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Utilization of Sugarcane Bagasse Waste for Eco-Friendly Roofing: Synergy of Agrowaste Management and Sustainable Architecture

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ABSTRACT

Sugarcane bagasse in Indonesia represents an underutilized resource, with East Java producing 1,132,963 tons in 2021. This study explores its potential as eco-friendly roofing through Sugarcane-Inspired Roofing (SIR). A descriptive method was applied, including literature review, material analysis, experimental testing of SIR's durability and efficiency, and SWOT analysis. Results showed that SIR has good waterproof qualities, strength, and potential for large-scale production (9,000 units/month) with local materials. Field testing demonstrated environmental benefits, economic feasibility, and market acceptance as a sustainable roofing material. In conclusion, SIR is viable for supporting sustainable construction and reducing agrowaste. Future research should focus on improving material composition and expanding market adoption.

Keywords: *Eco-friendly; Sugarcane-Inspired Roofing; Sustainable architecture; Agrowaste utilization; Circular economy.*

ABSTRAK

Ampas tebu di Indonesia merupakan sumber daya yang belum dimanfaatkan optimal, dengan produksi mencapai 1.132.963 ton di Jawa Timur pada tahun 2021. Penelitian ini bertujuan mengembangkan atap ramah lingkungan berbahan dasar ampas tebu, yaitu Sugarcane-Inspired Roofing (SIR). Metode yang digunakan meliputi penelitian deskriptif, studi literatur, analisis material, pengujian kekuatan dan ketahanan produk, serta analisis SWOT. Hasil penelitian menunjukkan bahwa SIR memiliki ketahanan air yang baik, kekuatan memadai, dan layak diproduksi skala besar (9.000 unit/bulan) menggunakan bahan lokal. Uji coba lapangan membuktikan manfaat lingkungan, kelayakan ekonomi, dan potensi diterima pasar sebagai material atap berkelanjutan. Disimpulkan bahwa SIR layak dikembangkan untuk mendukung konstruksi berkelanjutan dan pengurangan limbah pertanian. Disarankan penelitian lanjutan fokus pada optimasi komposisi bahan dan perluasan adopsi pasar.

Kata Kunci: *Ramah lingkungan; Atap yang terinspirasi tebu; Arsitektur berkelanjutan; Pengurangan limbah pertanian; Ekonomi sirkular.*

Introduction

The increasing demand for housing in the present day is closely linked to the rapid growth of the population. Consequently, this surge in housing needs directly correlates with a heightened demand for construction materials. Addressing this demand necessitates the exploration and discovery of building materials that can provide alternatives for ease of construction and cost- effectiveness. Various studies have been conducted in the hope of finding efficient construction techniques and the provision of building materials in large quantities and economically.

An emerging focus in recent times is the utilization of industrial waste as an alternative construction material. Industrial waste, when used as a component in roofing tiles, has shown the potential to enhance compressive strength. In this research, the author investigates the use of agricultural industrial waste, specifically sugarcane bagasse, as an alternative material for roofing tile production. Roofing commercial, as an alternative, is constructed from a mix of cement, sand, and water with specific compositions, serving as a roofing material (Surahyo et al., 2019). The composition of these materials significantly determines their quality. Concrete roofing tiles are defined as roof covering components made from fine aggregate (sand), cement, and water, with or without other additives that do not interfere with the cement binder (SNI-03-0096- 1995). According to SNI 0096:2007, concrete roofing tiles are building components used to cover building roofs made from a mixture of Portland cement or similar with fine aggregate and water, with or without pigments (Morou et al., 2023). Therefore, research is conducted on roofing made from sugarcane bagasse. Sugarcane bagasse is an underutilized agricultural waste. It is a byproduct of the sugar production process, accounting for more than 30% of the milling capacity.

Sugarcane bagasse waste can contribute to greenhouse gas emissions, making its utilization an effective means to reduce the greenhouse effect. The utilized sugarcane bagasse is the waste that has undergone the milling process. Sugarcane plants contain fibers, saccharose, fiber content, reducing sugars, and other components. The fiber content in sugarcane bagasse comprises cellulose, pentosan, lignin, with the dominant chemical compound being SiO2 (Silica) at 70.97% (Shah, 2022). This composition holds the potential to be used as a building material. Hence, we propose an innovative business titled: SIR (Sugarcane- Inspired Roofing) Advancing Sustainable Architecture and Agro-Waste Reduction in Modern Housing.

