Carbon-Sequestering Building Materials from Rice Husk Composites: A Preliminary Evaluation Frame Work and Carbon Footprint Assessment for India

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***Abstract*—India produces over hundred billion kilograms of rice annually, generating massive quantities of agricultural byproducts like rice husk—approximately twenty-five billion kilograms per year—that are largely underutilized and often contribute to greenhouse gas emissions through crop burning. This study explores the potential of rice husk as a primary component in carbon-sequestering composite building materials. Rich in cellulose, lignin, and silica, rice husk shows promising mechanical and environmental performance when developed into compressed bricks. Drawing on case studies of alternative materials and preliminary strength testing, the research situates rice husk composites within a growing movement toward decentralized, low-carbon construction. Early findings suggest significant reductions in carbon footprint compared to traditional brick systems, while also highlighting the need for further material testing, scaling methods, and evaluation of long-term durability.**

Keywords—Carbon-Sequestering Building Materials, Rice Husk, Rice Bran Wax, Beeswax, Plant-Based Brick Manufacturing, Sustainable Construction, Agricultural Byproducts, Composite Materials, Low-Carbon Alternative, Mechanical Performance, Binding Agents, Structural Integrity, Greenhouse Gas Emissions Reduction. Bending Strength, Compressive Strength, Architecture & Built Environment, Smart Materials & Advanced Construction

I. Introduction

A. *Material Premise: Rice Husk and Agricultural Waste as Carbon-Negative Construction Resources*

As global temperatures breach the 1.5°C threshold, the urgency to reduce carbon emissions from high-impact industries—especially the construction sector—has never been greater [1]. India, the second-largest agro-based economy in the world, produces agricultural waste at an unprecedented scale due to its year-round crop cultivation. Among these residues, rice husk—a byproduct of rice milling—is generated in staggering quantities. As the world's leading rice producer, India annually yields approximately 100 billion kilograms of rice, resulting in about 25 billion kilograms of rice husk [2]. Although agricultural waste is often repurposed for fodder or energy production, nearly 92 million tons are burned each year, particularly by small-scale farmers who lack access to sustainable alternatives for clearing fields [3].

This open-field burning releases large amounts of greenhouse gases, black carbon, and particulate matter that deteriorate air quality, degrade soil health, and contribute significantly to global warming. Delhi and other North Indian cities are among the worst affected, with pollution levels frequently spiking beyond safe limits [4]. Moreover, this practice strips the soil of its ability to sequester carbon, further aggravating droughts and altering regional climate patterns.

Rice husk, despite being underutilized due to its high silica and ash content, holds tremendous potential as a building material. It is inherently fire-resistant, water-impermeable, thermally insulating, and rich in structural compounds like lignin and cellulose [5]. When processed with appropriate methods, rice husk composites show potential as a durable and sustainable alternative to traditional bricks. Repurposing this waste stream not only mitigates the harmful effects of crop burning but also aligns with circular economy principles—upcycling an abundant byproduct into low-carbon infrastructure [6].

To complement rice husk in the brick-making process, our research explores the use of rice bran wax, another byproduct of the same crop. Traditionally discarded or processed for industrial use, rice bran wax exhibits water-resistant, mould-repellent, and air-barrier properties, making it a viable natural binder in construction applications [7]. By integrating both rice husk and rice bran wax—two agricultural wastes from a single plant—we aim to develop bricks that are carbon-negative, locally sourced, and cost-effective.

Transforming these waste materials into building solutions offers more than just environmental value. It provides farmers with an additional income stream while simultaneously supporting the creation of affordable, community-oriented infrastructure. This project explores the potential of agricultural waste as a resource to address air pollution, climate change, and rural poverty—while fostering community participation in sustainable development.

B. *Objective*

This paper represents the first phase of a larger, ongoing research project focused on the development and application of rice husk-based composite materials as sustainable alternatives within the Indian construction industry. The overarching objective is to explore the architectural, environmental, and socio-economic potential of rice husk valorization, particularly in response to climate, equity, and material challenges in India. The specific objectives of this initial phase are:

