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An Integrated Bamboo Industry for Upgrading the Livelihood of The Rural Community.

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ABSTRACT

The bamboo industry is a growing industry that offers various opportunities for both producers and consumers. The global market for bamboo reached USD59.3 billion in 2021. The bamboo industry provides numerous opportunities for the rural communities in Malaysia especially in Sarawak in terms of employment, income generation, and sustainable development. A 10 years program to develop an integrated bamboo industry from 2021 to 2030 is planned to benefit the Sarawak bamboo-based industry, especially the rural communities. Among others, it will involve activities in bamboo farming, handicrafts and furniture production, bamboo panel and composite, bamboo construction, eco-tourism, and carbon sequestration. Thus, rural communities with government support can promote sustainable development of the bamboo industry while generating income and employment opportunities. However, bamboo is susceptible to decay and insect attack if it is not properly treated. Harvested bamboo culms need to be paid for and treated properly in ensuring their durability and prevent decay development. Preservatives such as borax and boric acid, copper sulfate, creosote, and tri-sodium phosphate are the most common ways to treat bamboo. Heat treatment technique which is considered to be eco-friendly is another way to treat the bamboo effectively. Research and development studies in bamboo have been conducted since the late 1980s via the World Bank-assisted Small Scale Entrepreneurship Program in Malaysia. This paper discusses effective techniques in treating, processing and the development of the integrated bamboo industry in Sarawak.

Keywords: Tropical bamboo, processing steps, chemicals treatment, heat treatment, bamboo industry for rural communities.

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INTRODUCTION

Bamboo is a type of woody grass that belongs to the family *Poaceae*. Bamboo is known for its rapid growth and versatility. Over 1,500 different species of bamboo are found in diverse climates worldwide [1, 2]. Bamboo is considered one of the fastest-growing plants on Earth. Some species can grow up to 91 cm per day under optimal conditions. This rapid growth makes bamboo highly renewable, as it can be harvested within a few years compared to traditional trees that require decades to mature. Despite its lightweight appearance, bamboo exhibits impressive strength. It has a higher tensile strength than steel and can withstand heavy loads. Bamboo's durability and flexibility make it an excellent material for construction, furniture, and various other applications [3, 4].

Bamboo has a wide range of applications due to its versatility. It can be used as a building material for houses, bridges, and scaffolding. Bamboo furniture, flooring, and panelling are popular due to their natural beauty and strength [5, 6, 7]. Bamboo fibres can be processed into textiles for clothing and home furnishings. Additionally, bamboo is used for making paper, musical instruments, handicrafts, and even as a food source.

Bamboo has several environmental advantages. Its rapid growth and dense root system help prevent soil erosion and improve water quality by acting as a natural water filter. Bamboo plantations also contribute to carbon sequestration, helping to mitigate climate change. Due to its sustainable growth and minimal reliance on pesticides or fertilizers, bamboo cultivation is often considered an eco-friendly alternative to traditional forestry. Bamboo has deep cultural and historical significance in many societies, particularly in Asia. It is revered as a symbol of strength, flexibility, and longevity. Bamboo craftsmanship, such as weaving, carving, and basket making, has been passed down through generations, representing traditional arts and cultural heritage [8, 9].

Bamboo is increasingly recognized as a sustainable alternative to traditional materials like wood, plastic, and concrete [8, 9, 10]. Its rapid growth, minimal environmental impact, and diverse applications make it an attractive choice for environmentally conscious consumers and industries seeking sustainable solutions. Bamboo is a remarkable plant that offers numerous benefits, including its sustainable growth, strength, versatility, and cultural significance. It continues to be embraced in various industries, contributing to sustainable development and promoting a greener future.

Perceptions Of People Towards Bamboo

The perceptions of people towards bamboo vary depending on cultural, geographical, and socio-economic factors. In many cultures, bamboo holds deep traditional and cultural significance. It is often associated with qualities such as strength, resilience, flexibility, and sustainability [8]. Bamboo has been used for centuries in traditional practices, art, crafts, and architecture, and is often regarded as a symbol of natural beauty and harmony.

