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Development of Thermal Insulation Board Using Agricultural Waste: An Innovative Design

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Abstract: *This study developed a sustainable thermal insulation board from agricultural waste specifically bamboo, rice husk, and coconut coir—and evaluated its performance through simplified home-based tests and a perceptual survey. The development procedure followed seven phases: raw material preparation, binder preparation, mixing and molding, pressing and curing, demolding and finishing, performance testing, and data analysis. Results showed that the board met acceptable criteria for thermal insulation (keeping ice frozen longer than cardboard), density (200–600 kg/m³), water absorption (less than 30%), flexural strength (withstanding 13.5 kg load), and fire resistance (self-extinguishing within 3–5 seconds). Survey respondents rated the board highly across all criteria, with a grand mean of 4.6 out of 5, interpreted as "Highly Recommended." Durability received the highest rating (4.7), while safety scored 4.5, still highly positive. The study concludes that the developed board is an effective thermal insulator, possesses adequate mechanical properties for non-structural applications, meets basic fire safety standards, and offers significant environmental and economic advantages. The board serves as a viable alternative to wood-based insulation, helping to save trees and reduce deforestation. It also addresses agricultural waste pollution by converting discarded materials into a valuable product. The board is suitable for commercialization, especially in agricultural regions where raw materials are abundant, and is recommended for low-cost housing, school buildings, and community centers. Government support through policies and incentives is encouraged to promote adoption and support a circular economy.*

Keywords: Agricultural Waste, Thermal Insulation Board, Sustainable Building Materials

I. INTRODUCTION

Climate change is driving longer, more severe, and frequent heat waves, particularly affecting urban areas where buildings, vehicles, and human activity concentrate heat (Cui & Tang, 2024). This increases demand for cooling, yet structural inequality makes marginalized groups—especially the elderly and low-income households—more vulnerable due to limited access to air conditioning (Crimmins et al., 2020). Simultaneously, modern lifestyles demand reduced energy consumption, lower environmental impact, and sustainable use of natural resources, driving urgent interest in eco-friendly and efficient building materials (Cárdenas-R et al., 2022). Green building design now prioritizes maximizing natural resources while minimizing non-renewable demand, with energy efficiency achievable through responsive building facades, passive solar design, and effective insulation (Deraman et al., 2022; Li et al., 2024).

Thermal insulation is critical for reducing building energy use and cooling costs, directly lowering environmental pollution (M. Yu et al., 2022). However, conventional insulation materials present significant drawbacks. Expanded/extruded polystyrene has low biodegradability, dangerous fire behavior (burning droplets and dense smoke), and poor indoor air quality impacts (Zhao et al., 2022). Inorganic materials like mineral wool, fiberglass, and plastic foams can be hazardous to human health—adhering to skin and emitting toxic gases—while requiring high energy for production and posing disposal risks (Asdrubali et al., 2020).

Consequently, researchers are exploring alternative natural fiber insulation derived from plants, trees, or animals, which are renewable, require less energy to produce, and biodegrade easily, greatly reducing environmental

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harm (Manohar, 2020; X. Yu et al., 2024). Therefore, this research aims to develop a thermal insulation board using bamboo, rice husk, and coconut coir—agricultural wastes—to test its insulation capabilities and provide a viable, biodegradable alternative to non-biodegradable materials in building and house construction.

II. REVIEW OF LITERATURE

Thermal insulation materials reduce energy loss in residential and commercial buildings, lowering operating costs of air conditioners and heating systems while improving living conditions (Okokpujie et al., 2022). Proper insulation helps manage energy shortfalls, ensures appropriate use of HVAC systems, and significantly reduces electricity costs (Reilly & Kinnane, 2022). Thermal insulation retards heat flow by conduction, convection, and radiation; when properly applied, it reduces building energy use and allows smaller HVAC systems (Adil et al., 2024).

Key factors influencing insulation choice include thermal conductivity and thermal inertia, both negatively affected by moisture (Czajkowski et al., 2019). Environmental and health concerns are significant: chlorofluorocarbons (CFCs) from foam insulations like EPS and PIR contribute to ozone depletion and global warming, while isocyanate-containing foams irritate skin and eyes, and glass-fiber batt insulation causes respiratory issues (Zhang et al., 2024). Flammability is another critical factor; flame-retardant chemicals added to inherently flammable materials like cellulose reduce fire propagation but also diminish thermal performance (Marín-Calvo et al., 2023).

Declining energy resources and rising environmental pollution have driven demand for sustainable, renewable insulating materials. While insulation reduces building energy use, conventional materials are often petrochemical-based, energy-intensive, and environmentally harmful during production and disposal. Consequently, insulation made from discarded natural fibers offers an excellent substitute—they are abundant, inexpensive, require little energy to produce, and biodegrade rapidly (Rojas et al., 2019). Natural raw materials such as hemp, flax, and bamboo, or recycled cellulose-rich waste like paper and textiles, have been extensively studied. Research shows that organic materials embedded in building shells significantly improve thermal insulation efficiency due to their low thermal conductivity and fibrous nature, while also reducing acoustic levels, increasing thermal comfort duration, and providing fire protection (Biyada et al., 2023).

Agricultural waste, previously burned or converted into fertilizer, is now recognized as a valuable resource (Brzyski et al., 2019). Agricultural waste is rich in cellulose, lignin, and hemicellulose—cellulose being a non-toxic, biocompatible, renewable biopolymer with abundant hydroxyl functions (Gunjan et al., 2023). Bio-based cellulose insulating materials from agricultural waste have attracted attention for their sustainability, affordability, and renewability. Wheat straw, hemp fibers, and recycled pulp are considered environmentally beneficial cellulose sources with low whole-life carbon emissions (Wu et al., 2022). Cellulose, the most abundant renewable resource, possesses exceptional mechanical properties, is water-insoluble, and can form sophisticated nanostructures (Beluns et al., 2021). Cellulose fiber insulation, typically made from recycled newspaper, offers lower environmental impact and embodied energy compared to traditional insulating materials (Cintura et al., 2021).

