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From Agricultural wastes to green building blocks material: An overview

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Abstract

The construction industry faces mounting pressure to adopt sustainable alternatives to conventional, resource-intensive building materials, contributing significantly to global carbon emissions and environmental degradation. This review provides a comprehensive analysis of the transformative potential of lignocellulosic agricultural waste in developing eco-friendly green building materials, including green concrete, bricks, insulation, geopolymers, and nanocellulose-reinforced composites. By critically evaluating recent advancements (2023–2025), we highlight how these waste-derived materials enhance mechanical properties, thermal insulation, and durability while reducing energy consumption and CO_2 emissions. Key innovations include the integration of rice husk ash, sugarcane bagasse, and wheat straw in cementitious composites, developing of lightweight lignocellulosic waste geopolymers, and of applying nanocellulose for high-performance reinforcement. These lignocellulosic waste-based building materials enhance sustainability, reduce costs, and optimize resource utilization. Despite challenges in scalability and long-term durability, this review underscores the viability of agricultural waste as a cornerstone for circular economy practices in construction. Future research should focus on standardization, industrial adoption, and lifecycle assessments to accelerate the transition toward carbon-neutral building practices.

Keywords: Green Building Materials; Sustainable Construction; lignocellulosic wastes; Lignocellulosic Reinforcement of Building Blocks; Geopolymers.

Abbreviations

Alkali Activated Material (AAM)
Alternative Building Materials (ABMs)
Bacterial Nanocellulose (BNC)
Bamboo Leaf Ash (BLA)
Banana Leaf (BLA)
Blast Furnace Slag (BES)
Building Materials (BM)
Carbon Nanotubes (CNTs)
Cellulose Nanocrystals (CNC),
Cellulose Nanofibers (CNF),
Cement Lignocellulosic Composites (CLC)
Coconut Fibers (CB)
Corrugated Board (CB)
Empty Fruit Bundles (EFB)
Greenhouse Gases (GHGs)
Lignocellulosic (LF)
Lignocellulosic Fiber Composites (LFC),
Medium-Density Fibreboard (MDF)
Ordinary Portland Cement (OPC)
Rice Husk Ash (RHA)
Rice Husks (RH)
Rice Straw (RS)
Sawdust Ash (SDBA)
Sugar Bagasse Ash (SBA)
Sugarcane Ash (SCBA)
Volatile Organic Compounds (VOCS)
Waste Wine (WW)

1. Introduction

The production of conventional building materials such as cement, bricks, and steel consumes a huge amount of natural resources, thermal and electrical energy, contributes to global CO_2 emissions, and also pollutes air, water and land, leading to serious effects on the environment and human health [1, 2]. Agricultural and industrial waste disposal whether through burning or landfill dumping poses serious health and environmental risks. Thus, creating more uses for waste materials is very urgent [3-6]. The two above-mentioned problems may be addressed by using agricultural residues (Lignocellulosic wastes) to produce of sustainable construction materials. Agricultural residues are residues accumulated after the harvest of annual plants or the processing of agricultural products. Agricultural residues may be either converted to high-value-added products [7, 8] or burnt to harm the environment. Value-added products from agrarian residues include a wide range of varieties, e.g., green building materials, board, and paper, or converting these organic wastes to clean fuels such as hydrogen and/or petrochemical substitutes via pyrolysis. Such wastes may also be converted chemically by hydrolysis to sugars, further fermented to give bioethanol. The global annual amount

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of agricultural residues is huge estimated to be 3.7 ± 1.0 petagrams (Pg) of dry matter per year as depicted in the year 2025 emphasizing the importance of tackling these wastes [9, 10].
Due to the unique properties of lignocellulosic fibers, lignocellulosic wastes are excellent promising materials for producing green building blocks. They can enhance compressive strength, reduce density, and improve insulation [11]. However, these lignocellulosic materials are often thrown into the environment, causing environmental and health problems.
Geopolymers are new inorganic aluminosilicate polymers widely used in various civil engineering fields. Compared to cement, geopolymers emit less CO_2 and consume fewer resources. Due to these excellent properties, geopolymers are used as building blocks and fire retardant materials. They are eco-friendly materials and are considered promising alternatives to traditional cement [12, 13]. Utilizing of lignocellulosic residues in geopolymers presents a promising avenue for sustainable construction materials. These residues, which include agricultural by-products such as sugarcane bagasse, rice straw, and wheat straw, can be incorporated into geopolymer matrices to produce eco-friendly building materials. The incorporation of lignocellulosic residues not only enhances the mechanical properties of geopolymers but also contributes to waste reduction and environmental conservation. This approach aligns with the global shift towards sustainable and biobased alternatives, offering a viable solution to the environmental challenges posed by conventional construction materials [14-17].
Nanocelluloses are considered promising materials with significant demand for use in various applications. Researchers are paying more and more attention to applying renewable and sustainable nanocelluloses to cement-based materials. Cellulose nanofibers (CNF), cellulose nanocrystals (CNC), bacterial nanocellulose (BNC), and carbon nanotubes (CNTs) are widely used in cement-based materials [17]. Incorporating nanocelluloses derived from lignocellulosic residues into cement-based construction materials offers a sustainable and innovative approach to enhancing material properties. Nanocellulose, with its high strength-to-weight ratio and biodegradability, can significantly improve cement composites' mechanical properties, such as tensile strength and durability. This integration not only promotes the use of renewable resources but also contributes to reducing the environmental footprint of construction materials. The potential of nanocelluloses to act as reinforcing agents in cement-based materials opens new avenues for developing eco-friendly and high-performance construction solutions [18].
Despite the growing research on using agricultural residues in sustainable construction materials, several gaps remain unaddressed. Current studies primarily focus on lignocellulosic-based building materials' mechanical and thermal properties. Yet, comprehensive investigations into their long-term durability, biodegradability, and resistance to environmental stressors are still limited. Additionally, while geopolymers and nanocelluloses have demonstrated promising applications, the synergistic effects of combining these materials in hybrid composites remain largely unexplored. Standardization and scalability of production processes also pose significant challenges, as variations in agricultural waste composition can impact material performance. Furthermore, these materials' economic feasibility and life-cycle assessments require further scrutiny to ensure their widespread adoption in the construction industry. Addressing these gaps will pave the way for innovative, high-performance, and sustainable building solutions.

2. The Unsustainable Global Rate of Waste Generation

The significant emissions of greenhouse gases (GHGs) from conventional buildings have a significant negative impact on the global environment, like building materials that produce CO_2 and construction waste, such as plastic, concrete, glass, wood, and metal. Buildings, in particular, account for more than 40% of the world's energy consumption and almost the same CO_2 emissions. 64% of the world's CO_2 pollution comes from energy or activity, 35% is in manufacturing, 31% is in buildings, 27% is in transportation, and about 73% of the country's electricity consumption is in buildings [19]. As environmental awareness grows worldwide, governments are forced to reduce emissions and waste. As a result, much effort has been made in the construction field to minimize energy and natural resource consumption in buildings. Current trends in the construction sector to reduce and protect the environment include developing and producing of more sustainable building materials [20]. **Fig**ure 1 shows the expected amount of future waste to be generated worldwide by 2050. Therefore, using lignocellulosic wastes in construction solves waste disposal problems while addressing a variety of global environmental issues, including mass consumption of natural resources, greenhouse gas emissions, high energy consumption, pollution, etc. One of the properties of eco-friendly instructions using modern technologies to save water, energy, and materials.

