**Life Cycle Assessment of environmentally friendly building materials that can benefit the global field of residential construction**

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**Abstract:** This research paper will provide a thorough exploration of environmentally friendly building materials that can benefit the residential construction industry, with a focus on their Life Cycle Assessment. As the global residential construction sector has been facing strict monitoring for the pollutants it produces, the adoption of environmentally friendly building materials has emerged as a strategy for promoting sustainability and reducing the impact of residential construction on the environment. This study synthesizes existing literature, to offer a comprehensive understanding of the key principles, challenges, and advancements in the field.

The research's objectives aim to provide a clear understanding of environmentally friendly building materials for residential construction, their Life Cycle Assessment, benefits, disadvantages, environmental impacts, and why they should be used. Methodologically this paper employs a systematic review of relevant literature and integrates findings from empirical studies to present a holistic perspective.

Results indicate a growing trend towards the utilization of renewable resources, recycled materials, and energy-efficient technologies in the development of environmentally friendly building materials. The discussion encompasses the life cycle assessment (LCA) of these materials, and their recyclability. Furthermore, the paper addresses the economic implications and challenges associated with the widespread adoption of environmentally friendly building materials.

While the research highlights positive trends in adopting eco-friendly building materials, it's important to note some challenges. The study faces difficulties in combining various data sources and occasionally encounters issues with the availability and consistency of relevant information. Moreover, the rapidly changing landscape of construction practices and environmental standards introduces uncertainties in predicting long-term impacts. Despite these challenges, the research aims to provide valuable insights, recognizing the dynamic nature of the field and emphasizing the ongoing need for updates and refinements in future studies.

In Conclusion, this study emphasizes the importance of green building materials in transforming the construction industry toward a more sustainable and environmentally aware future. By combining existing knowledge and pointing out areas where more research is needed, this paper seeks to provide

insights to those involved in construction, policymakers, and researchers. It aims to share essential factors to consider when choosing and using green building materials for construction projects.

**Keywords:** environmentally friendly building materials, life cycle assessment (LCA), residential construction.

### *1.1. Introduction*

The topic of "Life Cycle Assessment of environmentally friendly materials that can benefit the global field of residential construction" is a very important topic that should be taken into consideration especially in this day and age where the pollution levels on our planet earth are continuously rising, which will inevitably lead to a catastrophe. This research has been done to spread awareness on environmentally friendly building materials that can be used in residential construction, as they will provide an opportunity to decrease the amounts of pollutants released by residential construction.

This research aims to shed light on multiple environmentally friendly building materials that can be used in residential construction, why they should be used, the impacts they have on the environment, and their Life Cycle Assessment (LCA).

Adopting eco-friendly practices is no longer a choice but a necessity. environmentally friendly building materials, characterized by their minimal environmental impact and energy-efficient attributes, stand as catalysts for change in the levels of pollutants harmful to the environment emitted by the residential construction industry.

### *1.2.0 Literature review*

#### *1.2.1 Environmentally friendly building materials that are common in the field of residential construction*

***Bamboo***

Bamboo has emerged as a promising sustainable building material, particularly in developing countries facing rapid urbanization (Rodolfo Lorenzo et al, 2020). In the quest for sustainable building materials, engineered bamboo and bamboo-reinforced concrete elements have also gained attention as viable options. These materials offer a sustainable alternative for construction projects, contributing to the reduction of carbon emissions and promoting sustainable development (Anu Bala et al, 2023).

**-Life cycle assessment:**

Bamboo's status as a sustainable construction material is rooted in its ability, when harvested sustainably, to provide a more favorable environmental footprint than alternative building materials. Sustainable harvesting methods entail selectively removing around 20% of mature stems while preserving a stable