III. CONCEPTUAL FRAMEWORK

This study is anchored in the published journal of Deraman, et.al 2022 titled Production of Roof Board Insulation Using Agricultural Wastes Towards Sustainable Building Material. This study implicates the potential use of agricultural wastes to produce roof board insulation material that can provide economic value added to agricultural waste, reduce the environmental issue and provide eco- friendly, sustainable building material. Additionally, the utilization of agricultural waste was very satisfying by promoting passive design through the improvement of material properties, specifically with the production of low thermal conductivity roof fiberboard insulators that can help humankind in the future to reduce energy consumption.

The first box involves the input of which it starts the process of developing thermal board insulator. (Biyada et al., 2023)clarifies that it is imperative to develop insulating materials with outstanding properties that have a lower impact on the environment and are relatively affordable. Agricultural and/or industrial wastes, and even natural fibers,

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are increasingly used as green insulation materials, as they are an eco-friendly, cost-effective alternative to conventional oil-based materials, as well as the fact that their end-of-life cycle does not pose a critical problem.

Second box implies the research analysis and the innovative design and concepts. This process involves the innovative technique being use in the study, how it develops a thermal insulating board, its design, functionality, workability and importantly its testing and evaluation. Third box indicates the output of the study. This indicates the finish product that can be utilized and ready for usage. This also undergo series of testing and evaluation so that the output product is proven effective.

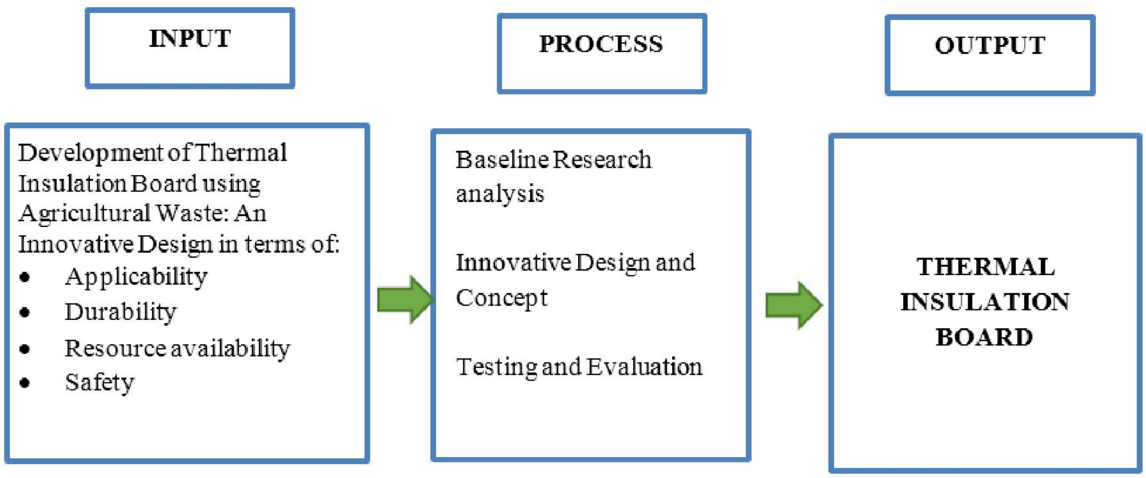

Figure 1: Research Paradigm

Statement of the Problem

This study aimed develop a thermal insulation board made from agricultural waste specifically, it sought answers to the following questions:

1. What are the materials to be used in the development of sustainable insulation board made from agricultural waste?
2. What is the performance evaluation analysis of thermal insulation board made from agricultural waste?
3. What are the procedures in the development of sustainable insulation board from raw material sourcing to production and testing?
4. What are the perceptions of the respondents on performance evaluation of the actual prototype outcome in terms of:
   4.1 Applicability,
   4.2 Durability,
   4.3 Resource availability,
   4.4 Safety,
5. How do these factors cited in problem 2 differ compared to regular insulation materials?

Significance of the Study

This study may contribute to the enhancement of using insulation materials in building houses and establishments locally. The researchers believed that this study would be beneficial to the following:

Construction Firms. The results of the study may provide them better insights and interest to understand the benefit of using biodegradable insulation material that are beneficial to the people and the environment.

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Researchers. This study may provide relevant information for their future research related to analyzing, designing, developing, implementing and innovating the product.

Scope and Limitation of Study

To facilitate delimitation in understanding the purpose and content of this study, the following parameters are specified

Focus. The main focus of this study is to design, develop, and evaluate thermal insulation board made from agricultural waste that can be used as a replacement insulation material form chemical-based insulation.

Respondents. The respondents of the study are construction firms that are constantly developing buildings, offices, houses and household and establishment owners.

Place and Time. This study will be conducted in Province of Dinagat this academic year 2024-2025.

Definition of Terms

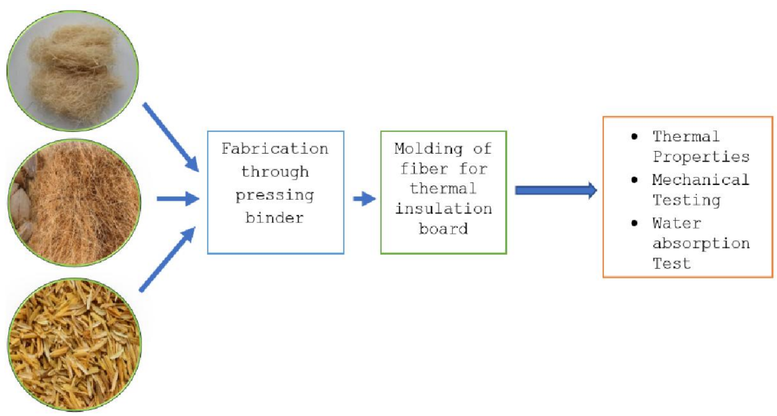
To facilitate clearer understanding of the content and purpose of this study, the following terms were conceptually and operationally defined:

Thermal Insulation. Thermal insulation is a material or combination of materials, that, when properly applied, retard the rate of heat flow by conduction, convection, and radiation.

Agricultural Waste. Agricultural waste is defined as waste left over after cultivating and processing agricultural products like fruits, vegetables, dairy and grains, as well as meat, poultry and crops.

