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An Experimental Analysis on the Effectiveness of Using Green Mussel *(Perna viridis)* Shells, Coconut *(Cocos nucifera)* Pith, and Water Hyacinth *(Eichhornia crassipes)* Fibres as Alternative Raw Materials in Producing Particleboards as Interior Wall Partition

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Abstract:

This study investigates the effectiveness of utilizing green mussel shells, coconut pith, and water hyacinth fibers as alternative raw materials for particleboard production intended for interior wall partition. The researchers made three proportions of particleboard to determine the suitable mixture from the different ratios among the raw materials. The produced six particleboards have dimensions of 40 cm by 40 cm by 1.2 cm, two for each proportion used in testing. Mechanical properties, including water absorption, thickness swelling, face screw withdrawal, modulus of rupture, and thermal analysis using Differential Scanning Calorimetry (DSC) were conducted to evaluate the performance of the produced particleboards. The particleboard performed satisfactorily in terms of its thickness swelling, passing the standard requirement of the Philippine National Standard. However, the other tests conducted need further improvement since various factors affected the results. Meanwhile, the produced particleboard provided more excellent value against some insulation materials except for glass wool insulation. The researchers concluded that the sample of 30% green mussel shells, 60% coconut pith, and 10% water hyacinth fibers, Proportion 3, is the best proportion to consider according to the overall data statistics. One notable aspect of this study is its cost analysis, where, based on the computations of the materials used with their particleboard compared to commercial particleboard, utilizing these alternative raw materials was more economical than the traditional materials used. Even with the areas in which improvement was needed, the significance of this study lies in the investigation of using alternative raw materials to produce particleboard.

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Keywords —**Particleboard, Green mussel shells, Coconut pith, Water hyacinth fibers, Mechanical properties, Interior wall partition**

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I. INTRODUCTION

Forests serve numerous purposes, but their role in climate change mitigation has grown in importance due to the urgent necessity of minimizing the effects of climate change. Photosynthesis in forests evacuates carbon dioxide from the atmosphere and stores it in biomass and soil. Only seven million hectares of land in the Philippines were estimated to be forested in 2021 [1]. This land accounts for only 23% of the country's total land area, which is regarded as bad news because it is unable to resist the emerging effects of climate change.

Forests are becoming increasingly scarce in the Philippines. Every year, approximately 47,000 hectares of forest are lost, according to the Forest Management Bureau of the Department of Environmental and Natural Resources (FMBDENR). Large capital-intensive development projects linked to the construction field are one of the major causes of deforestation [2]. The wood industry has long been a major source of income in the country, and it continues to grow each day to cater for the needs of various sectors for various purposes.

To address the issue of nonstop forest use, researchers and scientists have developed and implemented various proposals. There have been several proposed substitutes for raw wood materials, such as the production of plywood from timbers, but these are still problematic because they use timbre resources. This brought about the development of fibreboards and particleboards, which have since been utilized as effective alternatives to plywood.

Particleboard has been actively produced over a very long time. This alternative has grown to be the generic term for board products such as flax boards and chipboards on a global scale. These building materials are designed to be used instead of plywood in applications such as panelling, cabinets, door skins, furniture components, and ceiling installation. However, decreasing raw material availability and the need to conserve natural resources have prompted research into the use of non-wood fibres in particleboard production.

The Philippines, primarily an agricultural country, is known to be a key factor contributing to agricultural waste. Another environmental issue that is currently being addressed is the amount of agricultural waste that is being discarded rather than being used as efficiently as possible. The increased waste from the agricultural sector is also posing a threat to the environment. In the Philippines, bagasse, rice husk, rice straw, coconut husk, and coconut shell are the most prevalent agricultural wastes. [3]. To deal with these challenges, various researchers had attempted ways to utilize the residue through the manufacture of particleboards over the years.

Due to increasing demand and population, the forestry sector is under pressure to act as a primary source of renewable materials. Raw materials are needed as alternative wood due to the expanding global concern over scarcity of forest and the growing demand for wood-based panels for furniture and buildings. In order to produce more sustainably wood-based panels, researchers in this study [4] identified the viable substitute raw materials as well as the challenges to fully or partially substituting standard wood materials. This study contributed to forest conservation by investigating raw materials and supports national policies intended to promote the sustainable production and use of non-wood forest products. This study also highlighted the potential of woody biomass from non-forest sources. Particleboards are made with raw materials other than wood chips in order to save wood resources and manage large amounts of waste. Particleboard raw materials can come from two sources: the sawmilling industry, which produces wastes such as small-sized wood, edgings, slabs, chips, and sawdust from primary wood processing, or from nurturing trimmings, which is a part of forest management. One of the fundamental principles in the economy is

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repurposing raw materials and reusing biomass. Based on Pedzik, et al. [5], production of particleboard may contribute to addressing climate change, air pollution, and aquatic problems.

Cocos nucifera, also known as coconut, is one of the most common agricultural wastes. With more coconut trees than any other country, the Philippines is the world's primary producer of coconut oil and copra meal. Tightly packed coconut fibres and non-fibrous, fluffy, and light corky substance called coir pith or coir dust make up between 50 and 70 percent of the husk. [6]. Coir pith or dust is a lignocellulosic biomass residue that decomposes very slowly. Coir pith is traditionally disposed of by burning, which causes environmental issues.

As the Philippines is surrounded by water, it produces over 250,000 metric tons of shell, scale, and carapace waste [7]. Green mussels, also known as *tahong*, are bivalve mollusks with a two-part hinged shell that holds a soft-boiled invertebrate. It is the only mussel species grown economically in some sections of the Philippines. Alternative sources of chitin and chitosan, high-value naturally occurring biodegradable and biocompatible polymers, are aquatic bio-waste products. Asian green mussel, Perna viridis, waste contains a significant proportion of alternate chitin and chitosan [8].

It has been demonstrated that mussel shell has thermal and acoustic properties that make it suitable for installation as a building insulation material [9]. When mussel shells are kept in a contained environment, like a concrete box, their heat conductivity is similar to that of light conifer wood. When utilized as a construction material, it is an excellent base substance for producing a thermally maintained environment.

Under typical circumstances, the water hyacinth may produce over 200 tons of dry matter per hectare annually, making it possibly the most productive plant on the planet [10]. This plant aids bodies of water in reducing heat absorption to the point where biodiversity is maintained. Excess growth, on the other hand, becomes dangerous because it covers the surface, reducing light penetration into the body of water. Because it covers 20% of the lake's surface, this plant is considered a nuisance in some areas, such as Laguna de Bay. It is known to grow and completely colonize a standard-sized pool in only 20 days.

Due to the timely consequences of biodegradable wastes such as green mussel shells and coconut husk, along with the impact of a high rise in population of water hyacinth from many bodies of water, and the increasing demand for wood products, researchers had initiated a study of producing particleboards using green mussel shells, coconut pith, and water hyacinth fibres as substitute raw materials that could potentially contribute in solving the unmet demand for many wood products, and promote livelihood opportunity out of the pest plants on rivers and waste products. The research also innovated the use of these basic elements to create cost-effective and environmentally friendly products that may be utilized as a replacement for existing construction materials. Particleboard can be used in a variety of building materials such as forms, ceiling boards, doors, and residential applications such as cabinets, furniture, and dividers [11], [12], & [13]. The research focused on generating a board that is specifically put and utilized as an interior wall partition.

A. Waste Challenges in the Philippines: Exploring Different Environmental Impacts

The Philippines is one of the top five countries creating massive waste in Southeast Asia, producing 14.66 million tons, with Southeast Asian countries contributing 1.14 kg/capita/day of waste worldwide [14].

The Philippines produces most of the world's copra meal and coconut oil and has the greatest number of coconut trees worldwide. The three most commonly used coconut waste products are husks, coir dust, and coconut shell. In the Philippines, around 500 million coconut trees produce enormous amounts of biomass as husk, totalling to approximately 4.1 million tons per year [15]. When the copra has been removed from the coconut fruit, the coconut husk is typically discarded. This

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explains why there is a significant quantity of coconut waste in every area of the country.

The 14.72 million metric tons of coconut husk were thrown away in 2021, 1.5 percent more than the 14.49 million metric tons that the Philippine Statistics Authority (PSA) reported in 2020. Numerous reports in the Philippines highlight the negative effects due to the high amount of discarded coconut waste. Developing coco coir has been identified by the Regional Inclusive Innovation Centre (RIIC) as a priority in Eastern Visayas to address environmental concerns, based on the findings of the Tacloban City report in 2023 [16]. According to Department of Trade and Industry (DTI) Eastern Visayas Assistant Regional Director Ma. Delia Corsiga, one of the environmental problems is the growing amount of coconut husks from the production of copra. Moreover, based on Manila Bulletin News [17], The Las Piñas River has become a large disposal site for leftover coconut husks, causing obstructions in the river channels.