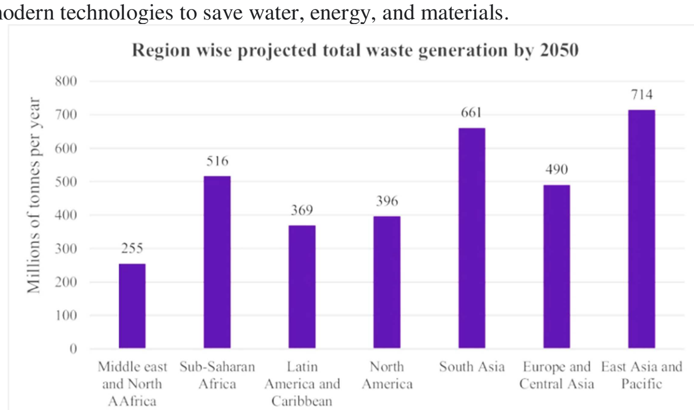

Figure 1: Region-wise projected total waste expected to be generated by 2050 [21].

2.1. Conventional Building Materials

Building materials (BM) are classified into conventional, traditional, and alternative building materials. Building materials (BM) are the main source of indoor emissions of volatile organic compounds (VOCs). Some VOCs are of particular concern as they can affect human health [22]. Formaldehyde and benzene are classified as human carcinogens [23]. The important indoor VOC sources include building materials (BM) such as hardwood, plywood, laminated flooring, adhesives, paints, varnishes, and decorative materials. In addition to these primary releases, many previous studies have shown that ozone reactions with BM result in secondary releases of aliphatic aldehydes, secondary organic aerosols, and other more critical products [24].

3. Classification of Agricultural Wastes Used for Sustainable Building Materials:

Recently, many studies have shown that agricultural waste can be used for sustainable building materials as follows:

1. Cement-based additives, such as straw and rice husks (RH), can be utilized as pozzolan substances. They react with the lime, producing silicate clinker through hydration, which makes the cement products eco-friendly [25].
2. Cement-based reinforcement: for example, long sisal fibers are used as reinforced materials for thinner laminated cement, and long bamboo fibers are very durable with a cement-based matrix.
3. Replace parts of the aggregate, palm and coconut shells waste can replace the traditional aggregate in concrete, so it saves energy and decreases the environmental impact [25].

3.1.1. Natural Plant Fiber

Natural plant fibers have been extensively studied to improve concrete performance and the hardness and ductility of cement-based compounds, but the durability of the alkaline cement matrix is a concern. In addition, natural plant fibers have restrictions on swelling and shrinkage in water after drying, such as a fiber-strengthening effect.

3.1.2. Agricultural Waste Ash

Ash from agricultural waste is the substance produced from burning the waste in an oven or the air. Ash has a volcanic character and can be used as a pozzolan for mortar and concrete to achieve the expected improved performance of mortar and concrete [26].

3.1.3. Multi-Applications Waste

Multi-purpose lignocellulosic waste can be understood as waste that can be reused in different forms, such as lumps, sand, ash, fibers, etc., in manufacturing concrete. The world production of rice straw (RS) is about 8 million tons/ year [27]. Egypt produced about 5.9 million tons of rice in 2013. About 310,000 tons of rice are disposed of annually by burning vast amounts of lands, causing pollution. Disposal of agricultural waste in an incinerator increases greenhouse gases in the air. Still, there is little research on RSA and its potential applications. Using a non-traditional approach, pure silica can be obtained from RS by a sulfuric acid process [28]. The manufacturing of sugar bagasse ash (SBA) has excessive potential. In 2014, Egypt produced about 4.8 million tons of sugar cane waste. Wheat is the main crop used to produce Egyptian staple food. It accounts for about 32.6% of all winter farms in Egypt.

4. Development of Green Building Materials Using Agro Wastes

Recent scientific research from 2023 to 2025 has significantly advanced the development of green building materials using lignocellulosic waste. Studies have explored the use of various agricultural residues, such as rice husk ash, sugarcane bagasse, and wheat straw, in creating sustainable construction materials. These materials have been found to enhance the mechanical properties and durability of green concrete, bricks, and insulation materials. Additionally, the incorporation of lignocellulosic waste into geopolymers and cement-based composites has shown promising results in reducing the environmental impact of construction activities. The findings underscore the potential of lignocellulosic waste as a viable alternative to conventional construction materials, contributing to economic, environmental, and social sustainability [29, 30]. Moreover, agricultural waste showed a trend of increasing substitution for concrete ingredients. The unexploited biomass is the most abundant source of lignocellulose wastes. It is composed of cellulose (30-50%), hemicellulose (15-35%), and lignin (10-20%). Cellulose and hemicellulose correspond to about seventy percent of biomass, and they are tightly bonded to lignin by covalent and hydrogen bonds. Also, there is a lesser extent of other components, such as proteins, pectin, ash, and extracts. Because AW is an eco-friendly material, it is used as an alternative raw material in construction [31]. Lignocellulosic waste can be introduced as a building material to reduce energy consumption, cost, and pollution. The current research has reviewed the applications of locally available agricultural waste materials based on building materials such as bricks, cement/binder, aggregates, particle boards, heat insulators, etc.

4.1. Bricks/Masonry Components

Brick is one of the main components in building construction. Clay bricks are made of (silica, alumina, lime, and iron oxides), they burn at elevated temperatures, consuming higher energy and releasing a large amount of CO_2 and other nitrogen oxides (NOx), which are responsible for global warming and acid rain. Approximately 15% of the total air pollution is caused by brick kilns, which has become a serious environmental problem; the second disadvantage of the process is the excessive use of non-renewable materials such as water and clay, which facilitates the depletion of natural resources [32].

Natural clay is often used to manufacture of bricks, so there may be a shortage of this substance. This shortage prompted scientists to investigate new materials as brick components and simultaneously upcycle wastes generated from various economic activities into brick components [33]. Recent scientific research from 2023 to 2025 has made significant strides in developing brick components from lignocellulosic residues. Studies have demonstrated that incorporating residues such as rice husk, sugarcane bagasse, and wheat straw into brick production can enhance mechanical and thermal properties. These residues not only improve the durability and strength of bricks but also contribute to waste reduction and environmental sustainability. The research highlights the potential of lignocellulosic residues as a renewable resource for eco-friendly brick manufacturing, offering a promising alternative to traditional materials [30, 34]. Sugarcane ash (SCBA) is incorporated into constructions for various uses, including brickwork. Some authors evaluated the addition of rice husk ash (RHA) and bagasse in clay bricks and found that the compressive strength and rupture modulus were decreased compared to untreated bricks. The addition of bagasse ash decreased the quality of the bricks, reduced the compressive strength and increased the water absorption index [35, 36]. Various flammable materials (ash) produced during combustion can be added to the brick-forming compound, making lightweight products that have high porosity and a low heat transfer coefficient. Combustible materials form pores in clay bricks. As a result, flammable substances change the structure of the product. The mechanical properties of bricks can be greatly reduced based on the amount of fuel and the maximum temperature [37]. Bricks made of clay-containing additives such as rice husk ash (RHA) were found to have higher shrinkage and compressive strength when calcined at 1000°C and modified for 4 hours. Other authors [38] argue that the burning temperature needs to be raised to 1050°C obtaining highly performance clay brick, but the optimum rice husk ash content is as high as 30%. The authors stated that the optimal content of rice husk ash in the ceramic body should not be more than 2%. The high content of ash negatively affects the strength of ceramic products. The additional effects of RHA on the thermal and acoustic performance of burned bricks were studied [39]. In the study, six different ratios of waste RHA were mixed with clay. The results showed that at 4% RHA, the optimum grade of bricks was obtained with improved strength that exceeded 32% over traditional clay bricks and showed high water absorption. In addition, the bricks exhibited lower internal temperature and noise reduction compared to conventional clay bricks.