population of live stems. This practice ensures that the harvested stems are replenished annually by new shoots, perpetuating bamboo forests and their beneficial environmental effects. Bamboo-based manufacturing processes require relatively low energy inputs compared to traditional materials like steel. This is attributed to bamboo's natural properties, such as its lightweight and ease of processing, which reduce the energy needed for fabrication. (Jun-Tae Kim et al, 2019). Bamboo emerges as a highly esteemed material for construction, boasting remarkable sustainability attributes due to its renewable nature, low energy consumption, exceptional strength, enduring quality, flexibility, and more. However, the inherent limitations of round bamboo present challenges over time, such as natural variations, susceptibility to pests and fungi, sensitivity to moisture, and constraints in size and shape (Jinjun Xu et al, 2023). Bamboo is a versatile material that has gained attention in various sectors, including construction and consumer goods. (Lucas Rosse Caldas et al, 2020) highlighted the potential of bamboo in the construction sector due to its mechanical properties, fast growth, low cost, availability, and CO2 sequestration capacity. The study evaluated the climate change impact reduction potential of using bamboo culms in housing construction, emphasizing the importance of considering end-of-life scenarios such as recycling, landfilling, and incineration. The results indicated that utilizing bamboo culms as scaffolding for housing construction could lead to negative emissions, making it a viable strategy for climate compensation. (Widodo Kushartomo et al, 2021)focused on bamboo splicing technology to enhance the service life of bamboo buildings. By improving bamboo grafting techniques, the study aimed to contribute to increasing the durability and longevity of bamboo structures. This aligns with the idea that with the right design, construction, maintenance, and care, bamboo can last for ages, potentially a lifetime.

**-Recyclability:**

Bamboo is increasingly being recognized as a sustainable and eco-friendly material with various applications in modern structures and composite materials. (Balaji Govindan et al, 2021) conducted performance assessments on bamboo-reinforced concrete beams, highlighting the ease of recyclability and high strength-to-weight ratio of bamboo in modern structures. (R. Harikumar et al, 2020) investigated the mechanical properties of bamboo fiber composites, emphasizing their recyclability and ecological benefits.

**-Visual examples of the usage of bamboo in residential construction:**

*Figure 1: House made entirely from bamboo* (laurent Gilet, 2008)

*Figure 2: Sharma Springs, a private home in Sibang Gede in Bali, has four bedrooms and stretches over six floors.* (Thu-Huong Ha, 2015)

***Hempcrete***

Hempcrete is a sustainable building material that has gained attention in recent years due to its environmentally friendly properties. Hempcrete is a bio-composite made from hemp hurd (hurd : the coarse parts of flax or hemp that adhere to the fiber after it is separated.) , the inner woody core of the hemp plant, and a lime-based binder (Wafaa Zuabi et al, 2021). Several studies have highlighted the sustainable aspects of hempcrete. (Wafaa Zuabi et al, 2021) provides a comprehensive review of hempcrete as a sustainable building material, discussing its mechanical, insulation, durability, and other properties, as well as the process of making hempcrete and its applications in construction. ( Salvatore Emanuele et al, 2021)evaluates the environmental sustainability of hemp as a building material through

life cycle assessment, emphasizing the importance of sustainable procurement of raw materials and ecological design in construction.

**-Life cycle assessment:**

Hempcrete stands out as a plant-based, sustainable building material renowned for its minimal environmental footprint. By eliminating waste production, reducing energy consumption, and lowering the demand for natural resources, hempcrete embodies a construction solution with low environmental impact. The hemp-lime composite material finds its primary application in wall construction, offering an eco-friendly alternative. However, its versatility extends to other components of building structures, including floor slabs, ceiling panels, and roof insulation. Of paramount importance, hempcrete demonstrates a negative carbon footprint, rendering it a highly favorable material for the construction industry. Hempcrete is recognized for its eco-friendliness and energy efficiency. Hemp plants are commonly cultivated for their fiber or seed, with the hurd being a by-product in either case. Large-scale hemp production can thus yield significant quantities of hurd for use in the construction and insulation markets. Furthermore, the incorporation of lime, renowned for its inherent antimicrobial and antifungal properties, enhances hempcrete's ability to resist mold, especially in environments with high temperatures and humidity. This resilience gives hempcrete a distinct advantage over other insulation materials, making it a desirable choice in both hot and cold climates, as well as in areas with elevated humidity levels. A notable drawback of hempcrete is its limited mechanical performance, which prohibits hemp from serving as a load-bearing material. This limitation primarily stems from hempcrete's high porosity, leading to inadequate adhesion to the lime binder and resulting in elastic-like behavior. stands out for its ability to sequester carbon dioxide, making it an environmentally friendly choice in mitigating the construction sector's negative environmental impact. It boasts good economic value, coupled with excellent thermal and insulative properties, rendering it a desirable construction material. With an impressive lifespan and low maintenance requirements, hempcrete offers cost-effective durability. Furthermore, the cultivation of hemp for this purpose necessitates minimal fertilizer use, contributing to its sustainability. Hempcrete's significance extends beyond the construction industry, providing opportunities across various sectors, including planting, building, and installation, thus fostering economic growth and innovation (Ravindra B. Malabadi et al, 2023)

