Sustainable Innovation: Applying Permaculture Architecture in the Mocaf Factory Design in Banjarnegara

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Abstract

Banjarnegara, a district in Central Java, possesses abundant natural resources suitable for cassava farming. However, the long distribution chain and the closure of several tapioca factories have significantly reduced the economic value of cassava in the region. To address this issue, this study aims to design a sustainable Modified Cassava Flour (Mocaf) industry using permaculture principles, focusing on resource efficiency, community welfare, and environmental sustainability. Mocaf flour, derived from fermented cassava, serves as an innovative substitute for wheat flour and supports regional food security. This research employs a descriptive method, which includes literature review, site surveys to evaluate land potential and accessibility, comparative studies, and analyses based on Permaculture Architecture principles. The factory design integrates sustainable strategies such as energy efficiency, waste management, and optimal resource utilization. Key features include zoning for production, storage, and waste treatment to streamline workflows and minimize environmental impacts. Solar panels are incorporated to enhance energy efficiency, while a wastewater treatment plant (IPAL) produces biogas from fermentation waste as part of an independent energy system. The proposed factory design highlights the principles of permaculture by emphasizing sustainability, resource efficiency, and harmony with the local ecosystem. By focusing on increasing local food production and minimizing environmental degradation, the design provides a model for sustainable industrial development and supports regional economic resilience.

Keywords: Permaculture Architecture, Energy Efficiency, Waste Management, Zonation

I. INTRODUCTION

Banjarnegara Regency, located in Central Java, is recognized as one of Indonesia's primary cassava-producing regions, with an annual cassava yield of approximately 130,000 tons as of 2021 [1],[5],[6] as the government's vision for 2005-2025, outlined in the Regional Long-Term Development Plan, is "Banjarnegara: Agriculture-Based Progress [9]. Cassava holds significant importance in Indonesia's agricultural landscape, as the country ranks fifth globally in cassava production [2]. Paradoxically, despite this robust production, Indonesia imported approximately 34,467 tons of wheat flour in 2019, contributing to a staggering 10.69 million tons of wheat imports in the same year [3]. This reliance on imported wheat highlights a mismatch between domestic cassava abundance and its underutilization for high-value processed products, exacerbating the economic challenges faced by local cassava farmers. Declining cassava prices have led to reduced planting activities, negatively affecting the overall cassava production in regions like Banjarnegara [4].

Existing studies reveal that cassava, or tapioca, is a crucial agricultural commodity in Banjarnegara, particularly in districts such as Pagedongan, Bawang, and Purwonegoro, which collectively produce over 93,319 tons of cassava annually [6]. Cassava's versatility has prompted efforts to transform it into higher-value products, such as modified cassava flour (mocaf), a gluten-free alternative to wheat flour with enhanced economic and health benefits [10]. Mocaf has the potential to improve the livelihoods of cassava farmers and promote food security by reducing Indonesia's dependency on wheat imports [7]. Furthermore, cassava's inherent physical characteristics, which hinder its storage in raw form, make processing into mocaf an attractive alternative to address storage challenges and enhance its marketability [1]. However, the absence of industrial infrastructure to process cassava sustainably limits its potential [5], [8].

Despite these opportunities, significant gaps persist in realizing the full potential of cassava as a sustainable food resource. Previous studies have primarily focused on cassava production and its traditional uses but have not addressed the integration of sustainability principles in processing facilities [7], [11]. Additionally, environmental challenges, including agricultural land conversion, poor water management, and extreme weather events, have adversely impacted cassava farming [11]. Existing industrial models for cassava processing are not designed with sustainability at their core, leaving room for innovations that align with ecological principles. This research addresses this gap by proposing the integration of permaculture principles into the design of a mocaf processing facility in Banjarnegara. The novelty lies in applying permaculture to achieve a harmonious balance between industrial efficiency, environmental conservation, and community welfare [12].

The main objective of this study is to design a sustainable mocaf processing facility in Banjarnegara Regency, integrating permaculture principles. This design aims to optimize land use, reduce environmental impact, and enhance resource efficiency in the industrial process. Additionally, the study seeks to improve the socio-economic conditions of local farmers by increasing the value of cassava production, thus enhancing their livelihoods. This approach will also contribute to reducing Indonesia's reliance on imported wheat. By applying permaculture principles, the study envisions creating a mocaf industry that not only strengthens food security but also sets a sustainable industrial model for other cassava-producing regions. The implementation of such a facility is expected to foster long-term ecological balance, improve agricultural practices, and provide an environmentally sustainable alternative to conventional industrial models [13].

