 2024
Wood-PLA gyroid-scaffold MBC, reported at 90% porosity	0.012	Specialized experimental system; not representative of standard MBCs	Sharma and Le Ferrand, 2025
Hollow-reinforced MBC	0.0370	Density reported as 195–249 kg/m^3	Zhou et al., 2025
Expanded polystyrene (EPS)	0.033–0.040	Established synthetic insulation	Alaneme et al., 2023
Mineral wool	0.030–0.045	Established mineral insulation	Alaneme et al., 2023
Expanded cork	0.040–0.055	Bio-based comparator	Al-Qahtani et al., 2023
Normal-weight concrete	1.36–2.00 W/m·K	Reference only; concrete is not ordinarily used as thermal insulation	Martínez-Martínez et al., 2021

Standard MBCs overlap the thermal-conductivity ranges of expanded polystyrene, mineral wool, and expanded cork. This supports their technical relevance as insulation materials, although it does not demonstrate consistent superiority. The lowest value identified in this review, 0.012 W/m·K, was measured by Sharma and Le Ferrand (2025) in a 90%-porosity composite grown within a 3D-printed wood-PLA gyroid scaffold. It is a specialized experimental result and should not be generalized to ordinary lignocellulosic MBCs. Zhou et al. (2025), by comparison, reported 0.0370 W/m·K for their hollow-structured reinforced material. Comparisons also remain sensitive to specimen density, moisture content, orientation, thickness, and testing method (Babenko et al., 2024; Wildman et al., 2025).

5.4 Mass and Logistics

Standard MBC densities commonly range from approximately 50 to 250 kg/m^3 (Alaneme et al., 2023; Ghazvinian & Gürsoy, 2022), compared with approximately 2,320–2,400 kg/m^3 for normal-weight concrete (ACI Committee 318, 2014). At equal volume, MBC components are roughly one order of magnitude lighter. This can reduce handling requirements and dead load, particularly in interior panels and retrofit applications.

Lower density does not automatically guarantee lower transport emissions. Actual logistics impacts depend on distance, vehicle utilization, product volume, packaging efficiency, local feedstock availability, and whether manufacturing is distributed or centralized. MBC panels may be light but volumetrically bulky, which suggests that LCAs should model both mass and transport volume rather than assuming a fixed benefit (Volk et al., 2024; Alaux et al., 2024).

5.5 End-of-Life Behavior

Conventional concrete is non-biodegradable. Although demolished concrete may be crushed and reused as fill or road-base aggregate, recycling into equivalent structural concrete is limited (Cerchione et al., 2023). MBCs, by contrast, can biodegrade under suitable conditions, although the rate and completeness of degradation depend on the specific fungal species, substrate type, density, moisture content, temperature, microbial activity, and any coatings or additives used in the final product (Alaneme et al., 2023; Lewandowska et al., 2025).

In a laboratory soil-burial experiment, Van Wylick et al. (2022) reported 43% mass loss after 16 weeks for heat-inactivated Ganoderma resinaceum / hemp composites, whereas living specimens of the same material lost 50.8%. Because conventional MBC products are normally dried or heat-treated to stop active growth, the heat-inactivated result is the more relevant construction comparison. Neither figure establishes certified compostability, landfill behavior, or expected service life in a building.

Biodegradability thus creates a central design trade-off. A product intended to remain stable for decades must resist moisture, microorganisms, and mechanical wear during service, whilst a product intended for biological end-of-life processing must eventually become degradable. Coatings, mineral facings, waxes, bio-resins, or flame retardants may extend service life but can reduce compostability, complicate disposal, increase embodied carbon, or raise costs (Appels et al., 2019; Alaneme et al., 2023; Lewandowska et al., 2025). Research should thus evaluate durability during use and controlled degradation after disposal as separate performance requirements.

