APPLICATION OF BAMBOO AS SUSTAINABLE BUILDING MATERIAL FOR REDUCING CARBON FOOTPRINT IN MALAYSIA

MOHAMMAD ARSHAD BIN AB AZIZ

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Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

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DEDICATION

This dissertation is dedicated to my family, who have supported me through all of my ups and downs throughout my life. It is also dedicated to my friends who never fails to cheer me up and encourage me in times of need.

ACKNOWLEDGEMENT

Thank Allah SWT for blessing me with the strength and capability to complete my dissertation. Obstacles and hurdles are part of life but are not an excuse to abandon the inquiry. I am working tirelessly to accomplish this paper, which I believe will be useful to those in need, particularly those in the architecture field.

By doing so, I would like to express my gratitude to the lecturers of the Department of Architecture, Faculty of Built Environment, Universiti Teknologi Malaysia, for their guidance and knowledge throughout my stay at UTM. It means a lot to me, and it makes me even more eager to pursue higher-level courses in the subject of architecture. I want to use this occasion to convey our heartfelt appreciation to Sir Azari bin Mat Yasir, who genuinely gave me his expertise over the one semester under his supervision. I will remember him for his service, sacrifice, and counsel.

Finally, I'd like to express my gratitude to you, my mother, Zoriah bin Mohd Yunos, and my father, Ab Aziz bin Ab Rahman, who have become the source of my strength and the secret of my success today. Not to mention my dear siblings and fellow friends who have supported me through thick and thin. The Faculty of the Built Environment instructors have helped and motivated me. Hopefully, everyone will profit from this dissertation. May Allah reward you all. Amin.

ABSTRACT

The issue of climate change, which is brought on by both natural and artificial emissions of greenhouse gases (GHG), is a severe problem on a global scale. Despite the efforts made by Malaysia's government to cut carbon emissions, the country now ranks thirty-first among the world's countries with the highest total levels of carbon emissions. According to the World Green Building Council and the International Energy Agency, the building sector is responsible for 39 per cent of the world's total carbon emissions. 28 per cent of those emissions coming from operational carbon emissions and 11 per cent coming from embodied carbon emissions associated with materials, transportation, and construction processes throughout the building's life cycle. Bamboo as a raw material in structural and non-structural works has the potential to be one of the most environmentally friendly and cost-effective construction methods in recent years. bamboo is a highly renewable and rapidly growing material with qualities that make it appropriate for use in the construction industry. Bamboo's high flexibility and growth rate, as well as its low weight-to-height ratio, give it a wide range of applications as a building material. The aim of this paper is to investigate the application of bamboo as sustainable building material while reducing a building's carbon footprint in Malaysia. The objective of this paper is to study the viability of bamboo as a building material in Malaysia and to determine a strategy in reducing carbon footprint of a building.

ABSTRAK

Isu perubahan iklim, yang dibawa oleh pelepasan gas karbon (GHG) secara semula jadi atau buatan, merupakan masalah yang besar pada skala global dan juga tempatan. Di sebalik usaha yang dilakukan oleh kerajaan Malaysia untuk mengurangkan pelepasan gas karbon, di kalangan negara-negara di dunia yang mempunyai jumlah tahap pelepasan karbon tertinggi, Malaysia kini menduduki tempat ketiga puluh satu. Menurut Majlis Bangunan Hijau Sedunia dan Agensi Tenaga Antarabangsa, sektor bangunan bertanggungjawab untuk 39 peratus daripada jumlah pelepasan karbon di dunia. 28 peratus daripada pelepasan itu datang daripada pelepasan karbon pada operasi bangunan dan 11 peratus datang daripada pelepasan karbon terkandung yang dikaitkan dengan bahan, pengangkutan dan proses pembinaan sepanjang kitaran hayat bangunan. Buluh sebagai bahan mentah yang berpotensi tinggi untuk menjadi salah satu kaedah pembinaan yang paling mesra alam dan kos efektif dalam beberapa tahun kebelakangan ini. Buluh ialah sumber bahan yang boleh diperbaharui dan berkualiti yang menjadikannya sesuai untuk digunakan dalam industri pembinaan. Fleksibiliti tinggi dan kadar pertumbuhan buluh yang pantas, serta nisbah berat-ke-tingginya yang rendah, memberikannya kepelbagaian dalam aplikasi sebagai bahan binaan. Matlamat kertas ini adalah untuk menyiasat penggunaan buluh sebagai bahan binaan lestari sambil mengurangkan kesan pelepasan karbon pada bangunan di Malaysia. Objektif kertas kerja ini adalah untuk mengkaji kemungkinan menggunakan buluh sebagai bahan binaan di Malaysia dan menentukan strategi dalam mengurangkan pelepasan gas karbon sesebuah bangunan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

GHG	-	Green House Gas
CO2	-	Carbon Dioxide
CH4	-	Methane
N2O	-	Nitrous Oxide
HFC	-	Hydrofluoro Carbon
SF6	-	Sulphur Hexafluoride
IPCC	-	Intergovernmental Panel on Climate Change
LCA	-	Life Cycle Assessment

