

GIANT REED (*Arundo donax*): EXPLORING AN ALTERNATIVE FORMWORK MATERIAL IN CONSTRUCTION

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Abstract:

The construction industry has a significant impact on structural building development and economic advancement. However, formwork materials commonly made from wood, steel, and plastic play a part in massive environmental issues like deforestation and high-energy production processes. This study is focused on the giant reed (*Arundo donax*) with its sustainability and use as an alternative formwork material in construction. Giant reed is a sustainable option maturing and growing rapidly in various soil types. The modified proportions of fiber, resin, and hardener of 53:46:1 were employed in designing, development, and evaluating the giant reed formwork boards with varying fiber patterns such as parallel, alternating, and crisscross. These boards were evaluated through various tests for internal bond strength, modulus of rupture, and water absorption. The results showed that the giant reed boards' three fiber patterns exceeded the strength of conventional plywood and particle boards. The alternating fiber pattern produced the best results across all tests conducted with an internal bond strength of 23.54 kg/cm², modulus of rupture of 825.43 kg/cm², and a water absorption test rate of 1.047%. A cost comparison between the traditional plywood and giant reed boards was conducted to assess their applications in a low-rise building considering both economic and financial feasibility. The study revealed that giant reed boards were found to be a valuable alternative with comparable strength as well as their environmental advantages and benefits. Giant reed formwork boards are a feasible and sustainable alternative to traditional formwork materials providing significant environmental benefits without sacrificing structural integrity. However, they had higher initial costs which needed to be tackled to improve financial feasibility. This study supports the development of sustainable building practices and is in line with the goal of the industry to reduce its environmental impact.

Keywords —giant reed, formwork material, fiber patterns, internal bond, modulus of rupture, economic feasibility.

I. INTRODUCTION

The construction industry has a vital part as a paramount driver for economic development, however, it also causes a considerable threat to the environment due to the amount of pollution it contributes and the use of decreasing natural resources non-sustainably. The acknowledgment of the urgent need for the construction industry to adopt sustainable practices has been increasing in recent years [1].

According to Sai and Achuthan [2], formwork stands as an integral and essential element in the field of construction. The selection of an appropriate formwork system plays a crucial role in construction and has the potential to contribute to sustainable construction applications. The concrete is shaped according to the specific types of formworks employed in construction, typically designed to meet the requirements of the building. Formworks are commonly constructed from materials such as wood, steel, aluminum, or

prefabricated forms into which concrete is poured. They are utilized for casting structural components like columns, beams, slabs, and shear walls and are also applicable for smaller building elements such as stairs, etc. Also, formwork serves as a temporary support during the construction of concrete structures, primarily used to shape and preserve fresh concrete until it attains sufficient strength.

Plywood is a conventional material used in wooden formworks, it is made by attaching thin sheets of cross-laminated veneer with strong adhesives under heat and pressure [3]. The main source of plywood material is acquired from trees. Unfortunately, it causes a major environmental problem due to around 11 million hectares of forest being cut down worldwide yearly. The reason for this significant loss of trees is because of different purposes, such as creating products and acquiring fuel, as well as expanding farming areas and cities [4]. Hence, the worldwide concern of a growing number of trees being cut down to produce wood-based construction formworks is a global problem that contributes to deforestation. The extensive deforestation in the recent past has led to an environmental imbalance in our ecosystem. To stop deforestation, the exploration of alternatives to wooden formwork is essential as a preventative measure [5]. Innovative alternatives, particularly regarding materials utilized for construction formwork are demanded in the environmental and structural challenges in modern construction.

The environmental impact of construction projects can be significantly decreased, if sustainable building materials are applied to construction projects, resulting in the conservation of energy, decrease of pollution, and the preservation of resources. Construction management has the potential to be enhanced through encouraging the use of more efficient construction practices and materials, and enriched communication and coordination among construction professionals, [6]. Sustainable materials in construction, such as recycled materials, natural resources, and renewable materials, are those acquired and made through environmentally-

safe means and are contributing to the reduction of waste and carbon emissions in the construction sector. On the other hand, sustainable construction, inspiring the use of environmentally friendly methods, involves the use of materials and practices with minimal environmental impact. Sustainable construction includes the reduction of waste, energy consumption, and carbon emissions throughout the construction process [7].

Regarding the increasing demand for environmentally friendly structures, as observed by Miyazaki [8], the construction sector is actively exploring materials prioritizing environmental considerations. Builders and developers are devoted to integrating sustainable materials and currently recognize the importance of diminishing the environmental impact of construction processes. The increasing demand for sustainable construction in the Philippines signifies a move towards a more environmentally responsible future. Acknowledging the notable environmental effects of buildings, those involved in the construction industry are actively embracing environmentally friendly methods and cutting-edge technologies to reduce their carbon footprint. Builders, through the utilization of green buildings and diverse sustainable construction materials, are not only addressing challenges like deforestation and climate change but also encouraging the evolution of innovative practices that prioritize the long-term well-being of our planet.

The research done by Malheiro et al. [9] emphasizes bio-based material's essential benefits in construction, underscoring their ability to isolate carbon and decrease the overall carbon footprint of buildings. These materials, particularly those obtained from fast-growing plants like reeds, provide thermal performance like conventional insulation materials but with lower embodied energy, improving the life cycle performance of structures. Their functions also help to expand carbon storage, showing a favorable advancement in sustainable building practices. Moreover, recent innovations have also seen this non-timber species gain attention in the fabrication of particleboard

panels, presenting a sustainable alternative to traditional wood derivatives [10]. This shift is driven by the high cost of natural wood and the desire to alleviate raw material shortages, reducing the environmental impact on forests. Governments and the EU promote recycling efforts. Searching for alternatives to natural wood, like non-woody plants and organic adhesives, is currently of interest [4]. An exploration of the use of giant reed particles in wood particleboards is studied by Ferrández-Villena et al. [4], exhibiting enhanced properties, specifically with 70% reed particles and a pressure of 2.6 MPa, yielding Grade P2 boards. These boards offer a sustainable alternative with less energy consumption compared to traditional wood board, and show good thermal properties, suggesting giant reed as a promising addition to produce more environmentally friendly materials.

