Brief Report

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Bio-Based Construction Materials in the Context of the EU Bioeconomy

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Abstract

The construction industry faces a dual imperative: continued growth to meet the demands of a rapidly expanding global population, and deep decarbonisation to align with planetary boundaries and climate commitments embedded in frameworks such as the European Green Deal and the EU Bioeconomy Strategy. This paper examines the potential of bio-based construction materials to bridge these competing demands, reviewing evidence across a broad spectrum of material categories — including fast-growing plant-based materials, bio-based admixtures and polymer composites for concrete, bio-based polyurethanes, nanocellulose and cellulose aerogels, plant-based biocomposites, and mycelium-based composites. The review demonstrates that bio-based materials offer compelling environmental advantages over conventional petrochemical-derived alternatives, including superior carbon sequestration potential, reduced embodied carbon, improved indoor environmental quality, and compatibility with circular economy principles. The strategic urgency of this transition has been rendered concrete by the 2026 Strait of Hormuz crisis, which triggered severe disruptions to global petrochemical supply chains and exposed the structural vulnerability of European construction to fossil-derived material inputs — reframing bio-based alternatives as a supply security imperative alongside an environmental one. However, the transition from demonstrator projects to mainstream specification practice remains constrained by persistent technical, economic, and regulatory barriers, including inconsistencies in life cycle assessment methodologies, the absence of harmonised performance standards, certification gaps, high initial costs, and fragmented supply chains. Crucially, the review identifies that resolving these barriers depends not only on continued material innovation but equally on governance configurations, policy stability, and actor coalitions, with the conditions under which green finance, circular procurement, and regulatory instruments successfully accelerate material adoption varying substantially depending on who orchestrates systemic coordination.

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1. Sustainability challenges, Resource Scarcity and the Bioeconomy's Path Forward

In a world grappling with limited resources exacerbated by unsustainable patterns of production and consumption and a burgeoning global population, the urgency to transition towards more sustainable economic models is widely recognised. Differing viewpoints emerge on the achievability of this transition. While Stoknes and Rockström (2018) express pessimism, contending that current approaches are insufficient to align human activity with the ecological capacities of the planet, Randers et al. (2018) suggest that meeting all Sustainable Development Goals by 2030, or even by 2050, may prove elusive. A study conducted by researchers at the University of Cambridge builds upon the seminal work of "The Limits to Growth," projecting temperature increases of approximately 8–12 °C under a 'runaway global warming' scenario and forecasting a precipitous decline in food production, with an estimated 6 billion lives at risk of perishing due to starvation by the year 2100 (Richards et al., 2023). In the absence of immediate systemic breakthroughs, incremental improvements represent the most viable short-term pathway. Institutions such as UNEP, the World

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Bank, and the European Commission accordingly advocate for the adoption of green economy and green growth principles, approaches that aim to achieve more with less by fostering enhanced human well-being and social equity.

Recent years have seen a surge in demand for natural, bio-derived, and biotechnology-based products in industrial settings, driven by concerns about environmental impact, waste management challenges, and the depletion of non-renewable resources. In 2002, the EU initiated its Strategy on Biotechnology (EU, 2002), followed by a significant milestone in 2012 when the European Commission introduced the world's first bioeconomy strategy and action plan. The bioeconomy is defined as an economic framework in which the fundamental components for materials, chemicals, and energy are sourced from renewable biological resources, encompassing all sectors and systems dependent on biological resources — including animals, plants, microorganisms, and derived biomass (Schanes et al., 2019). Global demand for bio-based products is on the rise, with EU demand projected to reach a market value of 50 billion euros and help create one million new jobs by 2030.

Ramcilovic-Suominen and Pülzl (2018) argue that the EU uses sustainable development as a marketing tool to promote its bioeconomy strategy, focusing on biotechnology, eco-efficiency, and economic output while neglecting broader sustainability goals such as biodiversity, equity, and social justice. The European Green Deal, launched by the European Commission in December 2019, seeks to transition the EU towards a low-carbon, sustainable growth model that prioritises food and energy security, biodiversity, and effective natural resource management, with the bioeconomy playing a crucial role. Pianta and Lucchese (2020) argue that the Green Deal must be integrated with a more ambitious industrial policy and a unified vision of future challenges, recognising that market-based solutions alone cannot resolve environmental problems and that public authorities must lead economic transformation.

D'Amato and Korhonen (2021) compared the green, circular, and bioeconomy models for their potential to achieve global net sustainability, emphasising the need for an economy grounded in renewable and biodiversity-friendly processes. They caution that without explicitly considering global net sustainability, implementing these models individually or jointly can result in unintended negative effects — such as problem displacement, cascade effects, and rebound effects — that undermine sustainability efforts. Ronzon et al. (2022) demonstrated that the bioeconomy has maintained its relative importance within the EU27 economy, with agriculture and the food industry as key drivers of the transition, though meaningful progress remains largely elusive in Eastern and Central Europe. Firoiu et al. (2023) emphasised the importance of bioeconomy statistics for evidence-based policymaking, finding that Western European countries consistently outperformed the Baltic states and Central and Eastern Europe, though the latter showed growth potential exceeding 20% above the EU average, with Belgium and Denmark highlighted as role models.

The policy landscape surrounding the bioeconomy has continued to evolve significantly. On 27 November 2025, the European Commission adopted a new Strategic Framework for a Competitive and Sustainable EU Bioeconomy (European Commission, 2025), marking the most substantial revision of EU bioeconomy policy since the original 2012 strategy. Unlike its predecessors, which prioritised research and innovation, the 2025 Framework explicitly shifts focus towards industrial deployment, market scale-up, and geopolitical competitiveness, positioning the bioeconomy as a core pillar of EU industrial resilience and strategic autonomy. The document sets a 2040 vision in which sustainable bio-based materials — including construction materials, biochemicals, textiles, fertilisers, and bio-based plastics — are widely deployed across the EU as fossil-free alternatives to petroleum-derived products. In quantitative terms, the EU bioeconomy already generates up to €2.7 trillion in value added and supports an estimated 17.1 million direct jobs, equivalent to approximately 8% of total EU employment (European Commission, 2025). The Framework establishes lead markets for bio-based materials, explicitly listing construction products, and creates a Bio-based Europe Alliance targeting €10 billion in collective procurement by 2030. Key legislative instruments including the revised Construction Products Regulation and the Ecodesign for Sustainable Products Regulation are expected to be progressively adapted to incorporate bio-based content criteria, certification pathways, and carbon storage accounting (European Commission, 2025). These developments represent a decisive institutional signal that the sector's transition from niche to mainstream is now an explicit political objective at EU level.