CHAPTER 1

INTRODUCTION

1.1 Introduction

The topic of global warming is becoming increasingly prevalent in the national discourse of a significant number of nations around the world. Suppose nothing is done to control the production of carbon dioxide. In that case, it will increase the earth's surface's average temperature and the rate of water evaporation (Mustafa M. A. Klufallah, 2014). The issue of climate change, which is brought on by both natural and artificial emissions of greenhouse gases (GHG), is a severe problem on a global scale. The most prevalent greenhouse gases are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6). Carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) are the three greenhouse gases that contribute the most to global warming. Together, they are responsible for approximately 97 per cent of the total potential for global warming. Other GHGs include ozone-depleting gases such as nitrous oxide and argon. The most well-known greenhouse gas, carbon dioxide (CO2), is responsible for approximately 80 per cent of the effect that global warming has. According to the World Green Building Council and the International Energy Agency, the building sector is responsible for 39 per cent of the world's total carbon emissions, with 28 per cent of those emissions coming from operational carbon emissions and 11 per cent coming from embodied carbon emissions associated with materials, transportation, and construction processes throughout the building's life cycle (Xiaoxiao Xu, 2022). Recent research indicates that buildings offer the most significant potential for lowering greenhouse gas emissions in the short term (Xiaoxiao Xu, 2022).

Despite the efforts made by Malaysia's government to cut carbon emissions, the country now ranks thirty-first among the world's countries with the highest total levels of carbon emissions (Mustafa M. A. Klufallah, 2014). Regarding the percentage each industry contributes, the construction industry is responsible for 24 per cent of the country's total carbon dioxide emissions. In fact, the construction industry is responsible for more than one-third of the overall energy consumption and greenhouse gas (GHG) emissions in developed and developing nations. Statistics indicate that buildings are responsible for around 20 per cent of the country's greenhouse gas emissions, placing them in third place after transportation (27 per cent) and industries (21 per cent) (Mustafa M. A. Klufallah, 2014). In the past, embedded carbon emissions have not received much attention. However, a seminal study conducted by the Intergovernmental Panel on Climate Change (IPCC) demonstrates that achieving significant reductions in all carbon emissions within the next decade is essential to maintaining a global temperature rise of 1.5 degrees Celsius or less. Therefore, tackling the issue of embodied carbon emissions is also extremely important in the fight against climate disasters.

As a result of climate change and a lack of available energy, sustainable building practices are becoming increasingly prevalent worldwide. According to the Fourth Assessment Report published by the Intergovernmental Panel on Climate Change (IPCC), several technologies can significantly cut greenhouse gas emissions but have not yet been extensively implemented, although they are relatively inexpensive. These technologies include but are not limited to high-efficiency ventilation and cooling systems, high-efficiency lighting and electrical appliances, passive solar design, insulating materials, solar water heaters, high-reflectivity building materials, and multiple glazing. Both embodied energy and embodied carbon of building materials are directly related, and both are regarded as equally important in the context of buildings and construction materials. Embodied energy is the amount of energy used to create the material. Embodied carbon is the amount of carbon (Mustafa M. A. Klufallah, 2014). The components that are utilised in the building process, the majority of which are sourced from fossil fuels. In addition, the construction industry is responsible for 24 per cent of the country's overall CO2 emissions. In addition, buildings are responsible for more than one-third of the overall energy consumption and GHG emissions in developed and developing countries.

The construction industry has recognised bamboo's potential in various constructional tasks and is working to take advantage of that potential. *Bamboo* is a versatile material that may be utilised to construct various structural elements, including walls, beams, columns, floors, roofing, and scaffolding. Although bamboo is good for the environment and has been used for thousands of years as a construction material, it is most commonly utilised in straightforward ways in traditional settings. For instance, many bamboo houses are called "Ekra," hundreds of years old in India, Nepal, and Bhutan. These houses typically have characteristics of traditional vernacular architecture (Liyin Shen, 2019). Bamboo is commonly regarded as an example of an exceptionally environmentally friendly material, and the promotion of sustainable construction practices is essential for the development and use of green building materials. In light of the preceding, the utilisation of bamboo as a sustainable resource for construction is gaining global popularity (Liyin Shen, 2019). Using bamboo as a construction material relieves pressure on the depletion of non-renewable building materials and contributes to the reduction of CO_2 emissions, savings in energy costs, and an increase in the amount of carbon that can be stored. These qualities have a direct impact on the performance of the product in terms of its environmental friendliness.