Bamboo is widely recognized as a sustainable and eco-friendly material. Its rapid growth, minimal environmental impact, and ability to regenerate quickly contribute to its positive perception as an environmentally responsible choice. Bamboo's reputation as a renewable resource often appeals to individuals seeking sustainable alternatives to traditional materials. Bamboo's versatility is appreciated by many people. It can be used in a wide range of applications, including construction, furniture, textiles, paper, handicrafts, and more. Its flexibility and adaptability allow for innovative design possibilities and creative expressions.

Bamboo's strength and durability are acknowledged by individuals familiar with its properties. Its tensile strength, hardness, and resistance to pests and decay make it a reliable material for various purposes [8]. People who value these characteristics may view bamboo as a long-lasting and reliable option. Bamboo's natural beauty and distinctive nodes and patterns are often admired. Its appearance adds a touch of elegance and warmth to spaces and products. Bamboo is appreciated for its ability to create a serene and natural ambience.

Bamboo's economic potential is recognized by individuals and communities. Its cultivation, processing, and manufacturing provide income-generating opportunities, particularly in rural areas. Bamboo's marketability and export potential contribute to its perception as a valuable economic

resource. While bamboo has numerous positive attributes, some people may be aware of its limitations. These include variations in quality and durability depending on species and processing methods, the need for proper treatment and maintenance, and the potential for overexploitation if not managed sustainably. People who are well-informed about bamboo may consider these aspects in their perceptions.

It is important to note that perceptions of bamboo are not uniform, and individual opinions may differ. However, the growing global interest in sustainability and eco-friendly practices has generally enhanced the positive perception of bamboo as a versatile, sustainable, and culturally significant material.

Important of the Bamboo Industry

The bamboo industry plays a significant role in various aspects, including environmental sustainability, economic development, and social welfare. Bamboo is one of the most sustainable and environmentally friendly resources available. It is a fast-growing plant that can be harvested in a relatively short period (typically 3-5 years) compared to traditional timber species [9]. Bamboo also has a high growth rate and can regenerate from its root system, eliminating the need for replanting. Its extensive root network helps prevent soil erosion, and bamboo plantations contribute to carbon sequestration, helping combat climate change. Bamboo is a renewable resource, which means it can be harvested without causing long-term damage to the environment. Unlike many hardwood trees that take decades to mature, bamboo reaches maturity quickly, allowing for sustainable harvesting and continuous replanting.

The bamboo industry has significant economic potential, particularly in developing countries. It provides employment opportunities for local communities, from bamboo cultivation and harvesting to processing and manufacturing of various bamboo-based products. The industry can contribute to rural development by creating income-generating activities, reducing poverty, and improving livelihoods. Bamboo has a wide range of applications, making it a valuable resource. It can be used in construction for scaffolding, flooring, wall panels, and even as a structural material. Bamboo is also popular in furniture manufacturing, where it is used to create aesthetically pleasing and durable pieces. Additionally, bamboo-based products include textiles, paper, handicrafts, kitchenware, and more, offering a diverse range of business opportunities.

The use of bamboo products can help reduce carbon emissions. As a fast-growing plant, bamboo absorbs a significant amount of carbon dioxide during its growth. When harvested and used as a replacement for other materials such as timber, plastic, or concrete, bamboo can help reduce the carbon footprint associated with those industries. The bamboo industry can have positive social impacts, particularly in rural areas. It provides income opportunities for small-scale farmers and artisans, empowering local communities and improving their standard of living. Moreover, the industry can contribute to skills development, knowledge transfer, and cultural preservation, as traditional bamboo craftsmanship and techniques are passed down through generations.



Figure 1: Bamboo plantation in Sabal, Sarawak



Figure 2: Promoting the local bamboo species through the plantation

The bamboo industry's sustainable and versatile nature, coupled with its economic and social benefits, make it an essential sector for promoting environmentally conscious development, supporting rural communities, and contributing to a greener economy [11].

Problems of the Bamboo Industry

While the development of a bamboo industry for the rural community in Sarawak offers numerous opportunities, it also faces several challenges that need to be addressed. The common problems associated with the bamboo industry are the:

One of the significant challenges is the limited awareness and knowledge about the potential of bamboo as a sustainable resource and its various applications [8, 12]. Many rural communities may not be aware of the economic and environmental benefits of bamboo, resulting in the underutilization of this resource.