As mussels are a cheap source of protein, the mussel industry is an important component of the aquaculture sector in the Philippines, and mussel farming provides additional income and livelihood to fisherfolk in many coastal locations because it requires little capital investment. Fresh mussel production generates up to 50,000 tons of shell waste per year as stated by a study [7]. Because it takes so long to decompose, green mussel shell leftover from processing and eating shellfish is a by-product that is challenging to get rid of.

Massive amounts of waste seashells were discarded into public waters and landfills, which resulted in many environmental issues. These issues included managing public water surfaces, polluting coastal fisheries, causing a bad smell due to organic materials decomposing on the shells, damaging the natural landscape, and creating health and sanitation issues [18]. According to Prihanto [19], green mussel shells are one example of the marine waste that leads to pollution. Inappropriate management of this waste has detrimental effects on the environment. In Samar, Philippines, numerous farmers dispose of their seashells by burning them. However, the existing environmental laws do not comply with this practice. It was found that the inappropriate waste disposal is due to inadequate access to facilities for disposing of waste [20].

Research conducted [21] stated that water hyacinth's rapid rate of reproduction has caused a serious infestation in Philippine bodies of water due to its proliferation at unusual rates, which clogs rivers and lakes. It causes primary issue in Taguig City due to growing amount of water hyacinth clogging waterways and other areas. According to Dersseh, et al. [22], numerous nations, including the Philippines, have experienced disruptions due to this plant. It was proven it brings negative impact on the ecosystem, such as the increase in the evapotranspiration of lake water.

B. Interior Wall Partition

A study [23] stated that a light wood frame wall is made up of wood studs and wall-panels that are lined on both sides and ought to be able to resist fire. However, the characteristics vary depending on the insulation materials, the species and size of wood stud, joint pattern, and thickness. This indicates that each wall partition has to possess an established feature in accordance with ISO standards.

Wall partitions are non-load bearing walls which offer privacy, improved acoustics, and fire isolation as well as spatial division. Conventional frame-filled walls have substantial material interactions between the frame and masonry, low ductility capacities, and high damage characteristics at low drift levels. [24]. Additionally, the most commonly used particleboard thickness for wall and ceiling lining is 12 mm [25]. The data therefore assisted the researchers in determining a thickness for the development of the material.

In the 21st century, more people are becoming aware of how building methods affect the environment and contribute to climate change. Building construction experiences rapid change as more individuals look for environmentally friendly solutions. The development of lightweight, sustainable technology for partition walls, essential components of buildings, is covered in this study

[26]. These walls must be strong enough to withstand accidental impacts and be used as decoration. In conclusion, employing lightweight technology can result in useful buildings that also have some environmental benefits.

C. Particleboard

Particleboards are comprised of resin-bonded wood fragments or lignocellulose components. Variations in particulate shapes and sizes, in addition to moisture content, among various grain species have a major effect on the attributes of particleboards generated [27]. Particleboard production should address preserving the raw material's features in order to make a product that is generally aligned with the requirements of wood-based goods such as plywood.

One of the most significant value-added panel products in the wood-based sector, particleboards have many uses. The need for wood, formerly mainly used for producing wood-based panels, has dramatically expanded worldwide due to the growth of other wood-based sectors and the energy sector. Due to these challenges, the wood-based industry has been compelled to switch to alternate raw materials. The creation of particleboard using alternative lignocellulosic raw materials has recently been the subject of numerous studies [28].

D. Green Mussel (Perna viridis) Shells

The green mussel shells contain between 14 and 35 percent chitin compounds, making them an ideal starting point for producing biomaterials like chitosan. Chitosan can be used as a bio adhesive to make particleboard instead of a chemical-based adhesive. Chitosan is the chosen biopolymer because of its biocompatibility, biodegradability, and lack of toxicity [29]. Using green mussel shells as an alternative raw material reduces the amount of garbage that builds up from them and contributes to environmental degradation.

Based on research finding [30], mussel shells exhibit a granular, irregular, and diverse composition, necessitating adjustments for thermal conductivity and sound reduction assessments. The acoustic properties of mussel shells have been identified as suitable for serving as a building insulation material. Thermal testing revealed that the thermal conductivity of mussel shells remains consistent regardless of material density. Acoustic analyses indicated that a confined section of mussel shells demonstrates behaviour akin to a double-glazed window. As a result, various architectural approaches have been developed that utilize mussel shells as an insulating material for walls, foundations, and roofs. A valuable waste product derived from the processing of about 50 tons of mussel shells has been utilized to create a bio-based material for construction.

E. Coconut (Cocos nucifera) Pith

A study [31] conducted stated that coconut goods are the Philippines' principal agricultural export. The huge yield is a result of the coconut tree being a tropical crop grown in a tropical country. As a result, a significant amount of coconut waste has been generated but only a percentage of it is repurposed for more beneficial purposes.

In regions abundant with coconut production, the disposal of coconut husks in the fields is a common practice. However, if left continuously, it can lead to untidy and unclean fields. Conversely, burning coconut husks often produce acrid smoke, negatively affecting the environment. One strategy to lessen these negative consequences is to turn leftover coconut husk into useful items. For example, coconut fibre can be used as a raw material for hardboards, automobile dashboards, industrial carpets, and upholstery. Coconut peat can also be used as a growing medium for short-season plants. Potential products that could be produced are coconut fibre boards and pots [32].

The coconut husk, composed of fibres rich in lignin, serves as a natural adhesive in the manufacturing process of binder-less particleboards [33]. Since it contains lignin, coconut husk has already been used as a raw material in the development of quality particleboards.

Furthermore, coir pith particleboard with phenol-formaldehyde has excellent mechanical properties.

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The boards produced from the largest-size particles and phenol-formaldehyde resin absorbed the least water and swelled the least. This demonstrates that the pith contains properties that can be used to create alternative particleboards in terms of both physical and mechanical properties. Moreover, alternative materials utilized as particleboards created by induced high density polyethylene (RHDPE) as a binder provided the best physical and mechanical qualities [34].

The study examined the impact of different combinations of wood particles (Pinus taeda L. and Eucalyptus saligna) and coconut fibre (Cocos nucifera) on the properties of homogeneous particleboards. Various physico-mechanical properties were assessed, including moisture content, density, swelling after 24 hours in water, perpendicular tensile strength, static bending strength, and modulus of elasticity. The results showed that coconut fibre can be effectively used in the production of homogeneous particleboards, meeting the required standards, particularly in terms of the swelling property after 24 hours, which was comparable to panels containing only wood particles [35].

According to Narciso et al. [36], their study's objective was to assess coconut husk's potential for use in conjunction with Pinus oocarpa wood to produce medium-density particleboard (MDP) panels. The incorporation of coconut fibres resulted in enhancements in both the thermal and physical characteristics of MDP (Medium Density Particleboard) panels. While a higher concentration of coconut fibres did cause the mechanical qualities to decline, it's noteworthy that all treatments still conformed to the standards' prescribed values. This suggests the feasibility of manufacturing MDP panels exclusively using coconut fibres.

Particleboard, one of the furniture's most popular composite panels, is created by adding glue to lignocellulosic materials—such as wood or non-wood—and thermally pressing them together to form a flat composite panel. The three main components of lignocellulosic materials are lignin, holocellulose, and extractive substances. The coconut fibre appeared to have a lot of lignin (62.9%). The high lignin concentration of the coconut fibre aids in the material's bonding as the particleboard melts to the surface when heat and pressure are applied. According to the study's findings, coconut fibre, which is typically wasted, would be appropriate for usage as an input to make panel goods with additional value [37].

F. Water Hyacinth (Eichhornia crassipes) Fibres

The water hyacinth, an afloat hydrophyte, is regarded as one of the worldwide 100 threatening alien species. On the contrary, certain groups use its biomass as a raw material to make various biodegradable products such as packaging and cardboard [38]. The adoption of such environmentally hazardous plants could benefit both the ecosystem and the agricultural sector.

Eichhornia crassipes, a weed, is a typical sight in rivers, lakes, and other bodies of water worldwide. Because water hyacinths have strong rates of growth, survival, and regeneration, cleaning up an infestation usually presents a challenge. These characteristics of water hyacinth can be viewed as positive traits, nevertheless. Studies on hyacinth's ability to absorb heavy metals, pollutants in water, and other substances have been conducted. Even though water hyacinth stems and leaves have been used as absorbent materials in numerous researches, there are a lot of other intriguing and cutting-edge uses for this plant [39].

