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The Potential of Sustainable Materials for Green Building Practices

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Abstract: The selection of materials is a critical aspect of any construction activity, and there is a significant reliance on man-made materials compared to those sourced from natural resources. The production of man-made construction materials produces significant amounts of carbon dioxide, carbon monoxide, nitrogen dioxide, and other ecologically harmful gases and byproducts. These substances can be deadly and hazardous to both human and environmental health. As a result, the infrastructure sector has become one of the major contributors to environmental deterioration. The recent population growth has led to a significant increase in the demand for man-made materials. To address this pressing need of the current situation, there is a call for sustainable and eco-friendly materials that offer energy efficiency, easy availability, and minimal disturbance to the environment's ecological system. The primary objective of using these green building materials is to mitigate the negative effect of construction projects on both human health and the natural environment. Typically, building materials are chosen based on their physical, chemical, and mechanical properties. However, the selection and utilization of green materials focus on their functional, technical, and financial attributes. Green materials encompass recycled and reused materials, products made through sustainable production practices, locally available resources, or those derived from environmentally friendly sources. The objective of this paper is to describe various green materials that can be used in building construction and emphasize their positive impact on reducing environmental degradation. These materials contribute to the creation of healthy, sustainable buildings that are beneficial for both occupants and the environment.

Keywords: Green Building, Green Materials, Sustainable Building, Sustainable Materials, Energy Efficiency, Recycling

1. Introduction

The increasing production of greenhouse gases has become a pressing environmental concern, with the building industry being a major contributor. Cement manufacturing alone accounts for approximately 8% of global carbon dioxide (CO_2) emissions, surpassing the combined contributions of China and the United States in CO_2 production [1]. In light of this, the construction sector recognizes the need for more sustainable methods to mitigate its impact. The choices made during the renovation or construction of a building, whether new or existing, have significant implications for the well-being and comfort of its occupants, construction expenses, and the surrounding community and environment. The green building embraces healthier and sustainable options through its efficient utilization of energy, water, materials, and site. The primary objective of adopting sustainable practices in building design and construction is to improve the overall quality of life. The concept of sustainability dates back to earlier civilizations, where various countries developed their own sustainable methods, such as China's concentrated solar power, America's use of hot springs as a geothermal alternative, and Egypt's utilization of wind energy (evidenced by the pyramids). The industrial revolution led to an increased demand for energy sources, resulting in the widespread use of coal despite its significant greenhouse gas emissions. However, The energy crisis in the 1970s spurred the practical application of sustainable methods, leading to a shift towards renewable energy sources and environmentally friendly building materials. This gave rise to the concept of "Sustainable Buildings" and competition among companies to develop precise and efficient methods, materials, and practices. Green buildings have gained significant traction in recent years as a means to monitor and control greenhouse gas emissions in the construction sector. To this end, the U. S. Green Building Council was established to promote maximum sustainability in building construction. Nowadays, not only industries but also societies as a whole are adopting energy-efficient methods to save money, conserve energy, and reduce waste production [2]. In this paper, the essential requirements and demands of various sustainable materials and techniques are outlined, demonstrating their contribution to creating eco-friendly construction practices.

2. Literature Review

Extensive research and analysis have been conducted to explore the realm of green materials, delving into a wealth of literature and gathering information on previous research and development endeavors. The focus has particularly been on investigating the possibilities of reusing or recycling construction waste and demolished building components, as well as studying research that highlights the transformation of hazardous construction elements into less environmentally vulnerable substances. This paper stands out for its groundbreaking approach of consolidating these individual studies into a cohesive framework, enabling the attainment of maximum benefits when selecting green materials. The comprehensive compilation provides a comprehensive overview of all available sustainable green materials. By gaining insights into the concepts and resources associated with these materials, individuals can effortlessly identify the most cost-effective, environmentally friendly, and aesthetically suitable options for their construction projects. Adopting such practices would pave the way for a significant acceleration in the replacement of conventional building materials, surpassing previous progress by leaps and bounds.

