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Review Article

The Potentials of Bamboo as Sustainable Building Material: Carbon Dioxide Level Interrogating in an Enclosed Space

OPEN ACCESS

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Abstract

The Construction industry is one of the vital industries that drives the economy of basically every country, providing jobs and opportunities in many aspects of the construction process. However, the construction industry is also one of the industries that produces the most CO_2 around the globe, primarily due to the production of cement binder, normally Ordinary Portland Cement (OPC), an important concrete material. As concrete is a widely used construction material that is preferred by the industry due to its proven strength and durability, the CO_2 emission also increases not only due to the production of its material, but also due to the properties of concrete, which may cause indoor comfort issues, leading to higher CO_2 emission during the occupation stage. This highlights the importance of considering sustainable and eco-friendly materials in conventional constructions to reduce environmental effects. The hypothesis that "bamboo has lower CO_2 levels as compared to concrete in an enclosed space" will be tested by using an IAQ meter to measure the CO_2 level difference of both bamboo and concrete in a sealed plastic box. The results will be compiled and analysed to determine the difference in CO_2 level between both materials in the plastic box to verify the hypothesis. This paper will acknowledge the researcher and industry stakeholders on the sustainable materials adaptation.

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1. Introduction

Carbon footprint is a global phenomenon, one of the subsets of the term "Ecological Footprinting" [1]. The common understanding of carbon footprint is that it represents the specified amounts of gaseous emissions contributing to climate change based on human production or consumption activities. Conceptually, it refers to the land area required to absorb all of the carbon dioxide (CO_2) produced by humans during their lifetime. It is important to pay great attention to the carbon footprint and the ways

to reduce it, as the increase in carbon footprint would result in global environmental effects, such as raising the Earth's temperature, ocean acidification, rising sea levels, etc.

According to research by the United Nations Environment Programme (UNEP) [2], the construction industry is the largest emitter of greenhouse gases, contributing to 37% of the global carbon footprint, more than a quarter of the world's total. Moreover, the construction industry must develop creative and innovative solutions that can help reduce CO_2 emissions. One of the ways to reduce the carbon footprint in construction is by encouraging the use of eco-friendly materials. In this case, bamboo will be studied.

Bamboo is one of the materials with increasing usage that acts as an alternative to timber in the last few decades. Bamboo (Bambusoideae) is one of the subfamilies of grasses (Poaceae). Yet it differs from the common grass as it is much bigger and far more resilient in strength, thanks to its unique anatomy. Bamboos are also referred to as bamboo culms, which are whole stems. Culms have a round cross-section and are hollow in the middle, shaping them like cylinders. Composed of nodes and internodes, they contribute to its joint-like physical appearance. Culms can grow up to 3 to 30 metres long within a 3- to 4-month period [3], making it one of the fastest-growing monocotyledonous or non-woody plants in the world. Due to its unique properties, it has a very good potential in making construction more efficient and eco-friendlier, whilst helping reduce CO_2 levels not only environmentally, but also for the occupants. Thus, this paper aims to assess the systematic review on bamboo's potential as a sustainable material in building constructions, focusing on its characteristics and CO_2 perspectives.

1.1. Literature Review

1.1.1. Carbon Dioxide (CO2) In Construction

CO_2 is a colourless, odourless, non-flammable gas that constitutes a very small part of the atmospheric content, about 0.04% [4]. Although it only constitutes a small part of the atmosphere, CO_2 significantly impacts Mother Earth. CO_2 plays a key role in Earth's carbon cycle, the processes that cycle carbon in many forms throughout the environment. CO_2 is formed from various activities such as volcanic outgassing, wildfire, combustion and respiration [5].

CO_2 relates to the construction industry through the carbon footprint. Carbon footprint is a term that has gained popularity over the past few decades. CO_2 is part of the carbon footprint, which explains certain gaseous emissions relevant to climate change and associated with human production or consumption activities. Wiedmann and Minx [6] proposed and defined carbon footprint as "a measure used to determine the total amount of carbon dioxide emissions of an activity or accumulated over the life stages of a product that is directly and indirectly caused."

Construction is one of the most energy-consuming industries and the primary contributor to greenhouse gases and carbon footprint. The construction sector directly and indirectly contributes to a whopping 25% of global CO2 emissions and 39% of the world's energy usage [7].

