Review Article

Journal of Environmental Nanotechnology

A Review on Brick Manufacturing Using Agro-industrial Wastes

K. Jeevanandan[1,2*], S. Shanmugapriya[2], M. Sheik Mohamed Anas[3] and Siddharthan[4]
[1]Department of Civil Engineering, Dhanalakshmi Srinivasan College of Engineering, Coimbatore, TN, India
[2]Department of Civil Engineering, Coimbatore Institute of Technology, Coimbatore, TN, India
[3]Department of Civil Engineering, Akshaya College of Engineering and Technology, Coimbatore, TN, India
[4]Department of Civil Engineering, Nehru Institute of Technology, Coimbatore, TN, India
Received: 27.12.2024 Accepted: 06.03.2025 Published: 30.03.2025
*jeevanandankanagavel@gmail.com

ABSTRACT

The construction industry is a large consumer of natural resources and a significant contributor to environmental deterioration. Sustainable construction practices, particularly in brick manufacture, have become important for mitigating these consequences. The use of agro-industrial waste as an alternative raw material in brick manufacture is an innovative approach to waste management and resource conservation. This research investigates the viability of using agro-industrial wastes such as rice husk ash, fly ash, bagasse, and other byproducts to make bricks. It assesses their environmental, economic, and technological advantages while confronting problems such as material variability, processing methods, and regulatory adherence. This thorough research seeks to establish a framework for using agro-industrial waste into conventional construction methods to attain sustainability objectives.

Keywords: Natural resources; Sustainable construction; Agro-industrial waste; Waste management.

1. INTRODUCTION

The construction business is critical to building contemporary civilisation by providing the infrastructure needed for housing, transportation, and industry. However, its fast expansion, fuelled by urbanisation, population growth, and industrial development, has caused considerable environmental issues (Maraveas and Chrysanthos, 2020). Among construction materials, bricks are fundamental. They are widely used for their durability, availability, and versatility. Unfortunately, traditional brick manufacturing is resource-intensive, relying heavily on the extraction of natural clay and the firing process, which contributes significantly to greenhouse gas emissions. The extensive use of clay leads to the depletion of fertile topsoil, a critical resource for agriculture, and disrupts local ecosystems. Additionally, the high energy consumption of kiln operations, often powered by fossil fuels, exacerbates air pollution and global warming (Chin *et al.* 2022).

Growing interest in sustainable building methods that strive to lessen the ecological impact of the sector is a reaction to these environmental worries. Sustainable building focusses on decreasing resource usage, waste, and environmental impact (Olajide, 2019). Within this framework, the use of agro-industrial wastes in brick manufacturing has emerged as a promising solution. Agro-industrial wastes, such as rice husk ash, fly ash, sugarcane bagasse ash, coconut shell ash, and other by-products, offer a dual benefit. On one hand, they address the issue of waste disposal, preventing these materials from accumulating in landfills or being openly burned. On the other hand, they reduce the reliance on traditional clay and energy-intensive production methods, thereby conserving natural resources and reducing emissions (Figaredo and Dhanya, 2018). The incorporation of agro-industrial byproducts in brick manufacturing aligns with global sustainability aims, notably the United Nations' Sustainable Development Goals (SDGs). It specifically contributes to objectives including responsible consumption and production, climate action, and sustainable urban development (Akshana and Arasu, 2020). Through the integration of recycled resources, the building sector may advance towards a circular economy, wherein waste is transformed into useful raw materials.

The use of agro-industrial wastes in bricks is not only an environmental imperative but also an economically viable option. These materials are often readily available and cheap, particularly in agricultural and industrial regions (Cintura *et al.* 2021b). For instance, rice husk ash is abundantly generated in rice-producing countries, while fly ash is a common by-product of coal-fired power plants. Utilizing these wastes in brick production can lower raw material costs, create opportunities for local businesses, and generate employment in waste collection and processing sectors. Moreover, waste-based bricks often exhibit enhanced properties, such as improved thermal insulation, reduced weight, and superior durability, making them competitive with conventional bricks (Duque *et al.* 2022). Despite the potential benefits, the adoption of agro-industrial wastes in brick manufacturing faces several challenges. The variability in the chemical composition and physical properties of these wastes can affect the quality and performance of the bricks. Standardizing the processing and proportioning of waste materials is essential to ensure consistent product quality (Meshram *et al.* 2022a). Additionally, the lack of awareness among manufacturers, builders, and consumers about the benefits of waste-based bricks can hinder market acceptance. Regulatory frameworks and policies that incentivize sustainable construction practices are crucial for encouraging the adoption of these materials on a larger scale (Chilukuri *et al.* 2021). Technological advancements in material processing and brick production techniques have facilitated the incorporation of agro-industrial wastes. Innovations such as mechanical blending, chemical treatments, and advanced firing methods have improved the compatibility and performance of waste-based bricks (Kachancheeri *et al.* 2024). Furthermore, research and development efforts continue to explore new waste materials, optimize production processes, and enhance the properties of sustainable bricks. Collaborative efforts among academia, industry, and governments are critical to overcoming technical and economic barriers and promoting the widespread adoption of these practices (Monedero *et al.* 2021).

This review aims to provide a comprehensive overview of the potential of agro-industrial wastes in brick manufacturing, highlighting their environmental, economic, and technical advantages. It also examines the challenges associated with their use and offers insights into strategies for scaling up production and adoption. By exploring the current state of knowledge and practice, this review seeks to contribute to the global transition towards a more sustainable construction industry (Sorte *et al.* 2020). Through innovative approaches and collective action, the integration of agro-industrial wastes in brick manufacturing can pave the way for a greener, more resilient future. The worldwide construction business is expanding rapidly, fuelled by urbanisation, population expansion, and infrastructural development (Azevedo *et al.* 2022). Conventional construction materials, including bricks, heavily rely on non-renewable resources like clay and contribute significantly to greenhouse gas emissions during production. Traditional clay brick production involves the excavation of topsoil, leading to soil degradation and loss of agricultural land. Furthermore, the firing process in kilns consumes substantial amounts of fossil fuels, exacerbating air pollution and contributing to global warming (Hafez *et al.* 2022). The urgent need for sustainable alternatives has led to increased interest in utilizing waste materials. By integrating agro-industrial wastes into brick production, the construction industry can reduce its environmental footprint while addressing the challenge of managing increasing amounts of industrial and agricultural by-products (Katare *et al.* 2020).

1.1 Importance of Sustainable Construction

Sustainable construction is an essential paradigm in modern building practices, aiming to minimize environmental impacts while enhancing resource efficiency and socio-economic benefits. The traditional construction industry has historically relied heavily on non-renewable resources and energy-intensive processes, leading to significant environmental degradation and carbon emissions (Kumar *et al.* 2022a). In contrast, sustainable construction prioritizes strategies that conserve resources, reduce waste, and promote the reuse and recycling of materials, aligning with global sustainability goals (Sangmesh *et al.* 2023).