Figure 3: Propagation of the bamboo at the nursery



Figure 4: One of the popular techniques of bamboo propagation through branch cutting

Insufficient infrastructure and outdated technology in bamboo processing can hinder the industry's growth. The absence of adequate facilities such as treatment plants, manufacturing units, and transportation networks can impede the efficient production and distribution of bamboo products. Maintaining consistent quality standards for bamboo products is crucial for market acceptance and consumer trust. However, ensuring uniformity in terms of size, strength, moisture content, and durability can be challenging due to variations in bamboo species, growth conditions, and processing methods.

Limited access to finance and markets can hamper the growth of the bamboo industry [6, 8]. Lack of capital for investment in infrastructure, equipment, and working capital can impede the development of processing facilities. Additionally, difficulties in reaching domestic and international markets and establishing trade linkages can limit the industry's expansion.

Inadequate policy frameworks and regulations specific to the bamboo industry can present obstacles. Ambiguities related to land tenure, licensing, and environmental regulations may create uncertainty and hinder investments in bamboo cultivation and processing. Developing a skilled workforce capable of bamboo cultivation, harvesting, processing, and product development is crucial.

However, there may be a lack of training programs and technical expertise in the region, limiting the industry's growth potential.

Bamboo's sustainability relies on responsible management practices. Overexploitation, improper harvesting techniques, and inadequate resource management can lead to the degradation of bamboo forests and loss of biodiversity. The bamboo industry faces competition from other materials such as timber, plastic, and metal. To succeed, bamboo products need to be competitive in terms of quality, pricing, design, and marketing strategies.

Addressing these challenges requires a comprehensive approach involving government support, industry collaboration, capacity building, research and development, and effective policies and regulations. Overcoming these hurdles can pave the way for a thriving and sustainable bamboo industry in Sarawak.

Effective Technique in Treating and Processing of Bamboo

Bamboo is a versatile and sustainable material that has been used for various purposes for centuries. To effectively treat and process bamboo, several techniques can be employed. Bamboo should be harvested at the right age to ensure optimal strength and quality. Generally, bamboo is harvested when it reaches 3-5 years of age, depending on the species. Harvested bamboo can be susceptible to insect infestation, decay, and mold growth. To prevent these issues, preservation techniques are applied. One common method is pressure treatment, where bamboo culms are treated with preservatives under high pressure to penetrate the fibres effectively.

Proper drying is crucial to reduce moisture content in bamboo and prevent warping or cracking. It can be done through natural air drying or kiln drying. Air drying takes several weeks to several months, while kiln drying is a faster process but requires specialized equipment. Bamboo can be treated with insecticides and fungicides to protect it from pests and fungal attacks. This is particularly important in regions where bamboo is vulnerable to specific pests or fungi.

Bamboo can be split into strips or shaped into desired forms using various techniques such as splitting, planing, and carving. Splitting is often done by hand or with machinery to create bamboo strips of different sizes [13, 14]. The utilization of modern machinery and technology also can enhance efficiency and precision in bamboo processing, such as automated cutting, shaping, and finishing equipment [15].

Heat treatment is a process that involves subjecting bamboo to high temperatures in a controlled environment [16, 17, 18, 19]. It helps to enhance the dimensional stability and durability of bamboo, making it less prone to swelling, shrinking, and decay. Carbonization is a technique used to darken the colour of bamboo and improve its resistance to pests and moisture. It involves heating bamboo under controlled conditions to remove sugars and starches, resulting in a darker, more uniform colour.

Finishing techniques such as sanding, polishing, and applying coatings can be used to enhance the aesthetic appeal and durability of bamboo products. These techniques provide a smooth finish, protect against moisture, and improve the lifespan of bamboo items.

The specific techniques used for treating and processing bamboo may vary depending on the intended use of the bamboo, regional traditions, and available resources. Consulting with local bamboo experts or artisans can provide valuable insights into the most effective techniques for a specific context.

Integrated Bamboo Industry

The integrated bamboo industry refers to a holistic approach to developing and utilizing bamboo as a valuable resource across various sectors. It involves the coordinated integration of bamboo cultivation, harvesting, processing, manufacturing, and marketing to create a sustainable and economically viable industry.

The industry begins with the cultivation of bamboo. This includes selecting suitable bamboo species, establishing bamboo plantations or agroforestry systems, and adopting sustainable and

responsible cultivation practices. Proper management techniques such as regular pruning, thinning, and replanting ensure the continuous growth and supply of bamboo [20].