This study is based on the assumption that integrating permaculture principles into industrial design can effectively promote sustainable development by creating a balance between agricultural production and environmental conservation. By incorporating these principles, it is anticipated that environmental challenges, such as land degradation, inefficient resource use, and ecosystem disruption, can be mitigated. Furthermore, this approach aims to foster economic growth and improve social welfare for local communities by increasing the value of agricultural products like cassava, thereby enhancing farmer livelihoods. A key hypothesis of this research is that establishing a mocaf processing facility based on permaculture principles will serve as a model for sustainable industrial practices. The design of such a facility is expected to address both environmental and socio-economic issues in Banjarnegara Regency, ensuring long-term viability for cassava farmers. Moreover, this permaculture-based model is anticipated to be replicable in other cassava-producing regions across Indonesia and potentially in similar agricultural contexts globally. By demonstrating the effectiveness of permaculture in agricultural processing industries, this study aims to contribute to a broader movement toward sustainable industrial practices that support both environmental and community resilience [12], [13].

II. METHOD

The initial step in planning a mocaf (modified cassava flour) factory using a Permaculture Architecture approach involves conducting a context and needs analysis. This entails understanding the requirements of cassava farmers and flour producers, as well as the geographical and social characteristics of the factory site. The findings of this analysis are then used to delve into and comprehend relevant permaculture architecture principles, such as energy efficiency and resource management, which are enriched through literature studies and consultations with experts. Next, the design concept is developed by engaging stakeholders in design workshops and SWOT analysis to create innovative and sustainable solutions.

The subsequent stage involves establishing comprehensive design guidelines that encompass layout, material selection, sustainability strategies, and expert consultation to ensure practicality. This phase entails developing various spatial development alternatives that align with the mocaf factory's requirements while also benefiting the surrounding community. Examples of implementation include educational spaces for farmer training, efficient production areas, and environmentally friendly water management systems, all aimed at achieving human-nature integration within the mocaf production process.

The design of the mocaf factory is a comprehensive process that balances functional, aesthetic, and sustainability aspects to ensure an efficient, environmentally friendly, and contextually appropriate facility. The design phase begins with a thorough site analysis, which examines the land's existing conditions, climate, accessibility, and infrastructure. Understanding the topography, vegetation, soil, and surrounding land use helps inform decisions about the suitability of the site. Climate conditions such as temperature, rainfall, and humidity guide the selection of materials and design features, while accessibility analysis ensures the site is easily reachable by road and public transportation. Additionally, an evaluation of available infrastructure, including water and electricity resources, is essential for planning the factory's operational needs.

Following this, user and activity analysis identifies the various users of the facility, including workers, visitors, and management, and defines the spatial requirements for each group. This ensures that the layout accommodates the necessary activities and workflows. Circulation analysis is next, focusing on both internal and external movement patterns. Internally, the flow of production, distribution, and emergency routes are optimized for safety and efficiency. Externally, access points for vehicles and pedestrians are strategically placed to minimize congestion and enhance operational effectiveness. This analysis also informs the zoning process, where the factory is divided into distinct functional areas such as production, storage, and administration.

Material selection is a critical part of the design, with choices made based on their compatibility with the local climate and their ability to withstand varying environmental conditions. Integrating natural elements into the design follows the principles of permaculture, which considers how the building can harmoniously interact with its surroundings. This includes incorporating vegetation, water management systems, and topography into the design, ensuring that the factory operates efficiently while minimizing its ecological footprint. Additionally, the integration of energy-efficient systems and water treatment technologies aligns with sustainable development goals.

The mass form analysis examines the overall composition of the building to ensure it responds well to the site's topography and environmental context, reflecting a cohesive aesthetic that blends with the natural surroundings. Zoning analysis further refines the spatial layout by grouping related functions together, optimizing space utilization and enhancing the movement of people, materials, and tools throughout the facility.

Finally, technology and utility analyses play a crucial role in ensuring the factory operates efficiently and sustainably. Technology analysis focuses on selecting production systems and automation technologies that reduce human error and increase operational efficiency. Utility analysis, on the other hand, involves designing the essential services such as clean water supply, waste management, electricity, ventilation, and security systems, while structural analysis ensures that the building is capable of supporting the design's functional and environmental needs. Together, these analyses inform a mocaf factory design that is sustainable, efficient, and well-integrated into its environment. Indeed, the framework for thinking in this design can be seen in Figure 2.

