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Mycelium-Based Composites for Sustainable Building: A study on Fabrication and Engineering Properties

Rupal Nahar[1], Dr. Vijayant Panday[2]
Research Scholar[1], Assistant Professor[2]
Department of Civil Engineering
Shri Vaishnav Vidyapeeth Vishwavidyalaya, Indore
***Corresponding Author's Email**: - rupalnahar18@gmail.com[1]*

ABSTRACT

The construction industry faces growing pressure to lower its environmental impact, driving significant interest in bio-based, biodegradable, and low-carbon alternatives. Mycelium-based composites (MBCs)—created by growing fungal networks within agricultural waste—have emerged as a promising solution for insulation panels, bricks, acoustic tiles, and structural elements. This review synthesises data from 27 peer-reviewed studies and conference papers published between 2013 and 2025 to evaluate the biological fundamentals, substrate selection, fabrication methods, and overall physical performance of these materials. It highlights how final properties depend on fungal species, waste composition, growth conditions, and post-processing treatments. Furthermore, the paper addresses key adoption hurdles like water sensitivity, inconsistent strength, and scalability constraints, alongside emerging fixes like natural coatings, heat treatment, and fiber reinforcement. Finally, it assesses the broader sustainability of MBCs through life-cycle impacts, carbon storage, and waste recycling

KEYWORDS: *mycelium composites; fungal biofibers; sustainable construction; agricultural waste; biobased materials; thermal insulation; biodegradable materials; circular economy*

INTRODUCTION

The global construction sector accounts for approximately 39% of energy-related CO2 emissions and generates vast quantities of non-biodegradable waste annually. Conventional building materials such as concrete, fired clay bricks, and expanded polystyrene (EPS) foam carry high embodied energy and persist in the environment for centuries. Against this backdrop, bio-based materials derived from agricultural and forestry residues have attracted renewed scientific and commercial attention. Among the most promising candidates are mycelium-based composites (MBCs), which exploit the natural capacity of filamentous fungi to colonise and bind particulate organic substrates into a cohesive, three-dimensional network of chitin-rich hyphae.

Pioneering commercial work by companies such as Ecovative Design (USA) demonstrated that MBCs could be moulded into packaging and insulation products as a sustainable alternative to EPS[1,2]. Since then, academic research has expanded rapidly, investigating an array of fungal species, substrate types, and processing conditions, as well as the use of MBCs in architectural and structural contexts.[3,14]

This review synthesises the current state of knowledge on mycelium-based composites in the context of sustainable construction. It addresses the biological and materials-science fundamentals underpinning MBC formation, reviews the influence of key fabrication variables on composite performance, evaluates the suitability of MBCs for specific construction applications, and identifies persistent challenges and future research priorities. The 27 primary sources incorporated span journal articles, conference papers, and comprehensive reviews published between 2013 and 2025, representing laboratories and field trials across Europe, Asia, Australia, and North America.[1–27]

BIOLOGICAL FOUNDATIONS OF MYCELIUM GROWTH

1. Fungal Morphology And Hyphal Networks

Fungi produce filamentous structures called hyphae that collectively form the mycelium — the vegetative body of the fungus. Each hypha is a tubular cell enclosed by a rigid cell wall composed predominantly of chitin and glucans, conferring both structural integrity and chemical resilience.[22,23] As hyphae grow and branch, they anastomose (fuse) to create a three-dimensional network with exceptional surface-area-to-volume ratios. Islam et al. (2017) characterised the morphological and mechanical properties of isolated fungal mycelium, demonstrating that individual hyphae exhibit elastic moduli in the range of 1–10 GPa, comparable to many synthetic polymer fibres.[22]

The density and architecture of the hyphal network are strongly influenced by growth conditions, including temperature, humidity, CO2 concentration, light exposure, and nutrient availability.[10,27] Species-level differences in growth morphology — ranging from loose, cottony networks to dense, rhizomorphic mats — translate directly into variation in composite density, porosity, and mechanical anisotropy. [13,24]