The bamboo should be harvested at the appropriate age and with proper techniques to maximize its quality and yield. The harvested bamboo is then subjected to various post-harvest processing methods such as preservation, drying, and treatment against pests and fungi, as mentioned in the previous response.

The integrated bamboo industry promotes value addition to bamboo by processing it into a wide range of products. This includes the production of traditional bamboo crafts, engineered bamboo products, bamboo-based panels, furniture, flooring, construction materials, textiles, and more. Advanced manufacturing technologies and techniques are employed to transform raw bamboo into high-value finished goods.

Continuous research and development play a vital role in the integrated bamboo industry. It involves exploring innovative processing techniques, developing new products and applications, improving bamboo cultivation practices, and conducting research on bamboo's environmental benefits and sustainable management practices.

The governments, policymakers, and industry stakeholders play a crucial role in supporting the integrated bamboo industry. Favourable policies, regulations, and incentives can encourage investment, promote sustainable practices, and create a conducive business environment. Market support through promotion, branding, and market development initiatives can help create awareness, increase demand, and enhance the marketability of bamboo products.

Collaboration among various stakeholders such as bamboo farmers, processors, manufacturers, researchers, policymakers, and market players is essential for the growth of the integrated bamboo industry. Capacity-building programs, training, and knowledge-sharing initiatives can enhance skills, promote best practices, and foster innovation within the industry.

The integrated bamboo industry emphasizes sustainable practices to ensure the long-term viability of bamboo resources and minimize environmental impact. This includes sustainable bamboo harvesting, responsible forest management, efficient use of resources, waste management, and promoting bamboo's ecological benefits such as carbon sequestration and soil erosion control.

The development of an integrated bamboo industry holds significant potential for economic growth, poverty alleviation, rural development, and environmental sustainability. It harnesses the unique qualities of bamboo as a renewable, versatile, and eco-friendly material to create a range of products with diverse applications.

Bamboo Modern Preservations

In contrast to traditional preservation methods, modern techniques have been developed to further enhance the durability and longevity of bamboo. Some of these modern preservation methods are determined by previous studies. The heat treatment involves subjecting bamboo to high temperatures in a controlled environment [21, 22]. The process alters the structure of the bamboo, making it more resistant to decay and insect attack. Heat-treated bamboo has improved dimensional stability and durability, making it suitable for various applications, including construction. Another type of heat treatment is carbonization. It involves exposing bamboo to high temperatures in the absence of oxygen. This process darkens the bamboo colour, making it visually appealing. However, carbonization reduces the strength and durability of bamboo, so it is primarily used for decorative purposes rather than structural applications [23]. Furthermore, the chemical treatments involve the application of preservatives to bamboo to protect it against decay, insects, and other forms of deterioration. Common preservatives used include borates, copper-based compounds, and synthetic resins. These treatments penetrate the bamboo, providing long-lasting protection [24]. In the vacuum pressure impregnation technique the bamboo is placed in a vacuum chamber and preservatives are forced into the material under pressure [25, 26, 27]. This method ensures deep penetration of the preservatives, resulting in effective preservation throughout the bamboo structure.



Figure 5: Preservation of the bamboo culms through sap-displacement technique



Figure 6: An electrical oil heat treatment machine

Bamboo lamination which involves bonding multiple layers of bamboo strips together using layers of adhesives may also be considered one of the techniques in modern preservation. The process strengthens the bamboo and improves its resistance to bending, warping, and splitting. Laminated bamboo is commonly used in furniture, flooring, and other structural applications [28, 29]. To improve the bonding and bamboo properties, the synthetic resin impregnation process can be applied. In this method, bamboo is impregnated with synthetic resins to enhance its strength, durability, and resistance to moisture and pests. The resin is typically applied under pressure, ensuring thorough impregnation and bonding [30, 31]. These modern preservation methods have significantly extended the lifespan of bamboo, allowing it to be used in various high-stress applications such as structural beams, and flooring, and even as an eco-friendly alternative to conventional building materials. These techniques have also contributed to the commercialization and widespread use of bamboo in modern industries.