Fernandes et al. [40] evaluated the possibility of using SCBA as a partial substitute for fine aggregate particles in concrete. They found that the compressive strength of SCBA concrete increased by 20% compared to the compressive strength of the reference material. Other authors have observed that SCBA particles have a filling effect, which fills the pores of the mixture, reduces the voids number, and helps maintain mechanical strength. Kazmi et al. found that incorporating RHA and SCBA into bricks reduced the compressive strength of bricks, and ash addition increased the pores of the material and reduced the compressive strength of the bricks. Other authors stated that SCB can be added by up to 20%. The burning temperature should be at least 1000°C; at temperatures above this, the liquid phase ash reacts to form new phases (mullite and cristobalite) [37]. Clay bricks have been proposed to improve brick performance and reduce by-products within the potential of bagasse use. In addition, it is a cost-effective alternative to outdoor burning. The heat released from the SCB burning process can be used to make bricks. The emitted gas can then be filtered and mixed into brickmaking [41].

Some authors explain that adding treated tea waste up to 5% to clay bricks fired at 900 °C improves their physical and mechanical properties, while low amounts of additives adversely affect strength properties. The authors [42] worked on producing lightweight bricks by mixing waste wine (WW) with clay, compared to previous studies; the WW ratios and evaluation of the produced bricks were altered. The results showed that bricks with better physical and mechanical properties were obtained using less than 5% by weight of wine residue. Density is also reduced by up to 13%, depending on the weight of the WW used. A study examined the use of empty fruit bundles (EFB) and coconut fibers (CB) as additional pore aids in producing clay bricks. In this study, different waste concentrations of 0%, 5% and 10% were added to study properties such as compressive strength, thermal conductivity and water absorption. The results showed that when 5% fiber was added, the bricks met the minimum requirements for water absorption and compressive strength [43].

4.2. Lignocellulosic waste-Cement Concrete

The most widely used building material in the world is concrete. About 17.5 billion tons of concrete are consumed annually, and the percentage of aggregate and cement is in the range of 13 billion tons and 2.6 billion tons, respectively [44]. However, its widespread use affects the depletion of natural resources. As a result, researchers have done many studies on how to dispose of waste and study the incorporation of waste into concrete as an alternative to natural resources.

Cement is the main component of mortar, accounting for 74-81% of the total CO_2 emissions from concrete production [44]. For every ton of Portland cement produced, approximately one ton of carbon dioxide is emitted into the atmosphere. As a result, researchers have made many attempts to reduce the waste disposal problem and study waste absorption into concrete as an alternative to natural resources. **Figure 2** shows the entire process of OPC production and application and the CO_2 companion [45]. CO_2 emissions during cement production occur primarily due to two key processes: limestone decomposition and fuel combustion. The calcination of limestone ($CaCO_3$) in cement kilns occurs at high temperatures, leading to its breakdown into lime (CaO) and carbon dioxide (CO_2), releasing substantial amounts of CO_2 into the atmosphere. This reaction alone accounts for approximately 50-60% of total CO_2 emissions in cement manufacturing. Additionally, the energy-intensive nature of cement production necessitates the burning of fossil fuels such as coal, natural gas, and oil to generate the required heat, further exacerbating greenhouse gas emissions. The combined impact of these processes makes cement production one of the largest industrial sources of CO_2 emissions, highlighting the urgent need for sustainable alternatives and emission reduction strategies [40].

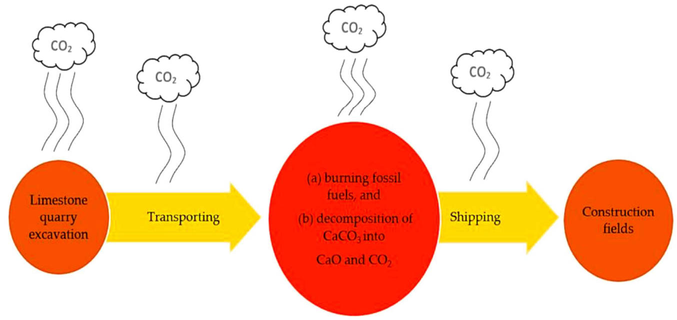

Figure 2: Main processes for manufacturing and using OPC [45].

With the continuous advancements of technology, the focus on cement lignocellulosic composites (CLC) with high performance has increased. Recent scientific research from 2023 to 2025 has made significant advancements in the development of lignocellulosic waste-cement concrete. Studies have shown that incorporating lignocellulosic residues, such as rice husk, sugarcane bagasse, and wheat straw, into cementitious materials can enhance their mechanical properties, reduce shrinkage, and improve thermal insulation. These residues not only contribute to waste reduction but also offer a sustainable alternative to traditional construction materials [46]. The importance is given not only to improving the strength of CLC but also to increasing its strong resistance against any external forces, durability, and higher hardening rate by considering the environmental impact [47].

Lignocellulosic fiber-based cement compounds are used as building materials. In addition to these uses, CLC has potential applications for pedestrian walkways in airports, highways, long bridges and the construction of impressive structures. CLCs mainly consist of two types: fiber-reinforced cement-based products and wood-based particle-bound cement. CLCs are increasing in popularity due to their durability, low cost, great compressive strength, resistance to deterioration, prevention of water absorption, barrier against insects, antibacterial performance, and low maintenance requirements [45]. The CLCs have also been used for insulation purposes for the last decades [38]. The CLC-based products are mainly applied for building materials and provide potentiality for siding panels, decorative applications, partition of walls, balconies, roof shakes, permanent frameworks, thermal insulation, specialized flooring, mobile homes, and sound barriers [39, 40], which are also some prerequisites to be considered for the ideal building materials. The cement binders could also provide colorful effects besides the durable surface of the CLC materials. Compared to traditional concrete materials, CLCs provide higher thermal insulation, workability, and acoustic properties [41]. Recently, sustainability has become a crucial factor in occupying the market, for why bio-based CLC is replacing traditional construction materials as competent and sustainable building solutions [42]. Lignocellulosic fibers are not easily compatible with cement due to the presence of some inhibitory substances in the fibers, such as tannin, sugar, starch, phenols, hydroxyl carboxylic acid, etc. Thus, researchers are trying new methods and techniques to improve the compatibility. The importance is given not only to enhance the strength of CLC but also to increase its strong resistance against any external forces, toughness, and higher hardening rate by considering the environmental impact [36]. Several studies have looked at the use of a variety of physical, chemical, and mechanical treatments to improve the suitability of fiber cement. Natural fiber processing improves wettability and proper distribution of the fibers in the matrix system. Various pretreatments of the fibers with hot or cold water are potential pretreatments to improve compatibility as hot water is more effective than cold water [43].