Research Design

This study is a developmental research method. Developmental method is utilized in the process of making the design and producing the output of the study.



Research Environment

The study will be conducted at the Province of Dinagat Islands (Plate 1). The Dinagat Islands was part of the First District of Surigao del Norte Province until it became a province on December 2, 2006, with the approval of Republic Act No. 9355 (authored by Rep. Glenda B. Ecleo), the Charter of the Province of the Dinagat Islands, in a plebiscite.

The province is one of the smallest island provinces in the country with a total land area of 1,036.34 square kilometers (400.13 sq mi).[18] Located to the northeast of Surigao del Norte, in mainland Mindanao, the Dinagat Islands are separated physically from Awasan and Nonoc Islands of Surigao del Norte by the narrow, 15 kilometers (9.3 mi) long, Gaboc Channel.[19] It takes about 75 minutes to cross from Surigao City Port to San Jose Port by

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pump boat. The Dinagat Islands province comprises seven municipalities, all encompassed by a single legislative district.

Research Respondents

The respondents of this study are the construction firms, households and establishment owners. The participants are selected through purposive sampling, to ensure that all perceptions are being represented. A purposive sampling is a sample selected in a deliberative and non-random way to achieve research objectives. The distribution of respondents is shown in Table 1 presented below.

Table 1

Distribution of Respondents

Respondents	Sample
Construction Firms	10
Household owners	20
Establishment Owners	10
Total	40

Research Instrument

The instrument used in this study is a questionnaire (Appendix A). The questionnaire addressed the analysis and evaluation which the respondents answered and rated accordingly. The questionnaire is divided into 3 parts.

Part 1 dealt with the analysis of the Thermal Insulation Board using Agricultural Waste as to: applicability; durability; resources availability; and safety.

Part 2 contains the observations and comments of the output.

Part 3 are the recommendations of respondents during the actual testing of the output.

The criteria in rating the analysis of the expected output is measured and categorized as follows:

Scale	Parameter	Verbal Interpretation
5	4.51-5.00	Strongly Agree (SA)
4	3.51–4.50	Agree (A)
3	2.51–3.50	Neutral (N)
2	1.51-2.50	Disagree (D)
1	1.00-1.50	Strongly Disagree (SD)

Validity. To ensure the validity of the research instrument, the researcher's adviser together with the experts were consulted as to the content and organization of the instrument. Corrections and suggestions are incorporated to come up with a valid instrument.

Reliability. Before the survey instrument was conducted to the respondents a run-rerun was given to 5 construction firms representatives, 5 household owners and 5 establishment owners. The data gathered is analyzed and interpreted using Cronbach alpha.

Data Gathering Procedure

Before the copies of the survey instrument (Appendix A) is conducted to the respondents of the study, the researcher asked permission through a written letter to the targeted respondents. When permission was granted, the researcher personally administered the survey instrument to the respondents, and to ensure that the respondents fully understand all the items being asked, further explanations were provided. After the conduct, copies of the distributed survey instrument were retrieved and the data collected were analyzed and interpreted.

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Data Analysis

The following statistical tools were used to analyze the collected data of the study.

Frequency Median. This tool was used to measure the ratings of respondents on the analysis and relevance of Thermal Insulation Board using Agricultural Waste.

Ordinal Rank. This tool was used to measure the extent of respondent's analysis and relevance on the Thermal Insulation Board using Agricultural Waste.

RESULTS AND DISCUSSIONS

In this diagram, there is outlines the core system architecture of a dual-power emergency lighting and hazard detection device. At its foundation is the Dual Power Source, which provides the system with two independent energy inputs: a standard AC wall outlet and a solar panel.

The primary agricultural waste materials selected for this study are bamboo, rice husk, and coconut coir. Bamboo provides strong, long fibers that serve as a structural reinforcement within the insulation board, improving its mechanical strength and dimensional stability. Rice husk, which is lightweight and rich in silica, acts as an excellent thermal insulator and also enhances the board's fire resistance due to its natural mineral content. Coconut coir contributes durability, water resistance, and mold resilience, helping the finished board maintain its integrity even under humid conditions. Together, these three agricultural wastes create a fibrous matrix that traps air and reduces heat transfer. For binding these fibers together, the study employs a synthetic thermosetting glue (such as urea-formaldehyde or phenol-formaldehyde) along with a catalyst or hardener. The synthetic binder creates permanent chemical cross-links when heated, producing a strong, water-resistant bond between the bamboo, rice husk, and coir fibers. The catalyst accelerates the curing process, reducing the time needed under the heat press.

Table 2: Materials needed in Developing Insulation Board

Category	Material	Purpose / Function in the Project
Primary / Main Materials (Agricultural Waste)	Bamboo	Provides strong, long fibers for structural reinforcement and thermal resistance. It can be shredded or split into fine strands.
	Rice Husk	Lightweight, high silica content → enhances fire resistance and low thermal conductivity. Acts as filler and insulating aggregate.
	Coconut Coir	Durable, water-resistant, and mold-resistant fiber. Adds tensile strength and improves board integrity.
Secondary Materials	Heat Press Machine	Apply controlled heat and pressure to cure the binder and compress the board into a uniform thickness.
	Heat Gun	Used for localized heating to dry layers or activate glue before pressing.
	Blow Torch	For rapid surface heating (e.g., testing flame resistance or drying thick sections).
	Object of 13.5 kg	Serves as a simple dead weight for manual compression if no hydraulic press is available.
	Digital Thermostat (Temp Controller)	Monitors and maintain precise curing temperature during pressing or drying.
	Face and Back Veneer (0.6 mm)	Thin wood layers added to both sides of the board → improves surface finish, strength, and moisture resistance.