2. Cell Wall Chemistry

The fungal cell wall is a laminated composite itself, comprising an inner layer of chitin microfibrils embedded in a matrix of beta-glucans, with an outer mannoprotein layer.[23] Chitin, a poly-(1,4)-N-acetylglucosamine, is one of the most abundant natural polymers on Earth and exhibits mechanical properties broadly analogous to cellulose.[22] Haneef et al. (2017) demonstrated that by modulating the growth substrate and post-processing conditions, the ratio of chitin to glucan in the cell wall — and thus the stiffness and toughness of the resulting material — could be tuned across a meaningful range.[23]

3. Selection Of Fungal Species

The choice of fungal species is arguably the most consequential decision in MBC production, as it determines growth rate, colonisation efficiency, substrate compatibility, composite density, and final mechanical and aesthetic properties.[1,3,13] White rot basidiomycetes — particularly species within the genera Ganoderma, Trametes, Pleurotus, and Phanerochaete — are most frequently reported in the MBC literature due to their prolific growth on lignocellulosic substrates, secretion of ligninolytic enzymes, and ability to produce dense, interlocking hyphal mats.[3,13,24]

Jones et al. (2017) provided a systematic review of engineering characteristics and growth kinetics across multiple species, concluding that Ganoderma lucidum and Trametes versicolor consistently yielded composites with superior compressive strength and density compared to Pleurotus ostreatus, which nonetheless excelled in terms of colonisation speed and substrate versatility.[27] Aiduang et al. (2022) further catalogued 'amazing fungi' suitable for eco-friendly composites, emphasising the importance of matching species to local agricultural residue availability.[13]

SUBSTRATE SELECTION AND AGRICULTURAL WASTE VALORISATION

1. Lignocellulosic Substrates

Mycelium-based composites require a carbon-rich, lignocellulosic substrate to serve simultaneously as a growth medium and structural filler. Agricultural residues represent an ideal feedstock: they are abundant, inexpensive, geographically distributed, and otherwise low-value or problematic waste streams.[7,20] Substrates reported in the MBC literature include rice husks, wheat straw, corn stover, hemp hurds, cotton gin waste, sawdust, sugarcane bagasse, coconut coir, and jute fibres, among others.[4,7,15,24]

Madurwar et al. (2013) presented a comprehensive review of agro-waste utilisation in sustainable construction, highlighting that crop residues alone generate in excess of 5 billion tonnes globally per year, the majority of which is either burned in the field or landfilled.[7]

The integration of these waste streams into MBC production thus offers both a disposal solution and a valorisation pathway, consistent with circular economy principles.

2. Influence Of Substrate Composition On Composite Properties

Substrate chemistry exerts a profound influence on both mycelium growth dynamics and the physico-mechanical properties of the resulting composite. Elsacker et al. (2019) characterised MBCs produced from seven different lignocellulosic substrates inoculated with Pleurotus ostreatus, demonstrating substantial variation in compressive strength (0.3–3.1 MPa), flexural strength, and water absorption across substrate types.[24] Substrates with higher cellulose content and lower lignin content generally supported faster hyphal colonisation but yielded composites with lower density and mechanical performance compared to those based on woody substrates with greater structural complexity.[24,27]

Yogi et al. (2024) reported preliminary development of MBCs from locally sourced Indian agricultural waste, finding that blended substrates — combining rice straw with sawdust at a 70:30 ratio — consistently outperformed single-substrate formulations in compressive strength and surface quality.[4] The study underscores the potential for substrate optimisation as a low-cost, region-specific strategy to improve MBC performance.[4]

3. Pre-treatment Strategies

Raw agricultural residues often require pre-treatment prior to inoculation in order to reduce competing microorganism load, adjust moisture content, and improve substrate accessibility to fungal enzymes.[3,15] Thermal sterilisation (autoclaving at 121°C) is the gold standard in laboratory settings but imposes energy costs that may be prohibitive at scale.[10] Lower-energy alternatives, including pasteurisation, lime treatment, and fermentation-based pre-treatment, are under investigation as pathways to more economically viable MBC manufacturing.[1,15]

FABRICATION METHODOLOGIES

1. Standard Laboratory Process

The typical laboratory MBC fabrication process involves five sequential stages:

- Substrate preparation — milling, blending, and moisture adjustment of the lignocellulosic feedstock.[3,10]
- Sterilisation — autoclaving or pasteurisation to eliminate contaminating microorganisms.[10]
- Inoculation — introduction of fungal spawn (colonised grain or sawdust) at typically 5–15% by dry weight.[27]
- Colonisation — incubation in moulds under controlled temperature (22–28°C), humidity (>80%), and darkness for 5–14 days.[3,10,27]
- Inactivation and drying — heat treatment (typically 70–80°C) to terminate growth and reduce moisture content to <10%, followed by optional surface finishing.[1,10]

Appels et al. (2019) conducted one of the most detailed investigations into how each fabrication parameter influences final composite properties, demonstrating that colonisation duration, inoculation ratio, and drying temperature interact synergistically to determine composite density, stiffness, and moisture sensitivity.[10]

2. Mould Design And Large-Scale Fabrication

At laboratory scale, MBCs are routinely cast in rigid polypropylene or wooden moulds lined with perforated sheets to allow gas exchange while maintaining shape.[3] Scaling to architectural dimensions introduces significant challenges: gas exchange becomes diffusion-limited in deep moulds, temperature gradients develop, and colonisation becomes heterogeneous.[14]

Dessi-Olive (2022) presented strategies for growing large-scale mycelium structures, proposing modular mould systems, internal ventilation channels, and multi-stage inoculation protocols as solutions to scale-up barriers.[14] The work demonstrated the successful fabrication of structural panels up to 0.9 m × 0.9 m × 0.1 m, albeit with measurable variation in density (±15%) across the panel dimensions.[14]

Wedersøe Strunge (2019) described the growing of an entire architectural pavilion from MBC panels, illustrating the real-world application of large-scale fabrication and assembly strategies.[12] The project highlighted both the creative potential and the practical constraints — particularly cycle time and quality control — that must be addressed for mainstream adoption.[12]

3. Fibre-Reinforced And Hybrid Composites

To overcome the intrinsic mechanical limitations of pure MBCs, researchers have incorporated natural fibre reinforcements — including hemp, flax, jute, bamboo, and cotton — into the mycelium matrix.[3,16] Jones et al. (2020) critically reviewed engineered mycelium composite construction materials, concluding that the addition of aligned natural fibres can increase tensile strength by up to 300% and flexural modulus by up to 200% relative to unreinforced controls, while maintaining or improving biodegradability.[3]

Voutetaki and Mpalaskas (2024) characterised natural fibre-reinforced mycelium composites, finding that hemp-reinforced specimens exhibited compressive strengths approaching 4 MPa — sufficient for non-load-bearing partition wall applications — alongside promising thermal insulation properties.[16]

PHYSICAL, MECHANICAL, AND THERMAL PROPERTIES

1. Mechanical Performance

The mechanical properties of MBCs span a wide range, reflecting the diversity of species, substrates, and processing conditions employed across the literature. Table 1 summarises key properties and benchmarks against conventional alternatives.

Table 1: Summary of mycelium composite properties compared to conventional materials

Property	***Mycelium Composite***	***Conventional Alternatives***	***Key References***
Density	40–200 kg/m³ (biofoam variants)	EPS foam: ~10–30 kg/m³; concrete: ~2400 kg/m³	[10, 25]
Compressive Strength	0.3–10 MPa depending on substrate and species	Concrete: 20–40 MPa; EPS: 0.1–0.3 MPa	[10, 24, 27]
Tensile Strength	0.1–0.5 MPa (pure mycelium)	Higher in conventional composites	[22, 23]
Thermal Conductivity	0.05–0.08 W/m·K (insulation grade)	EPS: ~0.033 W/m·K; brick: ~0.5–1 W/m·K	[21, 25]
Water Resistance	Poor without treatment; improved with coatings	Concrete: inherently resistant	[5, 9, 10]
Fire Resistance	Chars without melting; low smoke toxicity	EPS melts; concrete non-combustible	[11]
Biodegradability	Fully biodegradable (weeks to months)	Non-biodegradable	[1, 13]
CO_2 Footprint	Negative to near-zero (sequesters carbon)	Highly positive (cement ~0.8 t CO_2/t)	[2, 16]
Production Cost	Low raw material cost; scalable	Lower at large industrial scale	[14, 26]