Plant fiber also replaces synthetic fiber as a potential fortifier due to its excellent eco-friendly properties. Investigations into micro/nanofibrils (reinforced materials), jute fibers, cement composites, and analysis of the mechanical performance of the matrix have yielded very satisfactory results even in normal building climatic conditions [44]. On the other hand, a significant increase in lignocellulosic materials can also worsen the mechanical properties of composites. However, the addition of up to 6% (wt.) $CaCl_2$ improves mechanical properties. Silica and magnesium oxide-based composites containing plant fibers have been reported to provide a high decay coefficient after aging treatment [45]. One study showed the effect of replacing the amount of fine aggregate in concrete with untreated sugar cane bagasse ash (SCBA) at 0%, 10%, 20%, 30%, and 40% ratios. The results show that samples containing 10% SCBA substitutions give better results than samples with 0% SCBA. In addition, further increases in SCBA reduced compressive strength and reduced the properties of fresh concrete. It has also been studied what happens when replacing part of the weight of cement in concrete with different percentages of 0%, 5%, 10%, 15%, and 25% of SCBA. The results showed that the best rate of addition to concrete containing 10% SCBA led to improvement of properties such as higher compressive strength and flexural strength after 90 days [46, 47].

Recently, recycled paper has also been used as a source of cellulosic materials [48]. Lignocellulosic material is usually mixed with cement in 5-15% by weight. However, there are some restrictions on the use of cement-based materials due to the difficulty of mixing due to the presence of lignocellulosic materials and some extracts. Increasing the weight percent of fiber can complicate compression and blending. Recycled paper can be used to produce thin cement-based products by overcoming the brittleness and poor crack resistance of cement-based composites. Recycled materials include old construction waste, magazines/newspapers, tree trunks, furniture waste, wooden pallets, agricultural waste, etc., used as commercial or experimental products [49]. The final performance of the product may be improved by manufacturing and designing the processes and chemicals used. The mixing rate of cement and its settings with the water and wood or fiber particles as illustrated in **Figure 3**.

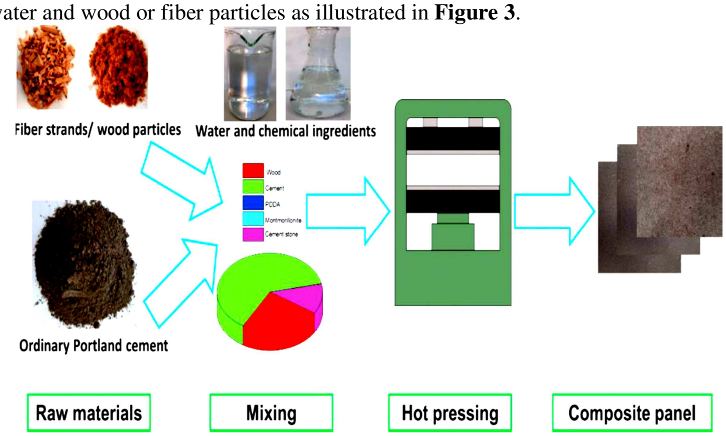

Figure 3: The preparation of cement-bonded wooden fiber composites [48].

Several studies have considered using a variety of physical, chemical and mechanical treatments to improve the suitability of fiber cement. Treating natural fibers improves their wettability and correct distribution in the matrix system. Different treatments of fibers with hot or cold water are considered possible pretreatments to improve compatibility, and hot water is more effective than cold water [49]. Cement-oriented composites are inherently brittle and have low tensile strength. However, the use of LF in composites can significantly enhance mechanical properties. Shearing and compressing the granular packing during extrusion is considered an important role in improving the mechanical properties of flax/cement composites [50]. Poplar had the highest percentage of LFs that could significantly enhance the mechanical properties in the fiber cement mixed panels. Another key component is pine, about (20%) of LF, and it helps produce lighter-weight panels [49, 50]. Thus, the combination of poplar and pine with other LF can improve the mechanical strength and efficiency of vehicles. Conversely, some chemical ingredients used for fiber-based cement, such as asbestos, are not compatible with sustainable products. Sawdust from different plants could reduce the effects on the environment and increase the possibility of applying green construction materials [51]. In general, cementitious materials have poor cohesion, which causes cracking/ fracture of the compound when force is applied. This problem can be overcome by using LFs as prominent raw materials in composites. Although short in size, LFs also increase the impact strength, tensile strength, and bending toughness in cement-bound compounds [52].

4.2.1. Lignocellulosic wastes Ash as an Active Pozzolans for Cement Concrete

A compound of little or no cementitious properties but in finely divided form, it reacts chemically with calcium hydroxide in the presence of moisture at room temperature. It exhibits cementitious properties known as a pozzolan. A process known as the pozzolan reaction [53]. Pozzolans may be naturally occurring or artificially produced materials with cementitious properties when mixed with calcium hydroxide and water. Historically, pozzolans such as volcanic ash have been utilized in construction, dating back to Roman times, where they were integral in creating durable concrete structures like the Pantheon and aqueducts. Modern applications of pozzolans include their use as supplementary cementitious materials (SCMs) in concrete, contributing to improved durability, reduced permeability, and lower environmental impact due to decreased reliance on Portland cement. The chemical composition of pozzolans typically includes high silica and alumina content, enabling them to react with calcium hydroxide released during cement hydration, forming additional calcium silicate hydrate (C-S-H) that enhances the material's strength and resilience. Research continues to explore various sources of pozzolans, including industrial by-products such as fly ash and silica fume, as well as natural deposits, to optimize their performance in contemporary construction practices [54, 55].

Recent scientific research from 2023 to 2025 has highlighted the potential of lignocellulosic waste ash as an active pozzolan for cement concrete. Studies have shown that incorporating ash from agricultural residues such as rice husk, sugarcane bagasse, and wheat straw can significantly enhance the mechanical properties and durability of concrete. These lignocellulosic waste ashes, when used as partial replacements for Ordinary Portland Cement (OPC), contribute to reducing the environmental impact of cement production by lowering CO_2 emissions and promoting the use of renewable resources. The research underscores the viability of lignocellulosic waste ash as a sustainable alternative to conventional cement materials, offering promising prospects for eco-friendly construction practices [56, 57]. Agricultural residues ash includes residues such as bagasse ash, rice husk ash, sawdust ash, peanut shell ash, tobacco waste, palm oil fuel ash, and coconut shell ash, all of which are characterized by the pozzolanic property of supporting building materials and improving properties [51].

Research in the agricultural industry has generated a new waste called pozzolan, which is considered an inexhaustible source of alternatives. However, when fired in the 600-800°C range, considering its physical and chemical properties, it performs well as cement auxiliary materials to improve the performance of mortar and concrete. The composition of industrial waste ash mainly contains SiO_2, CaO, Al_2O_3, and Fe_2O_3 and is closely correlated with Portland cement, making it a perfect alternative to cement materials [58]. Rice husk is produced through the rice milling process, with rice accounting for 78% of its weight and 22% husk. Due to its excessive interest in pozzolanic, silica for rice husk is used to obtain excess electric concrete as a substitute for silica fumes. Concrete of cement—rice husk provides the opportunity to use it as a cementitious material, to change cement, or to manufacture additional reinforcing materials [59].