The strategic logic underpinning this reorientation has been rendered concrete and urgent by the ongoing 2026 Strait of Hormuz crisis, which constitutes what the International Energy Agency has described as the largest supply disruption in the history of the global oil market (IEA, 2026). Since Iran declared the strait effectively closed in March 2026, tanker traffic collapsed and crude oil prices exceeded USD 100 per barrel, triggering cascading effects throughout global petrochemical supply chains that are directly material to the European construction sector. Naphtha — the primary feedstock for European steam crackers and the precursor to key construction polymers including polyvinyl chloride (PVC), polyethylene (PE), polyurethane insulation foams, and polypropylene — surged by approximately 74% in the first two weeks of the crisis, with polymer prices rising between 41% and 75% across product lines (Polymerupdate, 2026).

Taken together, these cascading vulnerabilities illuminate a structural asymmetry at the core of Europe's industrial base: sectors reliant on petrochemical inputs sourced from a single geopolitical chokepoint are, by definition, incompatible with the EU's stated objectives of supply chain resilience, strategic autonomy, and long-term industrial competitiveness. The substitution of petroleum-derived construction materials — EPS insulation boards, synthetic sealants, PVC window profiles, and polyurethane panels — with domestically produced bio-based equivalents such as cellulose fibre insulation, bio-based polyurethane from castor oil, cork composites, and mycelium boards, is therefore not merely an environmental proposition: it is a supply security imperative whose strategic salience has been demonstrated empirically by the events of early 2026. In this reading, the EU Bioeconomy Framework's designation of construction products as a priority lead market for bio-based materials acquires a dimension that purely ecological or circular economy framings cannot capture — that of critical infrastructure resilience in the face of systemic geopolitical risk.

2. The Promise of Bio-Based Materials Toward a Sustainable Construction Industry

2.1. The Construction Industry and the Case for Bio-Based Materials

Although the future of humanity remains shadowed by serious environmental challenges, the construction industry is certain to continue growing due to an increasing world population, projected to reach 11 billion by 2100. In this context, the use of bio-based construction materials is crucial for reducing the industry's environmental footprint. While bio-based materials like timber have long been used, particularly for structural purposes, they have struggled to compete with the superior performance of steel and reinforced concrete in the construction of increasingly taller skyscrapers. However, the imperative of sustainable development in recent years is changing this dynamic, and the scientific community is actively contributing to the revival and advancement of bio-based materials.

The imperative to decarbonise the construction sector has given renewed urgency to the study of fast-growing bio-based materials. A 2026 review identifies bamboo, hemp, straw and mycelia as a critical cluster of materials with substantial potential for simultaneous carbon capture and storage in the built environment, arguing that achieving a net-zero built environment will require the creation of intersectoral synergies and a deliberate move away from single-material solutions such as timber, which faces growing constraints from deforestation pressures and land-use competition (Göswein et al., 2026). A comparative life cycle analysis by Cosentino et al. (2024), employing the Building Emissions Accounting for Materials (BEAM) methodology, demonstrated that fast-growing bio-based materials — bamboo, straw, hemp and flax — store carbon more rapidly than conventional alternatives and contribute to healthier indoor environments through superior moisture regulation, directly supporting progress towards UN Sustainable Development Goals 11 and 12 on sustainable cities and responsible consumption. These findings reinforce earlier work by Pittau et al. (2018, 2019) while extending its scope to a broader range of fast-growing species and adding an explicit SDG framework. Mechanically, a comprehensive 2025 review of bio-based structural members concludes that, while moisture absorption and temperature sensitivity remain performance constraints relative to steel and concrete, advances in hybridisation and nanotechnology are progressively improving the mechanical robustness, durability and load-bearing capacity of bio-based composites (Barbhuiya et al., 2025). Taken together, these contributions confirm that the scientific trajectory of bio-based construction materials is shifting from demonstrating feasibility to quantifying system-level performance at the scale of buildings and urban stocks. The maturity and breadth of this research effort is reflected in the edited volume by Pacheco-Torgal and Tsang (2025), which consolidates advances across bio-based materials for construction and energy efficiency and provides a comprehensive reference framework against which the specific material categories reviewed in the following subsections can be situated

2.2. Bio-Based Admixtures and Polymer Composites for Concrete

Approximately 15% of the total ordinary Portland cement (OPC) concrete production — the most widely used construction material on Earth — contains chemical admixtures to modify its properties in both fresh and hardened states. These superplasticizers, based on synthetic polymers such as melamine, naphthalene condensates, or polycarboxylate copolymers, improve workability, strength, and durability. However, these admixtures are derived from the fossil fuel industry, which is responsible for significant environmental disasters. As oil exploration ventures into deeper, stormier, and icier seas, the associated risks escalate, underscoring the need for new biodegradable polymers derived from renewable sources. Examples of bio-based admixtures used in concrete include lignosulfonate, starch, chitosan, pine root extract, protein hydrolysates, and vegetable oils. However, investigations into the use of biopolymers in OPC remain limited; of the 10,000 Scopus-referenced journal papers on OPC published since 2000, less than 1% explore biopolymer applications.