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	Synthetic Binder / Thermosetting Glue	Chemically bonds agricultural waste fibers together under heat. Common example: urea-formaldehyde or phenol-formaldehyde.
	Catalyst (Hardener)	Accelerates curing of the thermosetting glue, reducing pressing time and improving bond strength.
	Flour (All-purpose)	Acts as a natural filler or auxiliary binder; can be mixed with water to make a paste that helps hold fibers before pressing.
	Improvised Cutting Equipment	For trimming raw fibers (bamboo, coir) to uniform length before mixing.
	Frame (plywood)	Serves as a mold or form to contain the fiber-binder mixture during pressing, ensuring rectangular board shape.
Other Materials	Saw	Cut bamboo, wood, or veneer to required dimensions.
	Nails	Assembles the plywood frame or attaches veneers temporarily.
	Tub	Used for soaking, mixing, or washing agricultural waste fibers.
	Straight Edges (ruler)	Ensures accurate measurement of board dimensions and veneer alignment.
	Cutter	Trims veneer, cuts fiber strands, or opens bags of binder.
	Screw	Provides adjustable clamping pressure when assembling the frame.
	Screw Driver	Tightens or loosen screws for frame assembly.
	Hammer	Drives nails into a plywood frame.
	Weighing Scale	Measures precise amounts of fibers, binder, flour, and catalyst for consistent formulation.
	Measuring Cups	Dispenses liquids (e.g., binder, water, catalyst) accurately.
	Hand Drill	Drills holes in plywood frame for screws or for inserting thermocouple of the digital thermostat.

Additionally, all-purpose flour is used as a natural filler and auxiliary binder; when mixed with water into a paste, it helps hold the fibers together temporarily before the synthetic glue fully cures, while also reducing the amount of chemical binder required. The fabrication process relies on several key pieces of equipment. A heat press machine applies both controlled heat and pressure to cure the binder and compress the fiber mixture into a uniform board. A heat gun and blow torch are used for localized heating, drying, or testing flame resistance. A 13.5-kg object serves as a simple dead weight for manual compression when a hydraulic press is not available. A digital thermostat (temperature controller thermometer) monitors and maintains precise curing temperatures, ensuring reproducibility across multiple test boards.

To improve the board's surface quality and overall strength, 0.6-mm thick face and back veneers are applied. These thin wood layers prevent fiber shedding, create a smooth finish, add bending strength, and act as a moisture barrier. The board is shaped using a plywood frame that acts as a reusable mold, and various hand tools are utilized: a saw, cutter, straight edges (ruler), hammer, nails, screws, screwdriver, and hand drill allow the research team to cut materials, assemble the mold, trim veneer, and install temperature sensors. A weighing scale and measuring cups ensure accurate proportioning of fibers, binder, catalyst, and flour. Finally, a tub (palanggana) is used for soaking and washing the agricultural waste to remove dust and improve binder adhesion. These materials collectively enable the systematic development of a sustainable, low-cost thermal insulation board from locally available agricultural residues.

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Table 3: Simplified Performance Evaluation and Acceptance Criteria

Performance Parameter	Simplified Test Method	Materials Needed	Acceptable Result
Thermal insulation	Ice cube melt test – compare melting time of ice cube covered by insulation board vs. cardboard vs. no cover	Ice cubes, plates, digital thermostat (to record room temperature), cardboard reference	Insulation board keeps ice frozen longer than cardboard
Density	Cut rectangular sample, measure dimensions with ruler, weigh, then compute mass divided by volume	Weighing scale, ruler, cutter	200 – 600 kg/m³
Water absorption	Soak small sample in tub of water for 1 hour, weigh before and after, compute percent weight gain	Tub (palanggana), water, weighing scale	Less than 30% weight gain
Flexural strength	Place board across two supports 15 cm apart, gently apply 13.5 kg object at center, observe bending or breaking	13.5 kg object, two supports (e.g., books), ruler	Board does not break under 13.5 kg
Fire resistance	Apply candle flame to small sample for 5 seconds outdoors, observe if flame continues after removal	Candle, lighter, pliers or tongs, water bucket for safety	Flame self-extinguishes within 3–5 seconds

The performance evaluation of the thermal insulation board made from bamboo, rice husk, and coconut coir was conducted using five simplified home-based tests due to the unavailability of a formal laboratory. For thermal insulation capability, the ice cube melt test was employed, wherein an ice cube covered by the insulation board was compared against an ice cube covered by cardboard and another with no cover at all, all kept at the same room temperature recorded using a digital thermostat. The board was considered effective if it kept the ice cube frozen longer than the cardboard reference, indicating lower heat transfer.

Density was determined by cutting a rectangular sample, measuring its dimensions with a ruler, weighing it on a weighing scale, and computing mass divided by volume. An acceptable density range for a lightweight insulation board is between 200 and 600 kilograms per cubic meter, which ensures ease of handling without sacrificing structural integrity. Water absorption was assessed by soaking a small sample in a tub of water for one hour, then weighing it before and after immersion to calculate the percentage of weight gain. A water absorption rate of less than 30 percent was considered acceptable, as higher moisture content would reduce insulation performance and promote mold growth.

Flexural strength was tested using a simple three-point bending setup, where the board sample was placed across two supports 15 centimeters apart, and the 13.5-kilogram object was gently applied at the center. The board passed this test if it did not break or show visible cracking under the load, demonstrating adequate mechanical strength for non-structural applications such as wall or ceiling insulation. Fire resistance was evaluated outdoors using a candle flame applied to a small board sample for five seconds. After removing the flame, the board was observed for continued burning, glowing, or dripping. A passing result was achieved if the flame self-extinguished within three to five seconds, which is critical for safety in building applications. The natural silica content of rice husk contributed to fire resistance, while the bamboo and coconut coir provided structural reinforcement. Overall, these simplified tests, while not equivalent to standardized laboratory procedures, provide valid comparative and exploratory data suitable for a school-level research project, and they allow for repeated testing to optimize the board formulation.