Alkaline-activated materials (AAM) are considered as a binder, and these are the latest trends in building materials. From alkali-activated sugar cane ash (SCSA) and blast furnace slag (BES) as solid precursors, SCSA is an alkali-activated material (AAM) and can also be a source of silicon. Bamboo leaf ash (BLA), rice husk ash (RHA), and SCBA show a strong reaction to pozzolan when used as a binder in concrete. The results showed that the pozzolanic properties of SCBA and RHA improve the pores in concrete and mortar and also significantly reduce the permeability to water, sulfate and chloride [60, 61]. Another study investigated the effect of adding SCBA and BLA on the wetting and pozzolan properties of cement paste. The results showed that the combination of BLA and SCBA had higher pozzolanic enhancement than SCBA alone. The study showed that replacing cement by 10% by weight SCBA and BLA resulted in good cement properties. However, one notable difference was that the incorporation of BLA into SCBA improved the compressive strength of the mortar. This directly indicates that replacing cement with multiple types of agricultural waste materials to produce green concrete has a positive effect on concrete properties [62]. It was also found that producing a ton of binders from agricultural ash consumes less energy than conventional cement.

However, a notable difference was that mixing BLA with SCBA improved the compressive strength properties of the mortar. This directly indicates that replacing cement with multiple types of agricultural waste materials to produce green concrete has a positive effect on concrete properties [62]. It was also found that producing a ton of binders from agricultural ash consumes less energy than conventional cement.

Banana leaf ash (BLA), obtained by burning at a controlled temperature, was used for pozzolan activity based on its amorphous silicon content. Using it as an additive in mortar and structural concrete has several advantages. It reduces the cost of building materials and consumes large amounts of bananas produced annually.

Concrete made from natural fibers has excellent mechanical properties in combination with other additives. Bamboo leaf wastes have been experimentally added as they can be incorporated into cement-based compositions to impart pozzolanic properties. The tested results showed that 78.7% of the composition of the bamboo leaf residue was SiO_2, which is a highly reactive pozzolan comparable to silica fume. Cement mixed with 10 and 20% Bamboo leaf waste showed the same compressive strength as packing cement [63, 64].

Sawdust is the waste of timber (timber and furniture) operations such as sawing, milling, planning, routing, drilling and sanding [65], and can be used and burnt combusted sawdust ash (SDBA) as a partial substitute for Ordinary Portland Cement (OPC) for interlocking blocks. SDBA cement was partially replaced in varying proportions of 0, 10, 20 and 30% by weight, and the results showed that up to 20% by weight of SDBA is the optimal replacement level for cement to achieve the desired density in the production of interlocking compacted earth blocks for sustainable construction [66]. It does not significantly improve the strength properties of interlocking block samples, although it has a cementitious property like natural pozzolan to prevent the failure of ease.

4.2.2. Lignocellulosic wastes Insulating Material

In addition, agricultural cement compounds have excellent thermal insulation as they adequately address the problem of industrial waste and thermal building effects [67]. Agricultural wastes such as flax, straw, tailings, coconut and hemp have also been used in construction to improve construction insulation. Sisal fiber/cement composites using core-coated polypropylene have been reinforced for the lightweight products proposed for new building panels that provide satisfactory thermal and construction efficiencies. Glass fiber-reinforced magnesium cement/rice straw composites have been addressed to improve flame retardancy and mechanical properties [68]. Another study examined the thermal properties of insulation panels made from hemp alone and combined with concrete. The results showed that the biocomposite has good insulating properties and excellent mechanical properties. The compound was lighter than conventional concrete, so it could only be used when construction required lower loads [69]. One study also examined the mechanical and thermal properties of hemp and lime concrete blocks. The results showed that increasing the slurry density led to an increase in the thermal conductivity and mechanical properties of the block. The results proved that concrete containing hemp and lime biocomposites is lighter than conventional concrete, as well as showing excellent thermal insulation and acceptable mechanical resistance [70]. There is a study of the use of straw in concrete, also with a mixture of a binder such as lime and gypsum. The addition of olive stone as an additive in lime cement mortar was also studied to improve thermal insulation on a large scale. It was observed that the addition of 70% olive stone in concrete led to a decrease in the thermal conductivity of the mortar by 76% [71]. In a study, it was found that adding cork to concrete by 10% and 20% increased the thermal insulation of concrete by about 16% and 30%, respectively. Other researchers demonstrated a rise in thermal insulation with growing proportions of cork from mortar (10-80%). It was also found that adding barley straw improves the thermal and physical properties of sandy concrete by decreasing the thermal conductivity by 5.71% and 21.97%, respectively [72]. Wang et al. [73] studied the mechanical and thermal properties of composite materials developed from rice straw, magnesium cement adhesives, and foaming agents. The composites were also treated with alkali (NaOH) instead of flaxseed oil. The binding properties of the compound and the straw were also evaluated. The results showed that there was an improvement in the mechanical properties of the compound, which reached the best value when mixing straw with 3% NaOH for 150 min. **Figure 4** displays the graphical abstract of the processes of production of the rice straw-magnesium cement composites.

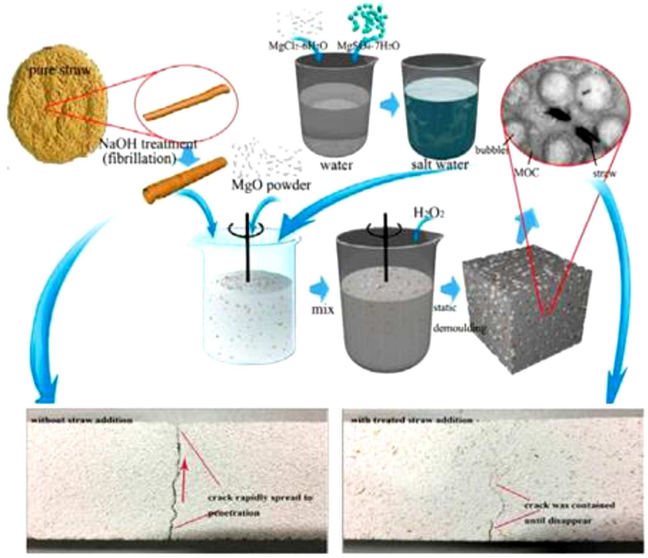

Figure 4: Manufacturing process of the straw/magnesia composite [71].

In a new study, natural fibers from corn husks and straw were used as an alternative material for materials made from petrochemicals in insulation molds. The results showed that the resulting block had good thermal conductivity and mechanical properties, such as stress and bending, as they were comparable with expanded polystyrene blocks. The same study also revealed that industrial sawdust and wood waste could also be used for lightweight composite production by ensuring toughness and thermal insulation properties. Even though these efforts are given for lignocellulosic fiber-based cement boards, the technology could also be feasible with wood particle-based composites as well. Using waste wood in larger amounts with little refining steps could bring attractive features with CLC by providing an eco-friendly approach [74].

4.2.4. Bio-Based Natural Fibers Cement Composites

Bio-based materials are now widely used in insulated concrete such as hemp concrete. The bio-based concrete material offers many advantages, such as lightweight, sound insulation, heat insulation and hydrothermal control while contributing to reducing the environmental impact of carbon sequestration during plant growth. Therefore, the development of plant materials is an important goal of construction. The next step is to introduce bio-based materials into construction mortar and concrete [75].