Recent research has begun to address this gap more systematically. Boutouam et al. (2024) conducted a comprehensive bibliometric and systematic review of plant-based biopolymers as viscosity-modifying admixtures (VMAs) in cement-based materials, evaluating cellulose, starch, alginate, pectin, and carrageenan as sustainable alternatives to synthetic VMAs. Their analysis, covering publications from 2000 to 2023, confirms a significant upward trend in research activity since 2017, while also noting that bio-based VMAs remain in an early commercialisation phase, constrained by inconsistencies in dosage optimisation and compatibility with superplasticizers. Complementing this, Ševčík et al. (2025) demonstrated a new class of bio-based latex admixtures synthesised from camelina, linseed, and rapeseed vegetable oils incorporated into OPC fine-grained mortars at 0.1 wt%, finding that the water absorption coefficient was reduced by approximately 40% compared to control mixes and that compressive strength was maintained at comparable levels to conventional cement mortar. These findings provide experimental confirmation that bio-based polymer admixtures can deliver functional equivalence to their petrochemical counterparts at relevant dosage levels.

Carbon fibre reinforced polymers (CFRP) represent a widely recognised technological solution for structural strengthening in civil engineering applications. Nevertheless, their expense and high environmental footprint are significant concerns raised by some authors. Ghorbel et al. (2021) confirmed that bio-sourced flax fibre-reinforced polymer is a promising material for confining recycled aggregate concretes, providing consistent strength and strain enhancements. This line of research has been extended by a systematic bibliometric review covering 87 experimental studies, which demonstrated that natural fibre reinforced polymer (NFRP) materials — using flax, jute, hemp, and bio-based epoxy matrices — can effectively strengthen concrete beams and columns, with some formulations achieving cost efficiencies 20–40% higher than CFRP, while also identifying durability and standardisation of design frameworks as the principal barriers to adoption (Adesina & Olutoge, 2022). Jahami et al. (2024) further synthesised the broader literature on natural fibre reinforcement in structural concrete, establishing that fibre chemical composition — dependent on species, environment, and geography — has profound implications for mechanical properties, and that optimal fibre concentrations vary considerably across species, underscoring the need for species-specific design guidance. Sain et al. (2021) synthesised formaldehyde-free bioresin adhesives from lignin and tannin obtained from softwood bark, an approach that has gained further traction as the pressure to eliminate formaldehyde from construction adhesives has intensified under EU indoor air quality regulations.

2.3. Bio-Based Polyurethanes and Thermal Insulation Polymers

Another important polymer widely used by the construction industry is polyurethane, applied primarily in thermal insulation. In recent years many investigators have dedicated effort to the development of bio-based polyurethanes derived from renewable polyols. Andersons et al. (2020) developed rigid high-density polyurethane foams using polyols derived from renewable tall oil fatty acids for use as structural thermal break materials. Oliveira et al. (2022) studied castor oil-based polyurethane reinforced with açaí waste as an alternative for eco-efficient building insulation. More recently, Zarmehr et al. (2024) published a state-of-the-art comparative review of bio-based polyurethane insulations specifically in the construction context, concluding that bio-based components such as plant oils and natural fillers maintain the mechanical integrity of insulation panels, enhance acoustic absorption and heat-transfer properties through their porous microstructure, and that the overall eco-friendliness of these systems depends critically on the selection of bio-components throughout the supply chain rather than being an automatic consequence of bio-based content. At the market scale, over 57% of polyurethane manufacturers globally had integrated at least one bio-based grade into their portfolio by 2025, with bio-based rigid foam applications accounting for approximately 30% of total bio-based polyurethane volume and representing roughly 34% of the total construction insulation market share in leading markets. This trajectory confirms that bio-based polyurethanes are completing the transition from research curiosity to mainstream commercial offering, though performance parity in fire resistance and long-life durability under real service conditions remains an active area of research.

2.4. Nanocellulose and Cellulose Aerogels

The nanotechnological advancements of the past decade have paved the way for the development of new and improved biopolymer-based materials. Research on cellulose nanocrystals — cellulose elements with at least one dimension in the 1–100 nm range — represents a significant and recent nanotech field that promises eco-efficient, high-performance materials. As the most abundant organic polymer on Earth, cellulose — producing about 1.5 trillion tons annually — is renewable, biodegradable, and carbon neutral, with the potential for industrial-scale, low-cost processing, making it a green biotech source for future building materials. Cellulose aerogel is another promising application for developing high-performance thermal insulator building materials. These insulators, with thermal conductivity lower than 0.020 W/mK, outperform current petroleum-based insulation materials like expanded polystyrene (EPS) and extruded polystyrene (XPS), which have values around 0.03–0.06 W/mK. The use of high-performance thermal insulation is critical for reducing heat losses in buildings, thereby increasing energy efficiency. Additionally, as non-flammable materials, aerogels do not release toxic fumes under fire conditions, unlike current insulation materials like EPS and XPS, providing a significant safety advantage.

Since the publication of Sen et al. (2022), the commercialisation landscape for bio-based aerogels has progressed considerably. At the market level, the global aerogel insulation sector is projected to grow at a compound annual growth rate of approximately 17% over the 2025–2035 period, driven by tightening energy efficiency regulations in the construction sector and improvements in ambient-pressure drying processes that reduce production costs relative to traditional supercritical drying (CAS, 2025). At the materials innovation level, Nanoplume, a Cambridge-based start-up, has demonstrated a cellulose-based aerogel manufactured through a bio-based, ambient-pressure

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process that achieves thermal conductivities within the super-insulating category, addressing the dual barriers of cost and scalability that have historically constrained cellulose aerogel deployment (Wakley, 2025). A particularly noteworthy development concerns the application of cellulose aerogels to building glazing.