According to a study [40], the utilization of water hyacinth plant fibre's biological waste as a reinforcement material in polymer composites demonstrates superior performance. Therefore, it is highly recommended for applications in lightweight materials and various commercial products.

G. Isocyanate Resin

Isocyanates offer high adhesion and cohesion strength as wood adhesives [41]. The resistance of the particleboard to water by Kawalerczyk, et al. in the year 2023 was improved overall when isocyanate resin was added to the phenol-formaldehyde (PF), and this improvement became more evident as the isocyanate resin content

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increased. Since isocyanate reacts with the hydroxyl groups in wood constituents to lessen water accessibility, based on the experiment, it may have a beneficial effect on thickness swelling. Isocyanate adhesives are also described by Frihart in 2015 [42] report as being adaptable, bonding well with high-moisture wood, and being particularly helpful in the production of composites, even on diverse surfaces like wheat straw.

According to the study of Phanopoulos [43], due to its outstanding qualities - like ease and speed of processing, strength and modulus, as well as physical and mechanical properties and environmental advantages like durability, moisture resistance, and no formaldehyde emission from resin - isocyanates are being used frequently. These advantages are achievable even at low resin consumption rates. Furthermore, the application of isocyanate strengthens wood's resistance to thickness swell. Regarding this, the study by Nuryawan and Alamsyah in year 2018 [44], mentioned that because of its remarkable strength and durability, isocyanate has been used extensively, particularly in research pertaining to wood products. Isocyanate resins react with the wood constituents when they are used as binders for wood materials.

Environmental issues are addressed, and ecologically friendly industrial practices are promoted through experimental research of alternative raw materials for particleboard manufacture. It generates substantial environmental difficulties because of the challenge to manage a significant amount of biodegradable waste from coconut husk, green mussel shell, and water hyacinth.

According to the numerous studies gathered, the process of making particleboard using substitute raw materials, green mussel shells, coconut husk, and water hyacinth, have a great potential to possess properties that may be of good use as a construction material. Furthermore, it has the capability to expand knowledge in the field of sustainable construction materials and advocate for more environmentally conscious construction practices. It emphasizes the significance of continuous research and innovation in the use of sustainable materials, which is critical for environmental conservation and the promotion of sustainable industrial practices in the Philippines.

The objective of the study is to produce a particleboard that may be a viable substitute as a construction material specifically as an interior wall partition, and it seeks to address the use of unconventional materials in the production of particleboard in the construction industry. The general objective of the study is to investigate the effectiveness of green mussel shells, coconut husk, and water hyacinth fibres as raw material substitutes on particleboards used in interior wall partitions. This was analysed by examining the mechanical properties of the proposed particleboard.

H. Conceptual Framework

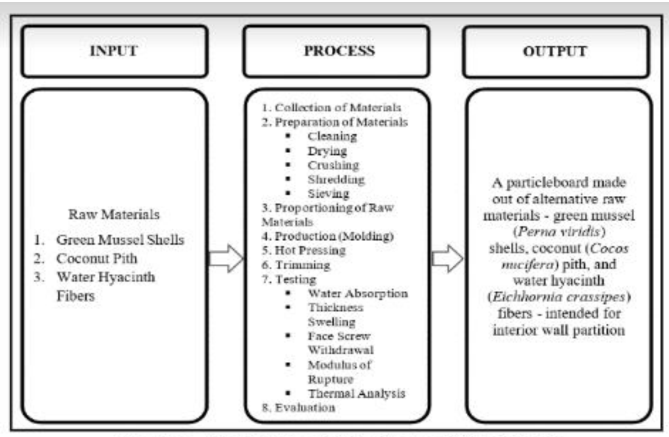

Figure 1. Conceptual Paradigm of the Study

Figure 1 illustrates the conceptual paradigm of study. The Input Section represents the materials required for particleboard production. These materials include green mussel shells, coconut pith, and water hyacinth.

The Process Section displays the sequence of steps for creating the particleboard. It begins with collecting materials, which involves gathering the necessary raw materials - green mussel shells, coconut husk, and water hyacinth. The preparation of the materials includes drying, shredding, crushing, shredding, and sieving before proceeding to the proportioning of these components. Subsequently, the next step is to produce the particleboards in various proportions by moulding, which afterwards go through hot pressing. Later, the produced particleboard is going to be trimmed according to the sizes appropriate for testing. The testing of the different particleboards is to assess the effectiveness of the three raw materials as particleboard and to identify which exhibits the best characteristics in terms of the tests performed, which are the water absorption, thickness swelling, face screw withdrawal, modulus of rupture, and thermal conductivity.

The output of the study is to produce a particleboard composed of green mussel shells, coconut pith, and water hyacinth fibres as raw materials designed for use as an interior wall partition.

II. METHODOLOGY

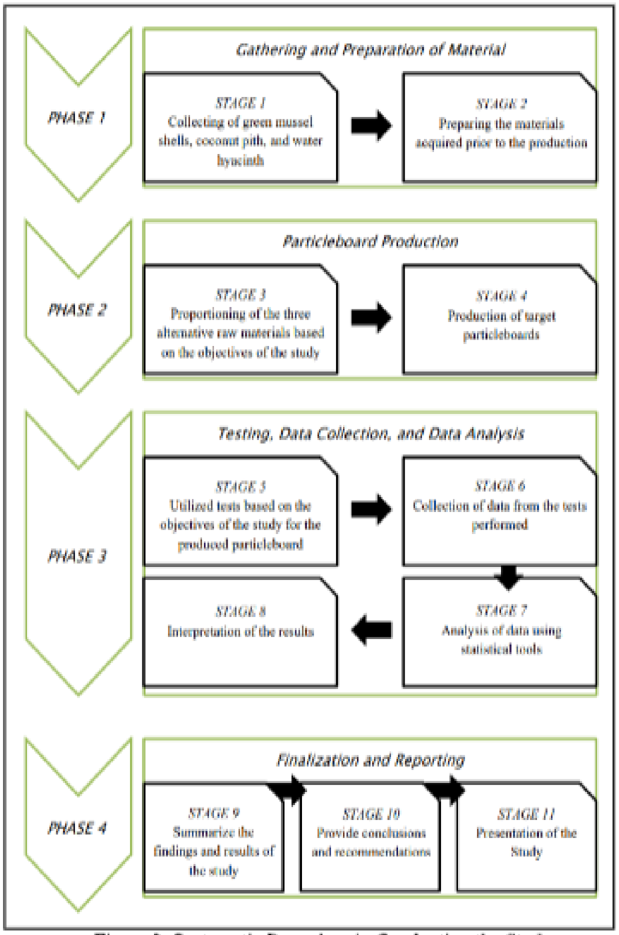

Figure 2. Systematic Procedure in Conducting the Study

Figure 2 depicts the methodological framework, which served as a tool for guiding the sequences of procedures to be carried out in order to collect data. It illustrates the step-by-step process of producing particleboard for use as an interior wall partition. Phase 1 highlights the foundation of particleboard production, including the collection of the raw materials in the study. The following phase specifies the actual manufacturing procedure for the product. Phase 3 involves the examination of the acquired data from the tests. Ultimately, the findings and outcome are presented at the final phase, along with conclusions and recommendations based on the purpose of the study.

A. Research Design

For this study, the researchers used an experimental type of research design. This research design was utilized to determine the interaction between the independent and dependent variables to identify their causal relationship. In this study, the researchers determined the interaction between the types of raw materials (independent variable) and the effectiveness of the produced particleboard (dependent variable). This study was considered experimental since different proportions from the three alternative raw materials were used to determine particleboard's effectiveness. Various tests were performed to know the particleboard's mechanical properties. Furthermore, different tests were based on the standards that were established by the American Society for Testing Materials (ASTM), and Philippine National Standards (PNS).

B. Data Collection Methods

The data collection method is the step-by-step process by which the researchers gained and were able to collect the data.

Green mussel shells were gathered from local restaurants in San Fernando, Pampanga since mussel shells are usually discarded by restaurants as waste. The researchers utilized the raw material in particleboard production.

In the particleboard production process, the first crucial step is to collect raw materials. Sacks of coconut pith were gathered from Angeles, Pampanga, where numerous vendors sell coconuts.

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The raw material plays an important role and serves as a strong backbone in producing particleboard.

Water hyacinth fibres were obtained in Barangay Dela Paz, San Simon, Pampanga, where water bodies such as rivers and ponds contain water hyacinths. These water hyacinths are beneficial and were used as one of the raw materials in particleboard production to be used as interior wall partition.