Others have lauded the utilisation of bamboo as a construction material since it has a minor impact on the environment when compared to other construction materials such as concrete. Bamboo is a type of plant notable for its rapid growth and widespread distribution over the earth. In addition, the age of a bamboo cycle is relatively brief. It can be collected between three and five years after planting and grows much more quickly than lumber. In addition, the process of collecting bamboo is more well-liked by the general populace than harvesting lumber. Because of its vast scale and rapid growth, bamboo is an excellent example of renewable and environmentally friendly building material. It has been given the nickname "vegetable steel" because it is both lightweight and powerful, and it is an alternative construction material that can also be renewed. In certain circumstances, bamboo has a higher tensile and bending strength than steel. According to the findings of some other research, bamboo is increasingly employed in place of traditional materials like wood and plastic in the construction of storage and drainage pipes. The usage of bamboo can contribute to the development of more environmentally friendly building practices. On the other hand, Malaysia's construction industry has not taken advantage of these benefits to the fullest extent possible.

1.2 Problem Statement

The increase in the average temperature of the atmosphere has led to global warming, resulting in several shifts in the climate and weather systems of the Earth. These rapid changes are taking place as a direct result of continued emissions of human heat-trapping greenhouse gases (GHG) into the atmosphere (Khozema Ahmed Ali, 2020). In addition, the construction industry is responsible for a significant amount of energy waste and pollutant production, including emissions of greenhouse gases, particulate matter, sulphur dioxide, carbon monoxide, and nitrogen oxide. The level of carbon dioxide in the atmosphere has increased as a direct consequence of the energy consumption in this industry, which has caused vast volumes of CO2 emissions. The increasing CO2 outputs caused by the utilisation of non-sustainable energy sources in the planning, construction, and operation of buildings present a challenge to the progression of the building sector toward more sustainable practices. In order to encourage a decrease in CO2 emissions, planning for energy saving and implementing methods to lower prospective emissions should take precedence (Khozema Ahmed Ali, 2020).

1.3 Research Aim

The aim of this research is to investigate the application of bamboo as sustainable building material while reducing a building's carbon footprint in Malaysia.

1.4 Research Questions

The objectives of the research are:

(a) How is application of bamboo as a sustainable building material in a building?

(b) What are the carbon footprint reduction strategies in a building?

(c) Does application of bamboo be able to reduce carbon footprint for a building?

1.5 Research Objectives

The objectives of the research are:

(d) To study the viability of bamboo as a building material in Malaysia

(e) To determine a strategy in reducing carbon footprint of a building

(f) To investigate the carbon footprint reduction for building by utilizing of bamboo as a sustainable building material

1.6 Scope of Study

The research focuses on the application of bamboo as an environmentally friendly building material in modern and large-scale construction. Because bamboo is still not widely used in the current era due to various problems and issues, this study will highlight the problem and investigate possible solutions. As CO2 has been identified as a global issue, and the building sector is one of the major contributors, an environmentally friendly material is one of the strategies for reducing it, and bamboo happens to be an environmentally friendly material with high potential. As a result, this study will compare the embodied carbon of bamboo materials to conventional materials such as concrete, steel, and bricks.

1.7 Significance of Study

Bamboo as a building material is not a new concept as it has been widely used as a traditional building material in some countries such as India, Indonesia, and Nepal for over a thousand years. However, bamboo is still not widely used in large-scale and modern construction, as conventional materials such as concrete, steel, brick, and etc are more commonly used, despite the fact that the embodied carbon for conventional materials is much higher than for bamboo. As a result, this research contributes to the use of bamboo in modern construction, resulting in a new environmentally friendly material option that reduces CO2 emissions into the environment.

1.8 Study Framework

Figure 2 shows the framework of the thesis, which progresses from objectives to data collection, data analysis and finally expected outcomes.