6. DOCUMENTED COMMERCIAL APPLICATIONS AND CASE STUDIES

MBCs have progressed beyond laboratory research into limited commercial production and architectural demonstration, although commercial deployment remains limited (Ecovative, n.d.; Mogu, n.d.; Museum of Modern Art, 2014; Biohm, n.d.). The following examples establish that manufacturing and deployment are technically possible, but do not by themselves demonstrate long-term durability, regulatory acceptance, industrial-scale environmental performance, or price competitiveness. Commercial claims are thus distinguished below from independently tested or peer-reviewed evidence.

6.1 Ecovative Design (United States)

Ecovative was founded in 2007 by Eben Bayer and Gavin McIntyre and commercially launched Mushroom® Packaging in 2010. The product uses agricultural residues bound by fungal mycelium to replace petroleum-based protective packaging foams. Ecovative reports a growth period of approximately seven days and has licensed the technology for distributed production (Ecovative, n.d.).

Ecovative originally investigated mycelium insulation and other construction materials, but its current commercial composites activities are centered primarily on packaging rather than certified construction panels. The company's history nevertheless demonstrates that mycelium composites can be manufactured commercially and transferred through licensing, although packaging performance does not establish suitability for long-service-life building applications (Ecovative, n.d.).

6.2 Mogu (Italy)

Mogu markets mycelium-based acoustic panels and flooring products for interior applications. The company describes its acoustic products as being manufactured from fungal mycelium and upcycled textile residues and distinguishes sound absorption from sound isolation in its product information (Mogu, n.d.).

Mogu's product line demonstrates commercial use of mycelium composites in interior acoustic and flooring applications. However, company-reported technical values and classifications should be interpreted according to the specific product, specimen thickness, test method, and certification status rather than generalized to all MBCs (Mogu, n.d.).

6.3 The Living / Hy-Fi Tower (MoMA PS1, New York, 2014)

In 2014, The Living, led by David Benjamin, constructed the Hy-Fi installation at MoMA PS1 in New York. The approximately 41-foot structure used 10,000 lightweight bricks grown from fungal mycelium and agricultural waste. According to the project's designer, the bricks grew into solid objects over approximately five days and were conceived as compostable components within a cycle from crops to construction, compost, and renewed crop production (Museum of Modern Art, 2014).

Figure 1. Hy-Fi Tower construction at MoMA PS1, New York, 2014.

Note. Photograph by Inhabitat (2014), Flickr, https://www.flickr.com/photos/inhabitat/14271849329. Licensed under Creative Commons Attribution–NonCommercial–NoDerivatives 2.0 Generic license, https://creativecommons.org/licenses/by-nc-nd/2.0/

The Hy-Fi installation demonstrated public-scale use of MBC masonry units in a temporary, low-load architectural structure (Museum of Modern Art, 2014).

6.4 Biohm (United Kingdom)

Biohm is developing Terraphyll, a mycelium-based insulation platform intended for construction applications. The company reports a thermal conductivity of 0.036 W/m·K, an untreated reaction-to-fire classification of B under EN 13501-1, and a compressive strength of 122 kPa. Because these values are company-reported, they should be distinguished from independently tested or peer-reviewed performance data (Biohm, n.d.).

7. LIMITATIONS, REGULATORY STATUS, AND FUTURE RESEARCH DIRECTIONS

Despite the material properties and documented applications discussed in preceding sections, several substantive barriers constrain the broad adoption of MBCs in mainstream construction. These barriers are technical and operational in nature.

7.1 Moisture Resistance and Durability

Moisture sensitivity is one of the most significant limitations of untreated MBCs. Immersion tests have produced very large but highly formulation- and method-dependent mass gains. Joshi et al. (2020), for example, measured water uptake of 237 ± 10% after 24 hours of complete immersion for a mixed sawdust / sugarcane bioblock. Jiménez-Obando et al. (2025) reported values above 1700% after 48 hours for very-low-density Arboloco-pith formulations. These results are not directly comparable and should not be presented as a universal maximum or as a water-absorption "rate."