C. Material Development

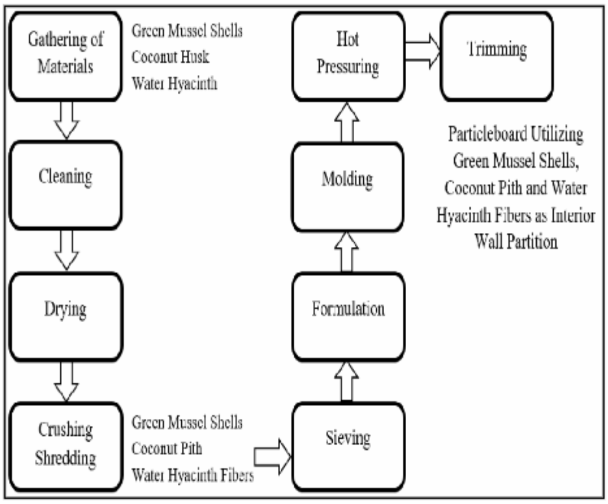

Figure 3. Flow Process in Producing Particleboard

During the implementation of the study, the researchers were able to secure and carry out a step-by-step process for developing the material to be used as an interior wall partition. The method involved the processes of gathering and preparation of the materials intended to serve as an alternative in creating particleboard until the trimming process as a preparatory step in subjecting the material generated to different testing relative to the objectives of the study.

C.1 Mixing and Proportion

The experimental samples were divided into three distinct proportions for categorization. These proportions were used as a variation to determine which proportions produced the best particleboard for use as an interior wall partition.

TABLE I
DESIGN MIXTURE OF EXPERIMENTAL SAMPLES

Proportion	**Green Mussel Shells (%)**	**Coconut Pith (%)**	**Water Hyacinth Fibers (%)**	**Isocyanate Resin (%)**
1	10	80	10	10
2	20	70	10	10
3	30	60	10	10

The constant proportion of water hyacinth at 10% was based on an experimental study [40] conducted, confirming its capabilities as a good adhesion material. The percentages of coconut pith and green mussel shells are based on their unique capabilities, strength, and thermal insulation, to provide features of particleboard that can be utilized as a wall partition. Furthermore, the various manufactured mixed proportions contain 10% isocyanate resin and 90% raw materials, with the amount variable by design mixture.

C.2 Board Preparation

The researchers prepared all the materials needed to produce the particleboard. The raw materials were mixed according to specific configuration ratios. Different particleboard setups ratios were considered as per Table 1. The board preparation includes the isocyanate resin, which serves as a binder, imparting strength to the raw materials, allowing them to firmly attach to one another and produce a more functional board.

Figure 4. Board Preparation for Different Proportion

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C.3 Moulding

The researchers filled the moulder with the proportion of different raw materials according to specific configuration ratios mixed in the basin. The filled moulder was then manually pressed to prepare for hot pressing.

Figure 5. Molding of Particleboard

C.4 Hot Pressing

In producing particleboards, it is essential to perform hot pressing on the prepressed mixture from the moulder. Hot pressing involves applying uniaxial pressure with a pair of heated plates. The machine was preheated to a temperature of 180°C. The sample was hot pressed for 10 minutes. Afterward, the sample underwent cool down for five minutes to solidify.

Figure 6. Solidified Particleboard After Hot Pressing

C.5 Trimming

TABLE II
SIZE OF PARTICLEBOARD FOR DIFFERENT TESTS

Test	Size	Specimen
Water Absorption	5 cm x 5 cm x 12 mm	3
Thickness Swelling	5 cm x 5 cm x 12 mm	3
Face Screw Withdrawal	10 cm x 5 cm x 12 mm	3
Modulus of Rupture	32 cm x 7.5 cm x 12 mm	3
Thermal Analysis	2.5 cm x 2.5 cm x 12 mm	1

Particleboards manufactured were trimmed into different distinct sizes relative to the minimum standard sizes of the different tests as shown in Table 2.

C.6 Laboratory Testing of Particleboard Samples

In accordance with the standards outlined by the American Society for Testing and Materials (ASTM D1037-12, and ASTM D3418), and Philippine National Standard for Particleboard (PNS 230:1989), the sample particleboards went through experimental conditions.

C.6.1 Water Absorption Test (PNS 230:1989)

The purpose of the water absorption test was to determine how much water the particleboard could absorb in a certain amount of time based on PNS 230:1989. The test specimens measuring 5 cm by 5 cm with a thickness of 12 mm were individually weighed before submersion in water. Following a 24-hour submersion period, each specimen was reweighed to assess any changes in weight.

C.6.2 Thickness Swelling Test (PNS 230:1989)

A dimensional test called the thickness swelling test was conducted to ascertain how much the sample particleboard's thickness changed after being submerged in water for a specific amount of time based on PNS 230:1989. The test specimens measuring 5 cm by 5 cm with a thickness of 12 mm engaged in thickness measurements before immersion in water. Following a 24-hour immersion period, the thickness of each specimen was then measured again to evaluate the addition in thickness after submersion.

C.6.3 Face Screw Withdrawal Test (ASTM D1037-12)

The face screw withdrawal test is based on the ASTM D1037-12 standards, which was used for analysing the capabilities of wood-based materials in screw test withdrawal. Screws were placed into each test specimen measuring 10 cm by 5 cm with a thickness of 12 mm until their tips become visible

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on the opposite side. Samples were tested by the Universal Testing Machine (UTM). The force meter is visible for reading when force is applied. Data was first read when the force meter's arrow hand began to increase, and it stopped at the force at which the screw from the sample could be withdrawn before it started to decrease.

C.6.4. Modulus of Rupture Test (ASTM D1037-12)

Modulus of rupture, based on ASTM D1037-12, is a testing which involves specimen being loaded face up on two support rods. The loading rod was positioned in the middle of the two support rods, and a steady force of 145 psi per second is given to the specimen until it breaks.

C.6.5 Thermal Analysis of Polymers Using Differential Scanning Calorimetry Test Method (ASTM D3418-21)

For the test of thermal conductivity through Differential Scanning Calorimetry (DSC), the recommended standard weight of sample specimens ranges from 5 to 20 milligrams for laboratory testing. The three determined particleboard configuration ratios were used. The data to be gathered from the DSC was interpreted and analysed by the researchers to compare the performances of the different particleboard samples.

III. RESULTS AND DISCUSSIONS

The results and discussion include a description of the data, analysis, and findings, as well as an interpretation of the results in light of the objectives of the study. The findings of several tests on particleboards are presented in the form of tables and graphs.

A. Data Description

The results obtained from several testing laboratories in the experimental group of particleboards were taken into consideration. The results from water absorption test, thickness swelling test, face screw withdrawal test, and modulus of rupture test of each of the proportion determined were analysed using the average of three samples for each proportion. The thermal analysis of the particleboard as interior wall partition was based on the interim report of the laboratory. The respective laboratory personnel conducted the experiment on the samples, which they measured and validated, and the proponents tabulated the results.

B. Data Analysis and Findings

The experiments subjected to the particleboards as interior wall partition were in accordance with the Philippine National Standards (PNS), and American Society for Testing and Materials standards (PNS 230:1989, ASTM D1037-12, and ASTM D3418). The experimental groups were executed on varying number of raw materials. Proportion 1 (P1) includes 10% green mussel shells, 80% coconut pith, and 10% water hyacinth fibres. Proportion 2 (P2) has 20% green mussel shells, 70% coconut pith, and 10% water hyacinth fibres. Proportion 3 (P3), the last proportion, contains 30% green mussel shells, 60% coconut pith, and 10% water hyacinth fibres. The results gathered in the process of the research were presented using tables.

C. Water Absorption Test (PNS 230:1989)

Water absorption tests were conducted on three different proportions following the test standard PNS 230:1989 assessing wood-based panel. Samples are initially weighed before being immersed in water for a specific period. After the submersion of the samples in the water, the samples were subjected to weighing again to be able to obtain the water absorption rate of the different proportions.