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Table 4: Development Procedure in making Sustainable Insulation Board from Agricultural Waste

Phase	Step	Activity	Materials / Tools Needed
1. Raw Material Sourcing & Preparation	1.1	Collect agricultural waste: bamboo, rice husk, coconut coir	Local farms, markets, or households
	1.2	Clean materials – remove dirt, stones, and debris	Tub (palanggana), water, strainer
	1.3	Dry materials under sunlight for 2–3 days until moisture is reduced	Sunlight, drying mat or tarp
	1.4	Reduce size – cut bamboo into small strips (1–2 cm), chop coir (2–3 cm), keep rice husk as is	Saw, cutter, scissors
2. Binder Preparation	2.1	Mix synthetic thermosetting glue with catalyst according to manufacturer's ratio	Measuring cups, mixing container, stirrer
	2.2	Prepare flour paste by mixing all-purpose flour with water (1:2 ratio) until smooth	Tub, water, spoon
3. Mixing & Molding	3.1	Combine dry fibers (bamboo, rice husk, coconut coir) in desired ratio (e.g., 30:40:30 by weight)	Weighing scale, tub
	3.2	Add synthetic glue mixture and flour paste to dry fibers	Measuring cups, mixing tool
	3.3	Mix thoroughly until all fibers are evenly coated	Hands (with gloves) or large spoon
	3.4	Transfer mixture into plywood frame mold placed on a flat surface	Plywood frame, flat table or floor
	3.5	Spread mixture evenly inside the mold	Straight edge (ruler), hands
4. Pressing & Curing	4.1	Place face veneer (0.6 mm) on top of the mixture (optional: also bottom veneer)	Veneer sheets
	4.2	Apply pressure using heat press machine OR manual method (place 13.5 kg object on top)	Heat press machine or 13.5 kg weight
	4.3	If using heat press: apply heat at 150–180°C for 15–20 minutes	Heat press machine, digital thermostat
	4.4	If using manual method: leave weight for 24–48 hours at room temperature to allow curing	13.5 kg object, timer
	4.5	Monitor temperature during curing using digital thermostat	Digital thermostat
5. Demolding & Finishing	5.1	Remove board from mold carefully	Hands, flat tool
	5.2	Trim rough edges using cutter or saw	Cutter, saw
	5.3	Apply back veneer if not yet applied (use same glue to attach)	Veneer, synthetic glue
	5.4	Allow board to dry completely for 2–3 days in a shaded, well-ventilated area	Drying rack or flat surface
6. Performance Testing	6.1	Cut board into smaller test samples (e.g., 10 cm × 10 cm for density, 20 cm × 5 cm for strength)	Cutter, ruler
	6.2	Conduct thermal insulation test (ice cube melt method)	Ice cubes, plates, digital thermostat, cardboard reference
	6.3	Conduct density test (measure, weigh, compute)	Weighing scale, ruler

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	6.4	Conduct water absorption test (1-hour soak)	Tub, water, weighing scale
	6.5	Conduct flexural strength test (13.5 kg weight on supported board)	13.5 kg object, two supports
	6.6	Conduct fire resistance test (candle flame for 5 seconds)	Candle, lighter, pliers, water bucket
7. Data Recording & Analysis	7.1	Record all test results in a data table	Notebook or data sheet
	7.2	Compare results with acceptable target ranges	Reference values from literature
	7.3	Draw conclusions and recommend improvements	Research paper or report

The development procedure for the sustainable insulation board made from bamboo, rice husk, and coconut coir follows seven sequential phases, beginning with raw material sourcing and ending with data analysis. In the first phase, raw material sourcing and preparation, agricultural wastes are collected from local farms, markets, or households. The bamboo, rice husk, and coconut coir are cleaned using a tub of water to remove dirt, stones, and other debris, then dried under direct sunlight for two to three days until moisture content is significantly reduced. After drying, the bamboo is cut into small strips measuring one to two centimeters using a saw or cutter, the coconut coir is chopped into two-to-three-centimeter pieces, while the rice husk is used in its original granular form.

The second phase involves binder preparation. The synthetic thermosetting glue is mixed with its catalyst or hardener according to the manufacturer's recommended ratio, which is typically measured using measuring cups. Simultaneously, an all-purpose flour paste is prepared by mixing flour with water in a one-to-two ratio until a smooth, lump-free consistency is achieved. This flour paste serves as a natural filler and auxiliary binder that helps hold fibers together before the synthetic glue fully cures.

In the third phase, mixing and molding, the dry fibers are first combined in a desired proportion, for example thirty percent bamboo, forty percent rice husk, and thirty percent coconut coir by weight using a weighing scale. The synthetic glue mixture and flour paste are then added to the dry fibers inside a tub and mixed thoroughly using hands or a large spoon until all fibers are evenly coated. The mixture is transferred into a plywood frame mold that has been placed on a flat surface, and it is spread evenly using a straight edge or the hands to ensure uniform thickness.

The fourth phase is pressing and curing. A 0.6-millimeter face veneer is placed on top of the mixture, and optionally a bottom veneer as well, to improve surface finish and moisture resistance. Pressure is applied either using a heat press machine or manually by placing the 13.5-kilogram object on top. If a heat press machine is available, heat is applied at 150 to 180 degrees Celsius for 15 to 20 minutes while monitoring the temperature with a digital thermostat. If only manual pressing is possible, the 13.5-kilogram weight is left in place for 24 to 48 hours at room temperature to allow the binder to cure naturally. Throughout curing, the digital thermostat monitors the temperature to ensure consistent conditions.

In the fifth phase, demolding and finishing, the board is carefully removed from the plywood frame using hands or a flat tool. Rough edges are trimmed using a cutter or saw to achieve a neat rectangular shape. If the back veneer was not applied earlier, it is attached using the same synthetic glue. The finished board is then allowed to dry completely for two to three days in a shaded, well-ventilated area on a drying rack or flat surface.

The sixth phase is performance testing, where the board is cut into smaller test samples using a cutter and ruler. The thermal insulation capability is evaluated using the ice cube melt test, where an ice cube covered by the board is compared against one covered by cardboard and another with no cover, with room temperature recorded by the digital thermostat. Density is determined by measuring a rectangular sample's dimensions with a ruler, weighing it, and computing mass divided by volume. Water absorption is measured by soaking a small sample in a tub of water for one hour, weighing it before and after, and calculating the percentage of weight gain. Flexural strength is tested by placing a board sample across two supports 15 centimeters apart and gently applying the 13.5-kilogram object at the

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center to see if it breaks or bends. Fire resistance is assessed outdoors by applying a candle flame to a small sample for five seconds, then observing whether the flame self-extinguishes within three to five seconds after removal, with a bucket of water kept nearby for safety.

