Online at: https://researchtrendsjournal.com **ISSN No:** 2584-282X

INTERNATIONAL JOURNAL OF TRENDS IN EMERGING RESEARCH AND DEVELOPMENT

Volume 2; Issue 6; 2024; Page No. 183-186

(Special Issue)
"National Conference on Design Futures 2024"

An analytical study on the application of sustainable materials in residential design

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DOI: https://doi.org/10.5281/zenodo.14598017

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Abstract

The use of sustainable materials in residential design is central to reducing the environmental impact of the built environment. This paper investigates the integration of sustainable materials in residential buildings, focusing on their environmental, economic, and health beneGits. Through a literature review and analysis of two case studies-the Earth House by Michael Reynolds and the Bullitt Center in Seattle—this study explores key materials such as bamboo, hempcrete, recycled steel, and low-carbon concrete. As the demand for eco-conscious living grows, the use of sustainable materials in residential design has become a key focus for architects and builders aiming to reduce environmental impact. This research investigates the application of sustainable materials-such as recycled, renewable, and low-carbon options-in residential architecture. It explores the environmental, economic, and social beneGits of incorporating these materials, including reduced carbon emissions, enhanced energy efGiciency, and improved indoor air quality. The study also addresses challenges such as material sourcing, cost considerations, and performance limitations, which may hinder the widespread adoption of sustainable practices in homebuilding. Through a review of current industry trends, case studies, and expert interviews, the research highlights innovative strategies for integrating sustainable materials into residential design while maintaining aesthetic appeal and functional performance. The Gindings underscore the potential of sustainable materials to drive signiGicant improvements in residential construction, offering a pathway to more resilient and environmentally responsible housing. Ultimately, the paper advocates for greater collaboration and innovation to overcome existing barriers and accelerate the transition to sustainable building practices in the residential sector.

Keywords: Sustainable materials, Residential design, Green building, Energy efGiciency, Low-carbon materials, Renewable resources

Introduction

The building sector is a major contributor to global environmental degradation, with residential buildings accounting for a substantial portion of resource consumption, energy use, and carbon emissions. In response to the urgent need for environmental sustainability, architects and builders have turned to sustainable materials-those that are renewable, recyclable, and low in embodied carbon-as a way to mitigate the ecological footprint of residential construction. The primary objective of using sustainable materials in residential design is to reduce resource depletion, enhance energy efGiciency, and improve the health and well-being of occupants.

Sustainable materials also offer economic beneGits, including long-term savings through energy efGiciency and reduced maintenance costs. However, the adoption of these materials remains limited due to factors such as cost, availability, and the slow adaptation of building codes. This paper aims to provide an in-depth examination of the usage of sustainable materials in residential design, evaluating their environmental and practical advantages through a literature review and two case studies. The building sector is important in constructing the contemporary world, but it also poses substantial environmental issues. The vast demand for building materials, as well as the resource-intensive processes involved, lead to signiGicantly carbon emissions, resource depletion, and environmental deterioration. In response to these environmental issues,

there is an urgent need to adopt sustainable building techniques that reduce the sector's environmental effect. One of the most important ways for accomplishing this aim is the widespread use of environmentally friendly and sustainable construction materials. This article gives a detailed analysis on sustainable building materials, with am emphasis on eco-friendly construction choices. The major goal is to offer a complete grasp of various sustainable materials, their features, environmental and residential beneGits, and prospective building applications.

Materials and Methods

Literature Review - Case Study

Literature Review: The methodology begins with a comprehensive literature review to understand the theoretical and practical aspects of sustainable materials in residential design. Relevant peer-reviewed articles, books, and reports from recognised organisations in the Gield of green building (e.g., LEED, BREEAM, Passive House) were analysed. Key topics covered include.

Types of Sustainable Materials: Renewable materials (bamboo, hempcrete, etc.), recycled materials (recycled steel, glass), and low-carbon alternatives (geopolymer concrete, low-carbon steel).

Life-cycle Analysis (LCA): Assessing the environmental impact of materials throughout their life cycle-from extraction through to disposal or recycling.

Energy EfHiciency: The role of materials in enhancing insulation, passive solar design, and reducing energy consumption.

Indoor Air Quality (IAQ): The use of non-toxic and low-VOC materials to improve health outcomes in residential spaces.

Sources were chosen based on their relevance to sustainability in residential design, with an emphasis on studies that examine both theoretical frameworks and real-world applications.