Bamboo Durability and Strengths

Bamboo is renowned for its impressive durability and strength, which contribute to its wide range of applications. Researchers have determined some key aspects of bamboo's durability and strengths. Bamboo possesses excellent tensile strength, meaning it can resist pulling or bending forces without breaking [32, 33]. It has a higher tensile strength than many traditional construction materials, including steel. This property makes bamboo suitable for structural applications where strength is required. Also, believed that bamboo has good flexural strength, which allows it to withstand bending or flexing without breaking. This makes it suitable for use as beams, columns, and other load-bearing elements in construction [8, 34]. Studies also show that bamboo also has a high compression strength, allowing it to withstand heavy loads without collapsing or deforming. This property makes bamboo suitable for applications where compressive forces are present, such as in the construction of foundations or flooring [35]. Wahab et al., [36], bamboo is relatively hard, giving it resistance to scratches and wear. This makes it suitable for flooring, furniture, and other applications that require durability and resistance to everyday use. Bamboo also exhibits a high degree of elasticity, which means it can flex and bend under stress without breaking. This property makes it resilient and able to withstand impacts or vibrations, making it suitable for earthquake-prone areas.

Bamboo also contains some natural chemicals that make it resistant to pests, such as termites and fungi. This natural resistance reduces the need for chemical treatments or preservatives, making it an eco-friendly choice for construction and other applications [18, 36, 37]. Then, discussed that the bamboo has good dimensional stability, meaning it resists shrinking or swelling due to changes in moisture content or humidity. This property ensures that bamboo-based products, such as flooring or furniture, maintain their shape and structural integrity over time. Last but not least, as reported by Wahab et al., [8] and Sulaiman et al., [32], bamboo's rapid growth and ability to regenerate quickly make it a sustainable and renewable resource. Its high strength-to-weight ratio allows for efficient use of materials, reducing environmental impact. It's important to note that bamboo's durability and strengths can vary depending on the species, age, and processing methods. Proper treatment, processing, and design considerations are essential to maximize bamboo's durability and ensure its long-term performance in various applications.



Figure 7: Bamboo undergoing above the ground testing



Figure 8: Ground testing of bamboo showing severe termites attacks

Economic Aspects of Bamboo Products

Bamboo products have several economic aspects that contribute to their significance in various industries[38, 39, 40]. Bamboo products have gained popularity globally due to their sustainability, versatility, and aesthetic appeal. There is a growing market demand for bamboo products, ranging from traditional crafts to modern engineered bamboo materials. This increasing demand has led to the growth of the bamboo industry and the expansion of markets for bamboo products.

The bamboo industry provides employment opportunities across the value chain. From bamboo cultivation and harvesting to processing, manufacturing, and marketing, the industry creates jobs for farmers, artisans, manufacturers, traders, and other stakeholders. This contributes to income generation and poverty alleviation, particularly in rural areas where bamboo resources are abundant.

Bamboo cultivation and the production of bamboo products can stimulate local and rural development. By promoting bamboo-based enterprises, small-scale industries can be established, creating economic opportunities and improving livelihoods in rural communities. This can help reduce migration to urban areas and contribute to balanced regional development.

Bamboo products have significant export potential, especially when they exhibit high quality, unique designs, and competitive pricing. Many countries have capitalized on their bamboo resources and developed export-oriented bamboo industries. Bamboo products such as furniture, flooring, textiles, handicrafts, and construction materials are exported to international markets, contributing to foreign exchange earnings.

The sustainable and eco-friendly nature of bamboo products attracts investment opportunities. Bamboo plantations and processing facilities offer avenues for investors interested in sustainable businesses. Governments and private investors can collaborate to establish bamboo industrial parks, provide infrastructure, and create favourable policies to attract investments in the bamboo sector.

Bamboo products provide an opportunity for farmers and landowners to diversify their income sources. Bamboo cultivation can be integrated into existing agricultural systems, providing an additional source of revenue. Farmers can sell bamboo culms, engage in value-added processing, or enter partnerships with manufacturers, enabling them to earn income from various bamboo-related activities.

Bamboo products are often considered cost-effective alternatives to traditional materials such as wood, metal, and plastic. Bamboo's fast growth rate and abundance make it a readily available and affordable resource. The lower production costs associated with bamboo products can translate into competitive pricing, making them accessible to a wide range of consumers.