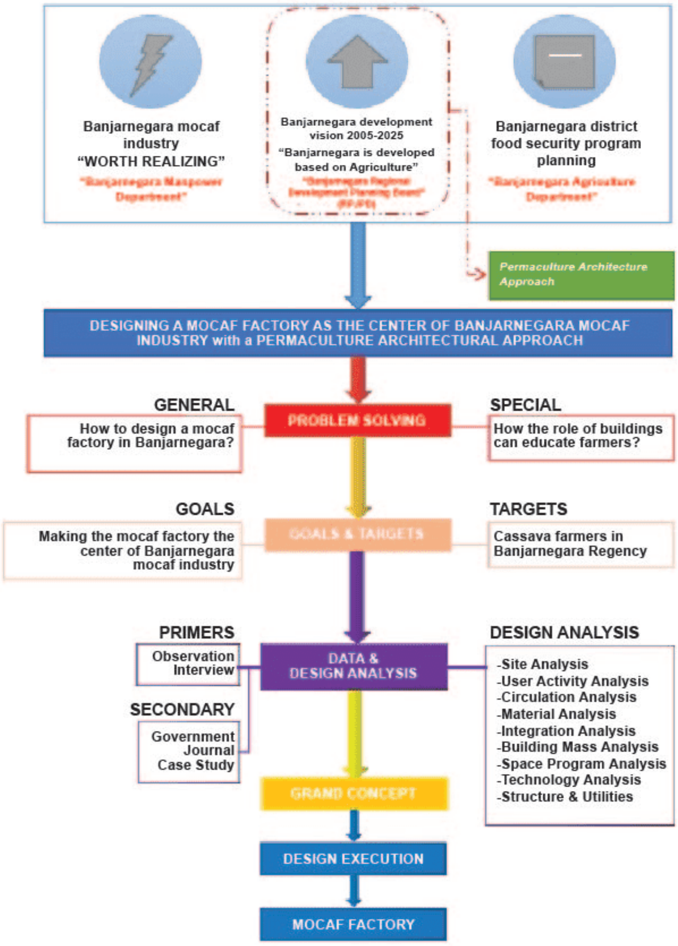

Figure 1 Thinking Framework Diagram

III. RESULTS AND DISCUSSION

A. Design Concept Development

The mocaf (Modified Cassava Flour) industry development concept focuses on improving sustainability and community welfare through a permaculture approach. The concept begins with the identification of several key issues, including agricultural land conversion, poor water management, climate change, unsustainable natural resource conservation, natural disaster management, dependence on fossil fuels, and waste management that does not meet standards. The strategies implemented include the principles of sustainable approaches, water management, integration, natural resource conservation, energy efficiency, and waste management. The goal is to create a mocaf industry center that not only provides employment opportunities and artisan offices, but also serves as an education center for farmers, finished product storage, and other supporting infrastructure. This development is expected to be able to accommodate cassava production on a wider scale, while supporting government programs in achieving sustainable development. This approach emphasizes the integration between people, nature, and buildings to achieve a sustainable balance. It is hoped that this step can change people's perspective on environmentally friendly agriculture [14].