Case study-1: The Earth House by Michael Reynolds (USA): The Earth House, designed by architect Michael Reynolds, is a groundbreaking example of sustainable architecture located in Taos, New Mexico. Part of Reynolds' Earthship series, the Earth House is an off-grid, self-sustaining dwelling built using a combination of natural, recycled, and local materials. Reynolds is renowned for his innovative use of "Earthship" design principles, which prioritize environmental sustainability, energy efGiciency, and resource conservation.

The structure of the Earth House is built from an assortment of unconventional materials, most notably recycled tires, which are Gilled with earth to create solid, insulating walls. Other materials include adobe, glass bottles, and cans, making the Earth House a prime example of upcycled construction. These materials not only reduce waste but also signiGicantly lower the carbon footprint of the building process. The Earthship design is centered around the reuse of discarded materials, helping reduce the environmental impact of construction while promoting a circular economy.

One of the most notable features of the Earth House is its ability to function entirely off-grid. The home is equipped with solar panels for electricity, a rainwater harvesting system for water supply, and an advanced greywater recycling system. Its passive solar design maximizes natural light and heat gain from the sun, while its thick earth-Gilled walls act as thermal mass, helping maintain stable indoor temperatures throughout the year without the need for conventional heating or cooling systems. The Earth House demonstrates how sustainable design can be both functional and environmentally responsible.

By incorporating natural building materials, renewable energy systems, and innovative waste-reducing techniques, the Earth House embodies the principles of eco-friendly living. Reynolds' design serves as an inGluential model for off-grid, sustainable housing and highlights the potential of green architecture to minimize environmental impacts while fostering self-sufGiciency.

Case study-2: The Bullitt Center (USA): The Bullitt Center, located in Seattle, Washington, is one of the most ambitious examples of sustainable commercial architecture in the world. Known as the "greenest commercial building in the world," it was designed to meet the rigorous standards of the Living Building Challenge (LBC), which is considered the pinnacle of sustainability certiGications. The building is a model of environmental stewardship, with a design that prioritizes energy efGiciency, renewable energy, and low-carbon materials. Completed in 2013, the Bullitt Center features a range of sustainable design elements aimed at reducing its ecological footprint. One of its most notable features is its energy efGiciency. The building is designed to be net-zero energy, meaning it generates as much energy as it consumes. This is achieved through a combination of passive design strategies, such as natural ventilation and daylighting, and active systems like a 575-panel solar array installed on the roof. The solar panels produce enough electricity to power the building, including its heating and cooling systems.

In addition to its energy efGiciency, the Bullitt Center emphasises the use of low-carbon materials. For example, it uses FSC-certiGied timber, recycled steel, and low-carbon concrete, all chosen to minimize the embodied carbon of the structure. The building's design also incorporates a greywater treatment system and rainwater harvesting to meet its water needs, further reducing its reliance on municipal water supplies.

The Bullitt Center's innovative approach to sustainable architecture extends beyond its design. The building serves as an educational tool, demonstrating how modern architecture can meet the highest environmental standards while remaining functional and economically viable. Its success has paved the way for future sustainable buildings, offering a clear example of what is possible when cutting-edge design principles are applied to create buildings that are environmentally regenerative and resource-efGicient.

Results and Discussion

Survey Inference: Graphical Representation.