Abraham et al. (2023) demonstrated highly transparent silanised cellulose aerogels — designated SiCellA — with visible-range light transmission of 97–99%, haze of approximately 1%, and thermal conductivity lower than that of still air, compatible with roll-to-roll processing and suitable for integration into multi-pane insulating glass units and window retrofits. This application extends the utility of cellulose aerogels well beyond opaque insulation panels and into the building envelope's weakest thermal link. In April 2024, Empa researchers further demonstrated the integration of cellulose aerogels into 3D-printable biodegradable materials, opening a path towards geometrically complex, customised insulation components fabricated through additive manufacturing (Sivaraman et al, 2024). These converging advances suggest that the commercialisation barriers identified in earlier literature are progressively being resolved, though large-scale industrial deployment in the construction sector remains at an early stage.

2.5. Plant-Based Materials: Biocomposites, Prefabrication, and Circular Economy Assessment

Petrescu et al. (2021) provided insights into the steps necessary for biocomposites to become ready-to-use products in the construction industry, specifically in structural roles. Their study addresses the development and adoption of these materials through two key concepts: technology readiness level and roadmapping. This approach is illustrated with a case study on "liquid wood." The study resulted in a customised roadmap highlighting a predominantly non-technical viewpoint regarding the material, identifying potential adoption and diffusion challenges and offering further recommendations to address these issues. A review by Boros and Tőzsér (2023) of 977 publications revealed a yearly increase in relevant papers, with most belonging to the engineering discipline. The literature thoroughly evaluates a wide range of plant-based building materials, which are primarily used to enhance the mechanical properties of conventional materials; many are also tested as substitutes for traditional ones. The most assessed plant-based materials and their documented uses in the construction industry are summarised in Table 1 (Boros & Tőzsér, 2023).

Table 1. The most assessed plant-based materials and their use in the construction industry in the studied literature Boros and Tőzsér (2023).

Building Material/Procedure	Plant-Based Material	Products Created after Plant-Based Material Use	Related Publication(s)
Cement production	agricultural palm waste	cement composites	[47,70]
	mixed plant-based agricultural waste	biocomposites as reinforcers, plasticizers, and insulators	[47,71]
	rice and reed fiber	reinforced cementitious panels and biocomposites with increased compressive strength	[72,73]
	hemp fiber	cement-based mortar with increased compressive and flexural strength	[74]
	sugarcane bagasse ash	cement-based products with increased compressive strength	[75,76]
Concrete production	palm kernel shell	lightweight concrete aggregate	[46,77]
	mixed plant fibers	reinforced concrete	[78]
	coconut fiber	high-strength reinforced concrete with increased compressive and bending strength	[46,49,79–82]
	biofilm with microorganisms	concrete with increased bioreceptivity	[83]
	hemp	concrete with reinforced internal structure and increased self-healing ability	[84–87]
	bamboo fiber	agent treating concrete cracks, high-performance concrete with decreased shrinkage	[53,88–90]
	juta fiber	reinforced concrete	[91–93]
	pineapple leaf fiber	reinforced concrete	[94]
	flax fiber	reinforced concrete with increased compressive strength	[49,95]
	granulated cork	concrete and mortar with increased insulating property	[54]
	tobacco waste	lightweight concrete	[96]
	resins from different origin	translucent concrete	[97]

Brick production	building waste materials with mycelium	bio-composite mycelium bricks	[61]
Wood-based products	delignified, succinylated birch wood	transparent wood	[37]
	chitosan	wooden surfaces with increased flame resistance	[98]
	fungal melanin, linseed, and tree tea oil	wooden materials with increased antibacterial effects and water resistance	[99]
	peanut husk	green composite panels with increased flame resistance	[56]
Sealing and insulation materials	nanocellulose	performance improvement of tannin-based foams	[43]
	various plant species	bio-green insulation panels	[100,101]
	coconut fiber	insulation ceiling board, fibrous thermal insulation	[102,103]
	peat	thermal insulation material	[104,105]
	sawdust	green insulation panels	[106]
	arch, pine, spruce, fir, and oak tree bark resins	insulation panels	[107]
	beet-pulp fiber with potato starch	biopolymer composites with increased insulation property	[108]
	almond skin	sound absorber materials	[109]
Other	spent coffee grounds	mortar with increased technical and sustainability performance	[110]

Le et al. (2023) reviewed 97 articles with the aim of categorising case studies, examining the state-of-the-art in sustainability assessments, and highlighting the pros and cons of circular bio-based building materials. The results indicate that material scale is the most researched aspect, with environmental analysis — primarily using life cycle assessment — being the most frequently studied dimension, followed by economic analysis. Research on social impact is still in its early stages. Regarding the balance of advantages and disadvantages, circular bio-based building materials generally outperform traditional materials in reducing initial production costs and mitigating environmental impacts, particularly in terms of climate change and abiotic resource use. However, some bio-based materials perform worse in categories such as eutrophication and land use, and may not be economically viable when considering the entire life cycle. These findings underscore that the sustainability case for bio-based materials, while broadly compelling, requires nuanced assessment at the level of individual material types, applications, and geographic contexts.

2.6. Mycelium-Based Composites: An Emerging Frontier

Among emerging bio-based materials, fungal mycelium-based composites (MBCs) have attracted exceptional research interest since 2022 and merit dedicated attention beyond the limited references available at the time of writing. MBCs are biocomposites produced through the controlled growth of filamentous fungi on lignocellulosic substrate waste — typically agricultural by-products such as straw, sawdust, or hemp shiv — which the mycelium colonises and binds into a dense, self-reinforced matrix upon drying or heat-treatment. Their appeal for construction applications derives from a combination of properties that few conventional materials can match simultaneously: thermal conductivities in the range of 0.036–0.06 $W \cdot m^{-1} \cdot K^{-1}$, acoustic absorption 70–75% superior to conventional ceiling tiles and polyurethane foams, inherent fire resistance conferred by chitin and β-glucan cell wall components, and a global warming potential that can be net-negative when biogenic carbon sequestered during cultivation exceeds lifecycle emissions (Motamedi et al., 2025; Parhizi et al., 2025). A critical review further reported Young's moduli of up to 3.66 GPa in optimised MBC formulations, indicating mechanical performance approaching that of low-density wood products, while separate analysis found that MBCs exhibit up to 70% lower embodied carbon than conventional insulation materials such as expanded polystyrene (Parhizi et al., 2025).