One of the main contributors to the construction industry's carbon footprint is the production of Ordinary Portland Cement (OPC), an important binder for concrete, contributing up to 8% to the worldwide CO_2 emission [8]. This is due to manufacturing OPC, where limestone will be decomposed by maintaining a burning process at 1500°C [9]. It is reported that 0.73-0.85 tons of CO_2 were released from producing every single ton of OPC [10]. By 2056, it is expected to grow to 6 gigatons of cement per year to supply the needs for the construction industry [11].

CO_2 measurement is important in providing the figures of CO_2 levels so that the colourless, odourless gas can be quantified and understood in numbers. One of the most used methods to measure

CO_2 emissions is the Life Cycle Assessment (LCA). The LCA is a state-of-the-art tool applied to assess a certain product's environmental impacts over its service life. For the LCA of buildings, a standard methodological framework for conducting LCA consists of goal and scope definitions, life cycle inventory analysis, life cycle impact assessment, and interpretation according to ISO 14040 [12].

Another type of measurement of CO_2 levels is through measuring in building envelopes, which are the indoor environment's CO_2 levels. The measurement method came from the Indoor Air Quality (IAQ) assessment. IAQ refers to the air quality within and around buildings and structures, which relates to the health and comfort of building occupants [13]. Indoor air quality is measured by using air quality monitoring equipment such as air quality monitors, CO_2 meters and so on to be placed in an enclosed area to measure out the CO_2 level, temperature, humidity, Volatile Organic Compounds (VOC), etc, that affect the quality of indoor air. The IAQ method, which measures CO_2 levels inside buildings, will be applied to this research, as this paper aims to find out the relationship between building materials and CO_2 levels.

1.1.2. Bamboo as a Sustainable Building Material

Due to its unique properties, bamboo has a very good potential for making construction more efficient and eco-friendlier while helping reduce CO2 levels not only environmentally but also for the occupants. Table 1 indicates a peer-reviewed research summary on bamboo characteristics as a sustainable building material.

Table 1: Peer-researches summary on bamboo as sustainable building materials.

Ref	Author	Findings	Remarks
[13]	Adier et al., 2023[a,b,c,d,e,h,i]	• Bamboo is versatile for various applications, including construction. • impressive strength-to-weight ratio enables it to bear substantial loads and stresses, while its good elasticity allows efficient energy absorption • elasticity • multiple species variants	• Treatment methods, the standardisation of procedures using natural, chemical, or a combination. • For bamboo codes and standards, the assessment of existing codes and standards for testing the mechanical properties of bamboo, highlighting the potential limitations and areas, uniformity, and differences with all existing similar standards.
[15]	Bala & Supratic, 2023[a,b,b,g,i]	• Treated bamboo-reinforced concrete (BRC) elements coated with the fire-protective compound can withstand higher temperatures (500 °C or more) • Constructing lightweight and cost-efficient walling systems. • Low Cost	• Bamboo is a sustainable construction material covering different aspects, namely, the processing of bamboo, its physical and mechanical properties, and the fire performance of bamboo-based structural elements. • The chemical and thermal treatment of bamboo, along with the optimisation of various processing parameters, significantly influence the physical and mechanical behaviour
[15]	Chowana et al., 2021[a,b,i]	• Lightweight material with high strength, particularly tensile strength. • The culmination characteristics and properties of three-year-old bamboo from five species • Promote bamboo's appropriate use for building applications and as a more sustainable architectural material.	• D. asper has highest ultimate load, T. oliveri received the lowest ultimate load. • Test results for stress (load per cross-section area), P. Makinoi showed excellent mechanical properties, while D. asper showed the worst mechanical properties.