Ries et al. (2006) highlighted the economic benefits of green building, emphasizing the evolving technique of conserving clean hot or cold air. An example mentioned is the California Academy of Sciences building, which incorporates vents in the domes to release hot air and motorized windows to allow cool air inside (Green building incorporates). While such methods efficiently control the temperature within a building, ensuring air quality is equally important considering people spend an average of 80-90% of their time indoors. Striking a balance between maintaining a consistent temperature with minimal energy consumption and keeping the air fresh presents an ongoing challenge. While most home heating and air conditioning systems prioritize accurate temperature control and filtration of mold, moisture, dust, and pollen, technology has yet to meet the same standards with significantly reduced energy usage [3].

Ali and Al Nsairat (2009) assert that green building is crucial for meeting building code requirements and minimizing its environmental impact over its lifespan. Selecting the right green building rating tool is essential and should consider the climate and specific agenda of the country [4].

3. Methodology and Materials

The use of building products and the reuse/recycling of waste materials for constructing buildings can significantly enhance their performance while reducing their impact on the environment and human health. The essential element for any high-performance building endeavor resides in the utilization of stable, visually pleasing, and environmentally sustainable building materials [5]. It is crucial to avoid materials that have severe detrimental impacts on the environment, such as those that release pollutants, exhibit toxicity, or deplete natural resources. To mitigate these negative effects, precautionary measures are implemented throughout the entire lifecycle of the materials, starting from the acquisition of raw materials, their production and manufacturing processes, to transportation. During the pre-building phase, there is an opportunity to limit the use of materials that pose risks to human health and are hazardous to workers due to toxic exposure. The manufacturing processes of green materials necessitate careful attention, including the conservation of natural resources, energy efficiency, reduction of pollutant disposal, and the use of additives, chemicals, and water. The focus is on materials that can reduce CO_2 emissions, mitigate the hazardous impact on human health, and minimize the extraction of natural resources. The selection of materials depends on various factors, such as aesthetic appeal to inhabitants, cost-effectiveness in transportation and installation at construction sites, ease of recyclability and reusability for glass and plastic materials, and meeting the requirements of cardinal building materials like concrete, bricks, cement, and lime in terms of strength, durability, and permeability. Additionally, organic components of green materials must be managed to prevent issues such as unpleasant odors, staining, water absorption, and excessive moisture content that may inconvenience occupants.

3.1. What Is Green Building Material

Green building materials are specifically designed to minimize harm to the human body. They are characterized by low levels of pollution and odor, ensuring a healthier indoor environment. Harmful toxins present in conventional building materials can be released during interior decoration, posing a significant risk to individuals who spend extended periods indoors. Therefore, the assessment of building materials primarily focuses on evaluating their impact on indoor air quality and overall safety. Materials that meet the required standards are labeled as "Green Building Materials," as they contribute to a healthier and safer built environment. In conclusion, green building materials prioritize the well-being of occupants by mitigating the risks associated with toxic exposure.

3.2. Characteristics of Green Building Material

The distinctive attributes of green building materials, widely recognized internationally, encompass reuse, reduction, and low emissions. These materials offer several notable advantages. Firstly, they contribute to a decrease in ecological burden and energy consumption associated with the production of chemical synthesis materials. Secondly, through recycling practices, they minimize energy and resource consumption. Lastly, incorporating natural materials and low-volatile organic compounds in construction mitigates the risks posed by synthetic materials. These advantages highlight the positive environmental and health impacts of adopting green building materials.

3.3. The Importance of Utilizing Green Building Materials

The utilization of green building materials is of utmost importance. Green building materials offer numerous advantages, including reduced environmental impact, improved indoor air quality, enhanced energy efficiency, and sustainable resource usage. It is imperative to incorporate Green Building materials for both interior decoration and floor surfaces. As per Wikipedia, the guidelines state that a minimum of 30 percent of the total interior decoration material and floor surface material should be Green Building material. Hence, the utilization of Green Building materials is absolutely essential for constructing sustainable buildings.

3.4. Alternative Eco-friendly and Sustainable Building Materials

3.4.1. Bamboo

While bamboo may appear as a trendy material, it has a long-standing history as a locally sourced material in certain regions of Bangladesh. In Bangladesh, With around 100 species available, 19 of them are commercially viable for construction and interior design purposes. Bamboo possesses exceptional sustainability characteristics, making it an attractive alternative to traditional building materials. As the fastest-growing plant on Earth, bamboo can reach maturity in just a few years, compared to several decades for other wood species. Its rapid growth rate allows for frequent harvesting without causing deforestation or depletion of resources. One of the key advantages of bamboo is its remarkable strength-to-weight ratio. Despite its lightweight nature, bamboo exhibits impressive structural integrity, making it suitable for a wide range of construction purposes. Its natural fibers provide high tensile strength, allowing bamboo to withstand heavy loads and seismic forces. In addition to its strength, bamboo is also known for its excellent sustainability features [6]. Bamboo plants absorb significant amounts of carbon dioxide and release oxygen into the atmosphere, contributing to the mitigation of greenhouse gas emissions. Its extensive root system helps prevent soil erosion and promotes water retention, contributing to environmental conservation.