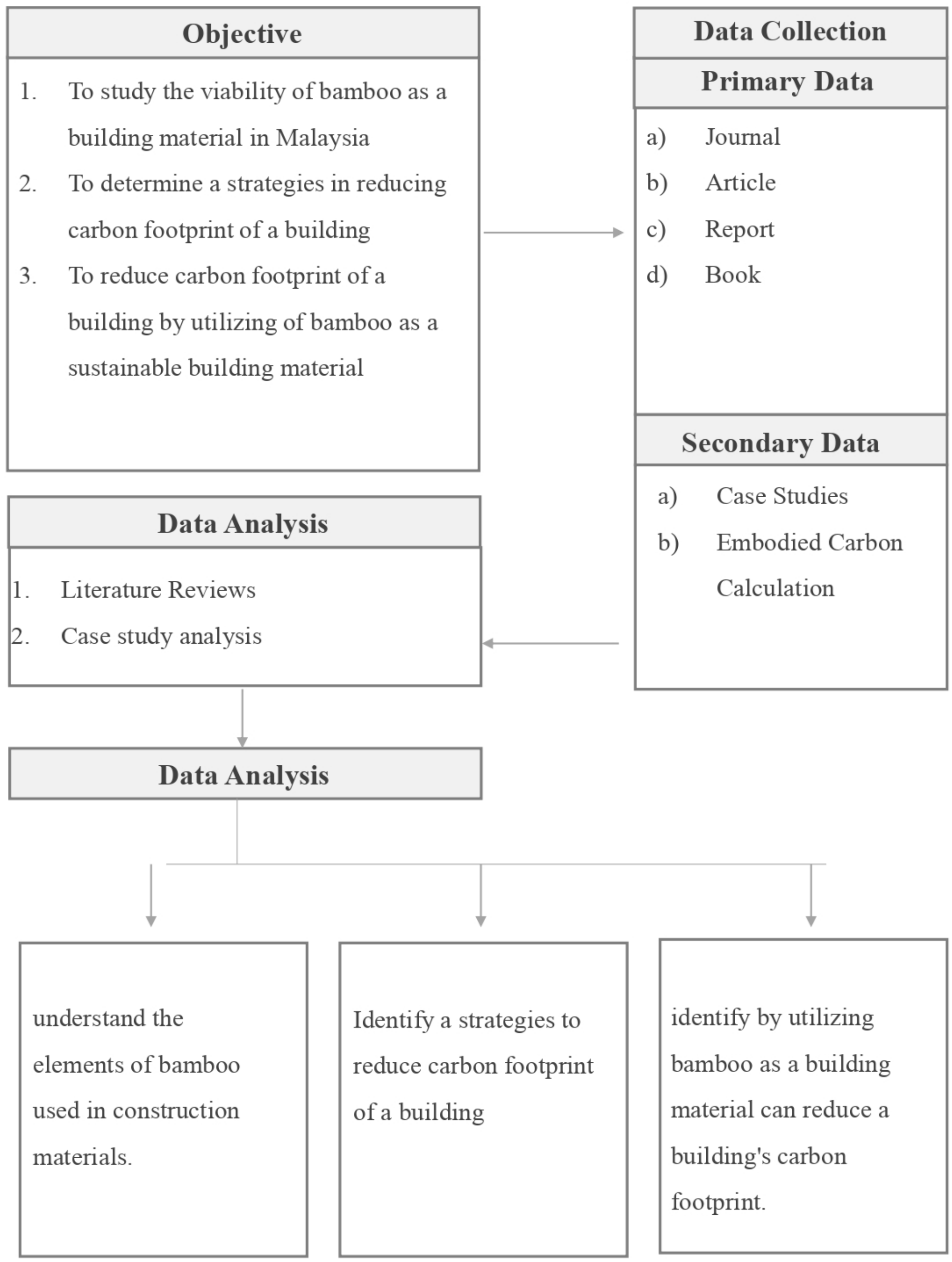

Table 1.8.1 : Thesis Framework

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature on the use of bamboo as a sustainable building material and the reduction of a building's carbon footprint is reviewed in this chapter. It also emphasises bamboo as a strategy for reducing CO2 emissions in construction. The literature review in this study helps to determine a strategy for reducing a building's carbon footprint as well as the viability of bamboo as a building material.

2.2 Carbon Footprint

It is anticipated that the current global warming trend will persist and possibly even increase over the next 100 years, wreaking havoc on both natural and societal systems (Wei Huang, 2017). The increase in the average temperature of the atmosphere has led to global warming, resulting in a number of shifts in the climate and weather systems of the Earth. These rapid changes are occurring directly due to the continued emission of heat-trapping greenhouse gases (GHG) into the atmosphere by humans. Carbon dioxide (CO2) is considered the most important artificial greenhouse gas because it is so abundant and may persist in the atmosphere for thousands upon thousands of years (Khozema Ahmed Ali, 2020).One of the top seven most significant contributors to the amplified effect of global warming is the building and construction industry, which is responsible for up to 30 per cent of yearly greenhouse gas (GHG) emissions. It is estimated that the current surge in urbanisation will result in a doubling of GHG emissions associated with the building and construction industry over the next 20 years if significant improvements in building energy efficiency are not made. This projection assumes that building energy efficiency will not improve significantly (Ali Akbarnezhad, 2017). A sizeable amount of these emissions can be attributed to the embodied carbon of the materials used in the construction process. Concrete is by far the most famous building material, and it also has a pretty high embodied carbon content, contributing to its relatively sizeable global carbon footprint. This is because of the vast amount of concrete that is produced all over the world (Xiaoxiao Xu, 2022).

For several years, investigations have been conducted in the published research to calculate the carbon footprint. These studies have looked at various techniques to cut greenhouse gas emissions and mitigate the effects of climate change on buildings. These techniques can be roughly categorised as follows:

1. Low carbon materials
2. Strategies for material minimisation and material reduction
3. Strategies for material reuse and recycling
4. Strategies for local sourcing and the minimisation of transportation

These methods increase quality, predictability, whole-life performance, and profitability while simultaneously leading to a decrease in cost, time, defect, and health and safety hazards (Alejandro Padilla-Rivera, 2018). Even though even the most recent studies based on carbon footprints have shown efforts to reduce greenhouse gas emissions related to material embodied carbon (emissions related to construction, transportation, and the production of building materials), there is still a need for a robust analysis that measures and quantifies the overall degree of greenhouse gas emission reductions and its relationship with the effect on climate change mitigation. This analysis should be conducted in a way that accounts for the fact that recent studies have shown efforts to reduce GHG emissions related to material (Alejandro Padilla-Rivera, 2018).