1) To investigate the necessity and relevance of rice husk reuse in India, establishing the environmental context and urgency. This includes a critical analysis of current disposal practices, the environmental costs of agricultural waste burning, and the potential of rice husk as a low-carbon, sustainable building resource.
2) To analyze precedents of alternative building material industries, in India and globally, as case studies that inform the technical development and implementation strategies of new composite materials. Lessons from these case studies serve as groundwork for approaching the R&D process of rice husk-based materials with an understanding of systemic challenges and opportunities.
3) To initiate the development and early-stage testing of rice husk composite materials, focusing on preliminary strength testing, binder experimentation, and design for scalability. Material testing in this phase will inform later full-scale testing processes aimed at meeting ASTM and IS standards. These advanced testing protocols are currently underway and will be detailed in a subsequent publication.
4) To assess the carbon footprint potential of rice husk-based materials in comparison with conventional building materials (e.g., brick, concrete, and gypsum board), in order to gauge the environmental benefits of adoption at scale.
5) To prepare for a full-scale prototype construction, which is currently under development. This built project will integrate the tested rice husk composite in architectural applications, with the aim of conducting post-occupancy evaluations related to structural performance, thermal and acoustic behavior, and user comfort. The results of this stage will be presented in a follow-up publication.
6) To engage with the local community in the design and implementation process of the built prototype, with the aim of understanding lived experience, material perception, and socio-cultural reception. This participatory process will be documented and analyzed in future outputs.
7) To lay the groundwork for a detailed socio-economic analysis, which will explore issues of accessibility, labor, decentralized manufacturing, and the potential of rice husk-based materials to contribute to a more equitable and regenerative construction ecosystem in India. This component of the research will be conducted and published in subsequent phases.

II. Literature Review, Case Study

A. *The Current Landscape of Alternative Building Materials*

In response to the industry's increasing climatic implications, a wide spectrum of low-carbon and bio-based building materials—such as bamboo, straw bale, and hempcrete—has emerged as viable alternatives. These materials offer significant advantages not only in terms of embodied carbon but also in decentralization of the construction process and accessibility. Their production often requires minimal industrial processing, enabling community-led fabrication and adoption. For example, bamboo is both a high-yield renewable material and structurally capable, used in scaffoldings, trusses, and walls [8]. Similarly, straw bale construction has proven effective in thermal insulation and carbon storage [9]. While each material's physical composition and application vary, they are commonly evaluated through standardized methods like ASTM C109 or ISO 8301 to assess structural and thermal properties, thereby ensuring their legitimacy in comparison to conventional materials [10].

B. *Agricultural Byproducts in Construction*

Rice husk ash (RHA), an agricultural waste product generated in vast quantities through global rice production, has shown promising applications in green construction. Rich in amorphous silica, RHA has historically been explored as a partial replacement for cement in concrete mixtures, where it contributes to strength gain and reduces permeability [11]. Its pozzolanic properties have been demonstrated to enhance compressive strength and durability when used appropriately, offering a low-cost and environmentally beneficial substitute to traditional cement [12]. However, the material's potential as a stand-alone binder or base material—especially in low-tech, plant-based composites—remains underexplored. Research into this direct application is critical, especially considering that uncontrolled disposal methods like open-field burning of husks continue to contribute to local air pollution and greenhouse gas emissions, leading to legal crackdowns in regions such as northern India [13].

C. *Precedents in Bio-Based Materials Research and Testing Methodologies*

The development and validation of alternative materials consistently rely on measurable, replicable testing frameworks. Materials such as hempcrete and compressed earth blocks are commonly tested for compressive strength (ASTM C39, C109), water absorption, flexural strength (ASTM C348), and thermal conductivity. These methods provide comparability across a wide range of materials, including those emerging from agricultural waste. For instance, rice husk ash-infused blocks have been studied using ASTM standards to assess mechanical viability and durability in humid environments [14]. Such studies are vital in positioning bio-based composites as viable construction materials beyond experimental or rural uses. Importantly, these tests do not necessarily require large-scale infrastructure, which aligns with the goal of decentralized and community-scale adoption—especially in rural or resource-scarce regions.

D. Decentralization, Accessibility, and Contextual Suitability

One of the most compelling aspects of bio-based and waste-derived construction materials is their alignment with community-led fabrication. Unlike concrete and steel—which depend on high-temperature kilns, petrochemical-derived inputs, and centralized supply chains—materials like rice husk, bamboo, or earthen blocks can often be sourced and manufactured on-site or within local networks. This makes them inherently more adaptable to localized conditions, labor systems, and climatic needs. In addition, they mitigate transport emissions and empower non-industrial builders. For instance, in studies on low-tech lime-hemp composites, researchers emphasize the importance of adapting mix ratios and curing processes to local contexts without compromising material performance [15]. Rice husk-based bricks, with minimal processing and binding additives such as natural waxes or clay, present a similar opportunity: creating durable, regionally adaptable structures without complex machinery or resource-intensive manufacturing.

III. Methodology

A. Carbon Footprint Assessment

A Life Cycle Assessment (LCA) was conducted to compare the environmental impact of rice husk–based biobricks with that of conventional fired clay bricks in the construction of a typical 12-story residential building. The study evaluated emissions across the full lifecycle—from raw material extraction to building operation [16].