Research Methods

Types of Research

The research utilized in this study was descriptive research. There are several methods to gain the information and data such as aims to get the basic principles of how sugarcane waste can be transformed into roofing materials. The literature review is also used for qualitative data about the existing studies on sustainable roofing materials, waste management, and sugarcane byproduct utilization.

Second phase, aims to get the benefit of sugarcane-based roofing materials. Then, is the experimental approach which is purpose for conducting the testing and validation of the tools such as durability, efficiency, and the performance of SIR. Moreover, the next method is the correlation approach that is used to find the relationship between sugarcane- based roofing and

various factors such as cost-efficiency, environmental impact, and statistical methods to find the SWOT (Strength, Weakness, Opportunity, Threats) of these products.

Data Sources and Types

This study heavily relied on secondary data sources, encompassing information gathered from various literature related to the discussed problem, and obtained indirectly through third parties. Primary references included journals addressing the manufacturing of automatic lighting, irrigation technology, and the shell-shaped model. The data obtained, as highlighted by Sigiro et al. (2022), comprised both qualitative and quantitative aspects.

To complement this research, a field experiment was conducted, implementing SIR in a limited number of homes to collect real-time data on installation processes, maintenance needs, longevity, and endurance in various weather conditions. Additionally, a comprehensive literature review was conducted, analyzing reports from research papers and articles focusing on sustainable building materials, agro-waste utilization, green construction trends, and the scientific principles underlying the development of SIR.

Problem Formulation Method

The problem formulation method of SIR is referred to Kondoh et al. (2019) that state:

1. Identification of the problem exists in environmentally friendly products, identification is necessary, namely entity, functional property, and the purpose of SDGs. High limitations of traditional roofing materials.
Regarding environmental impact there needs to be awareness of sustainable building materials in facing environmental challenges such as climate change, resource depletion and waste management.

2. Gap analysis and literature review in the current research, particularly in the utilization of sugarcane waste for roofing purposes. Assess the lack of comprehensive studies on the performance, feasibility, the impact to the greenhouse gasses and acceptance of sugarcane-based roofing materials.

3. Methodology outline that will be used to investigate the feasibility, performance, and environmental impact of sugarcane-based roofing materials. The methodology outlines also needed to find the experimental designs, material analysis, surveys, case studies, and the role to reduce agro-waste. The experimental designs are needed to make the best design for SIR. Material analysis needed to control and analyze any component that can be added in making sugarcane-based roofing.

Framework of Thingking

The framework of thinking is referred to Borgianni et al. (2022) such as sustainability framework which the process of developing this technology

commences with an exploration of literature concerning sugarcane bagasse and its potential, followed by the design phase of the tool. Once the tool design is finalized, the subsequent steps involve the procurement of necessary tools and materials. Subsequently, the tool is meticulously crafted in accordance and with the predetermined design standards to ensure optimal functionality. Furthermore, the evaluation stage is then undertaken following the tool testing phase. This stage aims to appraise the outcomes of the tool testing and generate results aligned with the initial plan. During this evaluation, the operational system of the tool is scrutinized, encompassing aspects such as tool stability, its impact on variations in weather conditions and sunlight intensity, and its influence on electricity generation. In the event that the tool falls short of the initial objectives, a reiteration of the tool manufacturing and testing stages becomes imperative.

Data Analysis Techniques

Qualitative Analysis

Qualitative analysis involves examining the non- numerical data. These are used to understand the tool's concept. In this technique there are several methods for collecting data such as journal review to gain the information about how sugarcane- based are made to be SIR. Second method is an interview to obtain data about experience using traditional roofing. From this interview there are several pieces of data about the importance of changing the traditional roofing into SIR both in terms of waste reduction and in terms of comfort and durability.

Observation

The data analysis is carried out by observing the situation related to SIR. Observation is used to collect the correlation on the agro-waste issue and how to handle these situations. The observation is also conducted by looking at climate change and the impact of agro-waste to the environment. These techniques will make a solution about the importance of using SIR for the environment.