Concerns regarding efficiently consuming resources and managing waste rise due to society is becoming more mindful of the environment. In both academic research and industrial practices there has been a substantial shift toward using materials and technologies that have a minimal environmental footprint in recent years [11]. This trend is especially seen in the growing interest in natural fibers over synthetic alternatives such as glass, carbon, or Kevlar fibers [12]. The rising preference for natural fibers is due to their various distinct properties, cost-effectiveness, and minimal environmental impact. The growing interest in natural fibers can be attributed to their distinctive characteristics, cost-effectiveness, and reduced environmental impact. Furthermore, these sustainable practices not only enhance the value of residual biomass from agriculture [13], [14] but also generate beneficial effects across the agricultural supply chain [15] and contribute positively to rural landscapes [16], [17].

Di Fidio et al. [18] highlight giant reeds known for their high environmental adaptability and high yields, could offer an opportunity to enhance agricultural incomes transforming previously unproductive. This initiative aligns with three out of the 17 Sustainable Development Goals (SDGs)

outlined by the United Nations, specifically SDG 2 focusing on food security and sustainable agriculture, SDG 7 addressing reliable, sustainable, and modern energy, and SDG 13 targeting actions to combat against climate change and its impacts.

Developing environmentally friendly construction materials utilizing plant residues is an effective solution [19]. The giant reed of all the plant fibers has captivated the attention of many research studies.

The research by Pilu [20] explores the genetic properties and origin of giant reed scientifically known as *Arundo donax*. The giant reed is a tall, invasive, and sterile reed utilized historically for different industrial and domestic functions. The reed can be as tall as more than 8 meters and has become invasive in different locations. The giant reed's abundance is astonishing due to it being a perennial plant that grows spontaneously around the globe. Moreover, Giant reed likely came from Asia and spread later to the Mediterranean and other locations around the globe. Giant reed flourishes in subtropical places from various places like the Mediterranean to temperate East Asia and the Philippines [21]. The reed can also thrive in different soils like sands, gravel, clay, and river sediment, according to the Arizona-Sonora Desert Museum [22]. Giant reed prefers wet environments, consuming significant water resources, usually observed along the stream banks, flood plains, and irrigation waterways, due to it being native to warm temperate and subtropical biomes in Asia [23]. Giant Reed is seen as a useful source of biomass because it grows a lot and does not need much water or specific soil conditions [24], [25]. It is also tough against heat and diseases [26].

Giant reed is stronger than hardwood, mainly because its fibers are similar in length and ratio. A distinctive quality of giant reed lies in its capability to thrive without the demand for high-quality soil or a substantial amount of fresh water. In less fertile soils, even in places where water is lacking, it can adapt and flourish. This is significant as it reduces the need to use fertile soil hence it could be used for cultivating crops [27].

A study on giant reed has been recently conducted by Fiore et al. [12] despite being invasive; its potential was recognized in the production of natural fiber composites. The fibers of the plant display favorable properties for composite materials, causing it to be a sustainable alternative in construction formwork applications. This up-and-coming field of study proposes that giant reeds can be employed for environmentally sustainable purposes, potentially diminishing some of the harmful impacts of their invasive nature.

The industry could preserve natural resources and drastically reduce its environmental impact by using giant reeds as an alternative formwork material.

The focus of the study on giant reed as an alternative formwork material is also on the materials and methods to be used in product development the tests to be carried out and the financial and economic viability of adopting giant reed into formwork board for construction application.

When evaluating the mechanical properties of the created giant reed formwork boards a Universal Testing Machine (UTM) is used as a precise piece of equipment. The testing procedure includes the three fundamental properties: internal bond, modulus of rupture, and water absorption. The UTM applies controlled forces in accordance with American Society for Testing and Materials (ASTM) 1037 standards to evaluate the board's resistance to pulling flexibility under bending stress and ability to withstand water absorption. Decisions regarding the structural strength, dependability, and suitability for the construction of the boards—specifically regarding their resistance to water absorption—are informed by this testing process.

The mechanical properties of raw materials and components can be evaluated using a Universal Testing Machine (UTM) by assessing their performance in different test methods under a range of strengths or stresses [28]. ASTM D1037 a standard specification developed by ASTM International provides procedures for evaluating the mechanical and physical characteristics of wood-

based fiber and particle panel materials. These procedures cover various test methods for determining properties like strength stiffness and dimensional stability [29].

The study uses a comprehensive approach to assess the economic and financial viability of the giant reed formwork boards. This includes comparing the developed boards' costs with those of conventional plywood boards as well as the costs of materials labor and potential savings from features like finishing. Large reed formwork boards in a low-rise building will also be used for a quantity survey. The purpose of the survey is to gather information regarding overall cost-effectiveness resource utilization and efficiency. All things considered, the analysis aims to give a thorough grasp of the giant reed formwork boards' economic viability offering important information for construction project decision-making.

II. METHODOLOGY

This research study sought to develop and evaluate formwork boards made from giant reed fibers. This chapter provides details on the methodologies of the study, including the process of fabrication and different tests. Testing assessed the strength and water absorption, among other factors, if it surpassed the strength requirements of plywood and particle board, and then the testing was done to determine the most suitable values for the properties. The testing results were consolidated in a systematic table format. This interpretation was shown in the discussion section of the study.

Furthermore, the cost of developed giant reed boards was compared to the cost of commercial formwork boards. These include the cost of material, labor, reusability, and finishing while considering mark-up price.

By using quantity surveying, the economic feasibility of the giant reed formwork boards is being assessed. Considering its estimated cost in low-rise applications. These holistic approaches contributed to a well-rounded understanding of the potential advantages and challenges associated with

adopting Giant reed fibers in formwork construction.

A. Methodological Framework

The methodological framework outlines the three phases of the study process, encompassing research procedures and data collection.