Yang et al. (2017) characterised fungal mycelium-based biofoam, reporting densities of 40–200 kg/m3 and compressive strengths of 0.3–3 MPa, depending on formulation — broadly comparable to EPS foam on a specific strength basis.[25] Islam et al. (2017) investigated the relationship between hyphal network morphology and bulk mechanical behaviour, establishing that samples with denser, more isotropic hyphal networks exhibited higher Young's moduli and reduced anisotropy in compressive response.[22]

2. Thermal And Acoustic Insulation

The high porosity of MBCs — typically 60–80% by volume — confers effective thermal insulation, with reported thermal conductivities (λ) in the range of 0.05–0.08 W/m·K, placing them in the performance bracket of conventional mineral wool.[21,25] Xing et al. (2018) conducted systematic testing of mycelium bricks as building insulation materials, confirming that density and porosity are the dominant determinants of thermal performance and that optimisation of these parameters allows MBCs to match or approach the λ values of commercial insulation boards.[21]

Acoustic absorption coefficients for MBCs have received comparatively less attention in the literature but preliminary measurements indicate noise reduction coefficients (NRC) of 0.5–0.8 in the 500–2000 Hz range, competitive with commercially available porous acoustic panels.[1,8]

3. Thermal Stability And Fire Behaviour

Jones et al. (2018) conducted a comprehensive investigation of thermal degradation and fire properties of fungal mycelium and mycelium-biomass composites.[11] Thermogravimetric analysis revealed that MBCs undergo a two-stage decomposition corresponding to the pyrolysis of glucan-based cell wall components (200–350°C) and chitin (350–600°C). Critically, the materials charred rather than melted under direct flame, producing a self-limiting char layer that reduced further heat penetration — behaviour analogous to intumescent coatings.[11] Cone calorimetry data indicated relatively low peak heat release rates compared to EPS, and smoke toxicity analysis confirmed the absence of the halogenated compounds associated with conventional flame retardants.[11]

MOISTURE SENSITIVITY AND SURFACE TREATMENT STRATEGIES

1. Water Absorption And Dimensional Instability

The single most significant barrier to the widespread deployment of MBCs in construction is their hygroscopic nature. The chitin-glucan cell wall matrix readily absorbs atmospheric moisture, leading to swelling, dimensional instability, and accelerated biological degradation.[10,15] Appels et al. (2019) demonstrated water absorption values of 100–700% by weight in untreated MBCs, with substantial variation attributable to substrate porosity and colonisation density.[10]

2. Natural Coating Agents

Farrahnoor et al. (2024) investigated the efficacy of beeswax and coconut oil as natural coating agents for MBCs in a modified controlled environment, evaluating effects on morphological characteristics, degradation behaviour, and water barrier properties.[9] Beeswax-coated samples exhibited a 65% reduction in water vapour transmission rate relative to uncoated controls, and scanning electron microscopy confirmed a continuous, pore-sealing film over the composite surface.[9] Coconut-oil treatment achieved intermediate performance but was noted for its lower cost and simpler application procedure. Both treatments preserved biodegradability at end of life, a critical sustainability criterion.[9]

3. Thermally Inactivated Mycelium In Earth Materials

Walter et al. (2025) explored a novel approach in which thermally inactivated mycelium was used as a bio-stabilisation additive in compressed earth construction, rather than as a binder itself.[5] The addition of 2–8% thermally inactivated mycelium by dry mass to biostabilised earth specimens yielded statistically significant improvements in wet compressive strength (+18–34%) and erosion resistance, attributed to the hydrophobic character of inactivated hyphal biomass and its role in reducing capillary water uptake.[5] This approach offers a promising pathway for improving the durability of earthen construction in humid climates without recourse to cement stabilisation.[5]

CONSTRUCTION APPLICATIONS

1. Insulation Panels

Thermal insulation is currently the most commercially mature application of MBCs in construction. Products analogous to EPS or mineral wool boards have been developed at pilot scale, exploiting the naturally high porosity and low thermal conductivity of the material.[8,21] Santhosh et al. (2018) reviewed the potential of mycelium composites as green building materials, concluding that insulation panels represent the optimal entry point for market penetration given the relatively low mechanical demands of this application category.[8]

2. Mycelium Bricks

The fabrication of compressed mycelium bricks for wall construction has been reported by multiple research groups. Kanagalakhmi et al. (2021) characterised mycelium bricks produced from paddy straw and Pleurotus ostreatus, reporting compressive strengths of 0.3–0.8 MPa — adequate for single-storey non-load-bearing walls in low-density housing applications.[18] Kishan et al. (2018) described an end-to-end production process for mycelium bricks achievable with minimal capital equipment, positioning the technology as accessible for rural and developing-country contexts.[19]