Sustainable methods may transform the brick production industry by tackling environmental and economic issues. Conventional brick manufacture requires the mining of vast amounts of clay, a limited resource, as well as the usage of significant energy, which is frequently supplied from fossil fuels (Anbarasu *et al.* 2024). This process not only depletes natural resources but also contributes to air pollution and greenhouse gas emissions. By adopting sustainable methods, such as incorporating recycled or waste materials into brick production, manufacturers can significantly reduce the demand for virgin raw materials and lower energy usage. For instance, typical clay in bricks may be replaced with industrial wastes like fly ash, slag, and quarry dust, minimizing resource extraction and keeping trash out of landfills (Divyabharathi *et al.* 2024). The adoption of sustainable materials also aligns with the principles of a circular economy, where waste is viewed as a resource to be reintegrated into production cycles. Using waste-based materials in brick manufacturing has dual benefits: it addresses waste management challenges and reduces the carbon footprint of construction materials. For example, utilizing agricultural residues, such as rice husk ash or coconut coir, in brick production not only enhances the thermal and acoustic properties of the final product but also provides an environmentally friendly solution to agricultural waste disposal (Soni *et al.* 2023a).

Sustainable building methods in brick production provide significant financial benefits in addition to environmental ones. The integration of recycled or locally available waste materials can lead to substantial cost savings by reducing the dependence on expensive raw materials (Singh *et al.* 2023a). Moreover, the development of eco-friendly bricks can open up new markets, catering to the growing demand for green building materials. Such innovation can create opportunities for small-scale entrepreneurs and startups to enter the construction industry with sustainable solutions (Ricciardi *et al.* 2020). Socially, sustainable construction contributes to community development by fostering job creation in waste management, material processing, and eco-friendly product manufacturing. The establishment of recycling facilities and the processing of alternative materials generate employment opportunities, particularly in rural and underdeveloped areas. These activities also promote environmental awareness and education, encouraging communities to adopt sustainable practices in their daily lives (Cintura *et al.* 2023a).

Furthermore, the use of sustainable construction materials enhances the overall durability and efficiency of buildings (Dirisu *et al.* 2022). For instance, bricks made from recycled or alternative materials often exhibit improved thermal insulation properties, reducing energy consumption for heating and cooling in buildings. This contributes to long-term savings for occupants and reduces the environmental impact of energy usage in the built environment (Gavali *et al.* 2019).

In conclusion, the importance of sustainable construction, particularly in brick manufacturing, cannot be overstated. By minimizing environmental impacts, conserving natural resources, and promoting economic and social benefits, sustainable practices support global efforts to combat climate change and transition to a circular economy (He *et al.* 2020). The integration of waste-based materials not only addresses pressing environmental challenges but also offers a pathway for innovation and economic growth. As the construction industry evolves, embracing sustainable methods will be critical to building a resilient and equitable future (Blesson and Rao, 2023).

1.2 Scope of Review

This review focuses on agro-industrial wastes used in brick manufacturing, evaluating their mechanical properties, environmental benefits, and economic feasibility. It also examines challenges in scaling up production and adopting these practices globally. The potential of agro-industrial by-products, such as fly ash, rice husk ash, sugarcane bagasse ash, and other local waste materials, as partial or total replacements for traditional brick-making components is specifically highlighted. Case studies, technical developments, and legislative frameworks that promote sustainable building methods are highlighted in the review. In order to hasten the building industry's adoption of waste-based bricks, it also points out research gaps and offers suggestions for additional study.

2. AGRO-INDUSTRIAL WASTES IN BRICK MANUFACTURING

The integration of agro-industrial wastes into brick manufacturing presents an innovative and sustainable approach to reducing environmental impacts, conserving natural resources, and enhancing the performance of bricks (Sathiparan *et al.* 2023). These materials, often regarded as waste, have beneficial properties that can improve the mechanical, thermal, and environmental characteristics of bricks. Below is a detailed discussion of key agro-industrial wastes used in brick manufacturing. Fig. 1 shows the Agro industrial waste used in brick manufacturing.

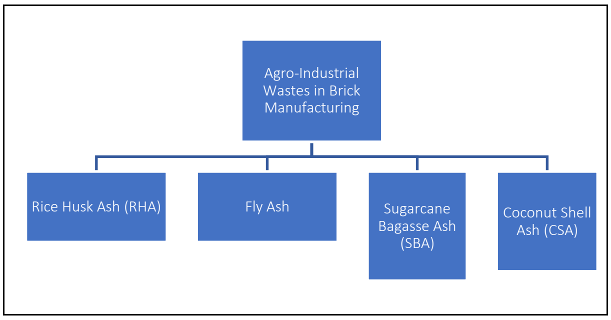

Fig. 1: Agro Industrial waste used in Brick Manufacturing

2.1 Rice Husk Ash (RHA)

An important source of silica, rice husk ash is a by-product of milling rice and usually makes about 85–90% of its composition. This high silica content makes RHA an excellent candidate for partial substitution of clay in brick production. Incorporating RHA into bricks has multiple benefits. Firstly, it enhances the thermal insulation properties of bricks, making them energy-efficient for use in construction (Kumar *et al.* 2022b). The improved insulation can reduce heating and cooling energy requirements in buildings, thereby lowering their overall environmental footprint. Additionally, RHA reduces the overall weight of bricks without compromising their structural integrity, facilitating easier handling and transportation. Its incorporation also diverts large quantities of rice husk from being burned or disposed of in landfills, thereby mitigating air pollution and waste management issues. Research indicates that bricks containing RHA exhibit improved durability and resistance to shrinkage, further enhancing their appeal as a sustainable construction material (Koul *et al.* 2022).

2.2 Fly Ash

Fly ash is a fine, powdery waste produced after the burning of pulverised coal in thermal power plants. It is one of the most commonly utilised industrial byproducts in brick manufacture due to its quantity and great qualities (Valenzuela *et al.* 2024). Fly ash bricks are noted for their higher strength and durability than traditional clay bricks. Their low water absorption rate lowers the possibility of moisture penetration and subsequent structural damage over time. The pozzolanic characteristic of fly ash improves compressive strength when utilised as a primary or auxiliary ingredient in brick manufacture. Furthermore, fly ash bricks are environmentally benign since they greatly reduce the need on natural clay and the carbon emissions associated with typical brick fire techniques (Khalife *et al.* 2024). By using fly ash, the sector handles the environmental problem of controlling coal combustion byproducts while simultaneously supporting waste valorisation and circular economy principles.

2.3 Sugarcane Bagasse Ash (SBA)

Burning sugarcane bagasse yields sugarcane bagasse ash, a byproduct of the production of sugar. Because it contains a lot of silica and other pozzolanic compounds, SBA is a great element for producing bricks. When added into bricks, SBA increases compressive strength by reacting with calcium hydroxide to generate calcium silicate hydrates, which improves the material's binding qualities. In addition to mechanical benefits, SBA helps to reduce the environmental impact of brick manufacture by providing an efficient way to recycle sugar mill waste. It also reduces the amount of clay required, which conserves natural resources and saves energy during the burning process (Anbarasu *et al.* 2025). The adoption of SBA in brick production supports sustainable waste management and promotes a circular approach to resource utilization in the agro-industrial sector.

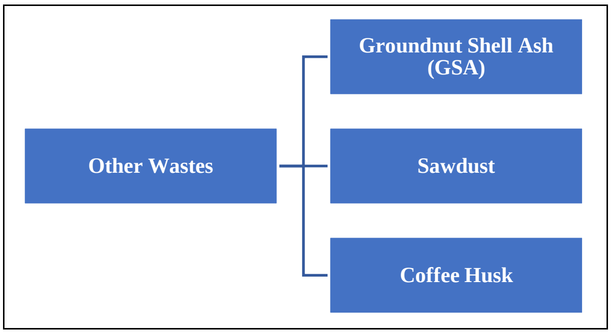

Fig. 2: Other waste used in brick manufacturing

2.4 Coconut Shell Ash (CSA)

Coconut shell ash is an emerging material in sustainable brick manufacturing, derived from the combustion of coconut shells, a common agricultural waste in tropical regions. It is characterized by its high carbon content and lightweight properties, which make it an attractive additive for producing lightweight and energy-efficient bricks (Anitha and Senthilselvan, 2022). The inclusion of CSA enhances the thermal insulation capabilities of bricks, making them ideal for energy-conscious building applications. Its use also contributes to waste reduction and provides a sustainable alternative to traditional materials. Furthermore, CSA's availability in regions with abundant coconut cultivation offers a localized and cost-effective solution for eco-friendly brick production (Sharma *et al.* 2024).