Phase 1: Research Procedure -Materials and Equipment -Preparation of Fibers -Modifying Material Proportions -Fabrication of Three (3) Types of Formwork Boards: Parallel Pattern, Alternating Pattern, and Crisscross Pattern
Phase 2: Data Collection - Testing - Cost Comparison - Quantity Surveying

Fig. 1. Methodological Framework








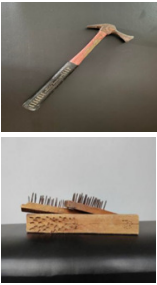
B. Phase 1: Research Procedure






This phase involved the materials, equipment, and procedures such as preparation of fiber, modifying material proportions, and fabrication necessary for the design and development of the giant reed formwork boards. Similarly, thorough documentation was also included. The material specifications comprised the giant reed as the primary material, premix polyester R 10-103 as the binding agent, hardener, and other materials such as the tools and equipment.

The procedure for the development of a giant reed board was adopted from a related study titled "Reed Board as Construction Material" [30] and was divided into two main parts: the preparation of the fiber and the fabrication of the formwork board samples. Additionally, modifying material proportions was included in the main parts of the procedure in giant reed board fabrication.

- 1) **Materials and Equipment:** The following materials and equipment were used in developing the three variations of giant reed boards.


TABLE I
 MATERIALS AND EQUIPMENT




Materials and Equipment	Picture	Use
Giant reed		The primary material of the study where the fiber is extracted using its stem.
Premix Polyester Resin R 10-103		The binding agent used in making the giant reed formwork material.
R 10-103 Hardener		The chemical mixed with the resin.
Knife/ Bolo		The material used for harvesting giant reed.
Gloves		The gloves is used in harvesting, cleaning, and extracting fibers of giant reed.
Container		Where all the cleaned giant reed stems were placed.
Weighing Scale		Used in weighing giant reed, other materials, etc. during the process.
Hammer and Steel Brush		Used for defibering the Giant reed. Hammer for smashing the stem and steel brush for defibering.





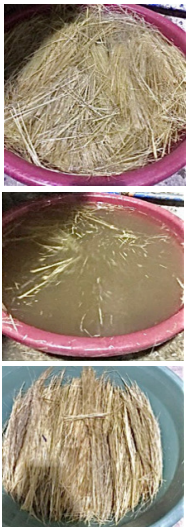

Scissor		Used to cut the fibers uniformly.
Moisture Content Detector		Used to detect the moisture content of the fibers if suitable for making formwork material.
Moulder		Where the mixed materials were put to shape the formwork board.
C-clamp		Used to securely hold the wooden molder and compressor in place, ensuring the fiber mixture with resin remains properly positioned and achieves the desired thickness.
Oven		It is an efficient tool, particularly beneficial when rapid drying is imperative and alternative drying apparatus is unavailable.

2) **Preparation of Fibers:** The following are the procedures conducted in preparation for the giant reed fibers.

TABLE II
 PREPARATION OF FIBERS




Preparation of Fibers	Picture	Procedure
Collecting of Giant Reed		Giant Reeds were harvested near Santa Rita, Pampanga, as this location was found to have a plentiful supply of reeds in that area. These reeds were young, harvested prior to reaching full maturity,

		exhibiting a yellow-green color, and standing tall at approximately 12 to 16 feet. Their stems resembled hollow canes, ranging from 1/4 to 2 inches thick. The leaves were robust and upright, with a green color, measuring about 2 inches wide and 24 to 36 inches long.
Cleaning of Giant Reed		The giant reeds were cleaned by carefully removing leaves and roots with a knife, ensuring that only the stems were retained. This process involved separating the undesirable parts to acquire the clean stems. Following this, the pristine giant reed stems were gathered and placed into a designated container, ready for further processing.
Soaking Giant Reed		The collected stems were soaked in a container filled with water for three days to facilitate the easy separation of fibers; it was

		<p>ensured that they were submerged completely.</p>	<p>Sun Drying Fibers</p>		<p>Three days were spent sun-drying the fibers. The fibers are now stronger and dryer, preparing them for formwork fabrication.</p>
<p>Defibering of the Giant Reed</p>		<p>The giant reed stems were broken with a hammer to expose the fibers that were hidden. With great care, a steel brush was used to extract and refine the fibers.</p>	<p>Moisture Determination</p>		<p>Making sure the fibers have fulfilled the required quality standards and have the proper moisture content (4 percent or less) for optimal use is crucial [31]. To ensure that the moisture content of the obtained fibers met the specified standards, a moisture detector device was used to check the content and make sure it was within the permitted limit.</p>
<p>Washing of Fibers</p>		<p>After extracting the fibers from the giant reed stem, the next step was to give the fibers a thorough wash after they had been extracted. This procedure guaranteed the cleanliness of the fibers and the elimination of impurities.</p>	<p>Cutting of Fibers</p>		<p>After being obtained, the fibers were carefully cut to ensure uniformity and consistent dimensions in preparation for the development of the formwork.</p>

3) **Modifying Material Proportions:** Fiber, resin, and hardener were utilized in the production of the fiber boards in the following ratios: 85:14:1. This percentage was calculated using data from the study Wood as a bio-based building material [32]. Giant reed boards could not be successfully developed with the first adopted proportion, leading to trial and error processes until the ideal proportion was achieved.