The economic aspects of bamboo products are closely linked to their environmental benefits. Bamboo is a renewable resource that grows rapidly, requiring minimal inputs such as water and fertilizers. Bamboo plantations also have positive environmental impacts, including carbon sequestration, soil erosion control, and biodiversity conservation. The eco-friendly nature of bamboo products adds value to their economic viability.

The economic aspects of bamboo products encompass market demand, job creation, income generation, local and rural development, export potential, investment opportunities, cost-effectiveness, and environmental benefits. The growth of the bamboo industry contributes to sustainable economic development, while also promoting social and environmental sustainability.

Engineered Bamboo Products

Engineered bamboo products offer several benefits compared to traditional materials, making them an attractive and sustainable choice in various applications. Engineered bamboo products, such as bamboo composites and bamboo-based panels, exhibit excellent strength and durability [36]. The manufacturing process involves bonding bamboo fibres together using adhesives or lamination techniques, resulting in materials that can surpass the strength of many traditional materials. Engineered bamboo products have high tensile and compressive strength, making them suitable for load-bearing structures and applications that require strength and durability.

Bamboo is a highly sustainable and renewable resource. It is one of the fastest-growing plants on the planet, with some species growing up to 1 meter per day. Engineered bamboo products utilize this renewable resource efficiently, reducing the dependency on traditional materials that have higher environmental impacts. Bamboo plantations contribute to carbon sequestration, as bamboo absorbs significant amounts of CO₂ from the atmosphere, helping mitigate climate change.

Engineered bamboo products come in various forms, such as boards, panels, beams, and veneers, providing versatility in design and applications. They can be engineered to have specific characteristics and properties, such as increased water resistance, fire resistance, or dimensional stability, making them suitable for a wide range of uses. Engineered bamboo products can be utilized in construction, furniture manufacturing, interior design, flooring, and many other industries.

Engineered bamboo products often retain the natural beauty and grain patterns of bamboo, offering an aesthetically pleasing appearance. They can enhance the visual appeal of products and architectural designs, adding a touch of natural warmth and elegance to the environment. The unique patterns and colours of bamboo can be showcased in engineered bamboo flooring, furniture, and decorative items, providing a distinct and attractive look.

Compared to many traditional materials, engineered bamboo products have a relatively low density, making them lightweight. This characteristic makes them easier to handle, transport, and install, reducing labour and transportation costs. Lighter weight can be advantageous in construction, especially for structures where weight is a consideration, such as in prefabricated elements or for applications in earthquake-prone areas.

Engineered bamboo products exhibit favourable thermal and acoustic properties. They have low thermal conductivity, meaning they can provide insulation and contribute to energy efficiency in buildings. Additionally, bamboo's cellular structure and fibre arrangement contribute to its sound absorption capabilities, making engineered bamboo products suitable for acoustic panels and interior spaces where noise reduction is desired.

Bamboo naturally possesses properties that make it resistant to pests and fungi. Engineered bamboo products retain these natural characteristics, reducing the need for chemical treatments or

preservatives. This resistance enhances the longevity and durability of engineered bamboo products, making them less prone to decay, insect damage, or mold growth.

Engineered bamboo products combine the strength, sustainability, versatility, and aesthetic appeal of bamboo with engineering techniques that enhance their performance. Their numerous benefits make them an attractive choice for designers, architects, builders, and consumers looking for sustainable and high-quality materials.



Figure 9: Glueing of bamboo splits forming into boards is the simplest way in bamboo engineering.



Figure 10: Bamboo weaving mat

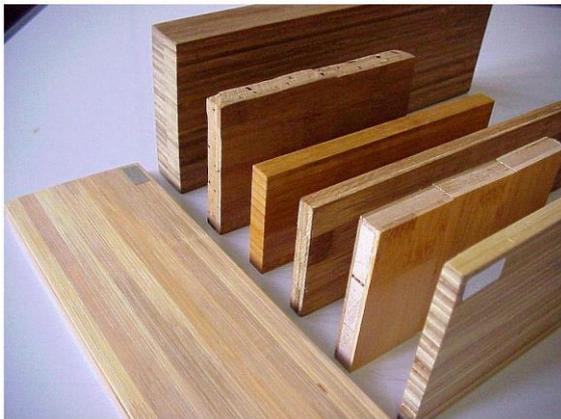


Figure 11: Various forms of bamboo-engineered products



Figure 12: Cross-laminated bamboo products.