**-Recyclability:**

Hempcrete can be recycled and serves as a carbon dioxide sink, actively sequestering CO2 from the atmosphere. (Madhura Yadav et al, 2022)

**-Visual example of the usage of hempcrete in residential construction:**

*Figure 3: 3000+ square foot Highland Hemp House in Bellingham, Washington after the hempcrete is cast and before the plaster is added.* (Tommy Gibbons, 2018)

***Cross-laminated timber***

CLT, also known as massive timber, is an innovative engineered wood product that has revolutionized timber's use in structural applications. It allows for the construction of large-scale or multi-story buildings, overcoming the limitations of traditional light-timber frame construction. A CLT panel consists of large, solid timber panels made by gluing together timber laminations at a 90° configuration. This construction provides strength and stability to the panels, reference to figure 4. ( Adel Younis et al, 2022)

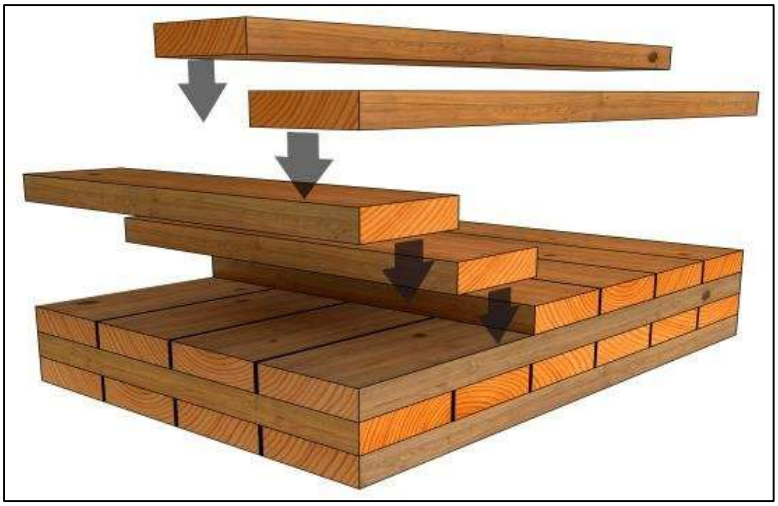

*Figure 4: Conventional assembly layup of cross-laminated timber* (Dietrich Buck, 2016)

**-Life cycle assessment:**

The surge in interest surrounding Cross-Laminated Timber (CLT) as a construction material can be attributed to numerous advantages it offers, notably its low environmental impact, particularly in terms of carbon footprint. Additionally, CLT boasts a high strength-to-weight ratio, ease of installation, and appealing aesthetic features. Its sustainability attributes are particularly noteworthy, as CLT has the capacity to store carbon during its service life, thus enabling buildings to function as 'carbon sinks.' This characteristic leads to a diminished global warming potential (GWP) impact during the production stage of mass timber structures, when compared to steel or concrete counterparts. Moreover, CLT panels can be reused or recycled, contributing to further reductions in the carbon footprint of buildings. As CLT is a relatively new construction material, contemporary CLT buildings represent pioneering ventures that have yet to complete their service life. Consequently, there is a pressing need to comprehend various aspects of these new "greener" materials to facilitate widespread adoption. Consequently, research interest in CLT has been steadily increasing in recent years to address critical knowledge gaps related to material efficiency, construction methods, structural performance, durability, and environmental impacts. However, real-life anecdotal evidence suggests that CLT may require replacement due to moisture-related issues over the building's lifetime ( Adel Younis et al, 2022)

**-Visual examples of the usage of cross laminated timber (CLT) in residential construction:**

*Figure 5: The Lake Mjøsa Skyscraper in Brumunddal, Norway, which is built of cross-laminated timber (CLT).* (Øyvind Holmstad, 2019)

*Figure 6: Brock Commons Tall wood House, a residence building where cross laminated timber has been implemented.* (Naturally: wood, 2017)

### *1.2.2 economic implications and challenges associated with the widespread adoption of environmentally friendly building materials.*

-Resistance/unwillingness to change: Stakeholders in the construction industry exhibit resistance to embracing new ideas, methods, and materials, preferring conventional approaches.