2.5 Other Wastes

Several other agro-industrial wastes have been explored for their potential in brick manufacturing, each offering unique advantages based on their chemical composition and regional availability. Fig. 2 shows the various other wastes used in brick manufacturing.

2.5.1 Groundnut Shell Ash (GSA)

Groundnut shell ash is an innovative material derived from the combustion of groundnut shells, which are abundant agricultural residues in many regions. Its high silica content, typically exceeding 50%, makes it an excellent additive in brick manufacturing. When used as a partial substitute for clay, GSA enhances the mechanical properties of bricks, particularly strength and durability (Soomro *et al.* 2023).

- **Strength and Durability**: The silica in GSA reacts with other compounds during the firing process, forming silicate structures that improve the compressive strength and weather resistance of bricks. This ensures a longer lifespan and reduces maintenance costs for structures made with GSA-enhanced bricks.
- **Lightweight Properties**: The reduced density of bricks made with GSA enhances their transportability, lowering logistical costs and energy consumption associated with distribution. This makes GSA bricks particularly advantageous in construction projects in remote areas.
- **Environmental Impact**: Utilizing GSA mitigates waste disposal issues associated with groundnut shells, which are often burned in open fields, contributing to air pollution. By recycling these shells into bricks, the agricultural and construction sectors work together to reduce carbon emissions and promote sustainability.

2.5.2 Sawdust

Sawdust, a by-product of the woodworking and furniture industries, is widely available in regions with active timber processing operations. Its integration into brick manufacturing offers several benefits, particularly in enhancing thermal insulation and promoting lightweight construction materials (Alawi *et al.* 2023).

- It provides thermal insulation by burning off organic material during fire, leaving tiny spaces in bricks. These holes increase the thermal insulation qualities of bricks, minimising heat transmission and increasing construction energy efficiency.
- It decreases brick density, making them simpler to handle, transport, and install. Lightweight bricks are especially useful in situations where

decreasing structural load is critical, such as earthquake-prone areas.

- It is a frequent industrial waste that requires proper waste treatment. By recycling it in the production of bricks, manufacturers lessen the environmental effect of the wood-processing sector and support a circular economy.
- It is a sustainable and locally supplied alternative to traditional materials, making it particularly useful in locations with a strong woodworking industry.

2.5.3 Coffee Husk

Coffee husk is a renewable by-product generated during coffee bean processing. It is rich in organic compounds, including cellulose and lignin, making it a viable raw material for eco-friendly brick manufacturing.

- **Eco-friendly Bricks:** Coffee husk bricks have lower embodied energy compared to traditional clay bricks due to their organic composition. During the firing process, the organic matter burns off, creating a porous structure that improves insulation and reduces the density of the bricks.
- **Thermal Insulation:** The porosity resulting from burned-off organic content enhances the bricks' thermal insulation properties, which is ideal for maintaining comfortable indoor temperatures in both hot and cold climates.
- **Waste Management Solution:** Coffee production generates large quantities of husk, which can pose environmental challenges if not properly managed. Using coffee husk in brick production provides an effective way to recycle this waste, reducing landfill accumulation and associated methane emissions.
- **Economic Potential:** In coffee-producing regions, integrating coffee husk into brick manufacturing offers opportunities for value addition, creating new revenue streams for coffee growers and processors while fostering sustainable practices (Soni *et al.* 2023b). It highlights the role of these agro-industrial wastes in promoting eco-friendly practices while enhancing brick quality and performance. The use of groundnut shell ash, sawdust, and coffee husk in brick manufacturing exemplifies innovative approaches to sustainable construction. These materials not only improve the performance characteristics of bricks but also address critical environmental challenges by reducing waste and conserving natural resources. By tailoring brick compositions to local waste availability, industries can create cost-effective and eco-friendly building materials, supporting global efforts toward a sustainable future (Scialpi and Perrotti, 2022).

3. ENVIRONMENTAL BENEFITS

The integration of agro-industrial wastes in brick manufacturing not only provides a sustainable solution to waste management but also brings several environmental and economic benefits. These benefits span waste management, carbon emissions reduction, and conservation of natural resources (Singh *et al.* 2024b).

3.1 Waste Management

Incorporating agro-industrial wastes such as groundnut shell ash, sawdust, and coffee husk in brick manufacturing addresses the pressing issues of waste disposal and resource conservation (Ralegaonkar *et al.* 2019).

- **Waste Diversion:** By using these materials, large amounts of agro-industrial waste are kept out of open dumping sites and landfills. For instance, bricks may be successfully made from rice husk ash and sugarcane bagasse ash, which are by-products of agricultural operations. This lessens the negative effects of waste on the environment, stops contamination of the land and water, and lessens the discharge of toxic gases from burning agricultural leftovers.
- **Resource Conservation:** By replacing conventional materials like clay with these agro-industrial by-products, the need for new raw materials is minimized. This reduces the pressure on natural resources, thereby conserving them for future use. The shift also helps in reducing the demand for energy-intensive manufacturing processes, contributing to sustainable development goals.

3.2 Reduction in Carbon Emissions

Traditional brick making uses high-temperature kilns that produce significant volumes of carbon dioxide (CO_2). The process of burning clay bricks is energy-intensive, sometimes reliant on fossil fuels, and contributes significantly to carbon emissions in building. However, the use of agro-industrial waste provides a potential alternative to this high-energy method (Rithuparna *et al.* 2021).

- Utilising elements such as fly ash and rice husk ash in brick manufacture can minimise energy consumption during burning. These materials already include silica and other chemicals that react with lime, thus clay bricks do not require high-temperature sintering. This reduction in energy usage results in reduced greenhouse gas emissions linked with the manufacturing process.

- The building sector may lower its carbon footprint by using waste materials instead of burning them. The use of agro-industrial wastes as partial replacements for clay saves energy and reduces emissions from typical brick kilns.

3.3 Conservation of Natural Resources

Replacing clay with agro-industrial wastes in brick manufacturing is crucial for the conservation of natural resources, particularly fertile topsoil, which is essential for agriculture. The global demand for construction materials has led to extensive extraction of clay, contributing to soil degradation and loss of arable land. Using alternative materials helps to mitigate these effects (Thangavel *et al.* 2024a).

- **Fertile Topsoil Preservation:** Clay is a vital resource for agriculture, providing nutrients and support for plant growth. The extraction of large quantities of clay for brick production can lead to soil erosion and desertification. By substituting clay with agro-industrial wastes, such as groundnut shell ash and sawdust, manufacturers can help preserve fertile topsoil and maintain agricultural productivity.
- **Sustainable Construction:** The use of these materials in construction not only conserves natural resources but also supports sustainable building practices. Agro-industrial by-products are often abundant, locally available, and can be sourced at a lower cost, making them economically viable alternatives to clay. This approach ensures that construction materials are aligned with the principles of a circular economy, where waste is repurposed and reused.