TABLE III
 MODIFYING MATERIAL PROPORTIONS

Modifying Material Proportion	Picture	Procedure
Proportion in Trial 1		<p>In the first trial, the 85:14:1 proportion and hardener were adopted, but with the use of a different resin of premix polyester, resulting in an unsuccessful output.</p>
Proportion in Trial 2		<p>In the second trial, a different resin was used, which was Shelwood white glue, while the same 85:14:1 proportion and hardener were retained.</p>
Proportion in Trial 3		<p>In the third trial, the hardener was changed, and the premix polyester resin was reused. However, for the previous trials, the board was developed, but the outcome was not desirable, so the proportions were adjusted until arriving at 53:46:1.</p>









		<p>from the giant reed fiber, which was measured at 265 grams, with 230 milliliters of premix polyester resin and 5 milliliters of hardener to develop 14 inches by 8 inches giant reed boards for each pattern.</p>
<p>Preparing the Molding</p>		<p>Molding phases were followed for preparing the three samples. Three wooden molds were used to accommodate the three samples, each at least 14 by 8 inches. The mold was properly wrapped with metallic foil to prevent the fiber resin mixture from sticking to the wooden molder. Additionally, this wrapping enabled the mold to transfer heat inside during the curing process.</p>
<p>Laying the Material in the Mold</p>		<p>Three fiber orientation patterns were included: parallel, alternating, and crisscross. In developing each giant reed board sample, each pattern consisted of five fiber layers following the modified proportion of 53:46:1. This process began by pouring the resin and hardener mixture into the mold. Subsequently, the first three layers of fibers were added, followed</p>

4) **Fabrication of Three (3) Types of Formwork Boards:**The following are the procedures for the fabrication of the three giant reed formwork variations: parallel, alternating, and crisscross patterns.

TABLE IV
 FABRICATION OF FORMWORK BOARDS

Fabrication of Formwork Boards	Picture	Procedure
<p>Weighing of Materials</p>		<p>The next step included weighing the materials using a weighing scale in the correct amount to make a proper formulation for a high and successful product. Fiber, resin, and hardener were used in a 53:46:1 ratio. The proportion came</p>

		by another portion of the resin mixture on top. Then, the last two layers of fibers were added followed by the remaining resin.	Manually Compressing Materials		The materials in the mold were manually compressed using the improvised compressor made of plywood until they reached a suitable thickness, secured with c clamps. A mark was made on each side of the molder to indicate a thickness of 1/2 inch. It was the basis for identifying if the compression was appropriate.
Laying the Parallel Pattern		In the parallel pattern, layers of fibers were placed in the same direction.			
Laying the Alternating Pattern		In the alternating pattern, layers of fibers were placed perpendicular to one another in an alternating manner.			
Laying the Crisscross Pattern					
			Curing		The curing period for the fiber resin mixture that was in the molder is three days. It allowed the resin to solidify and combine with the fibers, resulting in the development of the giant reed formwork board.
			Dressing		A layer of resin was added to both sides of the finished giant reed formwork board. It was improved to give it a more polished appearance and the board was strengthened by this process.

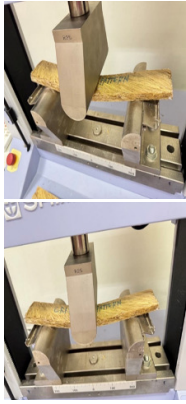

C. Phase 2: Data Collection

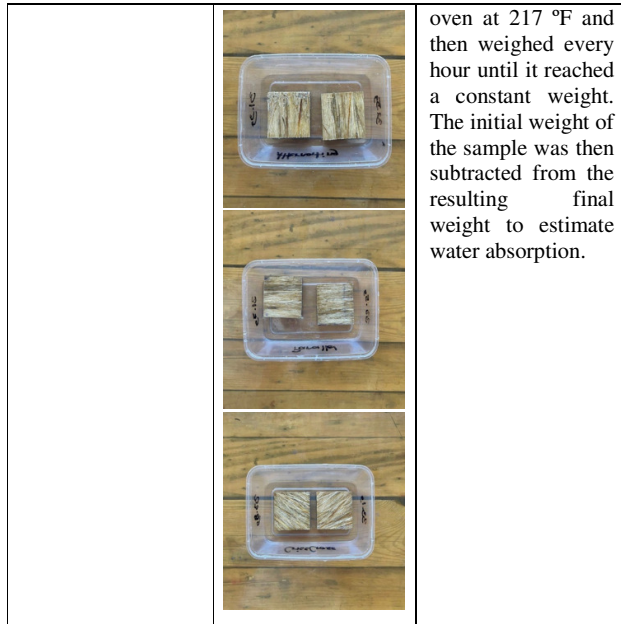
This phase was focused on data collection, involving testing the formwork boards for strength and properties, then a cost comparison analysis was carried out, and quantity surveying was done to determine the needs for construction.

- 1) **Testing:** Testing for strength, such as internal bond and modulus of rupture, was performed by the Department of Science and Technology - Forest Products Research and Development Institute OneLab Laboratory at the University of the Philippines, Los Baños, Laguna, adopting the ASTM D 1037-12 standards. Alternatively, a water absorption test was conducted onsite by also utilizing the guidelines outlined in the ASTM D 1037-12 standards.

TABLE V
TESTING PROCEDURES

Testing	Picture	Procedure
Internal Bond		Utilizing a universal testing apparatus, the board's internal bond was evaluated. It assessed the board's resistance to being pulled apart and their capacity to bear pressures applied perpendicularly to the surface. The Forest Products Research and Development Institute OneLab Laboratory of the Department of Science and Technology also carried out this process using ASTM D1037-12 guidelines.

Modulus of Rupture		Following the guidelines provided by ASTM D1037-12 this procedure was also carried out in the Department of Science and Technology - Forest Products Research and Development Institute OneLab Laboratory. A universal testing apparatus was also used to test the modulus of rupture. Measuring the board's resistance to deformation under bending forces was its primary goal. The comprehensive information regarding the board's mechanical characteristics overall stiffness and suitability for formwork was obtained from the test results.
Water Absorption		Water absorption was assessed manually in accordance with ASTM D1037 test protocols. A clean sample of a giant reed formwork board measuring 5 cm by 5 cm was first created and its weight was then determined. The boards were examined to make sure there were no flaws or obvious openings. The boards were then completely submerged in water and soaked for 24 hours in a container filled with water to simulate long-term exposure to moisture. After soaking, the sample was dried in an



2) **Cost Comparison:** A cost comparison between giant reed formwork boards and traditional formwork boards was used as a measure to analyze the economic and financial feasibility, including their price and other costs. Total cost was calculated with cost savings from reusability and cost savings from finishing.