Bio-based natural fibers are widely recognized as excellent reinforcements using Portland cement for increased strength. Various researchers report significant advantages for natural fiber-based cement products with improved fracture properties, improved toughness, improved impact resistance, and enhanced durability. The most commonly used biofibers for making cement-based composites are cotton stalks, flax, rice husks, hemp, Bamboo, sugar cane, etc. [76, 77]. Recently, extensive research has been underway to adapt various natural fibers to cement-based materials and use them successfully in the building and construction sectors. In addition to being compared to traditional rammed earth, stone, and sun-dried bricks, textile composite panels are also becoming increasingly popular due to their being more sustainable and environmentally friendly.

4.2.3. Particleboards utilizing lignocellulosic waste

Particleboard is chipboard made from a variety of wood lignocellulosic particles and binders that cure together under pressure and temperature. It is commonly used for structural purposes. About 5% to 20% of wood is lost during the manufacturing process [78]. The need to reduce reliance on timber and forest resources has led to great interest in using agricultural waste for chipboard manufacturing. However, some of this waste can be recycled into new eco-friendly products that add economic value. Recently, cement-bonded particle board is made from magnesia phosphate cement binder and wood waste. These are becoming more popular among researchers due to the excellent compatibility and useful properties of cement. Higher fracture energy and bending strength were also observed [79].

Recycled paper is a good material for making fiberboard instead of wood. Corrugated cardboard is used as the base material for packing folding panels and boxes. Low-quality corrugated waste is also used in the production of fiber packaging, such as egg trays [80]. Paper has been used for many years in furniture design. Corrugated board (CB) is used to make a lot of furniture and it has become a sustainable thing because it uses up to 99% less water in industry, consumes up to 50% less energy and wastes up to 50% Up to 90% less than the use of wood as a furniture manufacturing material [81]. The percentage of agricultural waste is about 30 million tons annually in Egypt and it was able to be used to produce types of corrugated board. In addition, medium-density fibreboard (MDF), straw, and bagasse boards have stronger properties, such as internal bond strength, breaking strength, and moisture resistance, compared to boards made of wood. It also has no effect harmful to health because it does not depend on the use of formaldehyde resin [82]. Binder-less board avoids the use of binders in its production. Thus, it is considered the most environmentally friendly board. Some research articles investigated the production of Binder-less boards from Egyptian agricultural residues, namely bagasse and cotton stalks [83, 84].

4.3. Gypsum-Based Lignocellulosic wastes

Recent scientific research from 2023 to 2025 has explored the potential of gypsum-based lignocellulosic wastes in sustainable construction materials. Studies have shown that incorporating gypsum from agricultural residues, such as rice husk ash and sugarcane bagasse ash, into cementitious materials can improve their mechanical properties and reduce environmental impact. These gypsum-based lignocellulosic wastes not only enhance the durability and strength of concrete but also contribute to waste reduction and lower CO_2 emissions. The findings suggest that gypsum-based lignocellulosic wastes are a viable alternative to conventional construction materials, promoting economic, environmental, and social sustainability [29, 85, 86]. There is little literature on hollow building products made from gypsum-based agricultural waste. In one study, the authors explained the acoustic insulating properties of gypsum board as a wall spacer. However, no studies were presented on compressive strength, fire resistance, water absorption capacity, sound transmission loss, as well as thermal insulation of hollow gypsum boards [87, 88]. One of the disadvantages of gypsum compounds is that it is fragile and wet and is sufficiently heat and sound insulators, as they shrink during exposure to fires, which makes their use limited. In contrast, deficiencies can be addressed by incorporating natural fibers into gypsum products, making them more versatile in construction applications.

Natural fiber sources such as rice, jute, coconut, hemp and sisal fibers can be used to enhance the properties of gypsum products [89]. The researchers studied the effect of incorporating rice straw into hollow gypsum boards/blocks for non-structural walls. Hollow straw and gypsum boards with sufficient mechanical strength, excellent heat and sound insulation and fire resistance are produced. Hollow cores help lower the overall weight of the block. The blocks can be filled with lightweight insulating materials to provide insulation. These cores can also be used for electrical wiring. Gypsum blocks can be used for agricultural waste in building materials, which helps reduce air pollution that results from burning agricultural waste in the air [90]. Hollow gypsum blocks based on agricultural residues can be used as a promising environmentally friendly material for drywall due to its thermal and acoustic insulation and its low density and fire retardant.

Few studies have shown that reinforcing gypsum with natural materials provides better performance properties. Wool and coconut wood are biodegradable natural fibers available in bulk and inexpensively and have some unique properties that aid in the development of green building materials. A mixture of wool and coir is used to improve the properties and performance of gypsum ceiling panels. The compound consists of 30% fiber and 70% gypsum, and the proportion of wool to walnut varies between 25% and 75%. Reinforced gypsum showed a higher strength of about 90% and good moisture resistance. Wool fibers were more moisture resistant, while coconut was strong. Not only does the coir and wool-reinforced gypsum improve thermal and acoustic properties, but it will also help reduce costs and make a large part of gypsum ceiling tiles biodegradable. This reduces the environmental burden and promotes green building initiatives [91]. Biomass ash has been proposed as an alternative material for low-cost building materials as it can be used as metal filler in asphalt mixtures. RHA Ash has been evaluated as filler for HMA Hot Mixed Asphalt Concrete. The results show that RHA can replace traditional mineral fillers while making a lot of agricultural waste. In addition, two types of biomass ash such as DSA and RHA palm ash have been mixed to replace the traditional filler. It was found from the results that 100% of the DSA residue was given the optimum proportion and that 75% of the RHA waste could be used. The product of HMA with RHA and DSA had particularly good stress resistance compared to the control mixture. In addition, HMA mixed with RHA and DSA gives particularly good stress resistance compared to the control mixture. This means that concrete with agricultural waste will have a longer fatigue life [92]. Comparing 2% cement as traditional fillers in asphalt production, various levels of RHA (2%-4%) as alternative fillers are superior to mineral fillers by reducing the optimum amount of bitumen in the asphalt concrete mixture [93].

4.4. Application of Agricultural Wastes in Geopolymers

Geopolymers are new inorganic aluminosilicate polymers that are widely used in various fields of civil engineering. Compared to cement, geopolymers emit 60% to 80% less carbon dioxide. Because of these excellent properties, geopolymers are widely used in various fields, such as building blocks and refractory materials [94]. In addition, geopolymers based on solid waste have lower carbon dioxide emissions and resource consumption compared to cement synthesis. It is important to anticipate green and sustainable development as an alternative to conventional cement [95]. The use of agricultural waste in geopolymers is gradually attracting people's attention, with biomass ash such as RHA, palm oil fuel ash POFA, corn cob ash CCA, and shavings ash as precursors, natural fibers and coconut husks as aggregates examined. Geopolymers are considered a new study to benefit from agricultural waste and achieve sustainability, and it is of great importance to developing countries that have large quantities of agricultural waste and low recovery rates. **Figure 5** shows the graphical abstract of lignocellulosic waste–geopolymer applications [96].