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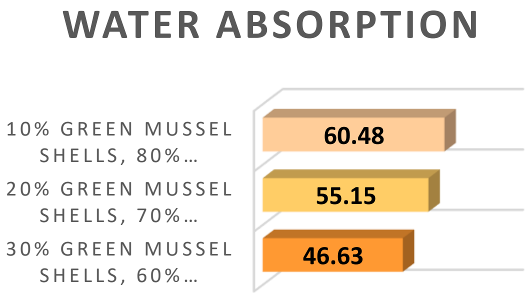

Figure 7. Average Water Absorption per Proportion

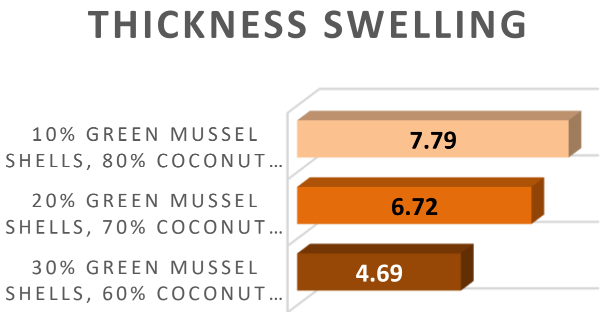

Figure 8. Average Thickness Swelling per Proportion

Figure 7 illustrates the relationship of coconut pith to the rate of water absorption of the particleboard. The proportion with 80% coconut pith resulted in 60.48% average water absorption, and as the percentage of coconut pith decreases based on the generated proportions, the average water absorption also decreases. It shows that as the amount of coconut pith increases, the particleboard's ability to absorb water also increases. A study of Hartono, et al. (2022) [45] found that particleboard comprised of fine particles has a larger contact area than coarse particles, which can absorb more water, increasing water absorption rate.

D. Thickness Swelling Test (PNS 230:1989)

Thickness swelling tests were performed according to PNS 230:1989 standard test. It is a method to assess the dimensional stability of wood-based panel products after the samples are exposed to moisture. The thickness of samples was initially measured before being submerged in water. After the submersion, the samples were to be measured again in order to evaluate the change in thickness caused by moisture.

Figure 8 demonstrates that the thickness swelling shows a tendency to decrease with an increase in the percentage amount of green mussel shells in the particleboard with three distinct raw materials. The results indicate that the amount of green mussel shells had a significant impact on rate of thickness swelling. Martínez-García, et al. in year 2020 [30] found that mussel shells contain calcium carbonate, and its structure is granular, irregular, and diverse. These characteristics and properties of green mussel shells may reduce porosity, which may have an impact on the ability of the particleboard to swell.

E. Face Screw Withdrawal Test (ASTM D1037-12)

A Universal Testing Machine was used to calculate the screw pull out force of the particleboards. Screw withdrawal test was subjected to the three proportions to determine the resistance of the board to the withdrawal of screw in a perpendicular direction to the board. According to ASTM D1037-12 requirements, test specimens must be at least 3 inches wide and 6 inches long with thickness varying on the purpose of the manufacturing. Though the researched samples were only a portion of the larger 40 cm by 40 cm boards generated, the test samples were nonetheless trimmed to meet the ASTM D1037-12 minimum specifications.

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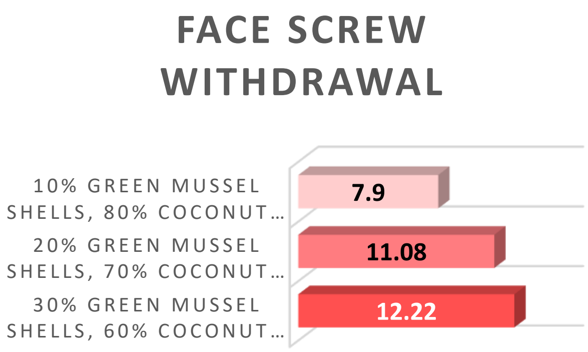

Figure 9. Average Face Screw Withdrawal Force per Proportion

Figure 9 shows an increase in the average maximum force the particleboard can withstand as the amount of green mussel shells increases relative to the weight of the particleboard in a given volume. Though the three samples per proportion do not necessarily show a solid linear relationship between the strength of the particleboard in withdrawing screws and the percentage of green mussel shells, it is said to introduce a concept that represents a direct relationship between the two variables.

F. Modulus of Rupture Test (ASTM D1037-12)

The term modulus of rupture, MOR, refers to measuring the strength of an object prior to failure. It has also been referred to as flexural strength and bending strength. When the specimen is mounted, the load is applied to the top surface of the specimen, which is loaded at the centre span. In particular, this study used ASTM D1037-12, the industry standard test technique for assessing the characteristics of wood-based fibre and particle panel materials.

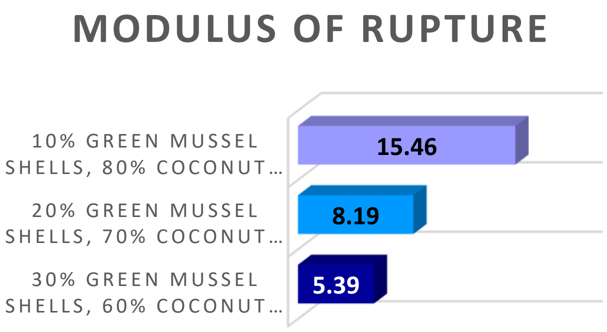

Figure 10. Average Modulus of Rupture per Proportion

Figure 10 shows the graph of the average modulus of rupture of the three different proportions obtained through testing. The graph shows that Proportion 1 acquired the highest value from the modulus of rupture test. Based on the data, the modulus of rupture also increases as the percentage of coconut pith increases. However, as a result, it can be concluded that Proportions 1, 2, and 3 are not enough to satisfy the standard for modulus of rupture, which is 80 kg/cm².

G. Thermal Analysis of Polymers Using Differential Scanning Calorimetry Test Method (ASTM D3418-21)

A Perkin Elmer DSC 4000 with a heating rate of 20°C/min under a nitrogen atmosphere was used to record the DSC thermogram of the produced particleboard. A standard aluminium pan was filled with approximately 5 mg to 10 mg of the dry sample and sealed. The sample was heated between 30 and 400 degrees Celsius. Over the temperature and time intervals, the thermal profile of samples was continuously recorded.

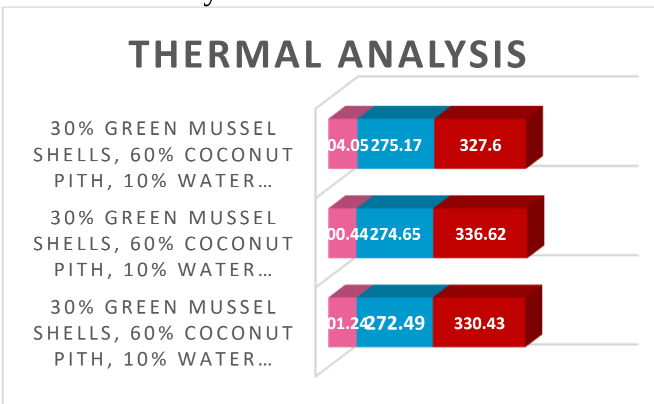

Figure 11. Thermal Analysis of Polymers Using Differential Scanning Calorimetry Test Method of the Three Proportions

However, Figure 11 shows that the variation in the percentage of green mussel shells shows no relationship with the differences in peak temperature. Proportion 1 obtained a peak temperature of 330.43°C. Proportion 2 acquired 336.62°C. Meanwhile, Proportion 3 has a peak temperature of 327.60°C.

According to ASTM D3418-21, due to the fact that milligram quantities of specimens are used, it is essential to ensure that specimens are homogenous and representative. Since particle size has an effect upon detected transition temperatures, the specimen to be compared should be approximately the same particle size produced in the process of making the particleboard.

Based on the guidelines of ASTM D3418-21, different conditions presented may have affected the obtained data of the samples. First, the produced particleboard is not a homogenous material since the three materials, green mussel shells, coconut pith, and water hyacinth fibres, can be visibly distinguished within the mixture, making it a heterogeneous material. Second, the three materials do not have a uniform particle size since the green mussel shells were crushed into smaller pieces, the coconut husk was shredded and sieved to obtain coconut pith, and the water hyacinth were shredded in order to acquire fibres. Lastly, the samples taken from each proportion were only approximately 5 mg to 10 mg of the produced 40 cm by 40 cm particleboard with a theoretical weight of 960 grams.

H. Effectiveness of Particleboard Utilizing Green Mussel Shells, Coconut Pith, and Water Hyacinth Fibers as Interior Wall Partition

Particleboards are engineering materials composed primarily of wood flakes and other wastes bound by various binding compounds to form wood-based panels for an array of applications. The effectiveness of the particleboard utilizing green mussel shells, coconut pith, and water hyacinth fibres for usage as an interior wall partition in contrast to other materials tested using standards and different studies were shown in tables.