The market price of the giant reed boards was obtained by first calculating the quantities of materials needed for a full-size formwork board, and then adding the labor costs and markup percentage. The market price of resin and hardener per liter was then multiplied by the amount of material to get the unit price. Once the market price of the giant reed board was calculated, it was then subtracted from the average market price of commercial plywood acquired through canvassing at three different hardware stores around Pampanga, Philippines: Unique Hardware & Electrical Supply, QDY & SONS COPR. Lumber & Hardware, and QUEEN's Steel HAUS & GEN. MERCHANDISE.

TABLE VI
 REUSABILITY AND FINISHING

Reusability	The formwork can be reused several times depending on the constructional demands. If giant reed formwork was well taken care of and did not get damaged during handling, it could be reused. This could also have saved the developers money and enhanced resource consumption. The reusability of the material was evaluated by using it twice, utilizing the two faces of the board.
Finishing	The three developed variations of giant reed boards were coated with premix polyester resin mixed with hardener to make their surface finish smooth, and sun-dried for one hour. The same procedure was done for the other side. This step could have led to savings in both material costs and labor associated with finishing processes.

3) **Quantity Surveying:** To assess the economic viability of giant reed formwork boards, the study conducted a Quantity Surveying. Through this approach, the costs and quantities involved in the giant reed formwork boards were analyzed. This included the cost estimation of formwork boards for low-rise buildings. It was one of the tools that helped the study analyze the potential of giant reed formwork boards economically. Since high load-bearing strength and durability were mandatory for high-rise buildings, wood-based boards or fiber boards were not preferable for formworks, whereas steel formworks were the most used. As a result, Quantity Surveying was limited to low-rise formwork applications of giant reed formwork boards.

To determine the quantity of formwork boards for a low-rise building, the procedure obtained from "Simplified Construction Estimate, 3rd ed" by Max B. Fajardo [33] was followed. First, the needed number of pieces of boards was solved by calculating

the area of members, then dividing by the area of commercial plywood, assuming the two faces of the boards were used. For the expenses, the total number of boards was then multiplied by the market price of giant reed formwork boards and commercial plywood to obtain the total expenses. The total expenses of the giant reed boards were subtracted from the expenses of commercial plywood to determine if the giant reed was cheaper or more expensive.

III. RESULTS AND DISCUSSION

This chapter presents the results of the fabrication, testing, and assessment described in the previous chapter. The results that are shown refer to the different tests performed on the different samples, namely: Parallel pattern, Alternating Pattern, and Crisscross pattern. Comparisons will be provided in terms of relevant relationships of the boards regarding their differences in testing.

A. Giant Reed Formwork Variations

The following are the giant reed boards developed using the modified proportion 53:46:1 of fiber, resin, and hardener.

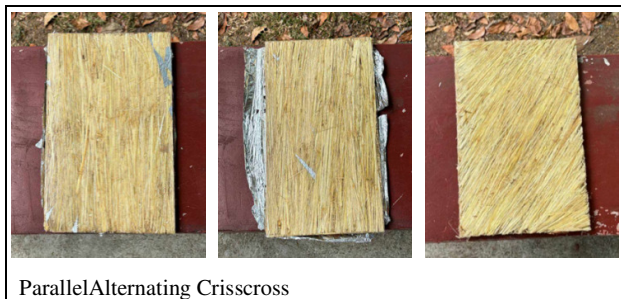


Fig. 2. Fiber Patterns

B. Strength and Water Absorption Testing

The results for the testing of the giant reed board samples were evaluated and interpreted based on the PNS 230-1939 specification for particle boards - type 200. Additionally, the study titled "Some Physical and Mechanical Properties of Bamboo Mat-Wood Veneer Plywood" [34] was used as a reference for plywood properties as it meets the

minimum standards specified by the ASTM standard.

1) Result of Internal Bond Tensile Testing

TABLE VII
 PARTICLE BOARD AND PLYWOOD STANDARD

Properties:	Particle Boards – Type 200	Plywood
Internal Bond Strength (kg/cm ²)	5	8.15773
Modulus of Rupture (kg/cm ²)	180	402.7879
Water Absorption (%)	40	30.83

TABLE VIII
 RESULTS OF THE SAMPLES IN INTERNAL BOND TENSILE TESTING

Specimen No.	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Load (kg)	IB (kg/cm ²)
Parallel-1	5.07	5.07	1.27	31.76	>600.00*	23.34
2	5.04	5.01	1.23	31.26	>600.00*	23.76
3	5.08	5.08	1.27	31.33	>600.00*	23.25
Avg	5.06	5.05	1.26	31.45	600.00	23.45
Alternating-1	5.06	5.00	1.37	31.01	>600.00*	23.72
2	5.07	5.04	1.35	31.46	>600.00*	23.48
3	5.06	5.06	1.32	28.28	>600.00*	23.43
Avg	5.06	5.03	1.35	30.25	600.00	23.54
Crisscross-1	5.07	5.06	1.23	30.18	>600.00*	23.39
2	5.08	5.08	1.14	28.98	>600.00*	23.25
3	5.10	5.08	1.17	28.09	>600.00*	23.16
Avg	5.08	5.07	1.18	29.08	600.00	23.27

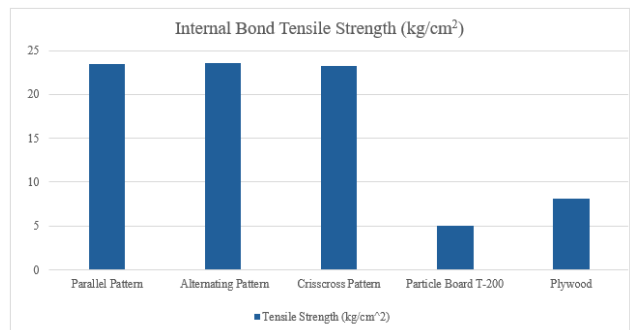


Fig. 3. Comparison of the Samples in Internal Bond Tensile Testing

The primary factors affecting the physical properties, mechanical properties, and formaldehyde emission of particleboard are the chemical composition of wood and the type of resin utilized [35]. As per Gisip et al. [36], higher resin content resulted in increased values for internal bond strength, modulus of rupture, and modulus of

elasticity, whereas a decrease in resin content was associated with an increase in water absorption and thickness swelling. The three patterns showed similar internal bond values, possibly due to only using one type of resin and proportion for all the patterns. The giant reed boards also surpassed the internal bond of plywood and particle board, which could be because of the high resin content inside of the giant reed boards.