Bamboo has been extensively used for framing buildings and creating shelters, offering a sustainable alternative to costly and heavy imported materials. It can serve as a substitute for concrete and steel reinforcement construction, particularly in challenging-to-access areas, post-disaster reconstruction projects, and low-income communities that have access to locally available bamboo resources. Embracing bamboo as a building material not only promotes environmental sustainability but also supports local economies and empowers communities to utilize their natural resources efficiently.

3.4.2. Insulated Concrete Forms

Insulated concrete forms (ICF) are known for their excellent thermal performance. ICF structures utilize a construction system where concrete walls are encased between layers of insulation materials. This approach not only ensures energy efficiency but also enhances the structural strength of the walls. ICF is considered a green building material known for its exceptional durability and long-lasting nature. It is primarily used in low-rise residential and commercial buildings. Research conducted by the U. S. Department of Housing and Urban Development in 2001 revealed that the cost of ICF construction is only about 3 to 5% higher compared to conventional building methods [7]. Despite the slight increase in cost, ICF offers numerous performance benefits, including fire resistance and superior energy efficiency. The insulating properties of the forms significantly reduce the transfer of heat and cold, leading to improved energy efficiency. The insulation helps to maintain a consistent indoor temperature, reducing the need for excessive heating or cooling. This leads to lower energy consumption for climate control and reduces greenhouse gas emissions associated with energy production. Incorporating ICF into construction projects supports sustainable and green building practices, promoting a more resilient and energy-efficient built environment.

3.4.3. Geotextiles

Geotextiles are widely recognized as eco-friendly, sustainable, and green materials for construction. They are permeable fabrics commonly used in civil engineering and construction projects due to their various environmentally beneficial properties. Geotextiles play a significant role in soil stabilization, particularly in applications such as roads, embankments, and slopes [8]. By preventing soil erosion and facilitating vegetation growth, they contribute to maintaining the stability of the natural environment. In drainage systems, geotextiles help ensure proper water flow while preventing soil particles from clogging the system. This helps prevent waterlogging and supports the natural water cycle. The use of geotextiles aids in erosion control by acting as a barrier between soil layers. They effectively retain soil particles while allowing water to pass through, minimizing the impact of water flow on vulnerable areas. Geotextiles are designed to have a long lifespan, minimizing the need for frequent replacements. This longevity not only reduces waste but also promotes sustainable construction practices.

3.4.4. Recycled Plastic

Recycled plastic is a green material that offers several environmental benefits due to its sustainable and eco-friendly nature. By diverting plastic waste from landfills and oceans, recycled plastic helps reduce pollution and supports a circular economy. Plastic waste, such as bottles, bags, and packaging materials, can be processed and transformed into useful construction products like plastic lumber, insulation materials, and composite panels. Utilizing recycled plastic reduces the demand for virgin plastics, leading to lower energy consumption and greenhouse gas emissions associated with plastic production.

By blending recycled plastic with virgin plastic, the cost of green building materials can be reduced without compromising performance. One example is the production of polymeric timbers used for furniture and fences. "ConceptosPlasticos," a Columbian company, recycles plastic into LEGO-like building blocks that individuals can use to easily construct their own homes, emergency shelters, community halls, and classrooms. Assembly of these blocks requires minimal time (around 4-5 days) and does not necessitate construction experience [9]. Moreover, with the addition of certain additives, these plastic blocks are earthquake and fire-resistant, providing practical and resilient building materials. Plastic materials also offer aesthetic potential and are utilized in sophisticated interior and outdoor designs. For instance, in the Netherlands, the "Ludwig Mies van der Rohe's Fransworth house" incorporates 40,000 plastic sheets from floor to ceiling, creating a visually captivating and illuminated interior during the day and transforming into abstract lantern-like curtains at night, enhancing the overall landscape design as envisioned by the project's architects [10].