The most commonly employed fungal species in construction applications are Ganoderma lucidum and Pleurotus ostreatus, cultivated on straw, wood, and sawdust substrates (Bonenberg & Bonenberg, 2025). An analysis of 90 real-world architectural and design projects between 2007 and 2024 confirms that modular building blocks and bricks represent the fastest-growing application category, though construction use remains largely confined to temporary and demonstration structures (Bonenberg & Bonenberg, 2025). A study focused on the Helsinki metropolitan area demonstrated that large-scale substitution of conventional insulation with mycelium-wood composites could enable building stocks to act as net carbon sinks, with stored CO_2 potentially equalling or surpassing the carbon storage of equivalent forest areas — though realising this potential

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is heavily contingent on increasing annual renovation rates (Ruta et al., 2024). Key barriers to wider adoption include process standardisation, moisture sensitivity, and the absence of harmonised performance standards, though recent advances in additive manufacturing and microstructural optimisation suggest a viable pathway towards broader industrial deployment (Motamedi et al., 2025).

2.7. Barriers, Upscaling, and the Path to Mainstream Adoption

Despite a growing body of evidence confirming the technical viability of bio-based construction materials, their transition from demonstrator projects to mainstream specification practice remains slow and uneven. The core argument of this section is that technical performance, while necessary, is not the binding constraint on adoption. The evidence consistently points instead to a compounding set of economic, institutional, and governance failures that reinforce one another, and which cannot be resolved through material innovation alone.

The most systematic practitioner assessment of these failures is provided by Dams et al. (2023), who conducted semi-structured interviews with senior professionals experienced in bio-based construction, identifying barriers clustered around three persistent categories: finance, knowledge, and policy. Within these, the most disabling constraints were difficulties scaling production, inconsistent life cycle assessment methodologies, and a lack of material certification frameworks that specifiers could rely upon. Critically, vested interests within the established construction industry were also identified as an active rather than merely passive obstacle — a point that distinguishes this analysis from purely technical accounts of the adoption problem. Buro Happold (2024) reached broadly compatible conclusions from an industry perspective, confirming that while bio-based materials demonstrate sufficient technical performance across a range of construction applications, mainstream adoption remains contingent on resolving supply chain fragmentation, improving cost predictability, and building specifier confidence through documented project evidence. Together, these two assessments establish that the gap between demonstrated capability and routine specification is not primarily a performance gap — it is a market and institutional gap.

The technical performance case is, in fact, substantially established. Ye et al. (2025), in one of the most extensive reviews yet published in this field, synthesised findings from 395 experimental studies across a range of engineered and natural bio-based insulators, providing quantitative relationships that were previously unavailable to practitioners at this scale. Their analysis confirms that thermal conductivity scales linearly with density and is largely unaffected by ambient temperature, while acoustic noise absorption increases with material thickness and decreases at higher densities — relationships that provide a solid empirical foundation for design optimisation. Critically, bio-based insulation materials were shown to enable near-zero carbon footprints through the combined mechanisms of biogenic carbon sequestration and displacement of petrochemical insulants, a finding that substantially strengthens the environmental case for adoption. However, Ye et al. also highlight that improved moisture resistance and standardised durability testing remain outstanding requirements before widespread adoption can be responsibly recommended — a qualification that directly explains the persistent caution of specifiers identified by Dams et al. (2023) and Buro Happold (2024). The technical evidence base is maturing, but it has not yet closed on the durability questions that matter most to practitioners operating under long-term liability.

At the policy and systems level, Chen et al. (2024) offer the broadest synthesis reviewed here, examining relevant policies and life cycle assessments across multiple case studies and estimating that bio-based materials in construction hold potential to mitigate over 320,000 tonnes of carbon dioxide emissions by 2050. Their findings also demonstrate more immediate operational benefits, including reductions in water absorption of up to 40% and decreases in energy consumption of close to 10%. Yet their conclusions are candid about the structural conditions that continue to impede realisation of this potential: a lack of harmonised standards across jurisdictions, durability risks arising from bioerosion, and regulatory frameworks that, while increasingly supportive of innovation in principle, can simultaneously impose constraints that slow commercialisation in practice. The

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policy environment is therefore neither uniformly enabling nor uniformly obstructive — it is inconsistent, and inconsistency is itself a barrier, as it raises risk for investors and discourages the long-term production commitments needed to bring costs down. Prefabrication has emerged as one of the more promising structural responses to these commercialisation challenges. Sutkowska et al. (2024), drawing on a bibliometric analysis of 949 research articles and focusing on single-family housing in Central and Eastern Europe, argue that natural material prefabrication technologies offer the production consistency, quality control, and cost competitiveness that bio-based materials require to compete at scale. Table 2 provides a comprehensive overview of various technological solutions in the realm of natural materials. The trajectory of research in this area is itself instructive: publications in this field grew from 29 in 2015 to 175 in 2023, with 17 already recorded in the first months of 2024 — a pattern that reflects both increasing practical interest and an emerging consensus that manufacturing process innovation, not only material innovation, is essential to the scaling problem.

Table 2. Description of selected available prefabrication technologies using biobased materials (Sutkowska et al. 2024).