2.3 Life Cycle Assessment

It is necessary to have methodologies and instruments that may help measure and assess the environmental impacts of supplying commodities and services (collectively referred to as "products") to our societies to accomplish the goal of "sustainable development." Consumption of resources, the release of compounds into the natural environment, and other environmental exchanges are all activities or processes that occur during the lifetime of a product, and they all impact the natural environment (G. Rebitzer, 2004). Life Cycle Analysis, also known as Life Cycle Assessment, is a method for systematically assessing the environmental aspects of a product's life, from the extraction of raw materials to the disposal or recycling of the product ("cradle to grave"). Life Cycle Analysis is also sometimes referred to as LCA. It is a tool used in accounting that helps make decisions about the environment and manage the risks associated with it (Pablo van der Lugt, 2015). The term "life cycle assessment" (or "LCA") refers to a methodological framework that is used to estimate and evaluate the environmental impacts that are attributable to the life cycle of a product. These impacts can include things like climate change and other similar occurrences (G. Rebitzer, 2004). The Life Cycle Assessment (LCA) is a quantitative method that can quantify environmental impacts associated with processes, products, or services throughout their life cycles (Hossein Omrany, 2021). Life cycle assessment, often known as LCA, is a method that may utilize to measure the benefits of these excellent qualities that construction materials based on bamboo possess.

LCA has been established as the primary method for quantitatively assessing the environmental impacts connected to the manufacture and use of commodities throughout their service life. This assessment can be done at any point in the product's life cycle (Edwin Zea Escamilla, 2018). The LCA followed the life cycle phases described in the European Norm EN 15978. It took into account two stages—A1–3 Product and A4–5 Construction process—and five phases: (A1) Extraction of raw materials, (A2) Transport, (A3) Manufacturing, (A4) Transport scenario, and (A5) Construction scenario. Figure 2.3.1 shows how these phases are broken down (Edwin Zea Escamilla, 2018).

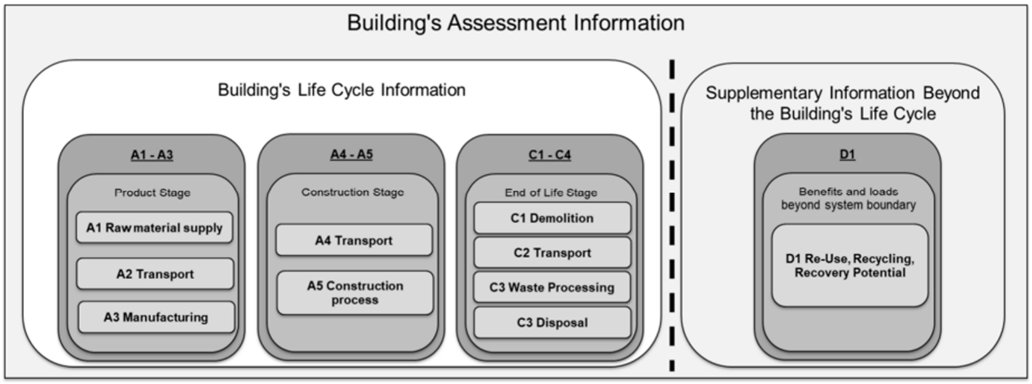

Figure 2.3.1 : Life cycle phase according to EN 15978 (Edwin Zea Escamilla, 2018)

2.4 Introduction to Bamboo

According to (Yingxin Goh, 2019), bamboo is a large, perennial, and woody grass that belongs to the angiosperms group of the monocotyledon order of plants. It is a blooming plant that never loses its leaves and is a member of the grass family Poaceae (formerly known as Gramineae), the subfamily Bambusoideae, and the tribe Bambuseae. It is the most prominent representative of the grass family. Culms, which are joint stems, are a distinguishing feature of bamboo. In most cases, the internodal sections of the stem are hollow, rather than being arranged in a cylindrical pattern, and the vascular bundles are dispersed throughout the cross-section of the stem. Bamboo is a grass in the Gramineae family that grows in tropical, subtropical, and mild temperate zones between 46° north and 47° south latitude. Generally, two primary groups of bamboo can be distinguished from one another based on the formation of upright canes and varieties of a rhizome. The first group consists of monopodial bamboos, more commonly called running bamboos. They generally have rhizome extensions that are long and thin, and the buds of those extensions produce single shoots at regular intervals. They typically develop into a scattering state and spread over a considerable distance as they mature. The second type of bamboo falls within the sympodial category. It has short, thick rootstocks, which are the sites of the formation of axillary buds, which subsequently develop into new stems. They tend to grow in groups most of the time. Bamboo is one of the plants with the quickest growth rate due to its one-of-a-kind system dependent on rhizomes (Yingxin Goh, 2019). Bamboo is classified into more than 90 genera and approximately 1,200 species (Perminder Jit Kaur, 2018). Bamboo is a versatile renewable resource that is distinguished by its high strength and low weight, as well as its ability to be easily worked with simple tools. Because of the tremendous socioeconomic benefits derived from bamboo-based products, it is widely recognised as one of the most important non-timber forest resources (AUWALU, 2019).This material is frequently used in the community for a variety of purposes, including crafts, furniture, and building materials. Aside from that, bamboo can be used as a building and construction structure because it has properties that are easily updated, lightweight, and strong, as well as flexibility that can withstand vibrations (Azmi Afifah Nurazka, 2021).