Bamboo Uses in Construction

Bamboo has been used as a construction material for centuries due to its strength, versatility, and sustainability. Its unique properties make it suitable for various applications in construction. Bamboo can be used as a structural material in buildings, especially in regions where it is abundant. It has an excellent strength-to-weight ratio, comparable to steel, and can be used as columns, beams, and trusses. Bamboo's tensile strength and flexibility make it suitable for withstanding loads and vibrations, making it a viable alternative to traditional materials [41, 42, 43, 44].

Bamboo flooring is a popular choice due to its durability, natural beauty, and eco-friendliness. Bamboo flooring can be engineered or solid, and it offers a sustainable and renewable option for indoor and outdoor spaces. Bamboo decking is also used in outdoor applications, providing a strong and visually appealing surface for decks, patios, and walkways. Bamboo can be used as wall panels or cladding material, adding a natural and decorative touch to buildings. Bamboo panels can be installed as interior or exterior wall coverings, providing insulation, acoustic properties, and an attractive appearance. Bamboo cladding can also be used for facades, creating a visually appealing and sustainable design feature. In

some regions, bamboo is used as a roofing material. Bamboo poles or split bamboo can be woven together to create roofs that are lightweight, durable, and provide good insulation. Bamboo thatching is also used in traditional and eco-friendly roofing systems, providing natural ventilation and protection from weather elements.

Bamboo is commonly used in the construction of temporary structures such as scaffolding, formwork, and shelters. Its lightweight and easy-to-handle nature makes it suitable for quick assembly and disassembly, making it a cost-effective solution for temporary construction needs. Bamboo is widely used in interior design and furniture manufacturing. It can be transformed into various furniture pieces such as chairs, tables, cabinets, and shelves. Bamboo's natural beauty and versatility make it a popular choice for creating sustainable and aesthetically pleasing interior spaces. Bamboo can be processed into composite materials such as bamboo composites, laminated bamboo, or engineered bamboo panels. These materials can be used for various purposes in construction, including doors, partitions, staircases, and structural components. Bamboo composites combine the strength of bamboo fibres with resins or adhesives, resulting in durable and high-performance materials.



Figure 14: Laminated bamboo flatpacks design.



Figure 15: Laminated bamboo chairs with modern concepts.



Figure 16: Bamboo chairs from bamboo veneers.



Figure 17: Laminated bamboo satee.

For landscape and garden structures, bamboo is also used in landscape architecture and garden structures. It can be used for pergolas, trellises, fences, and decorative elements, adding a natural and visually appealing touch to outdoor spaces. The specific uses of bamboo in construction may vary depending on regional traditions, building codes, and the availability of bamboo resources. Proper treatment, preservation, and maintenance are essential to ensure the longevity and performance of bamboo in construction applications.



Figure 18: Bamboo flooring from bamboo splits.



Figure 19: Bamboo parquets.



Figure 20: Joinery used in the traditional bamboo houses

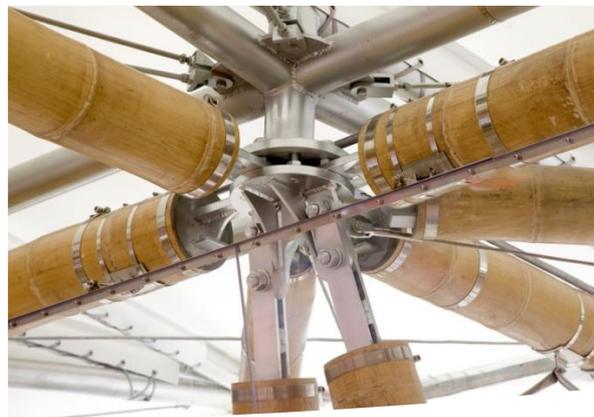


Figure 21: The use of metallic braces has become popular and added more strength to the bamboo houses



Figure 22: Bamboo houses which use a simple design



Figure 23: The use of modern designs and advanced bamboo processes technique enhanced the durability and strength of the bamboo houses.