Finally, using agro-industrial wastes in brick production offers a multifaceted way to address urgent environmental issues (Shankar *et al.* 2024). It tackles waste management, lowers carbon emissions, and preserves natural resources, all of which support sustainable growth in the building industry. A more robust and sustainable future may be achieved by the industry by incorporating these materials into industrial processes (Ramakrishnan *et al.* 2024).

4. BENEFITS AND CHALLENGES OF AGRO-INDUSTRIAL WASTE-BASED BRICKS

In terms of durability, cost savings, and mechanical qualities, using agro-industrial wastes in brick production has several advantages. However, there are other difficulties, especially with regard to quality control, processing, and long-term performance in various environmental settings (Saeed *et al.* 2018).

4.1 Mechanical Properties

Agro-industrial waste-based bricks exhibit varying mechanical properties depending on the type and proportion of waste materials used. Key mechanical parameters include (Athira *et al.* 2019):

- **Compressive Strength:** One important measure of a brick's capacity to support weight is its compressive strength. Bricks' compressive strength may be considerably increased by adding agro-industrial wastes like fly ash, rice husk ash, and groundnut shell ash. By reacting with lime during the fire process, pozzolanic qualities of these materials create calcium silicate hydrates, which increase the brick's overall strength.
- **Water Absorption:** Compared to conventional clay bricks, bricks made from agro-industrial waste often absorb water at a slower rate. This is beneficial because it lessens moisture intrusion, which can cause damage like cracking or efflorescence. For example, because fly ash is inert and reduces porosity, bricks made with fly ash exhibit less water absorption.
- **Thermal Conductivity:** Bricks can become better insulators by reducing their heat conductivity by the addition of materials like sawdust or coconut shell ash. Because it may assist maintain consistent inside temperatures and lessen the need for artificial heating and cooling, this characteristic is advantageous for building energy efficiency.
- **Flexural Strength:** The addition of waste materials can improve the flexural strength of bricks, which is their ability to withstand bending forces without breaking. This is especially true for bricks containing sawdust, which provides a lightweight yet strong structure.

Key mechanical parameters of bricks incorporating agro-industrial wastes include compressive strength, water absorption, thermal conductivity, and flexural strength. Because of their pozzolanic qualities, which react with lime during burning to generate calcium silicate hydrates, agro-industrial wastes such as fly ash, rice husk ash, and groundnut shell ash greatly increase compressive strength, hence enhancing the overall strength of the brick. These bricks generally exhibit lower water absorption rates compared to traditional clay bricks, reducing moisture infiltration and preventing issues like efflorescence and cracking. The inclusion of materials like sawdust or coconut shell ash also lowers the thermal conductivity, making the bricks better insulators and more energy-efficient for buildings. Additionally, the addition of these wastes can improve flexural strength, allowing the bricks to withstand bending forces without breaking, especially in bricks containing sawdust, which contributes to their lightweight yet strong structure (Parthasaarathi *et al.* 2024).

4.2 Cost Analysis

The incorporation of agro-industrial wastes into brick manufacturing generally results in cost savings. Using agro-industrial wastes in brick manufacturing offers significant economic benefits, including reduced raw material costs. These waste materials, such as rice husk ash, fly ash, and sugarcane bagasse ash, are often abundant and locally available, making them economically viable substitutes for clay or other traditional binding agents. Incorporating these materials also results in energy savings by reducing the temperature required during the firing process, which lowers fuel consumption. However, processing costs must be considered, as they include expenses for milling, drying, and homogenizing the waste to meet necessary specifications. Quality control is critical to ensure consistency in the mechanical properties of the final product. Additionally, transportation costs can add to overall expenses if the waste materials are not sourced locally. Therefore, while the use of agro-industrial wastes reduces the overall cost of production, efficient logistics and local sourcing strategies are essential to manage transportation costs effectively (Nandipati *et al.* 2023).

4.3 Durability and Long-term Performance

The durability of bricks incorporating agro-industrial wastes is generally adequate, but the long-term performance under varying environmental conditions needs further investigation. Bricks made with agro-industrial wastes demonstrate significant durability, withstanding exposure to environmental stresses such as moisture, temperature variations, and freeze-thaw cycles (Rao *et al.* 2023). Their resistance to degradation and weathering highlights their potential for long-term use in construction. However, the long-term performance of these bricks is influenced by factors such as the type and proportion of waste used, the firing process, and the specific environmental conditions in which they are deployed. For instance, bricks containing rice husk ash may exhibit reduced durability under high humidity conditions due to increased porosity. Therefore, more research is required to fully understand their long-term performance in various climates. Long-term field tests are crucial for monitoring the durability and performance of these bricks over extended periods, especially in diverse environmental settings. These tests will aid in refining mix designs and processing methods to enhance the bricks' durability and overall performance.

In the end, although there are many advantages to using agro-industrial wastes in brick production, including lower expenses and better mechanical qualities, there are drawbacks as well, including issues with processing, shipping, and guaranteeing long-term durability. Addressing these issues and maximising the use of waste materials in sustainable building will need ongoing research and development in this area (Dey *et al.* 2021). It highlights the improvements in mechanical properties, cost savings, and durability, along with the challenges of processing and ensuring consistent quality and long-term performance (Raut *et al.* 2023).

5. CHALLENGES AND SOLUTIONS

5.1 Material Variability

The heterogeneity of agro-industrial wastes presents a significant challenge in achieving consistent brick quality. Agro-wastes such as rice husk ash, fly ash, sawdust, and coffee husk can vary widely in composition due to differences in their source, processing methods, and regional characteristics. For example, rice husk ash from one mill may contain different levels of silica compared to another, affecting its pozzolanic properties in brick manufacturing. Similarly, the size and distribution of particles in fly ash can differ based on its origin from different coal types, impacting its effectiveness as a partial replacement for clay (Mawra *et al.* 2024).

Bricks made with this diversity may have uneven compressive strength, water absorption, and thermal conductivity, among other characteristics. The strength of bricks created using high-silica rice husk ash, for example, may be superior than that of bricks made with the same material from another source (Gurusamy *et al.* 2024). Standardised processing and quality control procedures are crucial to overcoming this obstacle. A homogeneous and consistent result is ensured by following procedures for grinding, drying, and homogenising agro-industrial wastes. Monitoring and managing the variability can be aided by routine testing for characteristics including particle size, moisture content, and chemical composition. Quality control laboratories equipped with the necessary equipment are crucial to ensure the desired characteristics are consistently met across different batches of bricks. Standardization also involves setting up specifications for the acceptable ranges of chemical and physical properties of these waste-based materials (Marut *et al.* 2020).

5.2 Technological Barriers

Adopting new manufacturing technologies for waste-based bricks presents significant technological challenges. The incorporation of agro-industrial wastes requires specific processing techniques to prepare these materials adequately for use in brick manufacturing. For example, advanced milling systems may be needed to grind waste materials to the required fineness for uniform mixing with clay or other binding agents. Similarly, drying technologies might be required to reduce the moisture content in waste materials before their incorporation into the brick mix, preventing issues like incomplete firing or poor durability.