[16]	Ji et al.,2022 [c,e,f]	• Textural properties, adsorption/desorption temperatures, desorption heat and cyclic stability among bamboo • Potential solution to carbon capture with low capital cost, low regeneration temperature and excellent adsorption capacity.	• Pore distribution on the surface of the BBC makes it challenging to retain and capture CO_2 when gas passes the sample
[18]	Xu et al., 2022[c,e,f]	• After implementing the proposed strategies, the average and median amount of carbon emissions changed from 1291.63 and 1290.75 kg to 1088.36 and 1090.29 kg. • Bamboo assembled components can reduce 249.92 kg CO2 from the atmosphere. Compared to dimensioned lumber, engineered lumber, cement, steel, timber, hempcrete, bamboo building materials have the highest CO_2 emissions and carbon storage. The carbon storage of bamboo assembled components per tonne is around 140 kg more than timber per tonne.	• Three strategies useful in reducing carbon emissions are proposed and validated.
[19]	Zachariah et al., 2016[e,f]	• Very high CO_2 effluxes from culm surface, nodes and buds of bamboos. • Positive gas pressure and very high concentrations of CO_2 were observed inside hollow sections of bamboo. • The CO_2 effluxes observed from bamboos were very high compared to their carbon sequestration potential. • Bamboos are net emitters of CO_2 during their lifespan.	Measuring carbon dioxide (CO_2) emissions from bamboo culms and comparing them with their biomass sequestration potential. Analysed diurnal effluxes from Bambusa vulgaris culm surface and gas mixtures inside hollow sections of various bamboos using gas chromatography. Measure variations in gas pressure inside the bamboo section and the culm surface.

a: durable b: strengths capacity c: efficient energy absorption d: elasticity e: thermal dynamics
f: air quality g: cost savvy h: versatile i: lightweight

Bamboo is a multi-purpose plant that is well-known for being the most important material in building construction. Table 1 summarises that most peer-researchers identify that bamboo has high strength capacity, good air quality adaptation, and is cost-savvy and lightweight. Its impressive strength-to-weight ratio enables it to bear substantial loads and stresses, while its good elasticity allows efficient energy absorption. It also acts as a means of reducing carbon emissions [18] by adsorption/desorption temperatures, desorption heat and cyclic stability of the structure. Various parts of bamboo plants act simultaneously [19]. Very high CO_2 effluxes from the culm surface, nodes and buds of bamboos. Positive gas pressure and very high concentrations of CO_2 were observed inside hollow sections of bamboos [19].

1.1.3. Building Envelope

The building envelope, also known as the building enclosure, is a significant part of the building that does more than it sounds [20] referred to a building envelope as a gathering of elements made up of different components that separates the indoor and outdoor environment of the building. Components of a building include walls, windows, doors and other openings for light and ventilation.

Bamboo as a building envelope has its advantages as it grows quickly and can be harvested quickly, between 3-5 years. Bamboo also possesses good mechanical strength, such as tensile and compressive strength, which helps in withstanding loads and makes it more resistant to earthquakes. During the bamboo plantation, it takes in a high amount of carbon dioxide, even after being transformed into durable products, creating carbon sequestration where the bamboo prolongs carbon storage, reducing the release of carbon dioxide to the atmosphere, making bamboo a material with low embodied carbon [21]. Moreover, bamboo material has a low thermal conductivity, making it suitable for places with tropical climates such as Malaysia. However, bamboo faced some challenges as a material for building envelopes. Since bamboo is an organic material, it is vulnerable to natural attacks from termites and fungal attacks if not properly treated with special techniques [21], which will affect the structural integrity and lifespan.

Concrete, one of the most used construction materials in the world, has been one of the dominant building materials. Concrete is typically used in any building due to its flexibility in being moulded into any shape while providing decent strength thanks to its properties. Concrete can also be enhanced through different admixtures and combinations of special binders, creating concrete with special properties for special occasions. Concrete is also fire-resistant, making it a protective material especially for high-density structures such as apartments and condominiums. However, concrete is also proven to be one of the materials that contributes to a high carbon footprint due to the production of Ordinary Portland Cement (OPC), the important binder for concrete, which contributes up to 8% to the worldwide CO_2 emission [8]. Furthermore, concrete's thermal conductivity makes it less ideal for Malaysia's tropical climate due to heat retention, increasing reliance on air conditioning.

1.1.4. Bamboo and Concrete

Bamboo is a giant grass and one of the fastest growing plants that achieve their final length ranging 20 m to 30 m high in merely a few weeks at a rate of growth of 50 cm/day [23]. Bamboo is commonly known to have a few properties, including lightweight, high tensile, and axially strong. The average compressive strength of bamboo is between 20 and 65 MPa, whereas the Elastic Modulus (MPa) ranges from 2500 to 17500 MPA [23]. Bamboo can become the material for any parts of the building envelope except for the fireplace and chimneys, involving both structural and non-structural elements.