3.4.5. Fly Ash

Fly ash is a byproduct of coal combustion in power plants and can be utilized as a supplementary cementitious material in concrete production. The utilization rates of fly ash vary widely across different countries, ranging from as low as 3.5% in India to as high as 93.7% in Hong Kong [11]. Fly ash is known for its pozzolanic properties, which means it reacts with calcium hydroxide in the presence of moisture to form additional cementitious compounds. This reaction leads to improved concrete performance, including increased strength, durability, and resistance to chemical attacks. Incorporating fly ash in concrete mixtures can enhance the overall quality and performance of the construction material, contributing to longer-lasting structures and reducing maintenance needs over time. The use of fly ash in concrete production has a significant environmental benefit by reducing carbon emissions. Fly ash replaces a portion of the cement content in concrete, and since cement production is a major contributor to carbon dioxide (CO_2) emissions, the incorporation of fly ash helps reduce the carbon footprint of concrete. Furthermore, the manufacturing process for fly ash involves less energy compared to cement production, resulting in additional energy and carbon savings.

3.4.6. Autoclaved Aerated Concrete

Autoclaved Aerated Concrete (AAC) is renowned for its exceptional thermal insulation properties, which help reduce the energy consumption required for heating and cooling buildings. The cellular structure of AAC contains millions of tiny air pockets, providing exceptional thermal insulation. This insulation capability enhances the energy efficiency of buildings, leading to lower energy demands, reduced reliance on heating and cooling systems, and decreased greenhouse gas emissions associated with energy production. AAC, also referred to as aircrete, is a lightweight, load-bearing, and long-lasting construction material available in various sizes and strengths [12]. AAC is manufactured using a combination of cement, lime, quartz sand, aluminum powder, water, and a foaming agent. The production process involves the use of a smaller amount of raw materials compared to traditional concrete. Additionally, AAC uses a large percentage of recycled materials, such as fly ash, which diverts waste from landfills and reduces the need for virgin materials. The use of recycled materials and reduced resource consumption contributes to resource conservation and promotes a more sustainable approach to construction. Comparing AAC blocks to conventional clay bricks reveals significant advantages. AAC blocks have a compressive strength of approximately 3 N/mm^2, similar to that of conventional bricks. However, AAC blocks require only 0.77 bags of cement per cubic meter of mortar, which is almost half the amount needed for clay bricks [13]. By using AAC, the construction industry can play a role in mitigating climate change and promoting sustainable development.

3.4.7. Recycled Tires

By utilizing recycled tires, we can divert a significant amount of waste from landfills. Tires are notoriously difficult to dispose of and can take hundreds of years to decompose naturally. Recycling them for construction purposes helps address this waste management issue. Tires are typically made from rubber, which can act as a good insulator. Recycled tires can be used in a wide range of construction applications, including roofing materials, flooring, insulation, road paving, and even as aggregate in concrete [14]. One of the most common methods of recycling tires is by incorporating them into cement composites and concrete in various forms such as shredded, chipped, ground, or crumb rubber [15]. Tires are designed to withstand various weather conditions and endure constant wear and tear on roads. These characteristics make recycled tire materials durable, long-lasting, and resistant to impact. Additionally, using recycled tires can also contribute to safer buildings, as they can have good fire resistance properties. Their versatility allows for creative and sustainable design options.

3.4.8. Straw Bale

Straw, an agricultural byproduct often burned or discarded, can be repurposed for construction purposes, effectively diverting it from contributing to air pollution and landfill waste. Notably, straw is a renewable resource that can be grown and harvested annually, ensuring a sustainable supply for building projects. Straw is made up of plant fibers that contain carbon. When used as a building material, straw bales can help sequester carbon dioxide, a major greenhouse gas, within the walls of the structure. This carbon storage helps mitigate climate change by reducing carbon emissions in the atmosphere. The production of straw bales requires minimal processing and energy compared to other construction materials like concrete or steel. This low embodied energy makes straw bales an environmentally-friendly alternative that reduces the overall environmental impact of the building. Traditional buildings often have poor insulation capabilities, resulting in inefficient heat retention and loss. This is particularly problematic when using coal for heating, as the heat escapes through the walls of the house. In contrast, Straw Bale Construction offers significantly improved heat preservation properties. It has emerged as a promising building alternative that effectively addresses housing needs and energy efficiency goals in rural communities [16]. Straw bales are typically free from harmful chemicals, toxins, and allergens, making them a healthier option for indoor air quality. The natural, breathable properties of straw bales can help regulate moisture levels and reduce the risk of mold growth. While straw bale construction offers numerous benefits, it is important to ensure proper construction techniques are followed to prevent moisture-related issues and ensure structural stability.