-Lack of green building experts/skilled labor: There is a shortage of skilled labor and experts proficient in green building methodologies, hindering the adoption of sustainable materials.

-High capital cost: The initial investment required for implementing sustainable construction practices is perceived as prohibitively high, deterring adoption.

-Lack of building code and regulations: The absence of adequate regulations and building codes specific to green building materials creates uncertainty and hampers their adoption.

-Lack of government incentives and support: Insufficient government incentives and support for sustainable construction impede widespread adoption of green building materials.

(Emmanuel Chidiebere et al, 2023)

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### *1.3.1 Methodology*

This research explores three environmentally friendly building materials that could transform residential construction worldwide. By gathering insights from various studies and sources, it offers a thorough review of existing literature on Bamboo, Hempcrete, and Cross-Laminated Timber (CLT). Through careful citation of authors and studies, the study examines the life cycle, recyclability, and environmental benefits of these materials. Additionally, it discusses the challenges and implications of adopting them

in the construction industry. Drawing on the expertise of multiple researchers, this approach provides a detailed understanding of the potential of Bamboo, Hempcrete, and CLT in both general and residential construction contexts.

This method of secondary research was chosen due to its simple accessibility, unlike other methods which require a higher level of knowledge and proper facilities to conduct primary research.

I chose qualitative research methods for this study because in the field of environmentally friendly building materials, information is mostly about the materials themselves, not statistics. By using methods like textual analysis, we can get detailed insights into how these materials are used in residential construction. This approach lets us understand the perspectives of different people involved. Qualitative methods are flexible and help us uncover important themes that might not show up in numbers.

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### *1.3.2 Findings*

**Three different environmentally friendly building materials with their pros and cons:**

**1-Bamboo:**

Bamboo is gaining recognition as a sustainable building material, particularly in developing countries facing rapid urbanization. It offers eco-friendly alternatives like engineered bamboo and bamboo-reinforced concrete, contributing to reduced carbon emissions and sustainable development.

**-Advantages of using bamboo:**

-Renewable and sustainable material.

-Low energy consumption in manufacturing processes.

-Remarkable strength and durability.

-Fast growth rate.

-Low cost and availability.

-Ability to sequester carbon dioxide (CO2).

**Disadvantages of using bamboo:**

-Natural variations in material properties.

-Susceptibility to pests and fungi.

-Sensitivity to moisture.

-Constraints in size and shape for certain applications.

**2-Hempcrete**

Hempcrete is a sustainable building material made from hemp hurd and a lime-based binder, gaining attention for its eco-friendly properties. Studies highlight its mechanical, insulation, and durability aspects, along with its applications in construction.

**-Advantages of using hempcrete:**

-Minimal environmental footprint.

-Negative carbon footprint.

-Energy efficiency and eco-friendliness.

-Recyclability.

-Ability to sequester carbon dioxide.

-Good thermal and insulative properties.

-Low maintenance requirements.

-Economic value and cost-effectiveness.

-Opportunities for innovation and economic growth.

**-Disadvantages of using hempcrete:**

-Limited mechanical performance, particularly as a load-bearing material.

-High porosity leading to elastic-like behavior.

**3-Cross Laminated Timber (CLT)**

Cross-laminated timber (CLT), also known as massive timber, is an innovative engineered wood product revolutionizing structural application. It enables the construction of large-scale or multi-story buildings, surpassing the limitations of traditional light-timber frame construction.

**-Advantages of cross laminated timber (CLT):**

-Innovative and versatile engineered wood product.

-Enables construction of large-scale or multi-story buildings.

-Provides strength and stability.

-Low environmental impact.

-High strength-to-weight ratio.

-Carbon storage potential during service life.

-Panels can be reused or recycled.

**-Disadvantages of cross-laminated timber (CLT):**

-Potential moisture-related issues requiring replacement over time.

-Ongoing research needed to address knowledge gaps in material efficiency and construction methods.

**-economic implications and challenges associated with the widespread adoption of environmentally friendly building materials.**

-Resistance to change.

-Lack of skilled labor.

-High capital cost.

-Absence of regulations.

-Government support lacking.