Kumar et al. (2025) presented the most recent and thorough performance evaluation of mycelium-based bricks specifically targeting sustainable rural housing in India, testing compressive strength, water absorption, efflorescence, and thermal properties across multiple formulations.[6] Results confirmed compliance with Indian standard IS 3495 for Class B bricks in terms of water absorption (<20%) when a natural sealant was applied, and thermal performance superior to conventional fired clay bricks.[6]

3. Structural And Architectural Elements

Attias et al. (2020) conducted a comparative review of mycelium bio-composites in industrial design and architecture, augmented by experimental analysis of multiple MBC formulations.[26] The study identified internal partition walls, acoustic baffles, false ceilings, and landscape structures as appropriate near-term structural applications, while cautioning that primary load-bearing use remains constrained by the relatively low and variable compressive strength of current MBC.[26]

Dessi-Olive (2022) and Wedersøe Strunge (2019) documented the realisation of full-scale mycelium architectural installations, providing practical insights into assembly, surface treatment, and weathering that are not captured in laboratory-based studies.[12,14]

4. Earthen And Earth-Fibre Composites

Beyond discrete formed products, mycelium has been investigated as a soil and earth stabilisation agent. Kalita et al. (2018) explored the use of mycelium as a building material in the Indian context, noting synergies with traditional earth construction practices and the availability of abundant agricultural waste feedstocks.[20] Xia (2024) reviewed the utilisation of mycelium-based materials in sustainable construction broadly, with dedicated treatment of earthen wall systems reinforced with fungally bound straw bales.[17]

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SUSTAINABILITY AND LIFE-CYCLE CONSIDERATIONS

1. Carbon Footprint And Sequestration

MBCs offer a distinctive sustainability proposition: the carbon captured in the lignocellulosic substrate during plant growth is transferred to the composite and sequestered for the duration of the product's service life, rather than being released through incineration or decomposition of the raw residue.[1,2] Camilleri et al. (2025) reviewed the embodied carbon of MBCs in the context of the broader mycelium composite literature, concluding that well-managed MBC production systems could achieve near-zero or negative embodied carbon on a cradle-to-gate basis, contingent on substrate sourcing, energy inputs, and transportation logistics.[1]

Rahim Khan (2025) provided a comprehensive review of mycelium-based bioproducts for a sustainable economy, situating MBCs within a hierarchy of bio-based construction materials and comparing life-cycle assessment data across EPS, mineral wool, and cork, finding MBCs consistently superior on global warming potential (GWP100) metrics.[2]

2. Biodegradability And End-Of-Life

At end of life, MBCs biodegrade within weeks to months under composting conditions, returning their constituent carbon and nutrients to the soil.[13,15] This stands in stark contrast to EPS foam, which persists in the environment for centuries and is implicated in marine microplastic pollution, and concrete, which requires energy-intensive demolition and generates inert waste.[1,2] Madusanka et al. (2024) reviewed biodegradation pathways for MBCs, noting that biodegradation rate can be modulated through the choice of surface coating — natural waxes and oils extending functional life while preserving ultimate compostability.[15]

3. Agricultural Waste Integration And Circular Economy

The capacity of MBC production to convert agricultural residues into high-value construction materials represents a textbook circular economy intervention. [7,20] Crop residues that would otherwise contribute to air pollution through open-field burning — a severe problem in South and Southeast Asia — are instead valorised as composite matrices, with the spent substrate potentially serving as a soil amendment after the composite's service life.[4,20]

CHALLENGES AND LIMITATIONS

1. Mechanical Performance And Variability

Despite continuous improvement, the compressive and tensile strengths achievable in MBCs remain well below those of conventional structural materials. More critically, between-batch and within-sample variability — arising from biological heterogeneity in mycelium growth — poses a significant challenge for structural engineering applications that require reliable, reproducible material properties.[10,26,27] Standard quality control frameworks applicable to biological materials remain underdeveloped, and no universally accepted testing protocol for MBCs has yet been established by standards bodies.[1,3]