3.4.9. Glass Reinforced Concrete

Glass stands out as one of the most versatile materials worldwide due to its exceptional properties, including chemical inertness, optical clarity, low permeability, and high strength [17]. The use of glass products has substantially increased, resulting in significant quantities of waste glass. Globally, approximately 209 million tons of glass are produced each year [18]. Recycling and waste reduction play pivotal roles in effective waste management systems as they help conserve natural resources, reduce the need for landfill space, and minimize water and air pollution [19]. One notable approach is the utilization of waste glass in the production of construction materials [20]. Recycling waste glass not only alleviates the demand for landfill sites in the construction industry but also contributes significantly to reducing the carbon footprint and conserving resources [21]. Glass Reinforced Concrete (GRC), also known as Glass Fiber Reinforced Concrete (GFRC), is a composite material that consists of a cementitious matrix reinforced with glass fibers. GRC is lightweight compared to traditional concrete, which reduces the overall material consumption in construction. This leads to lower resource extraction and less energy-intensive transportation, resulting in a reduced environmental impact. GRC exhibits excellent durability and weather resistance. Its resistance to corrosion, cracking, and weathering results in longer-lasting structures, reducing the need for frequent repairs or replacements. GRC can be molded into various shapes and sizes, offering design flexibility for architects and builders. This versatility allows for creative and innovative architectural designs, enabling sustainable and aesthetically pleasing building solutions. Overall, GRC offers several environmental benefits, including reduced material usage, energy efficiency, durability, design flexibility, thermal insulation, recyclability, reduced carbon emissions, and a low environmental impact. Its usage in building construction contributes to sustainable practices and supports green building initiatives.

3.4.10. Other Green Building Materials

Various materials can be transformed into green building materials by modifying their chemical and physical properties. Rice husk ash (RHA), an agricultural byproduct generated from burning rice husks, is abundantly produced in rural areas of Bangladesh. When wetted, RHA exhibits cohesive properties, making it an excellent supplementary cementitious material [15]. Discarded sand from steel and glass industries can be recycled and utilized. By repurposing these sands, the extraction of sand from rivers can be reduced, contributing to environmental restoration. Recycled carpet fiber can serve as reinforcement in building materials, although further studies and experimental work are necessary in this area. Hempcrete, created from the woody inner fibers of the hemp plant, is a lightweight material that resembles the properties of concrete. It is easily transportable and can be conveniently placed during construction. Ferrock, a novel material, is produced by recycling materials such as steel dust from the steel industry to create a concrete-like building material. Notably, Ferrock is even stronger than traditional concrete and has a unique characteristic where it absorbs and traps carbon dioxide as part of its drying and hardening process.

4. Conclusion

Sustainable building practices have emerged as a crucial pathway for the construction industry to protect the environment while promoting economic advancement. By integrating principles of resource efficiency, cost efficiency, and design for human adaptation, construction projects can achieve a harmonious balance between economic, social, and environmental performance. The growing global awareness of environmental protection has spurred the adoption of sustainable building practices, which offer a holistic and integrated approach to construction. This framework not only improves the quality and comparability of methods for assessing environmental performance but also fosters a deeper understanding and implementation of sustainability in building projects. With sustainability at the forefront, the construction industry can move towards a greener future, minimizing detrimental impacts on the environment and promoting long-term economic prosperity. By embracing sustainable building practices, we can create buildings and infrastructure that not only meet the needs of today but also safeguard the well-being of future generations. It is crucial for construction practitioners worldwide to prioritize sustainable development, aligning economic growth with environmental protection. By embracing this paradigm, we can forge a path towards a more sustainable and resilient built environment, contributing to the overall well-being of society and the preservation of our planet.

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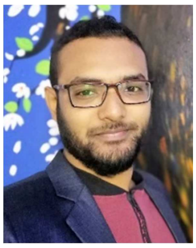
Biography



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