The building constructed with conventional bricks had a total carbon footprint of approximately 550.8 metric tons of CO_2. This included high embodied carbon, significant construction energy use, and substantial operational and transportation emissions [17].

In contrast, using rice husk biobricks resulted in a dramatically lower carbon footprint of about 70 metric tons of CO_2—an eightfold reduction. The biobricks demonstrated minimal embodied carbon and reduced emissions during construction, operation, and transportation phases [18].

These findings highlight the substantial environmental benefits of rice husk biobricks, positioning them as a carbon-negative material with strong potential for low-carbon construction, especially in climate-sensitive regions [19].

B. Material Strength Testing and Fabrication Protocols

Material sourcing for this research included rice husk, lime, beeswax, and rice bran wax. While rice husk is collected as agricultural waste in India, the material for current prototypes was commercially sourced due to geographical limitations in conducting experiments in New York.

The fabrication process begins with heating rice bran wax until fully liquefied (Fig. 1).

Shredded rice husk is then incrementally added along with lime, and the mixture is homogenized to ensure consistency (Fig. 2) and (Fig. 3)

This composite is poured into standardized molds in three successive layers, with manual compaction after each pour to enhance density (Fig. 4).

The specimens are left to air-set for 12 hours, allowing the wax matrix to cool and solidify, forming self-binding biobricks (Fig. 5).

Fig. 1. Heating of rice bran wax

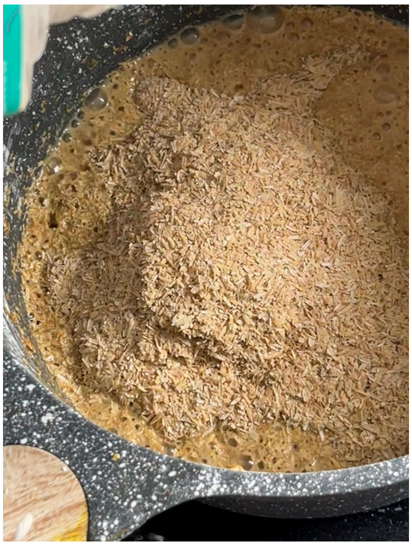

Fig. 2. Shredded rice husk is then incrementally added along with lime, and the mixture is homogenized to ensure consistency

Fig. 3. Shredded rice husk is then incrementally added along with lime, and the mixture is homogenized to ensure consistency

Fig. 4. Layer-by-layer pouring of the mixture into standardized molds with manual compaction.

Fig. 5. Final rice husk–wax biobrick after 12-hour air setting, fully solidified and ready for mechanical testing.

For mechanical evaluation, ASTM-equivalent standards were followed for compressive strength and bending strength tests.

Load-bearing capacity and fracture patterns were recorded to gauge the suitability of these materials for structural and non-structural applications.

These tests validated the potential of rice husk–wax composites as viable construction materials, especially for low- to medium-rise buildings [20][21].

IV. Results

A. *Result of Carbon Footprint Calculation*

A comparative Life Cycle Assessment (LCA) was conducted to quantify the environmental impact of rice husk–based biobricks relative to conventional fired clay bricks. The analysis encompasses the complete lifecycle—from raw material acquisition to fabrication—highlighting the emissions profile of each system.

To evaluate emissions at scale, a study modeled a typical 12-story residential building comprising 24 apartments (2 per floor) and approximately 120 internal partition walls. For the structure built with conventional fired clay bricks, the embodied carbon was calculated at 1.5 metric tons of CO_2 per square meter, and construction-related energy use contributed an additional 2 metric tons of CO_2 per floor. Operational emissions—largely due to HVAC—ranged between 48–120 metric tons of CO_2 per year, while transportation emissions added 1 metric ton per apartment annually. This yielded a total lifecycle carbon footprint of approximately 550.8 metric tons of CO_2 for the entire building [22].

By contrast, the same building constructed with rice husk–beeswax bricks demonstrated drastically lower emissions. The embodied carbon of the biobricks was a mere 0.0005 metric tons of CO_2 per square meter, with construction-related energy use at 0.0095 metric tons per floor. Annual HVAC emissions amounted to 67.2 metric tons, and transportation-related emissions were reduced to 0.8 metric tons per apartment, culminating in a total carbon footprint of 70 metric tons of CO_2—an eightfold reduction compared to the conventional case [23].

This analysis demonstrates the substantial environmental advantage of utilizing rice husk biobricks in architectural construction. The findings position these materials as not only low-carbon but also carbon-negative options that can directly reduce emissions in one of the most carbon-intensive industries.