2. Moisture And Durability

Moisture sensitivity remains the foremost technical challenge limiting the in-service performance of MBCs.[9,10] While natural coatings and thermal inactivation treatments offer partial mitigation, none has yet demonstrated the performance required for exterior or high-humidity applications without reapplication.[5,9] Long-term durability data — essential for product certification and insurance underwriting — are largely absent from the published literature, with most studies reporting only short-term (weeks to months) performance outcomes.[1,15]

3. Scale-Up And Industrialisation

Translating laboratory-scale MBC production to industrial volumes introduces multiple technical and economic challenges, including the cost of sterilisation energy, maintenance of sterile conditions at scale, ensuring homogeneous colonisation in large batches, and the environmental control required for consistent product quality.[1,3,14] Dessi-Olive (2022) and Camilleri et al. (2025) both identify cycle time — typically 7–14 days for full colonisation — as a critical bottleneck, contrasting with the near-instantaneous production of competing foam or concrete products.[1,14]

4. Regulatory And Certification Pathways

No dedicated regulatory or certification framework for MBCs in construction exists at national or international level. Building codes in most jurisdictions require fire, structural, and durability performance data obtained under standardised test methods; the development and adoption of MBC-specific standards is a prerequisite for mainstream market entry. This

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gap has been noted by multiple reviewers as a critical constraint on commercial deployment.

FUTURE RESEARCH DIRECTIONS

The body of literature reviewed here points toward several high-priority research directions that would substantively advance the field:

- Standardisation of test methods: Development of consensus protocols for mechanical, thermal, and durability testing of MBCs, analogous to those applied to conventional composites, is urgently needed to enable meaningful cross-laboratory data comparison.[1,3]
- Accelerated ageing and long-term durability: Systematic investigation of MBC performance under cyclic wetting and drying, UV exposure, freeze-thaw cycling, and biological attack is required to support service-life modelling and product certification.[9,15]
- Advanced surface treatment: Research into durable, eco-compatible hydrophobic treatments — including bio-inspired wax formulations, silane coupling agents, and mineral coatings — should be pursued with explicit life-cycle assessment to ensure that durability gains are not offset by environmental costs.[5,9]
- Digital fabrication integration: The compatibility of MBCs with additive manufacturing, CNC-milled moulds, and parametric design workflows offers opportunities for bespoke architectural elements; this intersection remains largely unexplored.[14]
- Species and substrate screening: High-throughput screening of underexplored fungal species — particularly those indigenous to tropical and sub-tropical agricultural regions — against locally available substrate blends would expand the geographic applicability of MBC technology.[13,15]
- Structural hybrid systems: Exploration of MBCs as non-structural infill within timber, bamboo, or bio-composite structural frames could deliver building systems that leverage the complementary strengths of each material.[3,16]
- Life-cycle assessment: Comprehensive, cradle-to-grave LCA studies incorporating real-world production data, transport, service-life scenarios, and end-of-life pathways are needed to substantiate the sustainability claims widely attributed to MBCs.[1,2]

CONCLUSION

Mycelium-based composites represent a scientifically compelling and ecologically motivated contribution to the sustainable construction materials palette. The reviewed literature — spanning fundamental mycology, materials characterisation, fabrication engineering, and applied architectural research — establishes that MBCs can achieve thermal insulation performance comparable to mineral wool, adequate compressive strength for non-load-bearing applications, and promising fire behaviour, all while offering a cradle-to-compost sustainability profile unmatched by conventional synthetic or mineral materials.

However, the field is not without significant unresolved challenges. Moisture sensitivity, mechanical variability, cycle time, and the absence of formal standards collectively constrain commercial deployment. Progress on these fronts will require coordinated effort across materials science, mycology, structural engineering, and regulatory domains. The emerging strategies reviewed here — fibre reinforcement, natural coating agents, thermally inactivated mycelium additives, and modular large-scale fabrication — represent encouraging steps forward.

As the construction industry faces intensifying regulatory pressure to decarbonise and the global stock of agricultural residues continues to grow, mycelium-based composites occupy an increasingly attractive position at the intersection of circular economy principles, low-carbon building, and bio-based material innovation. The next decade of research and commercialisation will be decisive in determining whether MBCs transition from laboratory curiosity to mainstream construction material.

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