Concrete is a mixture that comprises water, cement and aggregates (sand, gravel, etc) and will go through curing, which is hardened over time under the chemical reaction of hydration, creating a substance or object that is solid and hard, making it one of the most conventional and commonly used materials in the construction industry. Concrete has a density of 2.4g/cm3, giving it a moderate compressive strength at a range of 20-40 MPa, which is applied to most of the structures [25]. However, concrete doesn't score well in tensile strength, having only 2.07 MPa [25]. This is why concrete is usually reinforced with steel reinforcement to help resist stretching, bending, and twisting. Concrete can be applied to all sorts of construction, from small and simple low-rise buildings to tall and complicated skyscrapers [26].

2. Methodology

For primary data collection, an experiment to measure the CO_2 level of bamboo and concrete was designed and developed according to the objectives of this research. The measurement of CO2 levels will be carried out in a controlled environment of an enclosed space, which will be simulated by an Ikea Samla plastic box with dimensions of 39cm × 28cm × 28cm or 22 Litres.

The box will be placed in the room whenever measurements are taken, to ensure that the temperature and relative humidity outside and within the box will remain within a narrow range of 23°C - 26°C and 40% - 70% RH (ICOP 2010) [27] during the measurement of air quality for each specimen. Bamboo and concrete specimens of different quality/grades with identical dimensions of 125cm^3 and a surface area of 150cm^2 will be moulded. Each specimen will be placed in the box individually, and CO_2 levels will be measured and collected using an indoor air quality (IAQ) meter. The IAQ meter will measure the following three parameters: CO2 concentration, indoor temperature, and relative humidity, as stated in Table 2. The dependent and independent variables are listed in Table 3.

The dependent and independent variables are:

- Dependent Variables: CO_2 level
- Independent Variables: Bamboo and concrete blocks.
- Controlled Variables: Temperature: 23°C - 26°C, Relative Humidity: 40% - 70% RH (DOSH, ICOP 2010), size of bamboo and concrete blocks

Table 2: Measurement of Parameters According to [28].

Parameter	Range	Measurement Tool	Unit
CO_2 Level	-	IAQ Meter	Parts Per Million (PPM)
Temperature	23°C -26°C		Degree Celsius (°C)
Humidity	40%-70% RH		Relative Humidity (RH%)

Table 3: List of Variables.

Variables	Parameters
Dependent	CO_2 Level
Independent	Bamboo And Concrete Blocks
Controlled	Temperature, Relative Humidity, Size of Bamboo and Concrete Blocks

3. Results

Bamboo is versatile for various applications, including construction, and its impressive strength-to-weight ratio enables it to bear substantial loads and stresses. At the same time, its good elasticity allows efficient energy absorption. Bamboo has multiple species variants. By proper treatment methods, the standardisation of procedures using natural, chemical, or a combination. Bamboo achieves the optimum application, which entails bamboo codes and standards, the assessment of existing codes and standards for testing the mechanical properties of bamboo, highlighting the potential limitations and areas, uniformity, and differences with all existing similar standards.

Peer-reviewed research indicates that bamboo is a lightweight material notable for its significant strength, especially its high tensile strength. The culmination of characteristics and properties of various ages of bamboo from various species promotes bamboo's appropriate use for building applications and as a more sustainable architectural material. Textural properties, adsorption/desorption temperatures, desorption heat and cyclic stability of bamboo. Bamboo is also considered a potential solution to carbon capture with low capital cost, low regeneration temperature and excellent adsorption capacity.

4. Conclusions

The hypothesis that "bamboo has lower CO_2 levels than concrete in an enclosed space" will be tested by using an IAQ meter to measure the CO_2 level difference of both bamboo and concrete in a sealed plastic box. The results will be compiled and analysed to determine the difference in CO_2 level between both materials in the plastic box to verify the hypothesis. This paper will benefit and acknowledge the researcher and industry stakeholders on the sustainable materials adaptation.

Declaration of Conflict of Interest

The authors declared no conflict of interest with any other party on the publication of the current work.

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