These technological advancements often come with high costs, making the adoption of waste-based bricks a financial challenge for many manufacturers. Furthermore, these technologies might not be readily available in local markets, requiring investments in specialized equipment (Arasu *et al.* 2023). The financial burden can be a significant deterrent for manufacturers, especially small- and medium-sized enterprises (SMEs) with limited capital. To mitigate these challenges, support from governments and research institutions is crucial. Governments can provide subsidies, grants, or low-interest loans to encourage manufacturers to invest in the necessary technologies. Research institutions can play a key role by developing and demonstrating cost-effective, scalable technologies that make it economically viable to use agro-industrial wastes. These institutions can also help in training personnel and providing technical support to overcome the learning curve associated with new technologies (Meshram *et al.* 2023b). Collaborations between industry, government, and academia can lead to innovations in processing techniques, such as improved methods for drying and milling, or the development of new binders that enhance the properties of bricks made from waste materials.

5.3 Regulatory and Market Acceptance

The lack of regulations and market skepticism poses significant barriers to the widespread adoption of waste-based bricks. Many regions do not have clear standards and regulations regarding the use of agro-industrial wastes in construction (Chhetri *et al.* 2020). This creates uncertainty among builders, architects, and consumers regarding the quality, safety, and durability of waste-based bricks. For instance, a lack of regulatory guidelines may result in inconsistent quality across different batches of bricks, leading to apprehension about their performance over the long term. Without standards, there is also the risk of introducing substandard products into the market, which could damage the reputation of the entire category of waste-based construction materials (Thangavel *et al.* 2024b).

To overcome these barriers, policy interventions are essential. Governments need to set clear standards and regulations that define the acceptable properties of waste-based bricks. These standards should cover aspects such as compressive strength, water absorption, thermal insulation, and durability under various environmental conditions (Simón *et al.* 2022). The establishment of such regulations can provide a level playing field for all manufacturers and ensure the safety and quality of the materials. In addition to regulatory measures, promoting awareness is crucial. Public awareness campaigns can educate stakeholders about the benefits of using waste-based bricks, such as their environmental advantages, cost savings, and improved properties. These campaigns can highlight successful case studies and pilot projects that demonstrate the practical benefits of these bricks, fostering confidence in their use. Incentives like tax rebates or financial support for manufacturers using waste-based materials can also encourage broader market acceptance (Junior *et al.* 2024). By integrating these strategies, the adoption of waste-based bricks can be accelerated, aligning with sustainable development goals and contributing to a circular economy in the construction industry.

In summary, overcoming the challenges associated with material variability, technological barriers, and regulatory acceptance requires a comprehensive approach. Standardization, government support, and public awareness campaigns are crucial to promoting the use of agro-industrial wastes in brick manufacturing. Addressing these challenges will not only improve the sustainability of the construction industry but also support environmental protection and economic efficiency.

6. FUTURE PROSPECTS

6.1 Research and Development

Ongoing research is pivotal for enhancing the performance of waste-based bricks. This focus involves exploring innovative additives and processing techniques that can significantly improve the mechanical properties, durability, and cost-effectiveness of these bricks. For instance, the incorporation of pozzolans or nano-materials into agro-industrial waste-based bricks can enhance their binding properties, leading to better compressive strength and reduced water absorption. Advanced processing techniques, such as novel drying methods or the development of new binders, are also critical (Hakeem *et al.* 2023; Mishra *et al.* 2023). Research institutions, universities, and industrial labs are instrumental in conducting experimental studies, pilot projects, and field tests to optimize these additives and techniques. The outcomes of such research can establish best practices in the production of waste-based bricks, ensuring their reliability and sustainability under various environmental conditions (Aluga and chewe, 2022; Kumar *et al.* 2024c; Salleh *et al.* 2021). Ultimately, continuous research efforts are essential for maintaining the competitiveness of waste-based bricks in the construction market, paving the way for broader adoption.

6.2 Policy Frameworks

Strong regulatory frameworks are essential to drive the transition toward greener construction practices. These frameworks provide the necessary support for the adoption of sustainable materials like agro-industrial waste-based bricks by setting clear standards and guidelines for their use (Chen *et al.* 2020). Without such regulations, there may be hesitance among manufacturers and builders to incorporate waste-based bricks into their projects due to concerns over quality, safety, and performance. Governments can play a critical role by establishing standards for properties such as compressive strength, water absorption, and durability of these bricks. Clear certification processes and guidelines assure quality and performance, making these materials more attractive to the market (Kordi *et al.* 2024). Moreover, offering incentives like tax rebates or subsidies for manufacturers using waste-based bricks can further promote their use (Andrade *et al.* 2023). Effective policy frameworks not only ensure the quality and safety of waste-based bricks but also stimulate their demand, ultimately leading to a more sustainable construction industry (Ngayakamo and Onwualu, 2022).

6.3 Global Collaboration

International collaboration is a key strategy for promoting the use of sustainable construction materials, including waste-based bricks. The global nature of sustainability challenges requires knowledge sharing, technology transfer, and market development across borders (Cintura *et al.* 2023c). Collaborative efforts among countries, research institutions, and industries can facilitate the exchange of best practices, technologies, and research findings (Ngui *et al.* 2022). Joint research projects, technical assistance programs, and shared resources for testing and developing sustainable materials are crucial components of such collaborations. Global collaboration also aids in harmonizing standards and regulations across different regions, allowing manufacturers to access international markets and adopt best practices from around the world Hassan *et al.* 2022). This can accelerate the adoption of waste-based bricks, promoting innovation and the development of a circular economy in the construction industry. By fostering an environment of cooperation, global collaboration supports the growth of sustainable construction practices and enhances the overall sustainability of the industry (Singh *et al.* 2022a).

7. CONCLUSION

Agro-industrial wastes have significant potential to revolutionise brick manufacture by tackling urgent issues associated with waste management and resource sustainability. The incorporation of these elements into brick production aids in waste management, conserves natural resources, and mitigates the environmental problems linked to conventional brick manufacturing methods. Notwithstanding hurdles including material unpredictability, technological obstacles, and regulatory concerns, there are evident avenues for progress via research, policy formulation, and industry implementation. Ongoing endeavours to develop standardised processing methodologies, build supporting regulatory frameworks, and promote worldwide cooperation are crucial to surmount these hurdles.

To increase the effectiveness of waste-based bricks and make them appropriate alternatives to conventional materials, research and development are crucial. Advancements in additives and processing techniques are essential to improve the strength, durability, and efficiency of these bricks. Furthermore, governmental frameworks that offer explicit standards and incentives might motivate manufacturers to utilise waste-based bricks, therefore guaranteeing their quality and safety. International collaboration promotes the exchange of information and technology, fostering broader implementation of sustainable practices across various locations.

Integrating environmental and economic factors, the use of waste-based bricks can substantially advance global sustainability objectives. These bricks facilitate the circular economy and aid in mitigating climate change by decreasing the carbon footprint of construction operations. The shift to sustainable construction methods by utilising agro-industrial waste in brick production corresponds with the overarching goals of sustainability, promoting a more robust and eco-friendly construction sector.

FUNDING

There is no funding source.

CONFLICT OF INTEREST

The authors declared no conflict of interest in this manuscript regarding publication.

REFERENCES

Akshana, V., Naveen A. and Karthigaiselvi, P., Experimental study on concrete by partial replacement cement with silica fume, *JCR.*, 7(17), 3801–3805(2020).

