



Review Article

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



Liew Shao Yuet¹, Naziah Muhamad Salleh^{*1} 

¹ School of Housing, Building and Planning, Universiti Sains Malaysia, 11800 Gelugor, Penang, Malaysia

* Correspondence email: naziahmsalleh@usm.my

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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ levels as compared to concrete in an enclosed space” will be tested by using an IAQ meter to measure the CO₂ level difference of both bamboo and concrete in a sealed plastic box. The results will be compiled and analysed to determine the difference in CO₂ 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.

Copyright © 2025 KARYA ILMU PUBLISHING - All rights reserved

Article Info

Received 1 January 2025

Received in revised form 5 April 2025

Accepted 27 May 2025

Available online 26 July 2025

Keywords

CO₂ Level
Building Envelope
Bamboo and Concrete
Sustainable Material

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 (CO₂) 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 CO₂ 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 CO₂ 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 CO₂ perspectives.

1.1. Literature Review

1.1.1. Carbon Dioxide (CO₂) In Construction

CO₂ 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, CO₂ significantly impacts Mother Earth. CO₂ plays a key role in Earth's carbon cycle, the processes that cycle carbon in many forms throughout the environment. CO₂ is formed from various activities such as volcanic outgassing, wildfire, combustion and respiration [5].

CO₂ relates to the construction industry through the carbon footprint. Carbon footprint is a term that has gained popularity over the past few decades. CO₂ 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 CO₂ 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 CO₂ 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].

CO₂ measurement is important in providing the figures of CO₂ levels so that the colourless, odourless gas can be quantified and understood in numbers. One of the most used methods to measure

CO₂ 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 CO₂ levels is through measuring in building envelopes, which are the indoor environment's CO₂ 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, CO₂ meters and so on to be placed in an enclosed area to measure out the CO₂ level, temperature, humidity, Volatile Organic Compounds (VOC), etc, that affect the quality of indoor air. The IAQ method, which measures CO₂ levels inside buildings, will be applied to this research, as this paper aims to find out the relationship between building materials and CO₂ 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 CO₂ 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 CO₂ 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 CO₂ effluxes from culm surface, nodes and buds of bamboos. • Positive gas pressure and very high concentrations of CO₂ were observed inside hollow sections of bamboo. • The CO₂ effluxes observed from bamboos were very high compared to their carbon sequestration potential. • Bamboos are net emitters of CO₂ during their lifespan.	Measuring carbon dioxide (CO₂) emissions from bamboo culms and comparing them with their biomass sequestration potential. Analysed diurnal effluxes from <i>Bambusa vulgaris</i> 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 CO₂ effluxes from the culm surface, nodes and buds of bamboos. Positive gas pressure and very high concentrations of CO₂ 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 CO₂ 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 CO₂ 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 125cm³ and a surface area of 150cm² will be moulded. Each specimen will be placed in the box individually, and CO₂ 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: CO₂ 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 CO₂ levels than concrete in an enclosed space” will be tested by using an IAQ meter to measure the CO₂ level difference of both bamboo and concrete in a sealed plastic box. The results will be compiled and analysed to determine the difference in CO₂ 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.

ORCID

Naziah Muhamad Salleh  <https://orcid.org/0000-0001-9082-1088>

References

- [1] M. Wackernagel, and W. Rees, *Our Ecological Footprint: Reducing Human Impact on the Earth*, New Society Publishers, 1998.
- [2] UNEP Environment, UN, *Building Materials and the Climate: Constructing a New Future*, 2025. <https://www.unep.org/resources/report/building-materials-and-climate-constructing-new-future> (Accessed February 8, 2025).
- [3] V. Kleinhenz, and D.J. Midmore, Aspects of Bamboo Agronomy. *Advances in Agronomy* 74 (2001) 99 – 153. [https://doi.org/10.1016/S0065-2113\(01\)74032-1](https://doi.org/10.1016/S0065-2113(01)74032-1).
- [4] US Department of Energy, Carbon Dioxide 101. <https://netl.doe.gov/carbon-management/carbon-storage/faqs/carbon-dioxide-101> (Accessed February 8, 2025)
- [5] Education, UCAR Center for Science, Center for Science Education. Carbon Dioxide, Center for Science Education. <https://scied.ucar.edu/learning-zone/how-climate-works/carbon-dioxide> (Accessed February 8, 2025).
- [6] T. Wiedmann, and J. Minx, A Definition of ‘Carbon Footprint’, In: C. C. Pertsova, *Ecological Economics Research Trends: Chapter 1*, 2008: pp. 1 – 11.
- [7] C.C. Wang, and X. Tan, Estimating Carbon Footprint in the Construction Process of a Green Educational Building, In: *Proceedings of the 2012 International Conference on Construction and Real Estate Management*, Kansas City, MO, USA, 2012: pp. 175 – 179.
- [8] K. Ranjetha, U. Johnson Alengaram, A. M. Alnahhal, S. Karthick, W.J. Wan Zurina, and K.J. Rao, Towards Sustainable Construction Through the Application of Low Carbon Footprint Products. *Materials Today: Proceedings* 52 (2022) 873-881. <https://doi.org/10.1016/j.matpr.2021.10.275>.
- [9] A. Hasanbeigi, P. Lynn Price, and L. Elina Lin, Emerging Energy-Efficiency and CO₂ Emission-Reduction Technologies for Cement and Concrete Production: A Technical Review. *Renewable and Sustainable Energy Reviews* 16(8) (2012) 6220-6238. <https://doi.org/10.1016/j.rser.2012.07.019>.
- [10] T. Hills, N. Florin, and P.S. Fennell, Decarbonising the Cement Sector: A Bottom-Up Model for Optimising Carbon Capture Application in the UK. *Journal of Cleaner Production* 139 (2016) 1351-1361. <https://doi.org/10.1016/j.jclepro.2016.08.129>.
- [11] Rahman, Sherin Khadeeja, R. Al-Ameri, A Newly Developed Self-Compacting Geopolymer Concrete under Ambient Condition. *Construction and Building Materials* 267 (2021) 121822. <https://doi.org/10.1016/j.conbuildmat.2020.121822>.
- [12] M.N. Nwodo, and J.A. Chimay, A Review of Life Cycle Assessment of Buildings using a Systematic Approach. *Building and Environment* 162 (2019) 106290. <https://doi.org/10.1016/j.buildenv.2019.106290>.
- [13] EPA 2024, Introduction to Indoor Air Quality (IAQ), EPA, 2024. <https://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality>.
- [14] F.V.M. Adier, M.E.P. Sevilla, D.N.R. Valerio, and J.M.C. Ongpeng, Bamboo as Sustainable Building Materials: a Systematic Review of Properties, Treatment Methods, and Standards. *Buildings* 13(10) (2023) 2449. <https://doi.org/10.3390/buildings13102449>.