Material	Technology
	Cross Laminated Timber (CLT)
CLT panels-ZTC Latvia	The panels are made of spruce planks glued in perpendicular layers, from three to eight. The formaldehyde-free PUR glue makes the panels extremely durable and life-safe. Thanks to their high load resistance, building high-rise buildings using CLT timber is possible. The production process consists of cutting the material to specific dimensions, transferring it to the assembly stations, assembling the finished elements, packing them and transporting them to the finished products warehouse. The finished panels and timber elements are then transported to the construction site in the next stage. The prefabricated elements are assembled on-site. The panels are enriched with fire-resistant material between the layers of glued laminated timber. A thermal and acoustic insulation layer, such as wood wool, is also added to the panels. The production process is highly digitized. Timber for partition walls meets c16, and external walls meet c24. The maximum dimensions of a cross-laminated timber panel are 13,800 × 3100 × 400 mm [source:https://ztc.lv/en/prefabricated-houses-latvia/, access:November 16, 2023]
CLT frames-Tadeks Fertig Haus Poland	The material catalog presents a range of construction elements that includes panels and frames constructed from Cross-Laminated Timber (CLT) wood. These components are designed to accommodate insulation material, enhancing their thermal performance. The manufacturing process involves precision and efficiency, with the components being intricately cut using Computer Numerical Control (CNC) technology. Subsequently, the cut pieces are assembled and secured through adhesive bonding. Cross-laminated timber (CLT) is a versatile and sustainable building material known for its strength and dimensional stability. The use of CNC technology ensures accuracy in the cutting process, allowing for intricate designs and customized components. The adhesive bonding of the CNC-cut pieces

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contributes to the structural integrity of the assembled panels and frames, creating a durable and reliable construction solution. This approach combines the inherent benefits of CLT, such as its renewable and eco-friendly nature, with the precision and efficiency afforded by CNC technology. The resulting construction elements not only showcase the versatility of CLT but also exemplify a modern and efficient method of manufacturing components for sustainable building practices. [source:https://www.tadeks.pl/en/technology/prefabricated-houses, access:November 16, 2023]

Strawbale panels

Strawbale elements- Słomiany Dom, Poland

Słomiany Dom company, established in 2021, is manufactured in northern Poland. They prefabricate custom walls, roofs and floors with straw VestaEco FIBRA filling. It is a loose thermal insulation material made of annual plant fibers.

In the technology of wall-making, they use wooden frames and fill them manually with rectangular strawbales while compressing them using a press. Later, the excess straw is cut from both sides of the wall using a special blade machine. The panel can be as big as the cutting machine. Later, the walls are twisted together from smaller panels. The prefabricated panel lies flat throughout the creation process. The finished panels are stored vertically or horizontally on spacer boards. The size of the conveying machine limits the panel's dimensions.

Panels for external walls with a timber façade can have a wood wool insulation substructure and even cladding boards fitted straight away in the prefabrication process.

Strawbale parts -Modulina Latvia

Modulina specializes in the production of strawbale panels designed for exterior walls and roofs in construction. These panels are crafted by incorporating straw from round straw bales into a wooden framework. The utilization of round straw bales distinguishes this technology as particularly functional, especially considering the prevalence of round bales in contemporary agricultural practices compared to straw cubes. In the manufacturing process, the straw fibers are strategically laid within the wooden structure, primarily oriented across the wall. This arrangement ensures a robust and well-distributed composition within the panels. Strawbale construction leverages the natural insulating properties of straw, providing an effective thermal barrier. The panels contribute to sustainable building practices by utilizing a renewable and widely available agricultural byproduct. The incorporation of strawbale panels into exterior walls and roofs aligns with modern construction trends that prioritize eco-friendly materials and energy-efficient design. This approach not only offers an alternative to conventional building materials but also promotes the utilization of agricultural waste in construction, contributing to a more sustainable and environmentally conscious construction industry.

Strawbale

Ecococon is a company initially developing in Lithuania. The company is now

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modules - Ecococon Latvia/Slovakia	expanding internationally and is building another straw prefabricated factory in Slovakia. Their product catalog includes standard prefabricated modules assembled into walls on site. When designing, the designer can, therefore already plan at an early stage what the arrangement of the panels will look like. Panel thickness is 40 cm as standard.
	Hempcrete
Hempcrete pan–ls - DunAgroHemp Group, The Netherlands	Dun Agro Hemp Group is at the forefront of sustainable construction by producing tailor-made walls, partition walls, roofs, and floor panels. These components are crafted with precision to meet specific project requirements, showcasing the versatility of hemp-based construction solutions. The panels may even come pre-equipped with grooves designed for electrical installations, adding to the convenience and efficiency of the construction process. The construction process involves filling the wooden framework with a mixture of hempcrete, a composite material consisting of hemp fibers, lime, and water. This mixture serves as an environmentally friendly and insulating alternative to traditional building materials. Following the assembly of the wooden frame and the placement of hempcrete, a crucial step in the process is allowing the material to dry and set. This ensures the structural integrity and stability of the constructed elements. Dun Agro's approach enables the creation of entire walls or sections of larger walls, which are then assembled on-site. This modular construction method allows for flexibility in design and installation, contributing to efficient construction practices. Additionally, the use of hempcrete aligns with sustainable building principles, as hemp is a renewable resource with minimal environmental impact. The incorporation of hemp-based panels in construction projects reflects a commitment to eco-friendly building practices, emphasizing innovation, customization, and the utilization of natural materials. This approach contributes to the ongoing shift towards sustainable and resilient construction methods in the broader construction industry. [source:https://dunagrohempgroup.com/hemp-construction/, access:November 16, 2023]
Hempcrete structural blocks- JustBioFibers Canada	The utilization of prefabricated hempcrete blocks with integrated timber elements represents an innovative approach to construction, offering both structural support and insulation in a single, self-supporting unit. These blocks are designed to streamline the construction process by serving as building blocks that can be assembled much like traditional masonry blocks. Hempcrete, a mixture of hemp fibers, lime, and water, is the primary material in these blocks. The incorporation of timber elements adds structural integrity and support to the blocks. The combination of hempcrete and timber creates a cohesive, modular unit that provides both insulation and load-bearing capabilities. The assembly process is straightforward, akin to stacking blocks. The