Finally, in the seventh phase, data recording and analysis, all test results are recorded in a data table in a notebook or data sheet. These results are then compared against acceptable target ranges derived from literature on agricultural waste insulation boards. Based on this comparison, conclusions are drawn regarding the board's effectiveness, and recommendations for formulation or process improvements are documented in the research paper or report. This systematic procedure ensures reproducibility and allows for optimization of the insulation board in future studies.

Table 5. Perceptions of the respondents in terms of Applicability.

	A. **Applicability**	**Mean**	**Verbal interpretation**
1.	Low thermal conductivity indicates better insulation performance.	5	Highly Applicable
2.	material's bulk density and weight, which impact handling, transportation, and structural load on buildings.	4	Applicable
3.	material's ability to resist water absorption, as moisture can degrade thermal properties and lead to mold or decay.	5	Highly applicable
4.	The material's combustibility and resistance to fire, ensuring safety standards are met.	4.5	Highly applicable
5.	The eco-friendliness of using the waste, including its biodegradability, recyclability, and potential reduction of agricultural waste pollution.	4.5	Highly applicable

Table 5 indicates that all identified criteria are **highly applicable** in evaluating the suitability of insulation materials, as reflected by the consistently high mean scores. Respondents strongly emphasized **low thermal conductivity** and **resistance to water absorption** (both with a mean of 5.00) as the most critical factors, highlighting their direct influence on insulation efficiency, energy conservation, and long-term performance, since moisture intrusion can significantly degrade thermal properties and promote mold growth. **Fire safety**, reflected by the high applicability of combustibility and fire resistance (mean = 4.50), underscores the need for insulation materials to comply with established safety standards to minimize fire risks in buildings.

Ramanaiah, K., Sanaka, S.P., et al. (2024). Meanwhile, **bulk density and weight** (mean = 4.00) were considered applicable, indicating their relevance to ease of handling, transportation efficiency, and reduced structural load, though they are seen as secondary to performance and safety considerations. Finally, the strong rating for **eco-friendliness** (mean = 4.50) reflects growing recognition of sustainability, particularly the benefits of utilizing agricultural waste to reduce environmental pollution and support circular economy practices. Overall, the findings suggest that the selected criteria comprehensively capture the key technical, safety, and environmental considerations necessary for assessing the applicability of insulation materials. Wildman, J., Cascione, V., Henk, D. *et al).* (2026).

Table 6. Perceptions of the respondents in terms of Durability.

	B. **Durability**	**mean**	**Verbal interpretation**
1.	susceptibility to mold, mildew, insects, or rodents, which can compromise the material's structural and thermal integrity over time	4.5	Highly Durable
2.	material retains its thermal properties over extended periods under varying environmental conditions	5	Highly Durable

3.	material's ability to maintain its shape and insulation properties when subjected to pressure or load over time.	5	Highly Durable
4.	material's resistance to exposure to chemicals, pollutants, or acidic/alkaline environments that might degrade its structure.	4.5	Highly Durable
5.	outdoor or exposed applications, evaluate the material's resilience against UV radiation, rain, and temperature fluctuations.	4.5	Highly Durable

Table 6 shows that all durability-related indicators were rated Highly Durable, reflecting strong confidence in the material's long-term performance under various conditions. The high mean score for retention of thermal properties and ability to maintain shape and insulation under load (both with a mean of 5.00) indicates that the material is perceived as capable of sustaining its insulating efficiency and structural stability over extended periods, even when subjected to pressure and environmental stress, which are critical requirements for building insulation systems.

The high ratings for resistance to mold, mildew, insects, and rodents (mean = 4.50) highlight awareness that biological degradation can compromise both thermal and structural integrity, and that durable insulation materials must limit moisture retention and biological susceptibility. Wildman, J., Shea, A., Cascione, V. *et al(2026).* Similarly, the material's resistance to chemicals, pollutants, and acidic or alkaline environments (mean = 4.50) suggests confidence in its chemical stability, an important factor in urban and industrial settings where exposure to pollutants can accelerate material degradation.

Finally, the high applicability of resilience against UV radiation, rain, and temperature fluctuations (mean = 4.50) indicates that the material is considered suitable for outdoor or exposed applications, where weathering and thermal cycling commonly reduce service life. Overall, these results suggest that the material demonstrates strong durability characteristics, supporting its potential for long-term use as an insulation material in both indoor and outdoor environments. Kim, J.-H., Kim, S.-M., & Kim, J.-T. (2024)

Table 7. Perceptions of the respondents in terms of Resource Availability.

	C. Resource Availability	mean	Verbal interpretation
1.	quantity of agricultural waste available in the target area, ensuring it meets the demand for insulation production	4.5	Highly Available
2.	the impact of seasonal agricultural cycles on the consistent availability of waste materials.	5	Highly Available
3.	cost-effectively the agricultural waste can be gathered, sorted, and transported without significant losses.	4	Available
4.	agricultural waste is already used for other purposes, such as animal feed, composting, or bioenergy, which might limit its availability for insulation.	4.5	Highly Available
5.	the level of preprocessing (needed to convert the waste into insulation material and the impact on feasibility.	5	Highly Available

Table 7 shows that Resource Availability is generally perceived as highly favorable, as reflected by the high mean ratings across all indicators. The availability of agricultural waste in sufficient quantities (mean = 4.50) suggests that the target area can adequately support insulation production, consistent with studies noting the large and often underutilized volumes of agricultural residues generated annually.

Respondents rated the impact of seasonal agricultural cycles very highly (mean = 5.00), indicating confidence that seasonal variations do not significantly disrupt the consistent supply of waste materials, as many

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residues can be stored or sourced from staggered cropping cycles. Shafik, E.S., Wissa, D.A., Labeeb, A.M. *et al. (2025).* The indicator on cost-effective collection, sorting, and transportation received a slightly lower but still positive rating (mean = 4.00), implying that while logistics pose some challenges, they remain manageable and economically feasible when compared with the environmental benefits of waste reuse.

Interestingly, the high rating for existing competing uses of agricultural waste (mean = 4.50) suggests that, despite alternative applications such as animal feed, composting, or bioenergy, enough material remains available for insulation purposes. Ouda, M., Abu Sanad, A. A.et al. (2025) Lastly, the level of preprocessing required was rated highly available (mean = 5.00), reflecting the perception that necessary treatments and processing steps are technically feasible and do not significantly hinder production viability.