TABLE III
WATER ABSORPTION AND THICKNESS SWELLING OF VARIOUS MATERIALS

Wood-Based Material		**Water Absorption**	**Thickness Swelling**	
		WA %	**Standard/Findings**	**TS%**
Particleboard Utilizing Green Mussel Shells, Coconut Pith, and Water Hyacinth Fibres	P1	60.48	PNS 230:1989	7.79
	P2	55.15	PNS 230:1989	6.72
	P3	46.63	PNS 230:1989	4.69
Particle Board Produced from Saw Dust and Plastic Waste		124.71	Atoyebi, et al. (2018)	18.78
Particleboard Manufactured from Coconut Fiber Using a Potato Starch Based Adhesive		70.95	Owodunni, et al. (2020)	23.53
Type 100 Particleboard		40	Philippine National Standard	20

Table 3 compares water absorption rates among different types of particleboards based on their composition. The sample with the highest average water absorption rate in the investigation was found to be 60.48%, which is significantly higher than the type 100 particleboard which was based on the Philippine National Standard 230:1989. On the other hand, the water absorptions of the studies conducted by Atoyebi, et al. in 2018 [46], and Owodunni, et al. in year 2020 [47] exhibits an average of 124.71%, and 70.95% respectively which are significantly higher than the average thickness swelling procured by the study. However, the Philippine National Standards (PNS) for type 100 particleboard established that the maximum water absorption is 40%, and the particleboard developed by the researchers failed considering the three proportions yielded the lowest water absorption of 46.63%. Coconut husk is generally water absorbent [48], which is one of the reasons why the particleboard of the researchers failed the water absorption test. Even though the particleboard

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failed to the standard by PNS, it still shows that as the coconut pith increases its amount in the mixture, the water absorption rate also increases.

By observing the same table, Table 3 also displays the different results gathered from the same studies in comparing the thickness swelling of the particleboard to be used as interior wall partition. The produced particleboard with the highest thickness swelling is from Proportion 1 with 7.79% which was still significantly lower than the experiment conducted in the year 2020 by Owodunni, et al. [47]. Additionally, a study in 2018 by Atoyebi, et al. [44] acquired an average of 18.78% which is significantly higher when compared to each of the proportions of particleboard utilizing green mussel shells, coconut pith, and water hyacinth fibers. On the other hand, the maximum allowable thickness swelling by the Philippine National Standards (PNS) is 20% for type 100 particleboard. Based on the analysis of Lim, et al. in year 2021 [49], particleboards should not exceed 12% thickness swelling in order to not negatively affect its mechanical properties. Through this, the particleboard designed from green mussel shells, coconut pith, and water hyacinth fibres met the maximum permitted thickness swelling for type 100 particleboard by PNS. Among the supplied data, Proportion 3 had the lowest average thickness swelling of 4.69%, exhibiting its best attribute in terms of swelling.

TABLE IV
FACE SCREW WITHDRAWAL TEST OF VARIOUS MATERIALS

Wood-Based Material		**Face Screw Withdrawal**	
		FSW (kilogram)	**Standard/Findings**
Particleboard Utilizing Green Mussel Shells, Coconut Pith, and Water Hyacinth Fibres	P1	7.90	ASTM D1037-12
	P2	11.08	ASTM D1037-12
	P3	12.22	ASTM D1037-12
Type 100 Particleboard		30	Philippine National Standard

The face screw withdrawal test results show a significant relationship between the screw-holding capacities of particleboards and different proportions of alternative raw materials. The results of the analysis indicate that there is an improvement in the particleboard's ability to hold screws when the percentage of coconut pith reduces, and the percentage of green mussel shells increases.

Higher screw extraction values were found in a study conducted in year 2021 by Simanullang, and Sijabat [50] when isocyanate resin concentration was increased. The study manufactured four particleboards with varying raw material proportions, and the particleboard with the highest percentage of isocyanate resin, which constitutes to 35%, yielded the highest screw withdrawal index. Meanwhile, the researchers were assessing the effectiveness of alternative raw materials by keeping the isocyanate resin content at a constant 10%. A reasonable explanation for the increased screw-holding capacity observed in relation to a higher proportion of green mussel shells could be attributed to the existence of chitin compounds, which facilitate the production of chitosan, a bio adhesive substance. Furthermore, according to the results of the aforementioned study, the screw-holding capacity rises as adhesive levels increase as well.

The findings of the study did not match the particleboard standards set by the Philippine National Standards (PNS). The minimum face screw holding capacity under the type 100 classification is 30 kg. However, the study produced a result below the minimum even with the maximum screw withdrawal force of 12.22 kg. Nevertheless, in accordance with the data gathered by the researchers, the screw withdrawal force also increases with the amount of green mussel shells in every proportion.

TABLE V
MODULUS OF RUPTURE TEST OF VARIOUS MATERIALS

Wood-Based Material		Modulus of Rupture	
		MOR (kg/cm^2)	Standard/Findings
Particleboard Utilizing Green Mussel Shells, Coconut Pith, and Water Hyacinth Fibres	P1	15.46	ASTM D1037-12
	P2	8.19	ASTM D1037-12
	P3	5.39	ASTM D1037-12
Particleboard Made from Coconut Shell, Coconut Husk, and Palm Kernel		18.93	Atoyebi, et al. (2021)
Type 100 Particleboard		80	Philippine National Standard
Interior Wall Partition		0.00245	Minimum Requirement

The values of Modulus of Rupture varied from 5.39 kg/cm^2 to 15.46 kg/cm^2, as shown in Table 5. Proportion 1 would be found to have the highest value of Modulus of Rupture based on the data collected, whereas Proportion 3 would have the lowest value.

According to the study of Atoyebi, et al. in 2021 [48], they made particleboard from coconut husk, coconut shell, and palm kernel shell and analysed its different properties. The average modulus of rupture of the particleboard in the study conducted of the aforementioned study is 18.93 kg/cm2. The data obtained from the study implies that none of the particleboards can be used for structural purposes because of their poor mechanical properties as compared to the standards written in Philippine National Standards (PNS). The particleboard utilizing green mussel shells, coconut pith, and water hyacinth fibres shows that the data obtained in modulus of rupture test were not applicable for load-bearing purposes. Hence, the researchers intended the produced particleboard for non-load bearing purposes, an interior wall partition.

The study in 2015 by Philip [51] evaluated the performance of the particleboard composed of coconut and rice husks. From the results, coconut husk particleboard gave a better value than the particleboard made from rice husk. Due to its higher silica concentration, which reduces interactions with adhesive, and lower cellulose and lignin content than wood, rice husk had the lowest modulus of rupture value. Also, from the study of Atoyebi, et al. [57], from the results acquired in their experiment, the particleboard's mechanical properties increased as the coconut shell composition also increased.

Proportion 1 acquired the highest modulus of rupture, composed of 80% coconut pith. Meanwhile, Proportion 3, which acquired the lowest modulus of rupture, comprises 60% coconut pith. The study's data indicate that the modulus of rupture increases with the proportion of coconut pith.

According to the Particleboard properties set by the Philippine National Standards (1987) the standard for type 100 particleboard, which has a standard density of 0.4 g/cc - 0.8 g/cc and a thickness of 25 mm, procured a modulus of rupture of 80 kg/cm^2. The results of the study indicated that it did not conform to the standard for type 100 particleboards. Moreover, particleboards produced and experimented by Philip [51] made from rice husk and coconut husk did not conform to the requirement on the standard for exterior type particleboards.

Based on the data presented in the study, the modulus of rupture values obtained from the developed particleboard are significantly lower than the standard. The researchers used a low density of 0.5 g/cc for the sample considering the study was primarily intended to be a non-load-bearing structure and did not require a higher density board. Due to the low density, it can be concluded that the strength of the particleboard will yield a lower value.

Interior walls and partitions with heights greater than six feet, including their finish materials, must be solid and stiff enough to withstand stresses applied to them, with a minimum horizontal load of 0.240 kN/m^2 or .00245 kg/cm^2 [52]. The acquired modulus of rupture from the three proportions highlights the particleboard's ability to withstand significant loads and stresses. The minimum horizontal load requirement, which is 0.00245 kg/cm^2, indicates that the particleboard

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effectiveness meets the structural standards for interior applications.

Additionally, when designing floors for office buildings and other public use occupancies with interior partitions or cubicle separators that may move about, code-required partition loading is taken into consideration [53]. Throughout the entire span, the partition load is usually applied in parallel with the occupancy area live load specified by code at a rate of 15 pounds per square foot or 0.00732 kg/cm². In line with this, the obtained modulus of rupture values of the produced particleboard guaranteed that it can adequately withstand and maintain the applied loads without compromising stability in scenarios where interior partitions or cubicle separators may encounter shifting or dynamic loads. The particleboard demonstrated great structural integrity, surpassing the presented minimum load resistance of 0.00732 kg/cm². This means that the produced particleboard could support and maintain stability under dynamic conditions, ensuring durability and safety.

According to the results that were established, coconut pith is a major element that strengthens particleboard. The study found that as the amount of coconut pith increased, so did the bending strength. Although the resulting modulus of rupture cannot be utilized as a load-bearing material or as an exterior type of particleboard, it can be regarded as a material for various applications. The researchers designed this particleboard for internal wall partitions, which are non-load bearing structures.