End-of-life degradation data likewise require qualification. Van Wylick et al. (2022) reported 43% mass loss for heat-inactivated Ganoderma resinaceum / hemp composites and 50.8% for living specimens after 16 weeks in potting soil. Jiménez-Obando et al. (2025) reported maximum drying shrinkage of 53.6 ± 5.6% in fiber-containing Arboloco / Kikuyu-Ganoderma lucidum formulations. These are formulation- and test-specific results that identify possible failure modes; they are not expected values for every MBC.

Protective treatments investigated in the literature include bio-resins, natural waxes, mineral coatings, and composite facings. These may reduce short-term water uptake, but long-term performance under repeated wetting, drying, temperature change, abrasion, and coating damage remains insufficiently documented. Treatments may also increase embodied carbon and cost, restrict vapor movement, trap internal moisture, or reduce biodegradability (Appels et al., 2019; Alaneme et al., 2023; Lewandowska et al., 2025).

The literature identified in this review did not provide substantial multi-year, in-service durability evidence for complete MBC building assemblies. Future studies should evaluate complete assemblies under cyclic humidity and temperature exposure, including joints, fixings, facings, coatings, timber framing, plasterboard, and other adjacent materials (Ghazvinian & Gürsoy, 2022; Lewandowska et al., 2025).

7.2 Fire Performance

MBCs are organic composites, and thus require careful and precise fire-performance evaluation. Experimental studies report charring and variable resistance to ignition and flame spread, but results differ with density, substrate, specimen size, moisture content, coatings, and test method (Alaneme et al., 2023). The evidence does not support a single general fire classification for all MBCs.

Mineral coatings, silicification, intumescent layers, and other treatments have been investigated as flame-retardant strategies. However, published MBC studies have not consistently used directly comparable fire-test procedures. Relevant product-testing frameworks include EN 13501-1:2018 for European reaction-to-fire classification and ASTM E84-24 for comparative surface flame-spread and smoke-development measurements in the United States (Alaneme et al., 2023; CEN, 2018; ASTM

International, 2024). Small laboratory ignition tests do not alone establish performance relating to heat release, smoke production, combustion toxicity, or fire resistance in complete wall and ceiling systems (CEN, 2018; ASTM International, 2024).

Fire claims should thus report the exact testing standard, specimen configuration, treatment, and classification achieved. Product-specific certification will remain necessary before MBCs can be broadly used in occupied and regulated building applications.

7.3 Production Scalability and Feedstock Variability

Laboratory and pilot-scale MBC production has been demonstrated, but industrial scaling changes the energy, logistics, contamination-control, and quality-assurance requirements of the process. Cultivation also requires controlled temperature, humidity, airflow, and sanitation. These conditions add equipment, building-space, labor, and energy costs that may not be fully represented in laboratory assessments (Volk et al., 2024; Alaneme et al., 2023).

Current production rates are slower than many continuous industrial processes. Reviews report incubation periods ranging from approximately 5 to 42 days, depending on fungal species, substrate volume, geometry, and process conditions, followed by drying or heat treatment (Alaneme et al., 2023; Sydor, Cofta, et al., 2022). Although still experimental, faster-growing strains, optimized substrates, increased automation, and alternative processing systems may improve throughput.

Feedstock variability presents an additional challenge. Most published studies use prepared hemp hurd, clean sawdust, grain spawn, or other relatively standardized inputs. Real agricultural residues vary in moisture, lignin and cellulose content, particle form, storage history, contamination, harvest method, and geographic origin. Laboratory results may thus represent performance that cannot be reproduced consistently using minimally processed local waste (Alaneme et al., 2023; Sydor, Cofta, et al., 2022).

Industrial research should report feedstock rejection rates, preprocessing requirements, losses from contamination, production yield, energy consumption, batch-to-batch variability, and the percentage of products that meet specification. Without these data, laboratory material performance cannot be translated reliably into commercial cost or environmental performance (Volk et al., 2024; Lewandowska et al., 2025).