Overall, the results indicate that resource availability is not a limiting factor and strongly supports the feasibility of utilizing agricultural waste as a raw material for insulation production. Ramanaiah, K., Sanaka, S.P., et al. (2024).

Table 8. Perceptions of the respondents in terms of Safety.

	D. Safety	**mean**	**Verbal interpretation**
1.	Material flammability, ignition point, and ability to resist fire spread to ensure compliance with fire safety standards.	4.5	Highly Safe
2.	the potential release of harmful gases or particulates during normal use, decomposition, or in the event of fire.	4.5	Highly Safe
3.	material maintains its integrity under stress, preventing collapse, shedding, or sagging that could pose safety hazards.	4	Safe
4.	sharp edges, brittle fragments, or loose fibers that could harm installers or users during handling or installation.	5	Highly Safe
5.	the absence of harmful chemicals or additives, such as formaldehyde, during processing or production.	4.5	Highly Safe

Table 5 indicates that the proposed material is perceived as highly safe overall, with all indicators receiving Safe to Highly Safe verbal interpretations. The high mean rating for flammability, ignition point, and resistance to fire spread (mean = 4.50) highlights strong confidence that the material can meet established fire safety standards, which is critical given the role of insulation materials in influencing flame spread and smoke development during building fires.

Similarly, the perception that the material poses minimal risk in terms of harmful gas or particulate release during normal use, degradation, or fire exposure (mean = 4.50) suggests compliance with safety requirements that prioritize indoor air quality and occupant health. The material's ability to maintain integrity under stress (mean = 4.00) indicates that it is generally safe against sagging, collapse, or shedding that could create hazards, even though this aspect is slightly less emphasized than chemical and fire safety. The highest score was obtained for the absence of sharp edges, brittle fragments, or loose fibers (mean = 5.00), underscoring strong installer and user safety during handling and installation.

Finally, the high rating for the absence of harmful chemicals or additives such as formaldehyde (mean = 4.50) reflects growing awareness of material safety and health-conscious construction practices. Overall, these findings suggest that the material demonstrates a high level of safety across fire, health, and handling considerations, supporting its suitability for use as an insulation material. (*Commonwealth and Industrial Research Organization (CSIRO)2021). thermanexteam*. (2026).

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***Table 9: Summary of perception of* performance of the developed board in terms of Applicability, Durability, Resource availability, and Safety.**

	Characteristics/Performance	Average mean	Rank	Verbal interpretation
A	Applicability	4.6	2	Highly Applicable
B	Durability	4.7	1	Highly Durable
C	Resource availability	4.6	2	Highly Available
D	Safety	4.5	4	Highly Safety
	Grand mean	4.6		**Highly Recommended**

Table 6 presents a consolidated evaluation of the developed board's performance in terms of Applicability, Durability, Resource Availability, and Safety, with all criteria receiving high mean scores (4.5–4.7) and a grand mean of 4.6, verbally interpreted as Highly Recommended. Among the four indicators, Durability obtained the highest average mean (4.7), ranking first, which indicates strong confidence in the board's ability to maintain its structural integrity and functional performance over time. This finding aligns with existing literature emphasizing that insulation materials capable of retaining thermal properties, resisting moisture, and withstanding environmental stress contribute significantly to longer service life and reduced maintenance requirements in building applications. Kim, J.-H., Kim, S.-M., & Kim, J.-T. (2024).

Both Applicability and Resource Availability were ranked second, each with an average mean of 4.6, and were interpreted as Highly Applicable and Highly Available, respectively. The high applicability rating suggests that the developed board is well-suited for practical use in construction, meeting key functional requirements such as thermal efficiency, ease of handling, and environmental compatibility. This supports established design principles in building science, which stress that effective insulation materials must balance thermal, physical, and environmental performance to be viable for real-world applications. N.Sooriyalakshmi , Jane Helena(2021).

Similarly, the strong rating for resource availability reflects the feasibility of sourcing raw materials, particularly agricultural waste, in sufficient and consistent quantities. Previous studies have shown that agricultural residues are generated in large volumes and are often underutilized, making them a reliable and sustainable resource for alternative building materials. This reinforces the practicality of large-scale production of the developed board, especially in agricultural regions. Ramanaiah, K., Sanaka, S.P.et al (2024).

Safety, while still rated Highly Safe, obtained the lowest rank (4th) with an average mean of 4.5. Despite being comparatively lower, this score still indicates a very favorable perception regarding fire behavior, health risks, and handling safety. The result implies that the board is generally considered safe in terms of flammability, emission of harmful substances, and physical hazards during installation. This is consistent with standards emphasizing that insulation materials must limit fire spread, minimize toxic emissions, and pose minimal risks to installers and occupants. The slightly lower ranking may reflect respondents' cautious consideration of safety requirements, which are typically subject to strict regulatory compliance in building materials. (Cope.2015), Ramanaiah, K., Sanaka, S.P.et al (2024).

Overall, the grand mean of 4.6 demonstrates that the developed board is highly recommended, reflecting strong overall acceptance across all evaluated performance dimensions. The results suggest that durability and applicability are the board's strongest attributes, supported by readily available resources and a high level of safety. These findings indicate that the developed board has strong potential as a sustainable insulation material, capable of meeting technical, environmental, and safety expectations when compared to conventional insulation products.