TABLE VI
RESULTS OF THERMAL ANALYSIS OF POLYMERS USING DIFFERENTIAL SCANNING CALORIMETRY TEST METHOD OF VARIOUS MATERIALS

Insulation Materials		**Peak Temperature (°C)**	**Standard**
Particleboard Utilizing Green Mussel Shells, Coconut Pith, and Water Hyacinth Fibres	P1	330.43	ASTM D3418
	P2	336.62	ASTM D3418
	P3	327.60	ASTM D3418
Glass Wool Insulation		704	NOHSC
Polyethylene Foam	LD PE	108	ASTM D3418
	HD PE	125	ASTM D3418
Extruded Polystyrene Insulation Board (XPS)		93°C to 99°C	ASTM E84

Table 6 shows the thermal properties in terms of peak temperature of common insulation materials in the Philippines based on different standards. The experimental proportions of green mussel shells, coconut pith, and water hyacinth fibres obtained 330.43°C, 336.62°C, and 327.60°C based on the ASTM D3418 test.

Excellent materials for thermal insulation can be found in polyethylene foam, which is utilized for air duct, wall, floor, and roof insulation. Based on the test conducted [54], the DSC curves of the low-density polyethylene and high-density polyethylene are 108°C and 125°C respectively. Glass fibres are used to make glass wool, an insulating material. Glass wool insulation has an outstanding thermal insulation quality and is based on National Occupational Health and Safety Commission (NOHSC):1008. It has a melting point of 704°C.

Extruded Polystyrene Insulation (XPS) is a multipurpose building material with excellent insulating qualities and long-lasting. Its application in walls, floors, foundations, and roofing is widespread to regulate heat transfer and preserve energy efficiency [55]. XPS is a thermoplastic material that melts in the 93°C to 99°C range based on ASTM E84.

Wall partitions are non-load-bearing walls that offer privacy, improved acoustics, fire isolation, and spatial division [24]. Although researchers did not achieve the goal of showing the variation of the

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three proportions in terms of analysing its thermal conductivity based on the different percentages of the green mussel shells, it is still shown in Table 13 that the produced particleboard has the potential for being an insulation material according to its thermal property. Insulation is one of the characteristics that a wall partition must possess. The particleboard provided an excellent value and is significantly higher compared with the listed insulation materials in terms of peak temperature or melting point, except for glass wool insulation.

I. Cost Analysis

The cost analysis of the study compares the cost of raw materials employed in the production of the particleboard made by the researchers to commercially available particleboards. It demonstrates the total material costs per design mixture compared with commercially produced particleboards, and the total cost of particleboard in the market.

. TABLE VII
STANDARD DIMENSION OF COMMERCIALLY MADE PARTICLEBOARD

Standard Dimension		Volume (cm^3)	Average Density (g/cm^3)	Needed (kg)
Length (cm)	244	35721.6	0.755	27
Width (cm)	122			
Thickness (cm)	1.2			

The differentiation between the cost of particleboard of the study to the commercially made particleboards was relative to the standard dimensions of particleboard available in the market as shown in Table 7.

. TABLE VIII
MASS OF RAW MATERIALS PER PROPORTION

Raw Materials	Proportion 1	Proportion 2	Proportion 3
Green Mussel Shells	2.43 kg	4.86 kg	7.29 kg
Coconut Pith	19.44 kg	17.01 kg	14.58 kg
Water Hyacinth Fibres	2.43 kg	2.43 kg	2.43 kg
Isocyanate Resin	2.70 kg	2.70 kg	2.70 kg
Total	27.00 kg	27.00 kg	27.00 kg

Table 8 declares the mass of raw materials required in producing particleboards in accordance with the standard size available in the market. Furthermore, the isocyanate resin utilized by the researchers in the study accounts for 10% of the overall mass of the particleboard, signifying that the remaining 90% of the mass is going to be distributed to the respective percentage of raw materials per proportion.

TABLE IX
COST OF RAW MATERIALS IN PRODUCING PROPORTION 1

10% Green Mussel Shells, 80% Coconut Pith, and 10% Water Hyacinth Fibres			
Material	**Needed Mass (kg)**	**Price per kg (Php/kg)**	**Cost (Php)**
Green Mussel Shells	2.43	10.00	24.30
Coconut Pith	19.44	30.00	583.20
Water Hyacinth Fibres	2.43	-	-
Isocyanate Resin	2.70	100.00	270.00
Total	27.00	-	877.50

TABLE X
COST OF RAW MATERIALS IN PRODUCING PROPORTION 2

20% Green Mussel Shells, 70% Coconut Pith, and 10% Water Hyacinth Fibres			
Material	**Needed Mass (kg)**	**Price per kg (Php/kg)**	**Cost (Php)**
Green Mussel Shells	4.86	10.00	48.60
Coconut Pith	17.01	30.00	510.30
Water Hyacinth Fibres	2.43	-	-
Isocyanate Resin	2.70	100.00	270.00
Total	27.00	-	828.90

TABLE XI
COST OF RAW MATERIALS IN PRODUCING PROPORTION 3

30% Green Mussel Shells, 60% Coconut Pith, and 10% Water Hyacinth Fibres			
Material	**Needed Mass (kg)**	**Price per kg (Php/kg)**	**Cost (Php)**
Green Mussel Shells	7.29	10.00	72.90
Coconut Pith	14.58	30.00	437.40
Water Hyacinth Fibres	2.43	-	-
Isocyanate Resin	2.70	100.00	270.00
Total	27.00	-	780.30

The researchers obtained the cost of the green mussel shells by asking various restaurants in San Fernando, Pampanga, for supplies. A coconut plantation in Balibago, Angeles, Pampanga established the price of coconut pith, in addition to the usage of a coconut shredder for drawing out coconut pith. On the other hand, bundles of water hyacinth were collected from several bodies of water in San Simon, Pampanga without a need for purchase. Finally, the isocyanate resin was acquired from Premiere Adhesives and Coating, Inc., a distributor in Carmona, Cavite.

Tables 9, 10, and 11 represent the raw material costs for Proportions 1, 2, and 3, respectively, which are anticipated to be produced with the same dimensions as to that of commercial particleboards. The price per kilogram for each raw material was computed and reflected based on the actual amount paid by the researchers in order to purchase the raw materials needed for the production.

TABLE XII
COST OF RAW MATERIALS IN PRODUCING COMMERCIAL PARTICLEBOARDS

Raw Materials	Percentage (%)	Needed (kg)	Price per kg (Php/kg)	Cost (Php)
Wood Fibers	82	22.14	43.06	953.35
Urea-Formaldehyde Resin Glue	9	2.43	51.09	124.15
Water	8	2.16	0.08	0.17
Paraffin Wax	1	0.27	77.52	20.93
Total	100	27.00	-	1098.60

Table 12 elucidates the overall price of raw materials needed for particleboard production. A study suggested that a commercial particleboard is commonly made up of wood fibres, urea-formaldehyde resin glue, water, and paraffin wax [56]. These raw materials are consistently used to manufacture particleboard for the market.

The researchers calculated the cost of raw materials utilized for producing particleboard from green mussel shells, coconut pith, and water hyacinth fibres, as well as commercially manufactured particleboard, based on the individual costs of the materials.

I.1. Market Cost of Particleboards

The particleboards developed are envisioned to be constructed and introduced into the market at a specific cost, starting with the material cost and progressing to labour costs and procurement costs when the product becomes accessible in the market. According to Grzegorzewska, Burawska-Kupniewska, and Boruszewski in year 2020 [57], the cost of particleboards produced and sold in the market constitutes for 66% of total material cost, 11% for personnel cost, 10% for energy cost, 8% for sales and general management cost, and 5% related to the depreciation of machines and tools.

TABLE XIII
MARKET COST OF PROPORTION 1 PARTICLEBOARD

Section	Percentage (%)	Cost (Php)
Material	66	877.50
Personnel	11	146.25
Energy	10	132.96
General Management	8	106.36
Depreciation	5	66.48
Total	100	1329.55

TABLE XIV
MARKET COST OF PROPORTION 2 PARTICLEBOARD

Section	Percentage (%)	Cost (Php)
Material	66	828.90
Personnel	11	138.15
Energy	10	125.59
General Management	8	100.47
Depreciation	5	62.80
Total	100	1255.91

TABLE XV
MARKET COST OF PROPORTION 3 PARTICLEBOARD

Section	Percentage (%)	Cost (Php)
Material	66	780.30
Personnel	11	130.05
Energy	10	118.23
General Management	8	94.58
Depreciation	5	59.11
Total	100	1182.27

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TABLE XVI
MARKET COST OF COMMERCIALLY MADE PARTICLEBOARD

Section	Percentage (%)	Cost (Php)
Material	66	1098.60
Personnel	11	183.10
Energy	10	166.46
General Management	8	133.16
Depreciation	5	83.23
Total	100	1664.55

The total market cost of each proportion, as well as commercially made particleboard is determined based on the material cost calculated by the researchers. Also, Tables 13, 14, 15, and 16 illustrate the distribution of costs incurred prior to the release of particleboards in the market.