In general, sympodial bamboos are what you'll find when you look up Malaysian bamboos. It is estimated that there are approximately 59 different species of bamboo in Peninsular Malaysia. These bamboo species are from seven genera: Bambusa, Dendrocalamus, Dinochloa, Gigantochloa, Racemobamboos, and Schizostachyum. Thyrsostachys is also present in Peninsular Malaysia. It has been discovered that the state of Kelantan in Peninsular Malaysia contains 31,035,850 culms of bamboo, which gives it the most significant density of bamboo found inside forest districts. The utilisation of bamboo in building construction is limited to only a few species of plant. Based on (Yingxin Goh, 2019), the following species of bamboo are recommended for use as building materials and are listed in alphabetical order below:

• Bambusa oldhamii, also known as the Giant Timber Bamboo, because of its size and prominence in the industry. This tall species is native to China and has the potential to reach a height of approximately 65 feet, with a maximum diameter of 4 inches.

• Bambusa Lako has a useful diameter of four inches and can reach a height of up to fifty feet. Since it can keep its dark colour even after being harvested, it finds widespread application in furniture manufacturing.

• The Dendrocalamus Asper is a species that originates in Southeast Asia and is known to grow as tall canes with long straight sections of approximately 65–100 feet and a diameter of approximately 3–8 inches. This species is known to be very resilient.

• The Dendrocalamus Brandisii has canes capable of growing tall and straight. It has the potential to reach a height of approximately 60 feet and a diameter of 6–8 inches. It is one of the species found throughout the different regions of Southeast Asia, and it makes for excellent building material.

• The Dendrocalamus Yunnanicus is a species that can attain a height of approximately 70 feet and has robust and straight canes. Bamboo lumber can be produced successfully from this species and is also an excellent species for use in the building industry.

• Gigantochloa Apus has the potential to reach heights of approximately 60 feet and have a diameter of 4 inches. The Indonesian culture has a long history of employing this particular species in the construction industry.

• Gigantochloa atroviolacea is a very straight growing plant with strong black canes that will grow to a height of approximately 50 feet and a good 4-inch diameter. The canes will grow to a height of approximately 50 feet. It is a species that is useful for the construction of furniture.

• Gigantochloa Atter is a species that may reach an approximate height of roughly 60 feet and a diameter of 4 inches, and its canes are straight and powerful. • Gigantochloa Pseudoarundinacea is a species that has twisted canes.

2.5 Properties of Bamboo

Due to a distinctive rhizome-dependent process, bamboos are one of the plants that develop the quickest, with a growth rate that is three times faster than that of many other plant species. Some species of bamboo can reach their maximum height of between 20 and 30 metres in just a few weeks, growing at a rate of 50 centimetres per day throughout the growing season, while other bamboo species can grow to a height of 8 inches each day. (Madhura Yadav, 2021). Bamboo is a readily available material with a rapid growth rate. Bamboo has a lifespan durability suitable for use in a building of up to 5 years. If bamboo is preserved before being used in construction, its age will increase again (Azmi Afifah Nurazka, 2021). There are numerous positive effects that bamboo plants can have on ecology and the surrounding environment. In comparison to other types of plants, bamboo plants produce 35 per cent more oxygen. Bamboo plants have the ability to create a specific volume of oxygen in a given space. There is potential for a quicker arrival at the desired level of oxygen. This is because bamboo plants mature much more rapidly than other types of plants. In addition, bamboo plants take in a greater quantity of carbon dioxide than other types of plants. Planting one hectare worth of bamboo can cut annual CO_2 emissions by 12 tonnes (Muhammad Zakaria Umar, 2020).

Bamboo's high flexibility and growth rate, as well as its low weight-to-height ratio, give it a wide range of applications as a building material. Bamboo's light weight allows it to withstand greater loads than steel, concrete, and timber. Bamboo is one of the most durable building materials available. The tensile strength of bamboo is significantly greater than that of steel (28,000 pounds per square inch) (23,000 pounds per square inch). Compared to steel or concrete, the amount of energy needed to generate 1 m^3 of tension using bamboo structural materials is around fifty times lower. Consequently, bamboo is an attractive option to consider in place of steel in load-bearing applications (Perminder Jit Kaur, 2018). The solid stem of lumber is not as structurally sound as the hollow shape, which is why it is preferred. Densities of different kinds of bamboo range from 700 to 800 kg/m^3 on average. When designing buildings, this is an essential factor to take into account. The bending stress that will cause failure equals 0.14 times the mass per unit volume. Due to the material's large mass per unit volume, bamboo has a greater bending strength at the point of failure (Perminder Jit Kaur, 2018). Bamboo is a versatile and sustainable resource that may be used in various ways. They have long been identified with South and Southeast Asia due to the favourable growing conditions that may be found there. (Madhura Yadav, 2021).