The results indicate that the carbon footprint of a standard 12-storey building constructed using the proposed rice husk biobricks is approximately eight times lower than that of a similar structure built with conventional bricks. This substantial reduction underscores the potential of the material in contributing to low-carbon construction practices, particularly in climate-sensitive regions.

B. *Result of Material Strength Testing*

This study presents preliminary findings, as only one test per specimen was conducted in accordance with ASTM standards. Full validation will require a minimum of three tests per specimen, which will be reported in a future publication.

Preliminary compressive and bending strength tests were carried out following ASTM D2166 and ASTM C67/C67M, respectively. The initial results yielded compressive strengths of 2.62 MPa and 3.74 MPa, and bending strengths of 2.35 MPa and 2.59 MPa, depending on the material composition and additives used, as shown in Tables 1, 2, and 3 [24][25].

TABLE I. Composite Mixture Ratio

Specimen no.	Wax Ratio [%]	Rice Husk Ratio [%]	Lime Ratio [%]
1	48	52	0
2	58	42	4
3	41.3	57.1	1.6
4	40.3	58.1	1.6

TABLE II. Specimen Dimension, Weight and Density

Spec. No.	Dimension [mm]	Weight [g]	Density [g/cm^3]
1	Prizm L=150, b=40, d=40	239	1.0
2		245	1.0
3	Pipe L=100, r=25	213	1.1
4		227	1.2

Testing Standard and Compressive / BendingStrength

Spec. No.	Testing Standard	Strength [Mpa]
1	ASTM D2166 Compressive Strength	2.35
2		2.59
3	ASTM C67/C67M Bending Strength	2.62
4		3.74

Common burnt clay bricks typically exhibit compressive strengths ranging from 3.5 MPa to 35 MPa and bending strengths between 1.2 MPa and 2.5 MPa.

As rice husk is a fibrous material, it demonstrates relatively higher bending strength compared to compressive strength, which remains lower than that of conventional burnt clay bricks.

V. Discussion

This study lays a strong research foundation for the development of alternative building materials, rice husk-based brick, by examining both environmental and socio-economic impacts within the context of India. It aims to underscore the urgent need for sustainable material innovation. Ongoing material testing—using various combinations of rice husk, rice bran wax, and lime—is guiding the optimization of composition ratios. Once finalized, the materials will undergo comprehensive scientific testing in accordance with ASTM D2166 for compressive strength and ASTM C67/C67M for bending strength, including assessments for freeze-thaw durability.

The findings of this research will inform the construction of a prototype pavilion in Pune, India, intended to introduce a design methodology that embraces material deterioration and acknowledges the shorter lifespan of bio-based alternatives, such as the rice husk brick developed in this study. This experimental pavilion will serve as a testbed for evaluating human interaction with the material and conducting full post-occupancy assessments of structural degradation, contributing to a deeper understanding of performance in real-world conditions. Additionally, the project explores the decentralized socio-economic potential of localized material production and fabrication, aiming to empower community-driven construction practices and reduce dependence on industrial supply chains.

VI. Conclusion

This paper has established the foundational framework for the development of rice husk-based composite materials as environmentally and socially responsive alternatives within the Indian construction context. Beginning with an assessment of India’s material ecology—marked by the coexistence of material abundance and economic inequality—the research highlights the urgency of rethinking waste, particularly rice husk, not as an environmental burden but as a regenerative building resource. Through a combination of historical, environmental, and industrial analysis, we have traced how rice husk, often considered agricultural residue, can become central to reimagining low-carbon material futures.

By examining precedents in the global alternative materials landscape, the study situates rice husk within a broader network of ecological material innovation, offering insights into the infrastructural, regulatory, and perceptual hurdles such materials face. These lessons inform the early-stage development and testing of rice husk composites presented in this paper, where a range of binders, mixes, and casting techniques were explored to assess the feasibility and strength of the material. While preliminary, these tests reveal promising results for further optimization and standardization in future stages.

Furthermore, the comparative carbon footprint analysis underscores the material’s potential to significantly reduce emissions compared to conventional options, reinforcing the relevance of this research in addressing climate-related challenges in the building sector. This supports the proposition that rice husk, if locally processed and deployed, could serve not only as a sustainable material but also as a vehicle for decentralizing production and empowering regional economies.

It is important to note that this paper represents the first of three integrated research phases. While the current focus has been on conceptual groundwork, case study analysis, and initial prototyping, subsequent stages will involve comprehensive material testing to meet ASTM and IS standards, post-occupancy evaluation through the construction of a full-scale prototype, and direct community engagement to assess lived experience and reception. Parallel research will also investigate the socio-economic implications of implementing rice husk-based composites at scale—particularly with respect to labor equity, decentralized fabrication, and accessibility.

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