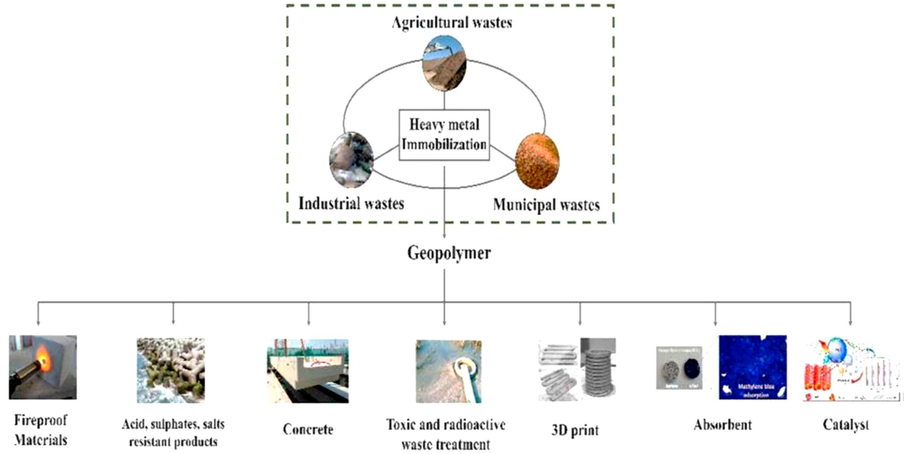

Figure 5: The agro wastes–geopolymer applications [90].

Recent scientific research from 2023 to 2025 has significantly advanced the application of agricultural wastes in geopolymer production. Studies have demonstrated that using agricultural residues, such as rice husk ash, sugarcane bagasse ash, and wheat straw ash, as precursors in geopolymer composites can enhance their mechanical properties and sustainability. These lignocellulosic waste-based geopolymers not only reduce the environmental impact by lowering CO_2 emissions but also offer a cost-effective alternative to traditional cement. The research highlights the potential of agricultural wastes in creating eco-friendly and durable construction materials, contributing to the global shift towards sustainable building practices [30, 97]. Burning rice husks removes organic matter, resulting in 20- 25% husk ashes. These ashes contain up to 95 % amorphous silica, have a specific surface area and are highly active. So, they are excellent pozzolans as a cement-based additive in the synthesis of geopolymers. Nano SiO_2 particles from rice husk ash have a filling effect and high reactivity, which improve the micro-pores of the geopolymer and the gel case. Another study used rice husk ash instead of 30 % from methacholine, which increased its mechanical strength by 57.18% and significantly improved heat stability. In addition, the fine structure of the geopolymer densifier after adding RHA to reduce the water amount in pores enhances the water resistance and softening factor. **Figure 6** shows the graphical summary of the rice husk-geopolymer construction [98, 99].

Figure 6: Rice husk ash–geopolymer construction [100].

Another research dealt with the incorporation of palm oil fuel ash into geopolymer concrete, and this helps in the development of the palm oil and geopolymers industry and also reduces the amount of waste that is neglected, which helps in improving environmental conditions. Palm oil is a vegetable oil and is usually burned as a by-product to give energy to palm oil factories. Palm oil fuel ash contains a large amount of SiO_2 particles (40%) and has been studied for its importance as a cementitious auxiliary material for geopolymers [101]. Several researchers have found that mixing palm oil ash can stimulate the compressive strength of geopolymers. It was found that the geopolymer made by mixing 30% of ash with 70% of kiln slag had the highest compressive strength during 28 days through the wetting process. Palm oil ash can also effectively reduce drying shrinkage [102]. Studies have also focused on combining geopolymers with natural plant fibers to form composite reinforcements such as short plant fibers and plant fibrous panels. Agricultural waste is a renewable resource, and its use in geopolymers not only protects the environment but also brings economic and environmental benefits [103].

4.5. New Materials for Different Sustainable Applications

With a size of 100 nm or less, nanocellulose is characterized by its high specific surface area, large porosity, high hardness, high conductivity, lightweight and low toxicity. It can be defined as a highly biodegradable cellulosic material with low immunogenicity. There are three types of nanocellulose: cellulose nanofibers (CNF), cellulose nanocrystals (CNC), and bacterial nanocellulose (BNC) (**Figure 7**) [104].

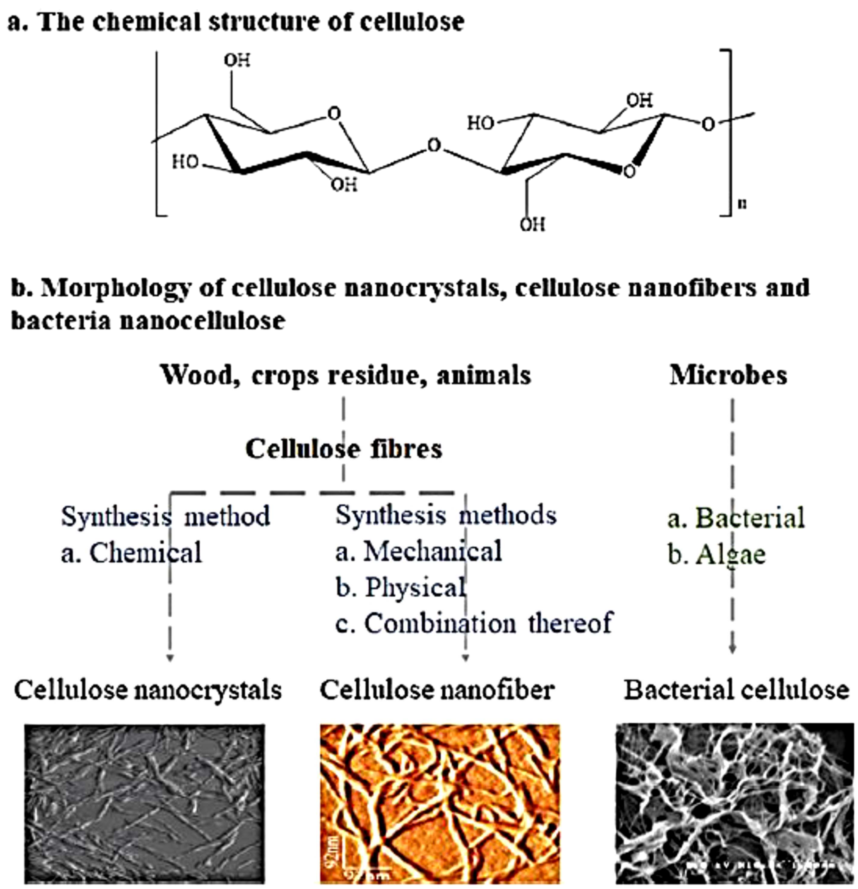

Figure 7: Chemical structures of cellulose and various types of nanocellulose [97].

4.5.1. Application of Nanocellulose in Cementitious Materials

Nanocellulose is used in many fields, including packaging, pharmaceuticals, electronics, cosmetics, food, automobiles, optical materials, aerospace, and construction [105]. Its distinctive properties, such as excellent mechanical properties, stress resistance, and lightweight, make it attractive for a wide range of applications [106]. The unique properties of nanocellulose, such as their high surface area and strong bonding capacity, make them ideal for reinforcing cement matrices. This not only enhances the composites' mechanical properties but also reduces their environmental impact by lowering CO_2 emissions [107]. The use of cellulose as an additive has important effects on cement-based lignocellulosic fiber composites (CLCs), e.g., improved mechanical performance, changes in Slurry rheology, reduction of porosity, and interaction with various components of fortified liquid fertilizers [108].