2.6 Bamboo Treatment Techniques

Although bamboo is an incredibly tough and resilient material, just like any other biological substance, it is sensitive to the effects of the natural world around it. After they have been gathered, drying and adequately curing the bamboo poles is essential. If not maintained, bamboo poles will eventually break and rot if left untreated. The bamboo is at risk of being attacked by other living organisms as well, such as mold, fungi, or boring insects, all of which have the ability to eat away at dry wood in a manner analogous to that of termites. When it comes to uses in buildings, bamboo that is still whole has a longer lifespan than bamboo that has been cleaved. This is because when bamboo is cleaved, it allows fungi and pests to access the bamboo pores more easily. Before bamboo can be used, it must first go through the preservation process. This is done to keep harmful organisms like fungi and parasites out. Both natural processes and chemical methods can be used to preserve bamboo (Nareswarananindya, 2021). The following are examples of natural preservation methods:

• Curing: in this approach, the bamboo stems are chopped at the bottom, but the leaves and branches are left intact. After that, the clump of bamboo is put away in a specific chamber for a particular period of storage. The assimilation process decreases the amount of starch present in the bamboo segments, but the leaves continue to exist.

• Resurfacing can be accomplished by sprinkling lime on bamboo sticks. The objective is to slow down the rate at which the bamboo absorbs water to increase its resistance to mould.

• The Bamboo Soaking Method: This technique uses bamboo stems that have been soaked for one month in either freshwater, brackish water, calm seawater, or flowing water to lower the amount of starch in the bamboo. After the bamboo has been dried while standing, it should be completely submerged in water before the soaking process can begin.

The bamboo submerged in water must be white and have a sour taste. It must not be yellow-green or black.

• Boiling: Boiling bamboo at a temperature of 55-60 degrees Celsius for ten minutes will induce the starch to undergo complete gelatinization, resulting in amylose that is insoluble in water. It is sufficient to reduce attacks from bugs if the food is boiled for one hour at a temperature of 100 degrees Celsius.

The following are examples of chemical preservation methods: Because it is successful and less harmful to the environment than other wood preservatives, curing bamboo with borax and boric acid is the most common method used to preserve bamboo (for indoor use) worldwide. In a ratio of 1:1.5, boric acid and borax combine to form an alkaline salt known as disodium octaborate tetrahydrate ($Na_2B_8O_{13} \times 4H_2O$). This salt can be purchased in pre-mixed powder form, typically under the trade names Tim-Bor or SoluBor, amongst other names. The powdered form of disodium octaborate tetrahydrate is white, has no discernible odour, is not combustible or explosive, and has an acutely low level of toxicity when ingested orally or applied topically. The product is flame resistant and does not exhibit any dangerous breakdown when burned. In addition to its function as an insecticide and fungicide, this salt is also effective against algae and other forms of microorganisms. It has an unbounded shelf life and is unaffected by changes in temperature. This chemical can be infused into bamboo, bamboo can be submerged in it, or it can be sprayed on the bamboo.

2.7 Bamboo as Sustainable Construction Material

Building materials are frequently chosen based on functional, technical, and financial considerations. The availability of timber is decreasing at an alarming rate, and getting timber is becoming increasingly challenging. To make matters even more challenging, products made from lumber are both very pricey and difficult to get by. A construction material that is not only easily accessible across the country but also economically priced, with sufficient structural qualities for construction, and can be replenished would be an ideal answer for this issue. Bamboo naturally possesses all of these qualities, making it a potential superior material to wood in various applications (Ezra Kassa Hailemariam, 2022). However, as sustainability has become a more important issue in recent decades, the environmental load of building materials has also become a more important criterion (van der Lugt, 2006). One of the SDG-aligned activities in architecture, specifically Goal 11 (Sustainable Cities and Communities), assists developed countries in building sustainable and resilient buildings using local materials. These materials should be cheap, always available, have good physical and mechanical properties, and be environmentally friendly (Kitti Chaowana, 2021). As a result of deforestation, high-quality timbers that may be used for construction are becoming increasingly difficult to come by. The fact that it takes wood a long time to regenerate and become fit for use as a building material is another factor contributing to the ever-increasing expense of wood. Every passing day makes it much more challenging to achieve the goal of teaching self-reliance through the utilization of local timber to satisfy local necessities. In this way, bamboo is a highly renewable and rapidly growing material with qualities that make it appropriate for use in the construction industry (Ezra Kassa Hailemariam, 2022).