For the first test, the giant reed boards were subjected to internal bond tensile strength testing as shown in TABLE VIII. The parallel pattern showed strength values of 23.34, 23.76, and 23.25 kg/cm², with an average strength of 23.45 kg/cm². The alternating pattern showed values of 23.72, 23.48, and 23.43 kg/cm², with an average strength of 23.54 kg/cm², while the crisscross pattern showed values of 23.39, 23.25, and 23.16 kg/cm², with an average of 23.27 kg/cm². The alternating pattern showed the highest internal bond strength values, followed closely by the parallel pattern, with the crisscross pattern showing the lowest.

The giant reed formwork boards have surpassed the minimum required internal bond strength for particle boards as per PNS 230-1939, which stands at 5 kg/cm². Also, as shown in Fig. 3., giant reed boards exhibit superior strength in comparison to plywood, with an internal bond strength of 8.15773 kg/cm².

2) Result of Modulus of Rupture Testing

TABLE IX
 RESULTS OF THE SAMPLES IN MODULUS OF RUPTURE TESTING

Specimen No.	Length (cm)	Width (cm)	Thickness 1 (cm)	Thickness 2 (cm)	Thickness (avg) (cm)	Weight (g)	Span (cm)	Load (kg)	MOR (kg/cm ²)
Parallel-1	34.00	5.21	1.59	1.55	1.57	218.61	29.00	235.86	798.93
2	34.00	5.40	1.60	1.55	1.58	222.31	29.00	217.22	705.40
3	34.00	5.11	1.54	1.67	1.61	229.02	29.00	258.24	853.38
Avg	34.00	5.24	1.58	1.53	1.55	223.31	29.00	237.11	785.90
Alternating-1	34.00	5.10	1.45	1.44	1.45	223.65	29.00	206.02	841.57
2	34.00	5.12	1.45	1.42	1.44	215.40	29.00	208.74	861.23
3	34.00	5.08	1.54	1.52	1.53	227.77	29.00	211.45	773.48
Avg	34.00	5.10	1.48	1.46	1.47	222.27	29.00	208.74	825.43
Crisscross-1	34.00	5.09	1.45	1.52	1.49	227.71	29.00	123.67	479.27
2	34.00	5.09	1.61	1.54	1.58	236.34	29.00	163.37	562.84
3	34.00	5.05	1.66	1.53	1.60	236.28	29.00	167.18	566.06
Avg	34.00	5.08	1.58	1.53	1.55	233.44	29.00	151.41	536.06

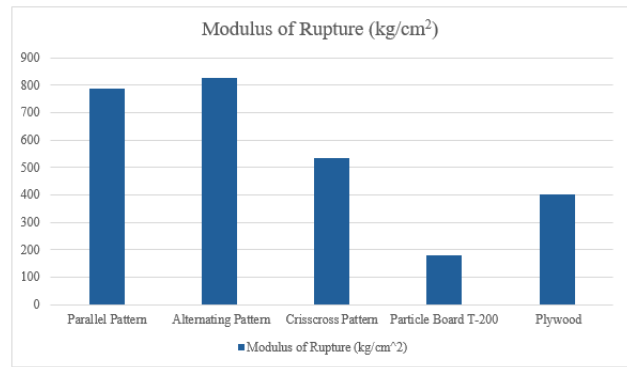


Fig. 4. Comparison of the Samples in Modulus of Rupture Testing

For the Modulus of Rupture test, the results are shown in TABLE IX. The parallel pattern had a modulus of rupture of 798.93, 705.4, and 853.38 kg/cm², with an average modulus of rupture of 785.90 kg/cm². The alternating pattern had a modulus of rupture of 841.57, 861.23, and 773.68 kg/cm², with an average modulus of rupture of 825.43 kg/cm². Lastly, the crisscross pattern had values of 479.27, 562.84, and 566.06 kg/cm² for its modulus of rupture, with an average of 536.06 kg/cm². Based on Fig. 4., the alternating pattern had the highest modulus of rupture values, followed by the parallel pattern, and lastly the crisscross pattern. Giant reed formwork boards are stronger in terms of modulus of rupture compared to plywood, with a modulus of rupture of 402.7879 kg/cm². The giant reed formwork boards also passed the minimum required modulus of rupture according to PNS 230-1939, which is 180 kg/cm².

According to S Zhao et al. [37], the main factor affecting wood strength is the grain angle. For the modulus of rupture, the alternating pattern is the governing pattern, followed by the parallel pattern, and lastly the crisscross pattern. The alternating pattern was the governing pattern due to the different orientations of fibers supporting each other per layer. In contrast, the parallel pattern is weaker because it maintains only one orientation throughout its layers, while the crisscross pattern is the weakest despite having different orientations; the fibers are at an angle, which means the fibers far from the center get smaller.

3) Result of Water Absorption Testing

TABLE X
 RESULTS OF THE SAMPLES IN WATER ABSORPTION TESTING

Specimen No.	Length (cm)	Width (cm)	Weight ₁ (g)	Weight ₂ (g)	Water absorption (%)
Parallel-1	5.00	5.00	31.7	32.2	1.577%
2	5.00	5.00	33.5	33.8	0.896%
3	5.00	5.00	32.9	33.3	1.216%
Avg	5.00	5.00	32.7	33.1	1.230%
Alternating-1	5.00	5.00	31.3	31.7	1.278%
2	5.00	5.00	32.5	32.8	0.923 %
3	5.00	5.00	31.9	32.2	0.940%
Avg	5.00	5.00	31.9	32.23	1.047 %
Crisscross-1	5.00	5.00	33.8	34.2	1.183%
2	5.00	5.00	33.1	33.5	1.208%
3	5.00	5.00	31.6	32.2	1.899%
Avg	5.00	5.00	33.45	33.85	1.430%