Alawi, A., Milad, A., Barbieri, D., Alosta, M., Alaneme, G. U. and Imran Latif, Q. B. A., Eco-Friendly Geopolymer Composites Prepared from Agro-Industrial Wastes: A State-of-the-Art Review, *Civ. Eng.*, 4(2), 433–53(2023). https://doi.org/10.3390/civileng4020025

Aluga, M. and Chewe, K., Agro-waste ashes as a feeder for the synthesis of SiO_2 nanoparticles for road construction, *Waste Manag. Environ.*, 257, 53-63(2022). https://doi.org/10.2495/WMEI220051

Anbarasu, N. A., Keshav, L., Raja, K. C. P. and Sivakumar, V., Unraveling the flexural behavior of concrete and compare with innovative fea investigations, *Matéria (Rio J.)*, 29(4), e20240656(2024a). https://doi.org/10.1590/1517-7076-rmat-2024-0656

Anbarasu, N. A., Sivakumar, V., Yuvaraj, S., Veeramani, V. and Velusamy, S., Pioneering the next Frontier in Construction with High-Strength Concrete Infused by Nano Materials, *Matéria (Rio J.)*, 30 e20240730(2025b). https://doi.org/10.1590/1517-7076-rmat-2024-0730

Andrade, J. P. D. S. C., Cecchin, D., Vieira, C. M. F., Delaqua, G. C. G., Silva, F. C. D., Hamacher, L. D. S. and Azevedo, A. R. G. D., Agro-Industrial Waste of Malt Bagasse: Perspectives on the Development of Eco-Friendly Ceramic Material, *Sustainability*, 15(11), 9120(2023). https://doi.org/10.3390/su15119120

Anitha, K. and Senthilselvan, S., Agricultural Waste Materials Applications in Building Industry - An Overview, *ECS Trans.*, 107(1), 2371–82(2022). https://doi.org/10.1149/10701.2371ecst

Arasu, A. N., Muthusamy, N., Natarajan, B. and Parthasaarathi, R., Optimization of high-performance concrete composites by using nano materials, *Res. Eng. Struct. Mater.*, 9(3), 843-859(2023). https://doi.org/10.17515/resm2022.602ma1213

Athira, G., Bahurudeen, A. and Appari, S., Sustainable alternatives to carbon intensive paddy field burning in India: A framework for cleaner production in agriculture, energy, and construction industries, *J. Clean. Prod.*, 236, 117598(2019). https://doi.org/10.1016/j.jclepro.2019.07.073

Azevedo, D., A. R., Amin, M., Hadzima-Nyarko, M., Agwa, I. S., Zeyad, A. M., Tayeh, B. A. and Adesina, A., Possibilities for the Application of Agro-Industrial Wastes in Cementitious Materials: A Brief Review of the Brazilian Perspective, *Cleaner Materials*, 3, 100040(2022). https://doi.org/10.1016/j.clema.2021.100040

Blesson, S. and Rao, A. U., Agro-Industrial-Based Wastes as Supplementary Cementitious or Alkali-Activated Binder Material: A Comprehensive Review, *Innov. Infrastruct. Solut.*, 8(4) 125(2023). https://doi.org/10.1007/s41062-023-01096-8

Chen, W., Oldfield, T. L., Patsios, S. I. and Holden, N. M, Hybrid life cycle assessment of agro-industrial wastewater valorisation, *Water Res.*, 170, 115275(2020). https://doi.org/10.1016/j.watres.2019.115275

Chhetri, R. K., Aryal, N., Kharel, S., Poudel, R. C. and Pant, D., Agro-based industrial wastes as potent sources of alternative energy and organic fertilizers, Current Developments in Biotechnology and Bioengineering, *Elsevier*, 121-136(2020). https://doi.org/10.1016/B978-0-444-64309-4.00005-2

Chilukuri, S., Kumar, S. and Raut, A., Status of agro-industrial waste used to develop construction materials in Andhra Pradesh region–India, *IOP Conf. Series Mater. Sci. Eng.*, 1197(1), 012075(2021). https://doi.org/10.1088/1757-899X/1197/1/012075

Chin, W., Yeong L., Mugahed A., Roman F., Nikolai V., Ahmad K. and Yee L., A sustainable reuse of agro-industrial wastes into green cement bricks, *Mater.*, 15(5), 1713(2022). https://doi.org/10.3390/ma15051713

Cintura, E., Faria, P., Duarte, M. and Nunes, L., Eco-efficient boards with agro-industrial wastes–Assessment of different adhesives, *Constr. Build. Mater.*, 404, 132665(2023a). https://doi.org/10.1016/j.conbuildmat.2023.132665

Cintura, E., Lina N., Bruno E. and Paulina F., Agro-Industrial Wastes as Building Insulation Materials: A Review and Challenges for Euro-Mediterranean Countries, *Ind. Crop. Prod.*, 171, 113833(2021b). https://doi.org/10.1016/j.indcrop.2021.113833

Cintura, E., Nunes, L. and Faria, P., A Review of Laboratory Tests to Evaluate Agro-Industrial Wastes Properties as Building Materials, *Test. Exp. Civil Eng.*, 41, 55–66(2023c). https://doi.org/10.1007/978-3-031-29191-3_5

Dey, T., Bhattacharjee, T., Nag, P., Ghati, A. and Kuila, A., Valorization of agro-waste into value added products for sustainable development, *Bioresour. Technol.*, 16, 100834(2021). https://doi.org/10.1016/j.biteb.2021.100834

Dirisu, J. O., Oyedepo, S. O., Fayomi, O. S. I., Joseph, O. O., Akinlabi, E. T., Babalola, P. O. and Oluwasegun, K. M., Thermal-Emission Assessment of Building Ceilings from Agro-Industrial Wastes, *Fuel Commun.*, 10, 100042(2022). https://doi.org/10.1016/j.jfueco.2021.100042

Divyabharathi, R., Kalidasan B., Sakthi S. R. J. S. and Subramaniyan C., Recent Advances in Sustainable Agro Residue Utilisation, Barriers and Remediation for Environmental Management: Present Insights and Future Challenges, *Ind. Crop. Prod.*, 216, 118790(2024). https://doi.org/10.1016/j.indcrop.2024.118790

Duque, A. M., Lancellotti, I., Andreola, F., Barbieri, L., Belmonte-Ureña, L. J. and Camacho-Ferre, F., Management of agricultural waste biomass as raw material for the construction sector: an analysis of sustainable and circular alternatives, *Environ. Sci. Eur.*, 34(1), 70(2022). https://doi.org/10.1186/s12302-022-00655-7

Figaredo, A. and Dhanya. M., Development of Sustainable Brick Materials Incorporating Agro-Wastes: An Overview, *Int. Res. J. Eng. Technol.*, 5(11), 721(2018). https://api.semanticscholar.org/CorpusID:218578986

Gavali, H. R., Bras, A., Faria, P. and Ralegaonkar, R. V., Development of Sustainable Alkali-Activated Bricks Using Industrial Wastes, *Constr. Build. Mater.*, 215, 180–91(2019). https://doi.org/10.1016/j.conbuildmat.2019.04.152

Gurusamy, M., Soundararajan, S., Karuppusamy, M. and Ramasamy, K., Exploring the mechanical impact of fine powder integration from ironwood sawdust and COCO dust particles in epoxy composites, *Matéria (Rio J.)*, 29(3), e20240216(2024). https://doi.org/10.1590/1517-7076-rmat-2024-0216

Hafez, A., Radwa, D., Bassam A. T. and Raghda O. A. F., RETRACTED: Development and Evaluation of Green Fired Clay Bricks Using Industrial and Agricultural Wastes, *Case Stud. Constr. Mater.*, 17, e01391(2022). https://doi.org/10.1016/j.cscm.2022.e01391