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prefabricated hempcrete blocks with timber elements interlock, creating a self-supporting structure. This method enhances construction efficiency, as the blocks can be quickly and easily assembled on-site. The modular nature of these blocks allows for flexibility in design and construction, accommodating various architectural styles and project requirements. Beyond their structural and insulating properties, these prefabricated blocks contribute to sustainability in construction. Hemp is a renewable resource with minimal environmental impact, and the use of hempcrete aligns with the growing emphasis on eco-friendly building practices. The integration of timber elements further enhances the overall strength and durability of the construction. Overall, this approach represents a fusion of natural materials and modern construction techniques, catering to both environmental concerns and the need for efficient and resilient building solutions. [source: https://justbiofiber.com/products/product_specifications/, access: November 16, 2023]

Hempcrete blocks- Hempcrete Blocks Belgium	The prefabricated non-structural blocks, measuring 60 × 30 × 7.5/9/12/15/20/25/30/36 cm, offer a versatile and customizable solution for construction projects. These blocks are designed to be assembled on-site using a special 3 mm mortar to create a bonded structure. The dimensions of the blocks allow for flexibility in design and construction, catering to various architectural requirements. Key specifications of these blocks include a dry bulk density of 340 kg/m³ (with a tolerance of ±10 %), providing a balance between lightweight construction and structural stability. The compressive strength is specified as mean > 0.22 MPa, ensuring that the blocks can withstand the necessary loads in construction applications.

In terms of thermal performance, the blocks exhibit a low thermal conductivity (λui) of 0.071 W/mK, contributing to effective insulation. This property is crucial for creating energy-efficient buildings by minimizing heat transfer. The water vapor resistance factor (μ) is specified to be less than 2.8, indicating good permeability to water vapor. Additionally, the coefficient of thermal dilatation is provided as 15.3×10^{-6} m/mK, indicating the material's response to temperature changes. This information is valuable for ensuring the stability and durability of the construction over varying environmental conditions. [source: https://www.isohemp.com/en/hemp-blocks-naturally-efficient-masonry, access: November 16, 2023]

Mycelium

Insulation panel GrownBio Netherlands	The products from GrownBio are created through a unique process involving the cultivation of mycelium combined with organic agricultural waste, particularly hemp fibers. This substrate is mechanically mixed and placed into molds, where it undergoes controlled conditions of temperature and moisture within special chambers. During this phase, the mycelium naturally grows over the substrate, creating a cohesive and integrated material. Following the growth period, the

material is baked to halt the mycelium growth process, resulting in a stable and durable product. The company offers panels with dimensions of 1200 mm × 600 mm × 60 mm, providing a versatile solution for various applications. These panels are grown from the mycelium and hemp fiber substrate, offering a sustainable and eco-friendly material option.

While GrownBio also produces bricks, the company emphasizes that its products are not yet utilized in the construction industry due to the absence of appropriate certification. The company is actively working on conducting tests, particularly in the areas of thermal insulation and fire safety, to ensure compliance with industry standards. As of now, GrownBio is directing its efforts toward the packaging industry, where its innovative products find applications while it continues to pursue certifications for broader use in construction. The use of mycelium-based materials represents a novel approach to sustainable and biodegradable construction, with ongoing research and development contributing to the expansion of these materials into diverse industries. [source:https://www.grown.bio/product/insulation-panel-set-of-10/?v=9b7d173b068d, access:November 16, 2023]

Insulation panel Mogu, Italy

Mogu's PLUMA interior acoustic and wall panels represent an innovative and sustainable solution for interior design and construction. These panels are designed to offer both acoustic and thermal insulation and are crafted from mycelium materials, along with upcycled textile residues or agricultural waste. The production process involves placing the mixture into molds, where it undergoes controlled conditions of temperature and humidity within chambers. During this phase, the mycelium naturally grows over the substrate, creating a unified material. After the growth period, the material undergoes a slow drying process to halt the growth, resulting in stable and fully formed panels. The panels are 2 cm thick and are available in four different sizes ranging from 50 × 50 cm to 60 × 120 cm. This variety in size provides flexibility in application and allows for versatile design options.

One of the noteworthy features of these panels is their decorative aspect, offering different textures and colors. This not only enhances their functionality but also allows for customization in design, making them suitable for a range of interior applications. Mogu's PLUMA panels showcase the potential of mycelium-based materials in delivering sustainable, visually appealing, and functional solutions for modern construction and design needs. [source: https://mogu.bio/pluma-panels/, access: November 16, 2023]

Mycelium House Ecovative, NY, USA.

Ecovative's innovative approach to building materials is exemplified through its involvement in the mushroomtinyhouse.com project. The process involves using agricultural waste and byproducts as a substrate for growing a tiny house using mycelium-based materials. While the company doesn't prominently feature building materials on its main homepage, the mushroomtinyhouse.com project provides insights into its mycelium-based construction methods. In the

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construction of the mushroom house, a substrate made from agricultural waste is utilized. Wooden boards are applied to two sides of the walls, leaving space in between to facilitate the growth of mycelium. Over a short period, the mycelium effectively bonds together corn stalks, transforming them into a cohesive building material. This mycelium material serves as both thermal and acoustic insulation for the house. Notably, the construction doesn't involve the use of traditional studs.

The mycelium-based construction takes a few days to form, and afterward, a drying period of a couple of months ensues. The resulting material demonstrates properties suitable for insulation, showcasing the potential of mycelium in sustainable construction practices. The tiny house, designed to be transportable on a car trailer, reflects Ecovative's commitment to eco-friendly and innovative building solutions. Moreover, Ecovative offers a preorder sale of their design and necessary components for building the hut, making their MycoComposite technology accessible to the public. The company has also established collaborations with other entities, such as GrowBio, contributing to the broader adoption and application of mycelium-based technologies. It's worth noting that while Ecovative is known for mushroom packaging and hemp fibers, they emphasize that their insulating panels are not certified for use in construction, highlighting the importance of adherence to certification standards in the industry. [source: https://mushroomtinyhouse.com/, access:November 16, 2023]

Mycelium bricks "The Living" Computation Lab, Princeton University 2014 USA

The Tower Hy-Fi project, executed in 2014 on the grounds of the Museum of Modern Art (MoMA) in New York, stands as a pioneering example of sustainable construction utilizing mycelium-based materials. The project employed a novel approach by utilizing low-value crop waste, such as corn husks, collected from farmers. This agricultural waste was then finely chopped and combined with a specially composed mycelium, forming the basis for a unique building material. The mixture of crop waste and mycelium was packed into brick-shaped molds, and the self-forming process initiated the transformation into a lightweight, solid building material within a matter of days. The team produced 10,000 compostable bricks from this mycelium-based material. These bricks were used to construct a remarkable 13-m-high tower, which remained assembled for three months. After this period, the structure was carefully dismantled, and the compostable bricks were then returned to nature through composting. The resulting soil was subsequently donated to local gardens, showcasing a closed-loop and environmentally friendly approach.