Bamboo as a raw material in structural and non-structural works has the potential to be one of the most environmentally friendly and cost-effective construction methods in recent years. According to a construction industry study, a bamboo envelope performs better than a conventional brick and reinforced cement building, and because it is cost-effective and green, it can be one of the major replacements for steel for concrete reinforcement (Madhura Yadav, 2021). Bamboo is a choice that is beneficial financially, particularly in places where it can be grown and is not difficult to get access. In most cases, machines are not required to construct bamboo structures; instead, the work may be done with just a few straightforward instruments. It is possible that bamboo can last just as long as its counterparts made of wood if it has been picked and appropriately treated. Bamboo is one of these materials used by the rural population in their construction. It has much promise in the construction sector, provided that it is given the proper treatment and labor to fulfill its potential (Ezra Kassa Hailemariam, 2022). The use of bamboo as a principal construction material is abundant in many parts of the world, particularly in South America, Africa, and Asia. As a consequence, it is utilised in constructing structures for applications like floors, ceilings, walls, windows, doors, trusses, and rafters. In addition, it is a popular choice for the construction of bridges, other modes of water transportation, and the scaffolding of tall buildings. (Kitti Chaowana, 2021).

Bamboo is considered an environmentally friendly and renewable building material because it can be harvested and refilled with minimal adverse effects on the surrounding ecosystem. Compared to other building materials such as concrete, steel, and plastic, the amount of embodied energy required to produce bamboo is relatively low. In most cases, bamboo is grown annually, and only the fully developed and ripe culms are harvested, while the younger ones are allowed to continue growing. After harvesting mature bamboo, the root system is left intact and healthy and is ready to produce additional shoots. This is analogous to the situation with grass. In addition to being a renewable resource, it is also the woody plant with the fastest growth rate on the entire world. The harvesting process typically only takes three to six years, which is around three times faster than the growth rate of most other species. Therefore, utilising bamboo helps to relieve the pressure that is being placed on the world's depleting natural forests and contributes to the protection of the global environment (Yingxin Goh, 2019). In addition, bamboos are believed to be biodegradable since their products can be burned or broken down by bacteria found in sewage (AUWALU, 2019). In addition to the technical benefits of being a sustainable construction material, bamboo also has the advantage of being one of the least expensive building materials. This economic benefit adds to the material's status as a sustainable building material. Prefabrication, ease of assembly, and the ability to quickly repair structural parts are three key advantages of using bamboo as a sustainable building material. Bamboo also has the added benefit of being environmentally friendly. Because it is so simple to take apart and put back together, it is an environmentally responsible choice for construction material. In addition, bamboo is utilised in building scaffolding, bridges, and fences (AUWALU, 2019).

2.8 Challenges of Bamboo as A Building Material

The most prominent organisms that are capable of destroying wood and bamboo while it is stored are fungus, termites, and borer beetles. The culm deteriorates while it is in storage due to the action of brown rot fungi such as G. trabeum, P. placenta, and P. monticol, as well as white rot fungi such as T. Versicolor, C. Versicolor, and P. versicolar, bacteria, and subterranean termites. One or more of these organisms will attack the culms in succession. Insects often infest bamboo through the softer tissues found within the internal hollow wall and at the budding node points. In contrast, fungus attacks are intense when bamboo is subjected to wet conditions (AUWALU, 2019). Bamboo culms can have their shelf life extended by using specific chemical preservatives, which are utilised not just by local craftspeople but also by industry. The nature of the material, which varies depending on the type of bamboo, the environment in which it grows, and the amount of humidity in the air, is one of bamboo's drawbacks. Because bamboo is susceptible to rain and sunlight, it requires specific handling in the construction process (Gallus Presiden Dewagana, 2022). The bamboo found in Southeast Asia is abundant but does not always grow in a single direction; instead, its diameters, culm thickness, and pronounced tapering vary. The use of bamboo in building construction is complicated by the fact that bamboo has these structural qualities. (AUWALU, 2019). Because bamboo is hollow, tapered, not perfectly round, and contains nodes at varying distances from one another, it is challenging to make joints out of it. Findings from tests are used to determine the material properties of bamboo at this time because grading standards are not yet available. As a consequence of this, it can be challenging to produce an accurate engineering calculation when modelling a structure made of bamboo (Ezra Kassa Hailemariam, 2022).

It has been determined that a lack of awareness among the various stakeholders is the primary cause of the poor development of Bamboo. Bamboo has earned the image of being a "poor man's timber" due to the lack of knowledge among the main stakeholders. This is because customers are unaware of the qualities Bamboo possesses, which causes them to be afraid to employ it as a construction material. In addition, there is a prevalent belief that working with Bamboo is an old occupation that offers little financial or social value (Ezra Kassa Hailemariam, 2022). Using bamboo as a construction material has additional obstacles or barriers, including a lack of innovation and institutional backing. Access to capital is limited in the bamboo industry since not many financial institutions support the construction of the bamboo sector. There is also a lack of information about the availability of resources and their use patterns. Because the data are usually unavailable or have become outdated, it is challenging to formulate particular plans for management and the distribution of resources. Even in areas with a significant potential for bamboo production, key inputs such as intense energy and water, as well as a range of chemicals for primary and secondary culm processing, are required. This can only be accomplished through advancements in technology (Ezra Kassa Hailemariam, 2022).

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