Hakeem, I. Y., Amin, M., Agwa, I. S., Abd-Elrahman, M. H. and Abdelmagied, M. F., Using a combination of industrial and agricultural wastes to manufacture sustainable ultra-high-performance concrete, *Case Stud. Constr. Mater.*, 19, e02323(2023). https://doi.org/10.1016/j.cscm.2023.e02323

Hassan, A. M. S., Abdeen, A., Mohamed, A. S. and Elboshy, B., Thermal performance analysis of clay brick mixed with sludge and agriculture waste, *Constr. Build. Mater*., 344, 128267(2022). https://doi.org/10.1016/j.conbuildmat.2022.128267

He, J., Kawasaki, S. and Achal, V., The Utilization of Agricultural Waste as Agro-Cement in Concrete: A Review, *Sustain*., 12(17), 6971(2020). https://doi.org/10.3390/su12176971

Junior, A. C. P., Teixeira, E. and Mateus, R., Improving the mechanical, thermal and durability properties of compressed earth block by incorporating industrial waste and by-products: A systematic literature review, *Constr. Build. Mater.*, 438, 137063(2024). https://doi.org/10.1016/j.conbuildmat.2024.137063

Kachancheeri, Muhanned S., Vijay S., Giri R. and Naveen A. A., E-waste as a sustainable coarse aggregate replacement in concrete: innovations and applications, Suranaree J. Sci. Technol., 31(4), 010313(1-9)(2024). https://doi.org/10.55766/sujst-2024-04-e03792

Katare, V. D., Madurwar, M. V. and Raut, S., Agro-Industrial Waste as a Cementitious Binder for Sustainable Concrete: An Overview, Sustainable Waste Manage. Policies Case Stu., 683–702(2020). https://doi.org/10.1007/978-981-13-7071-7_62

Khalife, E., Sabouri, M., Kaveh, M. and Szymanek, M., Recent Advances in the Application of Agricultural Waste in Construction, *Appl. Sci.*, 14(6), 2355(2024). https://doi.org/10.3390/app14062355

Kordi, M., Farrokhi, N., Pech-Canul, M. I. and Ahmadikhah, A., Rice husk at a glance: from agro-industrial to modern applications, *Rice Sci.*, 31(1), 14-32(2024). https://doi.org/10.1016/j.rsci.2023.08.005

Koul, B., Yakoob, M. and Shah, M. P., Agricultural Waste Management Strategies for Environmental Sustainability, *Environ. Res. J.*, 206, 112285(2022). https://doi.org/10.1016/j.envres.2021.112285

Kumar, D. C., Vasanthi, P. and Devaraju, A., Development of Agro-Industrial Wastes in Material Production, *Recent Adv. Mater. Modern Manufac*., 973–81(2022a). https://doi.org/10.1007/978-981-19-0244-4_90

Kumar, R., Rajni L., Bibhakar K. S., Mahesh S. and Negi. S. K., Agro-Industrial Wastes Incorporated Cement Stabilized Mud Composites for Roof and Wall Assembly in Energy Efficient Building Envelope, *Adv. Constr. Mater. Sustainable Environ*., 196, 187–96(2022b). https://doi.org/10.1007/978-981-16-6557-8_15

Kumar, V., Kutty, S. R. M., Shafiq, N., Adebanjo, A. U., Abd Razak, S. N., Shams, M. A. and Lohana, S., Valorizations of food wastes in infrastructural development and construction industries, *Food Waste Valorization*, 203-225(2024c). https://doi.org/10.1016/B978-0-443-15958-9.00013-7

Maraveas, C., Production of sustainable construction materials using agro-wastes, *Mater.*, 13(2), 262(2020). https://doi.org/10.3390/ma13020262

Marut, J. J., Alaezi, J. O. and Obeka, I. C., A review of alternative building materials for sustainable construction towards sustainable development, *JMM*., 7(1), 68-78(2020). https://doi.org/10.21467/jmm.7.1.68-78

Mawra, K., Rashid, K., Alqahtani, F. K., Zafar, I. and Ju, M., Load bearing geopolymer from agro-waste and its energy-environmental-economic (E3) performance: Application through building information modeling, *Constr. Build. Mater*., 440, 137425(2024). https://doi.org/10.1016/j.conbuildmat.2024.137425

Meshram, S. S., Raut, S. P. and Madurwar, M. V., Utilization of Agro-Industrial Waste in Production of Sustainable Building Blocks, *Rec. Trends Const. Technol. Manage.*, 260, 149–60(2023a). https://doi.org/10.1007/978-981-19-2145-2_13

Meshram, S., Raut, S. P., Ansari, K., Madurwar, M., Daniyal, M., Khan, M. A. and Hasan, M. A., Waste slags as sustainable construction materials: a compressive review on physico mechanical properties, *J. Mater. Res. Technol.*, 23, 5821-5845(2023b). https://doi.org/10.1016/j.jmrt.2023.02.176

Mishra, S., Dhada, I. and Haldar, P., Rice Husk: From Agro-Industrial to Modern Applications, Agricultural Waste to Value-Added Products, *Springer, Singapore*, 295–320(2023). https://doi.org/10.1007/978-981-99-4472-9_14

Monedero, E., Hernández, J. J., Collado, R., Pazo, A., Aineto, M. and Acosta, A., Evaluation of Ashes from Agro-Industrial Biomass as a Component for Producing Construction Materials, *J. Clean. Prod.*, 318, 128517(2021). https://doi.org/10.1016/j.jclepro.2021.128517

Nandipati, S., Srinivasa, G. V. R., Manjunatha, M., Dora, R. N. and Bahij, S., Potential use of sustainable industrial waste byproducts in fired and unfired brick production, *Adv. Civil Eng.*, 2023(1), 1-16(2023). https://doi.org/10.1155/2023/9989054

Ngayakamo, B. and Onwualu, A. P., Recent advances in green processing technologies for valorisation of eggshell waste for sustainable construction materials, *Heliyon*, 8(6), e09649(2022). https://doi.org/10.1016/j.heliyon.2022.e09649

Ngui, F., Muhammed, N., Mutunga, F. M., Marangu, J. and Kinoti, I. K., A review on selected durability parameters on performance of geopolymers containing industrial by-products, agro-wastes and natural pozzolan, *J. Sustainable Constr. Mater. Technol.*, 7(4), 375-400(2022). https://doi.org/10.47481/jscmt.1190244

Olajide, O., Abel. Development of Sustainable Building Materials from Agro- Industrial Wastes in Nigeria, *In Sustainable Construction and Building Materials*, x, xx-xx(2019). https://doi.org/10.5772/intechopen.81662

Parthasaarathi, R., Balasundaram, N. and Arasu, N., The experimental investigation on coconut shell fibre reinforced concrete (CSFRC) based on different loading condition, *J. Adv. Res. Appl. Sci. Eng. Technol.*, 35(1), 106-120(2024). https://doi.org/10.37934/araset

Ralegaonkar, R. V., Madurwar, M. V. and Sakhare, V. V., Architecture and Design: Breakthroughs in Research and Practice, *IGI Global*, 1385(2019). https://doi.org/10.4018/978-1-5225-7314-2