7.4 Economic and Commercial Uncertainty

The economic competitiveness of MBCs remains uncertain because most published research reports material properties rather than complete manufacturing and installed costs. Agricultural residues may be inexpensive or locally abundant, but raw substrate price represents only one component of production. Additional costs can also include sorting, grinding, sterilization or pasteurization, inoculation, climate-controlled incubation, contamination management, drying, labor, quality testing, rejected batches, coatings, packaging, transport, certification, and installation (Jiang et al., 2016; Lewandowska et al., 2025).

Batch incubation periods reported in the literature range from approximately 5 to 42 days and may limit throughput compared with mature insulation industries that use highly automated continuous manufacturing

(Jiang et al., 2016; Sydor, Cofta, et al., 2022). However, local production could reduce feedstock and product transport, avoid disposal costs for some agricultural residues, and support distributed manufacturing (Jiang et al., 2016; Ecovative, n.d.). The economic balance depends on facility scale, local labor and energy prices, feedstock preprocessing requirements, contamination rate, production yield, treatment system, product lifespan, and market demand.

Publicly available evidence remains insufficient to establish broadly transferable costs such as the cost per square meter, cost per unit of thermal resistance, or total installed life-cycle cost for construction-grade MBCs relative to expanded polystyrene, mineral wool, cork, hemp-based insulation, or other bio-composites. Commercial availability demonstrates that products can be sold, but it does not establish cost parity with mature incumbent materials (Lewandowska et al., 2025).

Future techno-economic assessments should report capital expenditure, operating expenditure, labor, energy consumption and production throughput, contamination losses, usable-product yield, coating and certification costs, transport distance, installation requirements, maintenance, replacement interval, and end-of-life cost. Comparisons should use equivalent functional units, such as cost per square meter at a specified thermal resistance and service life, rather than cost per kilogram alone.

7.5 Regulatory and Standards Frameworks

MBCs do not currently have a widely adopted product standard specific to their biological composition and performance characteristics. In the European Union, Regulation (EU) 2024/3110 provides the current construction-products framework, whilst transitional provisions retain parts of Regulation (EU) No 305/2011. For products not covered by a performance-harmonized standard, the European Organisation for Technical Assessment route provides a voluntary pathway to CE marking. A manufacturer may request a European Technical Assessment based on a European Assessment Document and, if one is issued, use it to prepare the applicable declaration and affix CE marking (European Parliament and Council of the European Union, 2024; European Commission, n.d.). In the United States, materials not specifically prescribed by the applicable building code may be considered under IBC Section 104.11, which allows approval when the building official finds the alternative equivalent in quality, strength, effectiveness, fire resistance, durability, and safety (International Code Council, 2021).

Existing insulation tests can measure properties such as thermal conductivity, but protocols have not yet been harmonized specifically for MBC biological variability, moisture cycling, degradation control, coating durability, and end-of-life biodegradability. Regulatory acceptance will thus depend on product-specific evidence and the eventual development of consistent test methods (Alaneme et al., 2023; European Parliament and Council of the European Union, 2024; International Code Council, 2021).

7.6 Future Research Priorities

Table 8. Priority Evidence Required for MBC Commercialization

Research Area	**Required Study**	**Minimum Reporting Elements**
Moisture and durability	Multi-year cyclic humidity, wetting, drying, thermal and abrasion tests	Specimen composition, coating, exposure cycles, strength retention, dimensional change
Fire performance	Harmonized small- and full-scale assembly testing	Test standard, heat release, flame spread, smoke, toxicity, treatment
LCA	Industrial-scale harmonized comparative LCA	Electricity mix, functional unit, transport, system boundary, biogenic carbon, respiration, service life, disposal
Feedstock variability	Testing across realistic regional and seasonal residues	Composition, moisture, contamination, preprocessing, batch variability
Manufacturing	Pilot and industrial production trials	Energy, labor, growth time, contamination, yield, rejected products
Economics	Full techno-economic comparison	Capital cost, operating cost, price per functional unit, installation, maintenance, replacement
Biodegradation	Controlled end-of-life testing	Coatings, additives, disposal conditions, degradation rate, residual material

Research Area	Required Study	Minimum Reporting Elements
Regulation	Product-specific and harmonized test development	Repeatability, safety thresholds, complete assemblies, certification routes

Note. Priorities synthesized from Appels et al. (2019), Ghazvinian & Gürsoy (2022), Alaneme et al. (2023), Volk et al. (2024), Wildman et al. (2025), and Lewandowska et al. (2025).