4.5.2. Recent scientific research from 2023 to 2025 has significantly advanced the application of nanocelluloses in cementitious materials. Studies have demonstrated that incorporating nanocellulose, such as cellulose nanocrystals (CNC), cellulose nanofibrils (CNF), and bacterial cellulose (BC), into cement-based composites can enhance their mechanical properties, including tensile strength, durability, and resistance to shrinkage. These nanocelluloses improve the microstructure and rheology of cementitious materials, making them more sustainable and environmentally friendly. Additionally, the application of nanocellulose in cementitious materials has been found to alter the hydration process, leading to improved workability and reduced water demand. The research underscores the importance of optimizing the type, dosage, and dispersion of nanocelluloses to achieve the desired performance in cementitious materials [18, 46].

4.5.3. Recent examples of studies on using different types of agricultural wastes for nanocellulose in cementitious materials include:

Wheat straw was investigated in the study entitled "Facile synthesis of nanocellulose from wheat straw as an agricultural waste" by Nehra and Chauhan (2022); researchers synthesized nanocellulose from wheat straw and

examined its characteristics. The synthesized nanocellulose exhibited high crystallinity, thermal stability, and mechanical properties, making it suitable for various applications, including cementitious materials [109].
Regarding rice straw, a study entitled "Utilization of Rice Straw-Derived Nanocellulose in Cementitious Materials" by Zhang et al. (2024) investigates the extraction of nanocellulose from rice straw and its application in cementitious materials. The research demonstrates that rice straw-derived nanocellulose can significantly enhance the mechanical properties and durability of cement composites, offering a sustainable and eco-friendly alternative to traditional cement additives [110].
Bagasse was also investigated in another study entitled "Application of Cellulose Nanocrystals from Sugarcane Bagasse in Cementitious Composites" by Hernindya Dwifulqi, Rosalina Tjandrawinata, and Joko Kusnoto (2023). This study explores the use of cellulose nanocrystals (CNCs) extracted from sugarcane bagasse in cementitious materials. The research demonstrates that incorporating CNCs from sugarcane bagasse can significantly enhance the mechanical properties of cement composites, making them more durable and sustainable [111].
Scientists have an increasing interest in CNC for cement materials, such as potential additives and reinforcements. Much research is being done in today's construction industry to develop better building materials, such as high-strength cement composites and eco-friendly composites. Also, in the production of cement mortar, the existing mortar is known as a non-bearing structure [112]. However, the addition of CNC to the mortar and concrete matrix can enhance the strength of the mortar and concrete without changing the density or workability of the matrix. Another study showed that CNC could improve bending resistance using 20% compared to non-reinforced cement by using 0.2% by volume of CNF. Within concrete, the micropores of concrete are filled with nanofibers for greater flexibility and strength. **Figure 8** shows a schematic diagram of the formation of CNF bonds with cement molecules. The use of nanocellulose as a high-performance cement filler reduces the amount of cement required, lowers material and labor costs, as well as lowers greenhouse gas emissions [113].

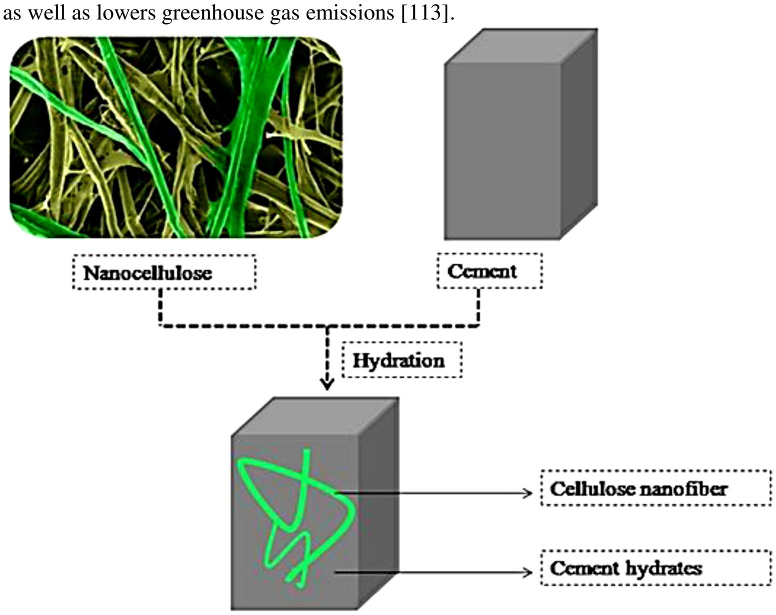

Figure 8: A schematic diagram of the formation of cellulose nanofibers/cement composite [113].

5. Positive Impacts of Lignocellulosic waste Construction Materials

The use of agricultural waste to develop building materials helps reduce the environmental pollution that is widespread in the construction industry. Alternative Building Materials (ABMs) have significant improvements in decreasing the functional (thermal) energy consumption of buildings and reduction in carbon dioxide emissions. The main positive impacts of ABMs can be summarized as follows:

- They are eco-friendly, have better indoor air quality, less embodied energy, low heat transmission, low carbon dioxide (CO_2) emissions, low volatile organic compounds (VOC) emissions, low toxic content, and low cost. Generally, ABMs such as carbonized corn stalk ash particles showed improved tensile strength, compressive strength, and tensile modulus of the composite.
- ABMs eliminate greenhouse gas emissions from the production process and raise the issue of sustainable agricultural waste management in conventional building processes.
- It solves the harmful effects on the environment and health by using less energy to manufacture building materials.
- In brickwork, they led to high-quality and lightweight bricks that adhered to established building codes. Similarly, using green concrete facilitated the development of cheaper and more effective building materials.
- For insulation, ABMs such as hemp have shown that biocomposites have excellent insulation and mechanical resistance, leading to both social and economic sustainability.
- The use of ABMs as a reinforcement for cement-based materials showed improved durability and performance.
- The use of ABMs in particleboard reduced its negative impact on the environment and promoted economic benefits.

- Brick-containing ABMs are lightweight and, therefore, suitable for some structural applications, such as roofs with increased durability and interior partitions that are not exposed to the elements of weather.
- ABMs are used in low-rise and high-rise buildings, especially those constructed in an earthquake-prone environment because they prevent concrete cracking.
- ABMs are used as a wall element in floating building structures that are commonly built on bodies of water.

7. Conclusion and Future Aspects

The effective use of ABMs in reducing the environmental impacts attributed to the construction sector helps to change the concept of considering them as waste materials into eco-friendly materials. ABMs are economical, durable, healthy and safe in construction. The main benefits of ABMs over traditional materials usually include low embodied energy, reduced GHG emission, ease of construction and being widely available. The developed agro-cement lightweight block can be used for various non-load bearing/non-structural lightweight applications in building construction.

The future aspects of applying ABMs can be summarized in the following:

➢ Studying the applicability of a stable, lightweight block based on lignocellulosic wastes for lightweight structural application in building construction.

➢ Assessing the real-world durability of green building materials through extended, non-destructive testing in non-load-bearing structures.

➢ Investigating the application of lignocellulosic aggregate as lightweight aggregate replacement in the production of other building materials.

➢ Investigating the design and manufacture of customized/innovative, energy-saving, and energy-saving manufacturing equipment for lightweight building blocks.

➢ Investigating the application of cement block manufacturing technology could investigate lignocellulosic waste to develop the same type of block from other types of waste paper, such as cardboard, packaging waste and office paper.

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