Notably, Tower Hy-Fi demonstrates the potential of mycelium-based materials in creating structural elements for architectural purposes. While the tower served as a temporary installation, it highlighted the adaptability and eco-friendly characteristics of mycelium-based construction. Companies like MycoWorks have also explored the use of modular bricks in construction, creating small art forms. However, the focus of some entities, including MycoWorks, has shifted towards

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applications in the textile industry. To make the mycelium-based construction accessible to the public, Grow. bio by Ecovative offers a "Grow-It-Yourself Starter Pack" for $19.99. This pack allows individuals to cultivate their mycelium bricks, contributing to a broader engagement with sustainable building practices. The pack's contents are designed to fill 3398 cm^3, emphasizing the scalable and user-friendly nature of mycelium-based construction initiatives. [source:https://www.buildwithrise.com/stories/mycelium-fungi-as-a-building-material, access: November 16, 2023]

What remains underexplored in much of this literature, however, is the governance dimension — specifically, the question of which institutional actors and policy configurations are most capable of orchestrating the systemic change required. This is the contribution of Rohrbeck and Kulkov (2026), who develop four plausible futures for the European Architecture, Engineering, and Construction industry to 2040. Their scenario analysis demonstrates that the conditions under which green finance, circular procurement, and regulatory instruments successfully accelerate material innovation vary substantially depending on who orchestrates systemic coordination and under what policy stability conditions. Importantly, they find no automatic alignment between environmental ambition and broader social or economic outcomes across any of the four futures — meaning that even in scenarios where bio-based materials achieve significant market penetration, this does not reliably translate into equitable or economically sustainable outcomes without deliberate governance design. This is a significant corrective to narratives that treat the scaling of sustainable materials as straightforwardly beneficial: the distribution of costs and benefits, and the institutional configuration that determines them, matter as much as the aggregate environmental outcome. Taken together, the evidence reviewed in this section points to a clear hierarchy of constraints. The technical case for bio-based materials is increasingly robust, though gaps in durability standardisation remain. The economic and supply chain conditions for scaling are improving but not yet self-sustaining, and depend heavily on policy consistency that currently varies by jurisdiction. The most intractable barrier is arguably institutional: the combination of vested interests, fragmented governance, and insufficient specifier confidence that Dams et al. (2023), Buro Happold (2024), and Chen et al. (2024) each identify from different vantage points. Resolving this barrier requires not only more documented case studies — though these are necessary — but a more deliberate effort to build the actor coalitions, certification infrastructure, and policy stability that would allow market signals to function. Without this, the risk is that bio-based materials remain technically proven but institutionally stranded: capable of mainstream adoption in principle, but not yet positioned to achieve it in practice.

3. Conclusions

The evidence reviewed across this paper leads to several interconnected conclusions that together define both the promise and the challenge of bio-based construction materials as a pathway towards a sustainable built environment.

The scientific case for bio-based construction materials is now well established and progressively moving beyond proof of concept. Across material categories ranging from fast-growing plant-based insulators and mycelium composites to cellulose aerogels and bio-based polyurethanes, the literature consistently demonstrates functional performance comparable or superior to conventional petrochemical alternatives in thermal conductivity, acoustic absorption, fire resistance, and carbon sequestration. The publication of large-scale empirical syntheses and predictive design equations marks a meaningful maturation of the evidence base that was not available to practitioners even five years ago.

The environmental benefits of bio-based materials, while broadly compelling, are not uniform and require nuanced, context-specific assessment. Life cycle analyses consistently demonstrate

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advantages in climate change mitigation and abiotic resource use, but trade-offs emerge in categories such as eutrophication and land use, and economic viability across the full lifecycle remains material- and context-dependent.

Commercialisation is accelerating but unevenly distributed. Bio-based polyurethanes have made the most visible transition towards mainstream market penetration, while cellulose aerogels are approaching commercial viability through ambient-pressure processing innovations. Mycelium-based composites, despite strong technical performance, remain largely confined to demonstration structures. Across all categories, supply chain development, certification frameworks, and practitioner knowledge have not developed in parallel with the technical evidence base.

The geopolitical dimension of this transition has been brought into sharp relief by the 2026 Strait of Hormuz crisis. The ensuing surge in naphtha and polymer prices — affecting key construction materials by between 41% and 75% — exposed a structural vulnerability at the core of Europe's construction sector: its deep dependence on petrochemical inputs sourced through a single geopolitical chokepoint. This episode reframes bio-based materials as a supply security imperative, one whose strategic salience goes well beyond what purely environmental arguments alone could justify.

The policy landscape is shifting accordingly, with the European Commission's 2025 Strategic Framework explicitly positioning bio-based construction products as a lead market. In the wake of the Hormuz crisis, this institutional commitment acquires added urgency, as strategic autonomy and industrial resilience have moved from planning objectives to demonstrated necessities.

Ultimately, the considerable technical potential of bio-based construction materials will only translate into impact at the scale that sustainability targets demand if material innovation, industrial scaling, regulatory harmonisation, and governance coordination are pursued simultaneously. The Hormuz crisis has made plain that delay carries costs not only environmental but geopolitical and economic — costs the construction sector can no longer afford to defer.

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