Ramakrishnan, T., Manickaraj, K., Prithiv, S. P., Aditya, S. L., Rajanarayanan, N. and Gopalsamy, S., Advancements in Aluminum Metal Matrix Composites: Reinforcement, Manufacturing, and Applications, *AIP Conf. Conf.*, 3221, 020030(2024). https://doi.org/10.1063/5.0235881

Rao, M. S. C., Vijayalakshmi, M. M. and Praveenkumar, T. R., Behaviour of green concrete (blended concrete) using agro-industrial waste as partial replacement of cement along with nanoparticles, *Appl. Nanosci.*, 13(3), 2285-2293(2023). https://doi.org/10.1007/s13204-021-01917-1

Raut, A. N., Adamu, M., Khed, V. C., Murmu, A. L. and Ibrahim, Y. E., Effects of agro-industrial by-products as alumina-silicate source on the mechanical and thermal properties of fly ash based-alkali activated binder, *Case Stud. Constr. Mater.*, 18, e02070(2023). https://doi.org/10.1016/j.cscm.2023.e02070

Ricciardi, P., Cillari, G., Carnevale Miino, M. and Collivignarelli, M. C., Valorization of Agro-Industry Residues in the Building and Environmental Sector: A Review, *Water Manage. Res. J. Sustainable Circular Economy*, 38(5) 487–513(2020). https://doi.org/10.1177/0734242X20904426

Rithuparna, R., Jittin, V. and Bahurudeen, A., Influence of Different Processing Methods on the Recycling Potential of Agro-Waste Ashes for Sustainable Cement Production: A Review, *J. Clean. Prod.*, 316, 128242(2021). https://doi.org/10.1016/j.jclepro.2021.128242

Saeed, T., Muntaha, S., Rashid, M., Sun, G. and Hasnat, A., Industrial Wastewater Treatment in Constructed Wetlands Packed with Construction Materials and Agricultural By-Products, *J. Clean. Prod.*, 189, 442–53(2018). https://doi.org/10.1016/j.jclepro.2018.04.115

Salleh, S. Z., Kechik, A. A., Yusoff, A. H., Taib, M. A. A., Nor, M. M., Mohamad, M. and Ter Teo, P., Recycling food, agricultural, and industrial wastes as pore-forming agents for sustainable porous ceramic production: A review, *J. Clean. Prod.*, 306, 127264(2021). https://doi.org/10.1016/j.jclepro.2021.127264

Sangmesh, B., Patil, N., Jaiswal, K. K., Gowrishankar, T. P., Selvakumar, K. K., Jyothi, M. S. and Kumar, S., Development of sustainable alternative materials for the construction of green buildings using agricultural residues: A review, *Constr. Build. Mater.*, 368, 130457(2023). https://doi.org/10.1016/j.conbuildmat.2023.130457

Sathiparan, N., Anburuvel, A. and Selvam, V. V., Utilization of Agro-Waste Groundnut Shell and Its Derivatives in Sustainable Construction and Building Materials - A Review, *J. Build. Eng.*, 66, 105866(2023). https://doi.org/10.1016/j.jobe.2023.105866

Scialpi, G. and Perrotti, D., The use of urban biowaste and excavated soil in the construction sector: A literature review, *Waste Manage. Res. J. Sustainable Circular Econ.*, 40(3), 262-273(2022). https://doi.org/10.1177/0734242X211000430

Shankar, S. S., Natarajan, M. and Arasu, A., Exploring the Strength and Durability Characteristics of High-Performance Fibre Reinforced Concrete Containing Nanosilica, *J. Balk. Tribol. Assoc.*, 30(1), 142-152(2024).

Sharma, T., Singh, S., Sharma, S., Sharma, U., Sharma, P., Gehlot, A. and Abbas, M., Implications of Agro-Industrial Wastes on the Durability and Erosion Characteristics of Unfired Soil-Blocks Reinforced with Paddy Straw Fibers: Sustainable Earth Construction, *J. Eng. Fiber. Fabr.*, 19 1-22(2024). https://doi.org/10.1177/15589250241239235

Simón, D., Palet, C., Costas, A. and Cristóbal, A., Agro-industrial waste as potential heavy metal adsorbents and subsequent safe disposal of spent adsorbents, *Water*, 14(20), 3298(2022). https://doi.org/10.3390/w14203298

Singh, S., Dalbehera, M. M., Maiti, S., Bisht, R. S., Balam, N. B. and Panigrahi, S. K., Investigation of Agro-Forestry and Construction Demolition Wastes in Alkali-Activated Fly Ash Bricks as Sustainable Building Materials, *J. Waste Manag.*, 159, 114–24(2023a). https://doi.org/10.1016/j.wasman.2023.01.031

Singh, S., Maiti, S., Bisht, R. S., Panigrahi, S. K. and Yadav, S., Large CO_2 reduction and enhanced thermal performance of agro-forestry, construction and demolition waste-based fly ash bricks for sustainable construction, *Sci. Rep.*, 14(1), 8368(2024b). https://doi.org/10.1038/s41598-024-59012-8

Singh, T. A., Sharma, M., Sharma, M., Sharma, G. D., Passari, A. K. and Bhasin, S., Valorization of agro-industrial residues for production of commercial biorefinery products, *Fuel*, 322, 124284(2022c). https://doi.org/10.1016/j.fuel.2022.124284

Soni, A., Chakraborty, S., Das, P. K. and Saha, A. K., Material Selection of Sustainable Composites by Recycling of Waste Plastics and Agro-Industrial Waste for Structural Applications: A Fuzzy Group Decision-Making Approach, *J. Build. Eng.*, 73, 106787(2023a). https://doi.org/10.1016/j.jobe.2023.106787

Soni, A., Das, P. K. and Kumar, S., Selection of Waste Plastics for Incorporation in Agro-Waste as Sustainable Building Construction Materials Concerning Circular Economy: An Integrated MCDM Approach, *Clean Technol. Environ. Policy*, 25(9) 2929–49(2023b). https://doi.org/10.1007/s10098-023-02539-7

Soomro, M., Tam, V. W. and Evangelista, A. C. J., Industrial and Agro-Waste Materials for Use in Recycled Concrete, *Recycled Concr*., 47–117(2023). https://doi.org/10.1016/B978-0-323-85210-4.00009-6

Sorte, A. M., Burile, A. N., Chaudhari, A. R. and Haldar, A., Utilisation of Agro Waste in the Development of Fired Clay Bricks – a Review, *Int. J. Environ. Waste Manage*., 26(4), 531(2020). https://doi.org/10.1504/IJEWM.2020.110400

Thangavel, N., Shanmugavel, N. K., Karuppusamy, M. and Thirumalaisamy, R., Friction and Wear Behavior of Premixed Reinforcement Hybrid Composite Materials, *Matéria (Rio J.)*, 29(4), e20240552 (2024a). https://doi.org/10.1590/1517-7076-rmat-2024-0552

Thangavel, N., Shanmugavel, N. K., Karuppusamy, M. and Thirumalaisamy, R., Friction and wear behavior of premixed reinforcement hybrid composite materials, *Matéria (Rio J.)*, 29(4), e20240552(2024b). https://doi.org/10.1590/1517-7076-rmat-2024-0552

Valenzuela, M., Ciudad, G., Cárdenas, J. P., Medina, C., Salas, A., Oñate, A. and Tuninetti, V., Towards the Development of Performance-Efficient Compressed Earth Blocks from Industrial and Agro-Industrial By-Products, *Renew. Sustain. Energy Rev*., 194, 114323(2024). https://doi.org/10.1016/j.rser.2024.114323