Results and discussion

The Design of SIR

Making a smart roof from sugarcane bagasse requires a futuristic design because it can give a good impression. This smart roof, which has a thickness of 4-6 cm, is also waterproof.

Figure 3.1 Design SIR, Source: Author Documentation (2024)

The elegant house design is very suitable for implementing this SIR because it looks elegant and gives a feeling of coolness to the users of the house, but even so, this house roof is very suitable to be placed in various conditions and house shapes.

Real Product of SIR

Figure 3.2 Product of SIR Source: Author Documentation (2024)

The product design has a good thickness and is impermeable to water so it is very suitable in any condition, making the Sugarcane-Inspired Roofing very suitable for futuristic and elegant homes.

The Tools Making and Working of SIR

The manufacture of SIR uses raw materials from sugarcane bagasse and obtain waste paper from sugar factory suppliers and goods collectors used in the area around Malang. Another additional material is white cement and we can get glue from a building shop. Meanwhile, the equipment required include roof tile molds, chopping tools, concrete mixer, spoon, container, shovel, and concrete roof mold.

The production process will be carried out accordingly with predetermined targets, where we have 5 employees with the production target is 375 units/day with a production time of 24 days produce 9000 units for a month. In the production process, we refer to the Indonesian National Standard (SNI) for roof tile products and will do further testing so that it is suitable to be marketed to consumers

Supporting SDGs and Environment

The utilization of sugarcane bagasse for house roofs is in alignment with various Sustainable Development Goals (SDGs), offering a positive contribution to environmental sustainability. Here are ways in which leveraging sugarcane bagasse for house roofs can bolster SDGs and foster an environment. Sugarcane bagasse, derived from sugar production, serves as a renewable and sustainable energy source. When transformed into roofing materials, it supports sustainable construction practices, aligning with SDG 7 (Almeida & Colombo, 2021).

The incorporation of sugarcane bagasse into house roofs representants an innovative approach to construction material, contributing to SDG 9 and aligning with SDG 11, which emphasizes the role of sustainable construction materials, including those crafted from sugarcane bagasse, in the development of environmentally friendly and resilient cities and communities. Additionally, utilizing sugarcane bagasse as a construction material promotes responsible consumption by repurposing agricultural waste and reducing dependence on traditional, less sustainable materials. Moreover, under SDG 13 for Climate Action, leveraging sugarcane bagasse for house roofs positively impacts climate action by diminishing the environmental footprint associated with conventional roofing materials, supporting a circular economy through the utilization of waste products in construction. The use of sugarcane bagasse further contributes to responsible land management and prevents agricultural byproducts from becoming waste, supporting sustainable land use practices. The reduced environmental impact of roofing materials made from sugarcane bagasse encompasses lower energy consumption, decreased greenhouse gas emissions, and minimized reliance on non- renewable resources (Koch & Krellenberg, 2018).

SIR Effectiveness

Assessing the environmental impact of SIR involves considering various factors such as the reduction of carbon footprint, utilization of renewable resources (specifically sugarcane bagasse), and potential contributions to a circular economy. Concurrently, the sustainable resource use of sugarcane bagasse in roofing material production needs to be evaluated to ensure an efficient manufacturing process that minimizes waste and maximizes the use of sustainable resources.

Furthermore, examining the durability and longevity of SIR is essential, as sustainable roofing solutions should demonstrate a lifespan comparable to or exceeding that of traditional materials for a lasting positive impact. The ability of SIR to withstand diverse weather conditions, including rain, extreme

temperatures, and wind, must also be considered, as weather resistance is critical for long-term effectiveness.

Additionally, an assessment of the energy efficiency of the manufacturing process is imperative, as sustainable solutions should minimize energy consumption. Evaluating the insulation properties of sugarcane bagasse- based roofing materials is crucial, as effective insulation contributes to energy efficiency by reducing the need for heating or cooling (Teotenio et al., 2018).

The Sustainability of Realization

The realization stage of an innovation is an important part, especially for products that support and pay attention to environmental issues. In the realization of SIR, of course, the main consideration is not only in terms of the environment, which is waste reduction, but also in terms of economics where to achieve the sustainability of its implementation, good economic feasibility is also needed so that production and continues to be disseminated in shaping and supporting environmental sustainability.