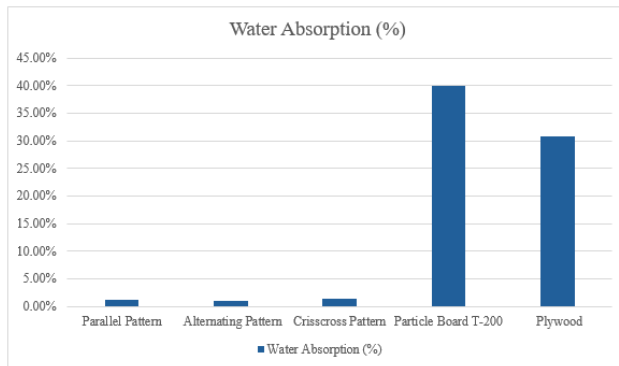


Fig. 5. Comparison of the Samples in Water Absorption Testing

The water absorption values of the giant reed formwork boards are shown in TABLE X as follows: for the parallel pattern, the water absorption is 1.577%, 0.896%, and 1.216%, with an average water absorption of 1.230%; meanwhile, the alternating pattern has 1.278%, 0.923%, and 0.940% water absorption, with an average water absorption of 1.047%. Lastly, the crisscross pattern water absorption has values of 1.183%, 1.208%, and 1.899%, with an average of 1.430%. The giant reed formwork boards passed the required

maximum water absorption, which is 40% according to PNS 230-1939, as well as the water absorption of plywood, which is 30.83% as shown in fig. 5.

Water absorption in plywood panels is related to the surface conditions of the veneers [38]. If plenty of cracks are present in the boards, the water absorption would be high. Since the results of the water absorption tests are low and show minimal differences, it is likely because of the coating added on the surface of the three boards.

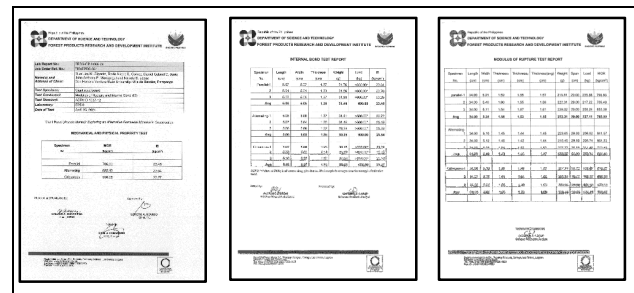


Fig. 6. Test Reports

C.Result of Cost Comparison

TABLE XI
 COST OF MATERIALS

Material	Giant Reed Board		Price
	14in x 8in	48in x 96in	
Premix Polyester Resin	0.229 L	9.439 L	Php 195.00 per liter
Hardener	0.004588 L	0.188 L	Php 340.00 per liter

TABLE XII
 COMPARISON OF THE SAMPLES IN PRICE

Boards	Price
Giant Reed Formwork Board	Php 2,205.00
Plywood	Php 984.00

The price of giant reed formwork boards was acquired by adding all the unit costs and labor costs, as well as a mark-up of 10%. Comparing the price of the two formwork boards, the giant reed formwork board with a price of Php 2,205.00 was Php 1,221.67 more expensive than the canvassed prices of plywood, which had an average price of Php 984.00.

D. Result of Quantity Surveying

TABLE XIII
 COMPARISON OF THE SAMPLES IN EXPENSES FOR A LOW-RISE
 COMMERCIAL BUILDING

Boards	Total Expenses
Giant Reed Formwork Board	Php 213,885.00
Plywood	Php 95,448.00

A detailed analysis of quantities and costs associated with giant reed formwork boards was done. The total formwork boards needed for a low-rise commercial building were acquired with a total number of 97 pieces of formwork boards.

Assuming the two faces of the boards were used, the amount of formwork needed was 7 pieces for footings, 15 pieces for columns, 45 pieces for beams, and 30 pieces for slabs, totalling 97 pieces. The total cost of the formwork boards, if the giant reed formwork boards were used, would have been Php 213,885.00, which was Php 118,437.00 more expensive than if the commercial formwork boards were used, which cost Php 95,448.00.

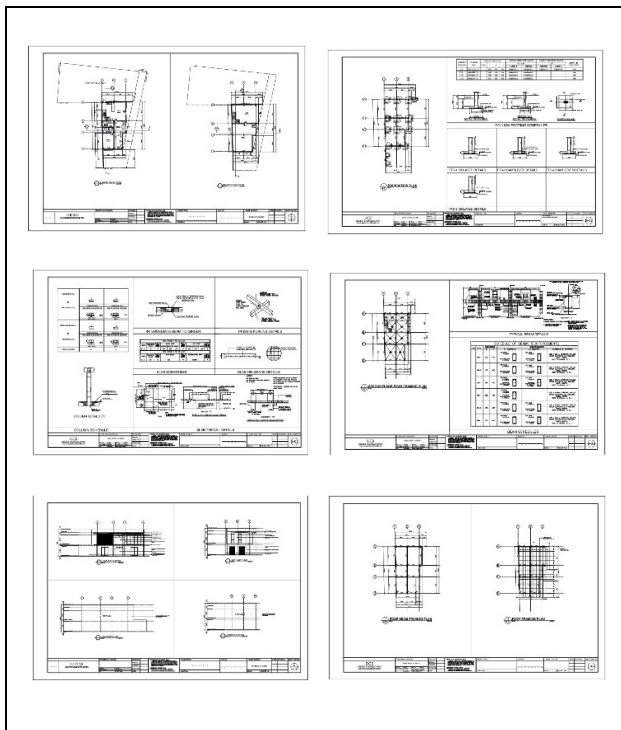


Fig. 7. Low-Rise Building Plans for Quantity Surveying

IV. SUMMARY, CONCLUSIONS, AND RECOMMENDSTIONS

This chapter presents the summary of all the findings, conclusion as well as recommendations on the study.