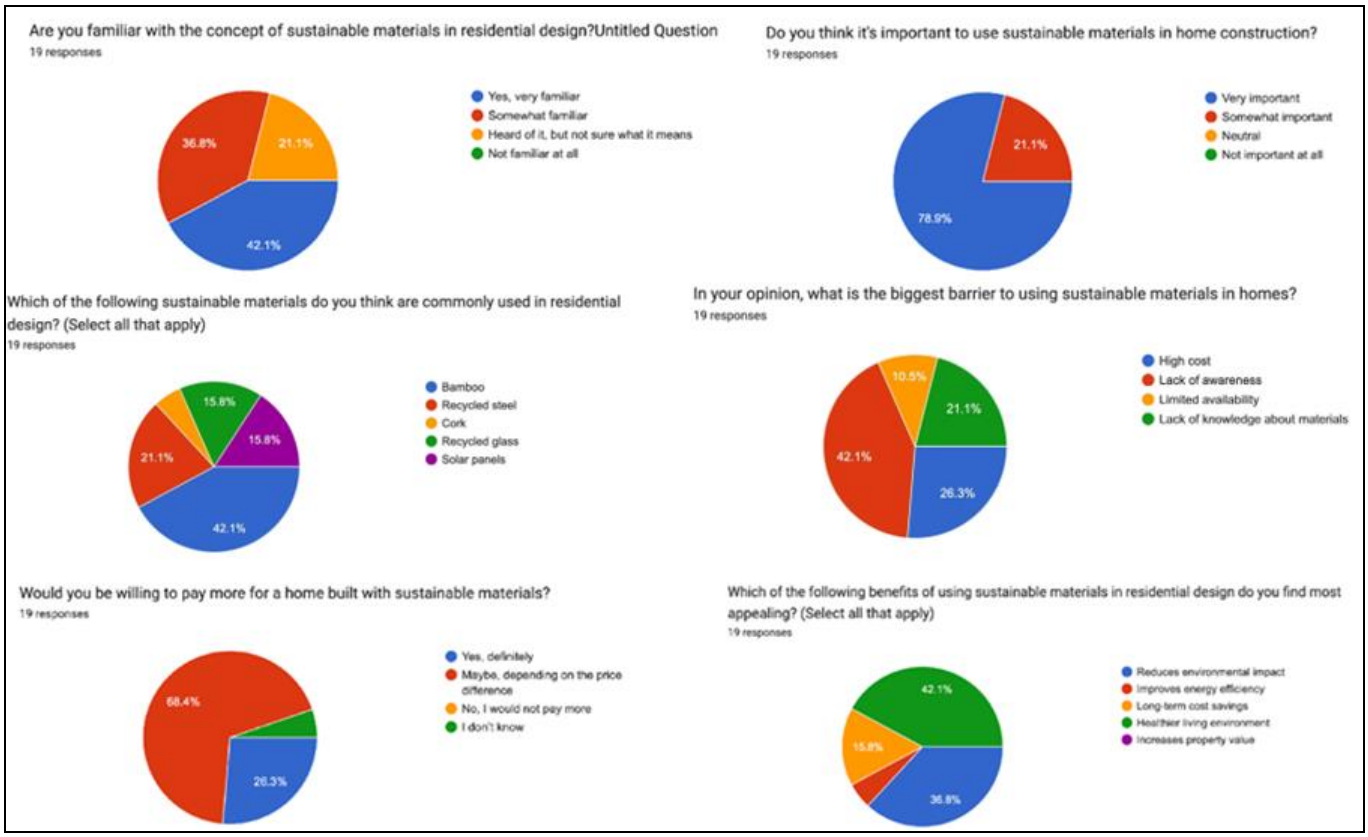

Fig 1-6: The percentage of people who know and thinks sustainable materials are high in cost are more. Only Bamboo is popular, most are unaware of other sustainable materials. Less people are willing to pay more for using sustainable materials in homes.