Figure 24: A modern concept in the uses of bamboo for a house construction



Figure 25: Another modern concept is the use of bamboo for a house construction



Figure 26: An eco-friendly bicycle which uses bamboo as its main frame

Future Role of the Bamboo Industry in the Rural Community

Due to its multiple uses, bamboo's cultivation is contributing greatly to the social needs of those who go into its growth as well as the community and the nation at large by offering various benefits and contributing to their overall development. There are a few key roles of the bamboo industry in terms of economic, social, and environmental [8, 38, 45, 46, 47].

The bamboo industry provides job opportunities for rural communities. Bamboo cultivation, harvesting, processing, and manufacturing of bamboo products create employment across the value chain. This can help alleviate unemployment and underemployment in rural areas, offering income-generating activities for individuals and households. For rural populations, the bamboo industry may provide a source of income. Bamboo farming offers rural residents the chance to engage in income-generating activities, which also helps to create jobs for those who participate in the industry as well as for small and medium-sized businesses.

Bamboo cultivation promotes sustainable land use practices in rural areas. Bamboo grows rapidly and does not require extensive land or chemical inputs, making it suitable for marginal or degraded lands. By cultivating bamboo, rural communities can restore and protect the environment, prevent soil erosion, and contribute to biodiversity conservation [48].

Opportunities for capacity building and skill development in rural communities are provided by the bamboo sector. Bamboo harvesting, processing, and cultivation procedures can all be learned by farmers and labourers. Through knowledge transfer, people in the industry gain vital skills that will help them in the workplace and as entrepreneurs in the future [49]. The bamboo sector offers a chance to diversify the rural economy. Rural communities can look into enterprises and businesses based on bamboo rather than only depending on conventional agriculture. This diversity can strengthen rural communities' resilience, lessen their reliance on a particular industry, and promote general economic growth and stability.

In rural areas, the bamboo sector can promote social inclusion and gender equality. Bamboo-related activities, including weaving, handcrafting, and producing value-added products, sometimes include a large number of women. Women and other marginalised groups can become economically independent, raise their social status, and participate in decision-making by working in the bamboo sector.

Bamboo has deep cultural significance in many rural communities, representing their traditions and heritage [8]. The bamboo industry helps preserve traditional knowledge and craftsmanship associated with bamboo cultivation and utilization. This ensures the continuity of cultural practices and contributes to the cultural identity and pride of rural communities. Bamboo forests provide food and shelter to large animals and birds, to the level of the less studied soil organisms, insects, and other plants that together make up the bamboo forest ecosystems. Its cultural value and central position in many of Asia's rural beautiful landscapes demonstrate its high amenity value.

The bamboo industry's roles in employment generation, income generation, sustainable land use, skill development, social empowerment, cultural preservation, and economic diversification collectively contribute to the holistic development of rural communities, fostering inclusive and sustainable growth.

CONCLUSIONS

The development of an integrated bamboo industry for the rural community in Sarawak presents significant opportunities for economic growth, employment generation, environmental sustainability, and cultural preservation. By implementing the following key strategies, the industry can thrive and benefit the rural community:

- Ensure sustainable bamboo cultivation practices and responsible resource management to protect biodiversity and prevent overexploitation.
- Provide training and skill development programs for farmers, artisans, and entrepreneurs to enhance their knowledge and expertise in bamboo cultivation, processing, and product development.

- Establish necessary infrastructure, including bamboo nurseries, processing facilities, and transportation networks, to support the efficient production, processing, and distribution of bamboo products.
- Foster collaborations between bamboo growers, processors, and product manufacturers to create a seamless supply chain and promote the use of bamboo in various industries, such as construction, furniture, handicrafts, and textiles.
- Identify domestic and international markets for bamboo products, develop effective marketing strategies, and participate in trade fairs and exhibitions to showcase the unique qualities and sustainability of Sarawak's bamboo products.
- Collaborate with government agencies to develop supportive policies, regulations, and incentives for the bamboo industry, including land tenure, licensing, and financial assistance, to encourage investment and growth.
- Encourage research and development activities to explore new applications, technologies, and value-added products derived from bamboo, fostering innovation and competitiveness in the industry.

By addressing these aspects and promoting a holistic approach, the integrated bamboo industry can drive rural development, create income-generating opportunities, preserve cultural heritage, promote sustainable practices, and contribute to the overall socio-economic development of the rural communities in Sarawak.

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