- [15] A. Bala, and S. Gupta, Engineered Bamboo and Bamboo-Reinforced Concrete Elements as Sustainable Building Materials: A Review. *Construction and Building Materials* 394 (2023) 132116. <https://doi.org/10.1016/j.conbuildmat.2023.132116>.
- [16] K. Chaowana, W. Supanit Wisadsatorn, and P. Chaowana, Bamboo as a Sustainable Building Material-Culm Characteristics and Properties. *Sustainability* 13(13) (2021) 7376. <https://doi.org/10.3390/su13137376>.
- [17] Y. Ji, C. Zhang, X. J. Zhang, P. F. Xie, C. Wu, and L. Jiang, A High Adsorption Capacity Bamboo Biochar for CO₂ Capture for Low Temperature Heat Utilization. *Separation and Purification Technology* 293 (2022) 121131. <https://doi.org/10.1016/j.seppur.2022.121131>.
- [18] X. Xu, X. Peiyu, Z. Jianjun, L. Haitao, and X. Zhenhua, Bamboo Construction Materials: Carbon Storage and Potential to Reduce Associated CO₂ Emissions, *Science of the Total Environment* 814 (2022) 152697. <https://doi.org/10.1016/j.scitotenv.2021.152697>.
- [19] E.J. Zachariah, B. Sabulal, D.N.K. Nair, A.J. Johnson, and C.S.P. Kumar, Carbon Dioxide Emission from Bamboo Culms. *Plant Biology* 18(3) (2016) 400–405. <https://doi.org/10.1111/plb.12435>.
- [20] Y. Luo, L. Zhang, M. Bozlar, Z. Liu, H. Guo, and F. Meggers, Active Building Envelope Systems Toward Renewable and Sustainable Energy. *Renewable and Sustainable Energy Reviews* 104 (2019) 470-491. <https://doi.org/10.1016/j.rser.2019.01.005>.
- [21] X. Song, G. Zhou, H. Jiang, S. Yu, J. Fu, W. Li, W. Wang, Z. Ma, and C. Peng, Carbon Sequestration by Chinese Bamboo Forests and their Ecological Benefits: Assessment of Potential, Problems, and Future Challenges. *Environmental Reviews* 19(NA) (2011) 418-428. <https://doi.org/10.1139/a11-015>.
- [22] E.A. Nurdiah, The Potential of Bamboo as Building Material in Organic Shaped Buildings. *Procedia-Social and Behavioral Sciences* 216 (2016) 30-38. <https://doi.org/10.1016/j.sbspro.2015.12.004>.
- [23] M. Yadav, and A. Mathur, Bamboo as a Sustainable Material in the Construction Industry: An Overview. *Materialstoday: Proceedings* 43 (2021) 2872-2876. <https://doi.org/10.1016/j.matpr.2021.01.125>.
- [24] M. Fahim, M. Haris, K. Khan, and S. Zaman, Bamboo as a Construction Material: Prospects and Challenges, *Advances in Science and Technology. Research Journal* 16(3) (2022) 165–175. <https://doi.org/10.12913/22998624/149737>.
- [25] A. Hassan, M. Arif, and M. Shariq, Use of Geopolymer Concrete for a Cleaner and Sustainable Environment–A Review of Mechanical Properties and Microstructure. *Journal of Cleaner Production* 223 (2019) 704-728. <https://doi.org/10.1016/j.jclepro.2019.03.051>.
- [26] B.N.A. Al-Gabri, A.B. Nabilah, F.N.A. Abdul Aziz, and I.A. Karim, Numerical Analysis of Out-of-Plane Deformation of Shear Wall. *IOP Conference Series: Earth and Environmental Science* 357(1) (2019) 012001. <https://doi.org/10.1088/1755-1315/357/1/012001>.
- [27] W. Li, L. Xiaoshan, W.B. Ding, and Y.M. Xie, A Review of Formwork Systems for Modern Concrete Construction. *Structures* 38 (2022) 52–63. <https://doi.org/10.1016/j.istruc.2022.01.089>.
- [28] Industry Code of Practice on Indoor Air Quality 2010 - Dosh. Department Of Occupational Safety and Health. <https://www.dosh.gov.my/index.php/legislation/codes-of-practice/chemical-management/594-02-industry-code-of-practice-on-indoor-air-quality-2010/file> (Accessed February 9, 2025).