The total cost of commercial particleboard is 1664.55 Php (Refer to Table 16) while the costs of particleboard utilizing green mussel shells, coconut pith, and water hyacinth fibres are 1329.55 Php for Proportion 1 (Refer to Table 13), 1255.91 Php for Proportion 2 (Refer to Table 14), and 1182.27 Php for Proportion 3 (Refer to Table 15).

$$\text{Proportion 1 } Percent\ Difference = \frac{1664.55-1329.55}{1329.55} \times 100\% = 25.20\%$$

$$\text{Proportion 2 } Percent\ Difference = \frac{1664.55-1255.91}{1255.91} \times 100\% = 32.54\%$$

$$\text{Proportion 3 } Percent\ Difference = \frac{1664.55-1182.27}{1182.27} \times 100\% = 40.79\%$$

In accordance with the data obtained, the cost of particleboard developed from green mussel shells, coconut pith, and water hyacinth fibres is considerably less than the price of commercially made particleboard by 25.20%, 32.54%, and 40.79%, respectively, from Proportion 1 to Proportion 3. The difference in the total cost of the particleboard used in the study is considerably cheaper than the entire cost of commercial particleboard on the market.

I.2. Comparative Analysis

This section compares the qualities and costs of produced particleboard with commercially available particleboard. The comparison demonstrates the created particleboard's potential to function as an interior wall partition as well as its market viability.

TABLE XII
COMPARISON OF PRODUCED PARTICLEBOARD TO COMMERCIAL PARTICLEBOARD

Property	Proportion 1	Proportion 2	Proportion 3	Commercial
Density (g/cc)	0.5	0.5	0.5	1.2
Water Absorption (%)	60.48	55.15	46.63	45
Modulus of Rupture (kg/cm^2)	15.46	8.19	5.39	0.0084
Market Cost (Php)	1350.00	1250.00	1200.00	1880.00

The comparative analysis between the produced particleboard by the researchers and the commercially available particleboard for wall partition indicates differences in their properties and market costs. The researchers have used a density of 0.5 g/cc for all three proportions of particleboard, much lower than the 1.2 g/cc density of the commercial particleboard. Partition walls present several advantages, including flexibility, cost-effectiveness, and ease of installation [58]. The produced particleboard is lighter due to its lower density. It may be favourable for specific applications, such as easy installation, which is one of the advantages of partition walls.

Regarding the water absorption property, particleboard utilizing green mussel shells, coconut pith, and water hyacinth fibres showed areas that needed improvement. Proportions 1 and 2 show higher water absorption rates that relate to the potential swelling of the particleboard when exposed to moisture. Meanwhile, Proportion 3 obtained the lowest percentage for water absorption, 46.63%, slightly higher than the water absorption value of commercial particleboard, which is 45%. Proportion 3 approaches the commercial

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particleboard performance in terms of water absorption.

Regarding the particleboard's strength in terms of its modulus of rupture, all three proportions of the produced particleboard were significantly higher than the commercial ones. Despite having a lower density, the particleboard is stronger and more resistant to bending forces than the commercial particleboard.

Regarding market costs, from the prices shown in Table 17, all three proportions were more economical than the particleboard present in the market. The produced particleboard intended for interior wall partitions shows its potential to become an alternative in markets as its cost is much less than the commercial ones. As mentioned, partition walls offer many advantages, one of which is its cost-effectiveness. Additionally, despite having a lower density, it shows a superior mechanical strength compared to commercial ones. Although more improvements were needed regarding water absorption property, Proportion 3 shows that it is close to reaching the performance of the commercial particleboard.

IV. CONCLUSIONS

The final chapter of the study incorporates a summary of all the findings based on the data collected, conclusions that may be presented based on the findings, as well as recommendations from the researchers that can be used as an outline for future researchers carrying out studies in the same field for enhancing the issues under the research and be able optimize the core of the study.

In the study, a particleboard intended for interior wall partition was successfully developed using alternative materials of green mussel shells, coconut pith, and water hyacinth fibers. After producing the particleboard, the researchers conducted various tests to determine its mechanical properties. The data from the testing was undertaken in the laboratories of Department of Science and Technology in Laguna and Taguig. The tests performed within the particleboard showed both areas of success and areas that needed improvement.

The researchers concluded that the sample of 30% green mussel shells, 60% coconut pith, and 10% water hyacinth is the best proportion to consider according to the overall statistics of data. It recorded a value for thickness swelling of 4.69%, which passes the minimum standard requirement for type 100 particleboard, which is a maximum of 20%, according to Philippine National Standards (PNS). Proportion 3 also obtained the lowest value for its water absorption, with 46.63%. The obtained value did not conform to the standard of 40%, but it still can be enhanced by changing percentages in the proportion of the three raw materials used, significantly increasing the number of green mussel shells. This proportion also recorded the highest value for the face screw withdrawal test, which is 12.22 kg. Although this value was lower compared to the required minimum standard of 30 kg, it can still be further improved, such as the increase of green mussel shells and isocyanate resin. For the modulus of rupture test, Proportion 3 acquired the lowest value among the samples. However, when considering the other mechanical properties relevant to non-load-bearing applications, Proportion 3 is the best option among the tested proportions. While modulus of rupture is an indicator of material strength, it may have less direct relevance to the performance of the produced particleboard since it is intended for a non-load-bearing application, an interior wall partition. Additionally, since the particleboards produced used low density and lesser thickness, the bending strength can still be further improved by increasing its density and thickness.

For the thermal analysis using the Differential Scanning Calorimetry method conforming ASTM D3418, the highest obtained value for peak temperature was Proportion 2. Although the results showed no relationship regarding the variation in the amount of green mussel shells, the particleboards provided a higher value than the traditional insulation except for glass wool insulation in terms of their peak temperature. One of the notable characteristics that a wall partition must possess is its insulation. It can be concluded that all the proportions utilized to make

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particleboard have a high potential for usage as interior wall partitions since none of the test findings differed significantly from one another.

One significant finding of this study is its cost analysis. Based on the computation of the materials used in this study compared to the commercial particleboard, utilizing green mussel shells, coconut pith, and water hyacinth fibers was more economical than the traditional materials used. This notable aspect of the study highlights the opportunity for using alternative raw materials to help lessen the costs of manufacturing particleboard while promoting environmental sustainability.

Even with the areas in which improvement is needed, the significance of the study lies in the investigation of using alternative raw materials to produce particleboard. The research presents that utilizing green mussel shells, coconut pith, and water hyacinth fibers shows opportunities to lessen conventional materials' dependency on particleboard manufacturing. The emphasis of the study on cost-effectiveness and sustainability highlights the graveness and suitability of the material in developing environmentally friendly construction materials.

A. Recommendations

The study focused on the mechanical characteristics of particleboard, such as water absorption, thickness swelling, face screw withdrawal, modulus of rupture, and thermal analysis, as well as production cost analysis. It also examined the suitability of particleboards as interior wall partitions, incorporating various proportions of green mussel shell, coconut pith, and water hyacinth fibers. The research identified the strengths and weaknesses of particleboard after thorough investigation incorporating laboratory experiments. In order to further strengthen the findings, the following recommendations are presented.

1. Utilization of the entire produced particleboard or producing a particleboard with the dimension required for testing to comprehensively assess the strength derived from the proportioned raw materials.
2. Conducting further research and testing to assess the mechanical characteristics of the particleboard such as acoustical properties.
3. Following studies may increase the density of the particleboard to improve its bending strength. On the other hand, increase the proportion of green mussel shell to enhance water absorption, thickness swelling, and face screw withdrawal ability.
4. Future researchers may need to adjust the thickness of the particleboard to obtain satisfactory values for different tests conforming to the Philippine National Standard.
5. A different base raw material other than coconut pith may be incorporated, that is not water absorbent, to decrease the water absorption rate without sacrificing the bending strength of the particleboard.
6. Succeeding studies may increase the amount of isocyanate resin used to improve face screw withdrawal capacity or use another resin to condense the raw materials.
7. Further research is necessary to enhance the particleboard's mechanical properties for load-bearing applications.

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