Prospective Market User

Considering the increasing population growth and that shelter is one of the necessities of human beings, the prospective market for SIR products is huge. This is also supported by people who are becoming more aware of environmental sustainability and waste utilization. This product can also be used as a cheap alternative for roofing houses compared to other options, and can even avoid the dangers of using asbestos roofs. The target market of this product when viewed from the family life cycle (FLC) is for the honeymooner stage and parenthood stage.

According to Soeharso & Kusumowidagdo (2016), in the honeymooner phase or what is called newly married and parenthood, the need for a house is the main focus. With the increasing demand for housing, sir products can be marketed as an alternative in purchasing to fulfill housing needs. SIR products can also be marketed with a Business to Business (B2B) and Business to Government (B2G) company scheme where it can be used as an option by housing developers or companies engaged in real estate and also government that related to infrastructure development and have a common perspective on a sustainable environment.

SWOT Analysis

The realization of SIR requires SWOT analysis, which is an analysis used to look at strengths, weaknesses, opportunities and threats. The SWOT analysis of SIR is as follows:

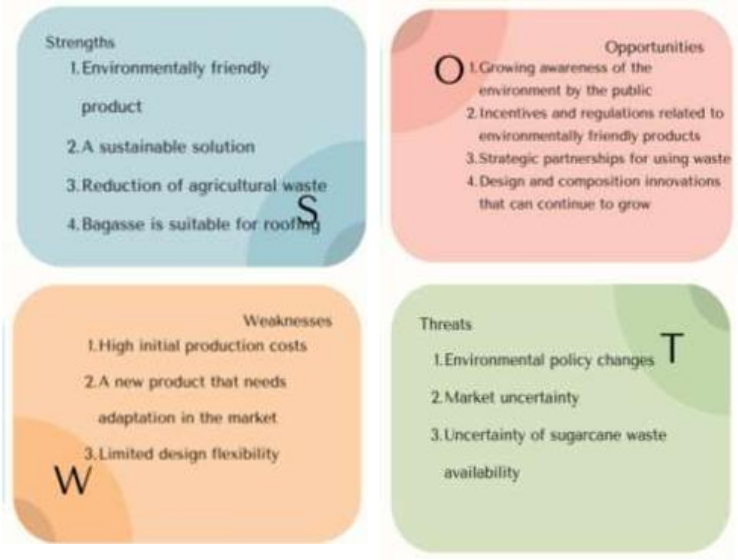

Figure 3.3 SWOT Analysis of SIR
Source: Author Documentation (2024)

Time Bound Implementation

The realization of SIR requires time and limits as well as milestones to be achieved within a certain time limit. In the implementation of SIR innovation, we set a time of 6 years to be able to establish and ensure the sustainability and feasibility of the business we plan to achieve as follows:

2025-2027	2028-2029
Licensing, patents, product standardization and feasibility tests. Building a small- scale business, experimentation and research, collaboration with sugarcane waste suppliers, and collaboration with local government	Developing medium- sized businesses. Marketing to the community with introduction and socialization to increase product- aware community, and collaboration with building material distributors and government related to infrastructure development.

In realizing this innovation, we need a lot of support and collaboration from various parties, ranging from government, academics, business communities and the media so that the role of each sector can help in realizing the innovation of SIR.

Conclusion

The surge in housing demand due to rapid population growth has led to a corresponding increase in the need for construction materials. To address this demand, there is a growing focus on exploring alternative, cost-effective building materials. Recent research has investigated the use of industrial waste, specifically

sugarcane bagasse, as a potential alternative material for roofing tiles. Sugarcane bagasse, an underutilized agricultural waste from sugar production, has shown promise in enhancing compressive strength when incorporated into roofing tiles. Sugarcane-Inspired Roofing is an environmentally friendly roofing innovation derived from bagasse waste that is designed with a futuristic and waterproof appearance. In its manufacture bagasse waste is combined with paper waste, glue and white cement. In its manufacture SIR follows the Indonesian National Standards (SNI) for roof tile products, with a target of 375 units per day for a total of 9,000 units per month. It is hoped that the application of this innovation can support Sustainable Development Goals (SDGs) such as renewable energy, sustainable cities and communities and climate action.

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