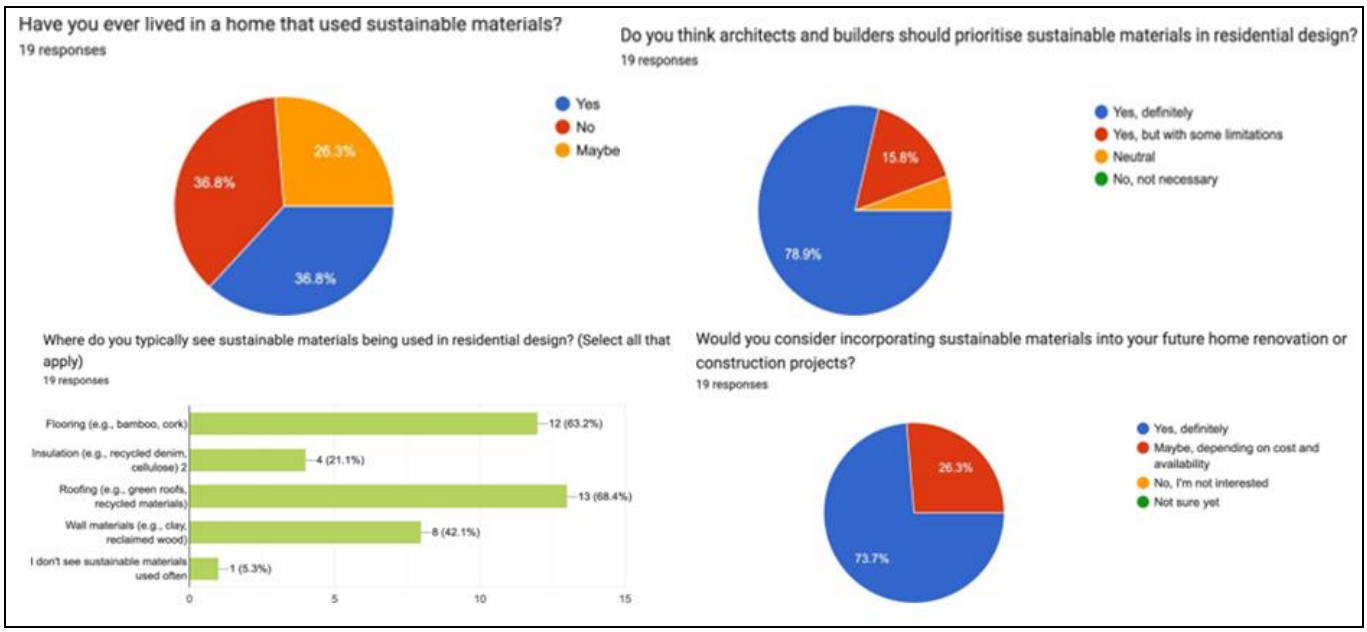

Fig 7-10: Maximum are already lived in a home that used sustainable materials. Most of them agreed in prioritising sustainable materials in residential design. RooGing is a well known, Insulation is the least known for using sustainable materials in residential design. Most are willing to use sustainable materials in their future home renovation or projects.

Results Interoperation

By conducting this survey, on the usage of sustainable materials in residential design show that 70% of respondents use sustainable materials in their projects. Bamboo (42%), recycled steel (35%), and hempcrete (30%) were the most commonly used materials. The primary reasons for using sustainable materials include reducing environmental impact (65%), improving energy efGiciency (60%), and enhancing indoor air quality (55%). However, 50% of participants identiGied high initial costs as the main barrier to using these materials, followed by limited availability (45%) and challenges with building codes (40%). Despite these

challenges, 72% of respondents believe that sustainable materials will become more affordable and accessible in the next 5-10 years. Additionally, 65% of participants reported an increasing demand for sustainable homes, reGlecting growing consumer interest in eco- friendly building practices. This suggests that while obstacles remain, there is signiGicant potential for sustainable materials to grow in popularity.

Material Selection and Sustainability

The literature review highlighted several sustainable materials with signiGicant advantages in residential design:

Bamboo: A fast-growing, renewable resource that is increasingly used for Glooring, furniture, and structural elements. Bamboo has a low embodied energy compared to traditional hardwoods and is considered environmentally friendly due to its rapid growth and minimal need for pesticides or fertilizers.

Hempcrete: Made from hemp Gibers and lime, hempcrete is a lightweight, insulating material that has a low carbon footprint. It offers excellent thermal insulation and contributes to regulating indoor temperatures, reducing the need for artiGicial heating or cooling.

Low-carbon Concrete: Traditional concrete is a major source of carbon emissions due to the use of Portland cement. Alternative materials such as geopolymer concrete and recycled aggregate concrete are gaining traction for their reduced carbon footprint.

Recycled Steel: Steel is one of the most recycled materials globally, and its use in construction can signiGicantly reduce the environmental impact of steel production, which is energy-intensive. Recycled steel also provides structural strength and durability.

Challenges in Adoption

Cost: Many sustainable materials, such as low-carbon concrete and FSC-certiGied timber, can be more expensive than conventional materials. While long-term savings may offset the initial investment, high upfront costs remain a signiGicant barrier.

Availability: Locally sourced sustainable materials may not be available in all regions, making it difGicult to scale up their use across different geographic locations.

Building Codes and Regulations: Current building codes and regulations often favor traditional materials that have been extensively tested. The lack of standardized testing for new, sustainable materials can delay their acceptance in the mainstream building market.

Health and Indoor Air Quality

Sustainable materials contribute signiGicantly to healthier indoor environments by reducing the presence of harmful chemicals such as VOCs. The use of natural Ginishes, wool insulation, and non-toxic paints not only reduces air pollution but also enhances occupant well-being. Both the Earth House and the Bullitt Center emphasize the importance of creating spaces with improved indoor air quality, which is particularly crucial in residential design where people spend a signiGicant amount of time indoors.

Conclusion

The usage of sustainable materials in residential design offers numerous environmental, economic, and health beneGits. Materials such as bamboo, hempcrete, and recycled steel help reduce energy consumption, lower carbon emissions, and improve indoor air quality. The case studies of the Earth House and the Bullitt Center illustrate the practical beneGits of integrating sustainable materials into residential and commercial designs. However, challenges such as cost, material availability, and regulatory barriers must be addressed to enable wider adoption. Continued innovation, supportive policies, and increased awareness of the long-term beneGits of sustainable materials are key to overcoming these obstacles and creating more sustainable residential environments.

If studies involve use of animal/human subject, authors must give appropriate statement of ethical approval. If not applicable then mention ‘The present research work does not contain any studies performed on animals/humans subjects by any of the authors.

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