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Table 10: Comparison of regular insulation material with Insulation board made out from agricultural waste

Statements	Regular Insulation Materials	Developed Insulation Materials
Low thermal conductivity indicates better insulation performance.	*	**
material's bulk density and weight, which impact handling, transportation, and structural load on buildings.	*	**
material's ability to resist water absorption, as moisture can degrade thermal properties and lead to mold or decay.	*	*
The material's combustibility and resistance to fire, ensuring safety standards are met.	*	*
The eco-friendliness of using the waste, including its biodegradability, recyclability, and potential reduction of agricultural waste pollution.	*	*
susceptibility to mold, mildew, insects, or rodents, which can compromise the material's structural and thermal integrity over time	*	**
material retains its thermal properties over extended periods under varying environmental conditions	*	**
material's ability to maintain its shape and insulation properties when subjected to pressure or load over time.	*	*
material's resistance to exposure to chemicals, pollutants, or acidic/alkaline environments that might degrade its structure.	*	*
outdoor or exposed applications, evaluate the material's resilience against UV radiation, rain, and temperature fluctuations.	*	**
quantity of agricultural waste available in the target area, ensuring it meets the demand for insulation production	*	*
the impact of seasonal agricultural cycles on the consistent availability of waste materials.	*	**
cost-effectively the agricultural waste can be gathered, sorted, and transported without significant losses.	*	**
agricultural waste is already used for other purposes, such as animal feed, composting, or bioenergy, which might limit its availability for insulation.	*	**
the level of preprocessing (needed to convert the waste into insulation material and the impact on feasibility.	*	*
material's flammability, ignition point, and ability to resist fire spread to ensure compliance with fire safety standards.	*	*
the potential release of harmful gases or particulates during normal use, decomposition, or in the event of fire.	*	*
material maintains its integrity under stress, preventing collapse, shedding, or sagging that could pose safety hazards.	*	*
sharp edges, brittle fragments, or loose fibers that could harm	*	**

installers or users during handling or installation.		
the absence of harmful chemicals or additives, such as formaldehyde, during processing or production.	*	**

Legend: *Recommended **Highly Recommended

Compared to regular insulation materials, the developed board demonstrates competitive and, in some aspects, advantageous performance across durability, applicability, market availability, and safety. In terms of durability, the board shows strong moisture resistance and thermal stability, which are common weaknesses of several bio-based or fibrous insulations, such as untreated cellulose or low-density fiberglass that tend to lose thermal efficiency when exposed to moisture. Conventional synthetic insulations like EPS and XPS offer good moisture resistance but are more susceptible to thermal deformation and long-term environmental degradation, whereas the developed board maintains its thermal properties and dimensional stability under varying environmental conditions.

SUMMARY, FINDINGS AND CONCLUSIONS

Summary

This study developed a sustainable thermal insulation board from agricultural waste—bamboo, rice husk, and coconut coir—and evaluated its thermal insulation, density, water absorption, flexural strength, and fire resistance using simplified home-based tests due to the absence of a formal laboratory. A perceptual survey also assessed respondent views on applicability, durability, resource availability, and safety. The development followed seven phases: raw material preparation, binder preparation, mixing and molding, pressing and curing, demolding and finishing, performance testing, and data analysis. Results from both physical tests and the survey consistently showed that the board is effective, sustainable, and highly recommended as an alternative insulation material, offering competitive performance in durability, safety, and environmental friendliness while utilizing locally available agricultural waste.

Findings

1. Thermal insulation was acceptable. The ice cube melt test showed the board kept ice frozen longer than cardboard, indicating effective heat transfer reduction suitable for building applications.
2. Density fell within ideal range (200–600 kg/m³). The board is lightweight, easy to handle, and imposes minimal structural load.
3. Water absorption was within limits (<30% after one hour). The board demonstrates moderate moisture resistance, though improvement is recommended for high-humidity environments.
4. Flexural strength was adequate for non-structural use. The board did not break or crack under a 13.5 kg load on a 15 cm span, proving sufficient for wall or ceiling insulation.
5. Fire resistance was satisfactory. The board self-extinguished within 3–5 seconds after flame removal, attributed to rice husk's natural silica content, meeting basic safety expectations.
6. Respondents rated the board highly. Grand mean score of 4.6/5 ("Highly Recommended"). Durability received the highest mean (4.7), while safety scored 4.5 (still highly positive).
7. Resource availability strongly supports production. Mean score of 4.6 indicated bamboo, rice husk, and coconut coir are abundant, accessible, and not significantly limited by seasonal cycles or competing uses.
8. The board compares favorably to conventional materials. Compared to fiberglass, EPS, and XPS, it offers better moisture resistance than untreated bio-based insulations, greater sustainability than petrochemical products, and lower toxicity with minimal harmful additives.

Conclusions

1. The board is an effective thermal insulator. Its ability to keep ice frozen longer than cardboard confirms that the fibrous matrix traps air and reduces heat transfer, making it suitable for building insulation.

2. The board possesses adequate properties for non-structural applications. With density of 200–600 kg/m³, water absorption below 30%, and ability to withstand 13.5 kg without breaking, it meets basic requirements for wall and ceiling insulation.
3. The board meets basic fire safety standards. Self-extinguishing within 3–5 seconds, likely due to rice husk's silica content, confirms low fire risk for residential and commercial use.
4. The board is highly accepted by potential users. Grand mean of 4.6 across applicability, durability, resource availability, and safety indicate strong stakeholder confidence.
5. The board offers significant environmental and economic advantages. Utilizing locally available agricultural waste reduces pollution, supports circular economy principles, and provides a low-cost, sustainable insulation solution, particularly for agricultural regions.

Recommendations

1. Use as an alternative to wood-based insulation. The board saves trees and reduces deforestation by replacing virgin wood with agricultural waste, contributing to forest conservation and biodiversity protection.
2. Reduce agricultural waste pollution. Transforming rice husks, coconut coir, and bamboo scraps into a valuable product reduces open burning, lowers greenhouse gas emissions, and minimizes landfill disposal problems.
3. Commercialize in agricultural regions. Abundant raw materials enable small-scale entrepreneurs and cooperatives to produce the board at low cost, creating income opportunities while promoting sustainable construction.
4. Apply in low-cost housing, schools, and community centers. Lightweight nature, acceptable thermal performance, and basic fire resistance make it ideal for rural or disaster-relief housing where affordability and local materials are prioritized.
5. Seek government support through policies and incentives. Agricultural extension offices, environmental agencies, and housing authorities can provide training, startup funding, or tax incentives to encourage production and use, promoting a circular economy.
6. Conduct further research to improve market competitiveness. Additional studies on enhancing water resistance, fire retardancy, and surface finishing will make the board more attractive to mainstream builders and hardware stores, increasing commercial success.

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