### *1.4 Conclusions*

In my perspective, this research successfully achieves its goal of providing insights into several environmentally friendly building materials. I believe this research paper has the potential to serve as a valuable guide or reference for individuals engaged in construction projects, especially in residential settings. It aims to raise awareness about green building materials that may not be widely known and underscores their potential to significantly benefit the environment and the future well-being of humanity. Additionally, I contend that these materials hold great promise for further advancement, offering compelling opportunities for environmental sustainability and human health.

### *1.5 References*

Adel Younis et al, 2022. Cross-laminated timber for building construction: A life-cycle-assessment overview. *JOURNAL OF BUILDING ENGINEERING.*

Salvatore Emanuele et al, 2021. Evaluation of The Environmental Sustainability of Hemp As A Building Material, Through Life Cycle Assessment. *ENVIRONMENTAL AND CLIMATE TECHNOLOGIES.*

Anu Bala et al, 2023. Engineered bamboo and bamboo-reinforced concrete elements as sustainable building materials. *CONSTRUCTION AND BUILDING MATERIALS.*

Balaji Govindan et al, 2021. Performance Assessment on Bamboo Reinforced Concrete Beams. *INNOVATIVE INFRASTRUCTURE SOLUTIONS.*

Dietrich Buck, 2016. *Further Development of Cross-Laminated Timber (CLT): Mechanical Tests on 45° Alternating Layers.* Vienna , World Conference on Timber Engineering (WCTE 2016).

Emmanuel Chidiebere et al, 2023. Assessment of barriers to the adoption of sustainable building materials (SBM) in the construction industry of a developing country. *Frontiers in Engineering and Built Environment .*

Jinjun Xu et al, 2023. Carbon emission-based life cycle assessment of rural residential buildings constructed with engineering bamboo: A case study in China. *Journal of Building Engineering.*

Jun-Tae Kim et al, 2019. Environmental, social and economic sustainability of bamboo and bamboo-based construction materials in buildings. *Journal of Asian Architecture and Building Engineering.*

laurent Gilet, 2008. *Wikipedia.* [Online] Available at: https://en.wikipedia.org/wiki/Bamboo_construction#/media/File:Construction_maison_bambou.jpg [Accessed 21 04 2024].

Lucas Rosse Caldas et al, 2020. Assessment of the Climate Change Mitigation Potential Using Bamboo Stalks in Brazilian Civil Construction.

Madhura Yadav et al, 2022. Opportunities & challenges of hempcrete as a building material for construction: An overview.

Naturally: wood, 2017. *Naturally: wood.* [Online] Available at: https://www.naturallywood.com/project/brock-commons-tallwood-house/ [Accessed 21 04 2024].

Øyvind Holmstad, 2019. *Wikipedia.* [Online] Available at: https://en.wikipedia.org/wiki/Plyscraper#/media/File:Narsot%C3%A5rnet_IV.jpg [Accessed 21 04 2024].

R. Harikumar et al, 2020. Evaluation of Mechanical Properties of Bamboo Fiber Composite with Addition of Al2O3 Nano Particles. *MATERIALS TODAY: PROCEEDINGS.*

Ravindra B. Malabadi et al, 2023. Industrial Cannabis sativa (Hemp fiber): Hempcrete-A Plant Based and Eco-friendly Building Construction Material. *INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE.*

Rodolfo Lorenzo et al, 2020. Digitisation of Bamboo Culms for Structural Applications. *JOURNAL OF BUILDING ENGINEERING.*

Thu-Huong Ha, 2015. *ideas.ted.* [Online] Available at: https://ideas.ted.com/gallery-these-buildings-are-made-of-bamboo/ [Accessed 21 04 2024].

Tommy Gibbons, 2018. *Wikipedia.* [Online] Available at: https://en.m.wikipedia.org/wiki/File:Highland_Hemp_House_finished_hempcrete.jpg [Accessed 21 04 2024].

Wafaa Zuabi et al, 2021. Review of Hempcrete As A Sustainable Building Material. *INTERNATIONAL JOURNAL OF ARCHITECTURE, ENGINEERING AND, CONSTRUCTION.*

Widodo Kushartomo et al, 2021. SAUNG BAMBU KOMPOSIT DENGAN SAMBUNGAN PELAT BUHUL. *PROSIDING SENAPENMAS.*