Research opportunities should be evaluated together rather than independently. A coating that improves moisture or fire performance may alter embodied carbon, cost, vapor behavior, and biodegradability. Similarly, faster manufacturing may change density or material performance. Future studies should thus report technical, environmental, and economic consequences within the same product system.

8. CONCLUSION

This review finds that MBCs are credible lower-carbon candidates for selected non-structural applications, particularly thermal insulation, acoustic treatment, interior panels, packaging, temporary architectural elements, and other low-load applications. Standard MBC thermal conductivity commonly falls between approximately 0.038 and 0.058 W/m·K, overlapping the ranges reported for expanded polystyrene, mineral wool, and expanded cork. Their density, commonly approximately 50–250 kg/m^3, is also substantially below the approximately 2,320–2,400 kg/m^3 density of normal-weight concrete (ACI Committee 318, 2014; Alaneme et al., 2023; Joshi et al., 2020; Zhou et al., 2025).

The evidence does not support MBCs as a complete replacement for structural concrete. Standard MBC compressive strengths commonly fall between approximately 0.05 and 0.50 MPa, whilst selected experimental studies have reported values from 2.409 MPa to approximately 7.5 MPa using substantially different formulations and test procedures (Joshi et al., 2020; Zhou et al., 2025; Sharma & Le Ferrand, 2025). These results are not directly comparable, remain below the 20–80 MPa structural-concrete comparator range used here, and do not establish code-qualified structural use. MBCs may nevertheless offer advantages in non-structural applications where concrete's strength and mass are unnecessary.

Published life-cycle assessments indicate potential climate-change advantages over selected synthetic insulation systems, but they do not support a universal 70–90% reduction. Volk et al. (2024) reported 0.3668 kg CO_2-eq/kg for a laboratory-scale German cradle-to-gate model, whereas Alaux et al. (2024) found greenhouse-gas emissions about half of those of PUR and XPS and only slightly below rock wool in a prospective, functionally based cradle-to-grave comparison. Results remain conditional on production scale, electricity mix, system boundary, functional unit, service life, biogenic-carbon accounting, and end-of-life assumptions.

Durability remains the most important technical uncertainty. Reported examples include water uptake of 237 ± 10% after 24-hour immersion in one mixed-substrate bioblock, 43% soil-burial mass loss after 16 weeks in one heat-inactivated composite, and maximum drying shrinkage of 53.6 ± 5.6% in particular Arboloco / Kikuyu formulations (Joshi et al., 2020; Van Wylick et al., 2022; Jiménez-Obando et al., 2025). These are study-specific results rather than universal material properties, but they demonstrate the need for moisture control, dimensional-stability testing, and long-term service-life evidence.

Commercial products and architectural demonstrations provide evidence of technical feasibility (Museum of Modern Art, 2014; Ecovative, n.d.; Mogu, n.d.; Biohm, n.d.), but they do not yet establish industrial-scale cost parity, multi-decade durability, or broad regulatory acceptance. Published evidence remains limited regarding capital and operating costs, contamination losses, quality-control requirements, treatment costs, installed price, maintenance, and replacement intervals.

MBCs should thus be understood as a developing class of bio-based materials rather than a universal concrete replacement or a fully mature construction technology. Their environmental and functional case is strongest when they replace synthetic insulation or unnecessary non-structural concrete. Broader adoption will depend on whether industrial-scale research can demonstrate consistent feedstock performance, durable and fire-safe assemblies, transparent life-cycle advantages, economic competitiveness, and compliance with recognized construction standards.

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