A. Summary of Findings

The main goal of this study was to design, develop, and evaluate different types of giant reed formwork boards, varying in fiber patterns, with a focus on optimizing their performance in terms of strength and water absorption. Additionally, the study aimed to assess the economic and financial feasibility of implementing these innovative formwork solutions in construction projects.

After undergoing three trials, the giant reed formwork boards, including parallel, alternating, and crisscross patterns, were successfully developed using the premix polyester resin and its hardener, with a proportion of 53:46:1.

Following an analysis of the internal bond strength, it was determined that the giant reed boards had passed the strength requirements for plywood and particle board which are 8.15773kg/cm² and 5 kg/cm² respectively. Whereas, the average values for the giant reed boards are 23.45 kg/cm² for parallel, 23.54 kg/cm² alternating, and 23.27 kg/cm² for crisscross.

After testing the boards for the modulus of rupture, it was found that the giant reed boards passed the required modulus of rupture, which was led by the alternating pattern, followed by the parallel pattern, and lastly the crisscross pattern, with average values of 825.43 kg/cm², 785.90 kg/cm², and 536.06 kg/cm², respectively. While, both the particle board and plywood, with values of 180 kg/cm² and 402.7879 kg/cm², respectively.

After the conducted water absorption test, the data were analyzed, indicating that the giant reed boards, including parallel, alternating, and crisscross patterns, with values of 1.230 %, 1.047 %, and 1.430 % respectively, passed the water absorption requirements of particle board and plywood, with values of 40% and 30.83% respectively.

Cost comparison and quantity surveying were conducted to assess the financial and economic feasibility of the giant reed formwork boards. For the cost comparison, the cost for materials such as polyester resin and hardener, labor costs, as well as the markup of the boards were obtained and added to get the total price of Php 2,205.00. The price was then compared to the average market price of commercial plywood, which was Php 984.00 around May 2024. For the quantity surveying, the amount of formwork boards needed was first obtained by solving for the area of the members, which was then divided by the area of the commercial plywood. Assuming both faces were used, the number of pieces of board needed was 97 pieces. If commercial plywood was used, the total expense for formworks would have been Php 95,448.00, while Php 213,885.00 would have been needed for giant reed formwork boards, resulting in a difference in expenses of Php 118,437.00.

B. Conclusions

The giant reed boards were successfully developed using the proportion of 53:46:1 fiber, premix polyester resin, and hardener. Despite the successful development of the giant reed boards, they underwent several trials. One reason was the unavailability of the resin, so an alternative resin was used instead. Another reason was the incompatibility of the initial hardener with the alternative resin. Lastly, the board was developed, but due to the lack of the proper proportion of fiber, resin, and hardener, adjustments had to be made.

The three samples were subjected to testing, which included assessments of internal bond strength, modulus of rupture, and water absorption. The laboratory at the Department of Science and Technology – Forest Products Research and Development Institute, University of the Philippines, Los Baños, conducted the tests for internal bond strength and modulus of rupture. By adapting the ASTM-D1037 standard testing procedure, the water absorption test was successfully executed despite being conducted on-site.

For internal bond strength, all patterns of giant reed boards passed the required strength for particle board and plywood, led by alternating, followed by parallel, and lastly crisscross.

For modulus of rupture, all patterns of giant reed passed the required strength of particle board and plywood, led by alternating, then parallel, and lastly crisscross.

For water absorption, all patterns of giant reed boards did not exceed the maximum water absorption of particle boards and plywood. Alternating had the lowest, followed by parallel, and lastly crisscross.

In all three tests, the giant reed formwork boards passed the required strength for particle board and plywood. In conclusion, the giant reed boards can be applied as actual formwork due to passing the strength requirements of the tests. Additionally, the optimal design for the giant reed board was the alternating pattern because it was the leading pattern for all tests conducted.

The economic and financial feasibility of the study was assessed through cost comparison and quantity surveying of a low-rise building. The boards are economically feasible due to giant reeds being inexpensive, easily accessible, and having strength comparable to plywood. However, they are not financially feasible due to their high initial costs and being an alternative material with better performance but higher costs than commercial plywood.

C. Recommendations

The following recommendations were formulated based on the conclusiveness of the study:

1. In order to enhance efficiency, consistency of the proportion of materials, as well as the overall quality of the product, the employment of machinery and fabrication facilities for defibering of the giant reed and production of giant reed formworks can be done to further automate the process.
2. An assessment of how many times the giant reed formwork boards can be used repeatedly while maintaining the quality and integrity of

- the product can be considered to improve the cost-effectiveness of the product can be improved.
3. The findings and information of the study may help to further develop innovations for the fabrication process as well as further formwork board improvements. This can serve as a reference for additional research in the future.
 4. It is possible to conduct various experiments to find the best type and quantity of resin to obtain the proper proportion for the formwork boards. In addition to fine-tuning the ratio of fiber resin and hardener used in the creation of the enormous reed formwork boards various resins could be investigated to enhance the board's look and characteristics.
 5. Not only could the strength and other qualities of the giant reed boards be tested but they could also be used in real construction proving the boards' appropriateness and usefulness as a real formwork material.
 6. Beyond their use as formwork material investigating the possible applications of giant reed boards in different construction applications like sheathing for roofs partition walls or insulation could help increase their adaptability affordability and other benefits over commercial formwork materials.
 7. To enhance the reliability, accuracy, as well as overall credibility of test results, the number of samples for tests conducted can be increased.
 8. It is possible to adjust the proportion of fibers, resin, and hardener used in the samples to lessen product costs while maintaining strength. The proportion of materials could be below the acquired proportion of 53:46:1 and above the first proportion of 85:14:1. Further studies can be conducted to identify the optimal ratio and proportion of materials that balance both strength and cost-effectiveness.
 9. To enhance the understanding and control over the modulus of rupture and internal bond tests, manual computation methods can be explored along with laboratory testing.
 10. The labor costs associated with the preparation of fibers could be considered, in addition to fabrication labor costs. It is recommended to include labor costs for harvesting, cleaning, and defibering. These labor costs may be considered since they can significantly contribute to the overall costs of the giant reed boards.

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