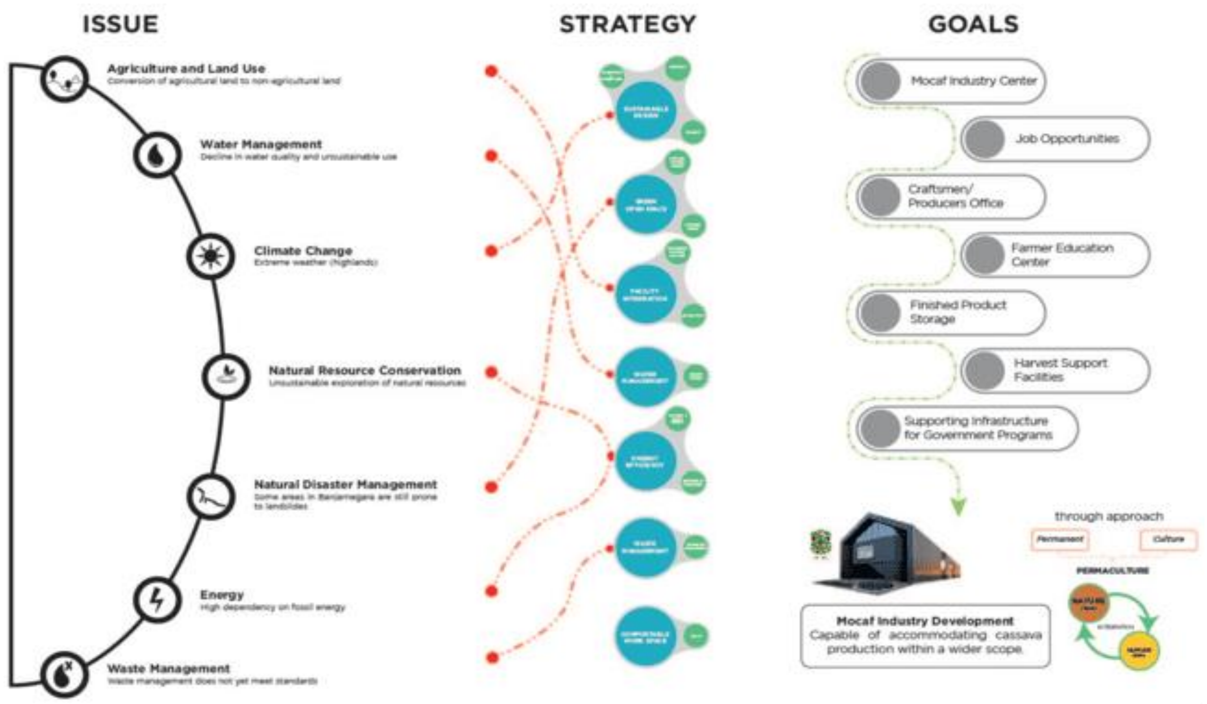

Figure 2 Grand Concept

In terms of sustainable design, [13] in their research, it explores how permaculture principles are applied in the context of natural landscapes and gardens in Japan, which can also be applied in industrial development [13]. Slightly different in the design of the mocaf factory in Banjarnegara Regency, one of the major issues is the problem of landslides and dynamic land topography in some places. This underlies the focus on implementing a permaculture approach that is prioritized to adapt to land topography and minimize site changes. Other studies by Tzanakakis, [15] examine various water management strategies in sustainable architecture, including the use of advanced technologies to support water conservation and flood prevention efforts [15]. This strategy inspired the design of the mocaf factory in Banjarnegara Regency to plan an efficient water management system by applying the principle of rain water harvesting.

B. Sustainable Design

Permaculture refers to a self-sustaining agricultural ecosystem. This term is an abbreviation of permanent agriculture. As implied by the name, this system emphasizes a farming method that attempts to replicate the relationships and patterns found in nature [16]. Sustainable design in the mocaf factory design is implemented with the principle of stability, emphasizing the creation of a balance between the building and the natural environment [17]. In this case, the design is developed in accordance with applicable government regulations (Figure 4). The development of the design on a site of 13,445.67 m² includes a Maximum Building Basic Coefficient of 70% (9,411,969 m²), a Minimum Green Area Coefficient of 30% (4,033,701 m²), a Maximum Building Floor Coefficient of 3 floors, and a Road Boundary Line of 7 meters from the centerline of the road.

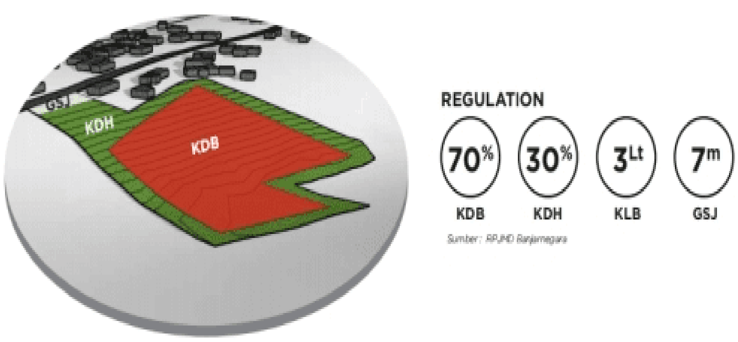

Figure 3 Illustration of Regional Zoning Regulations

In addition to the principle of stability, another strategic consideration is the use of the main structure from steel material. Steel is chosen because of its high strength and durability, and has a higher tensile strength compared to concrete. Steel is also an environmentally friendly material that can reduce maintenance and replacement costs, as well as support environmental conservation efforts by reducing construction waste. An overview of the structural system design with steel material can be seen in Figure 5.

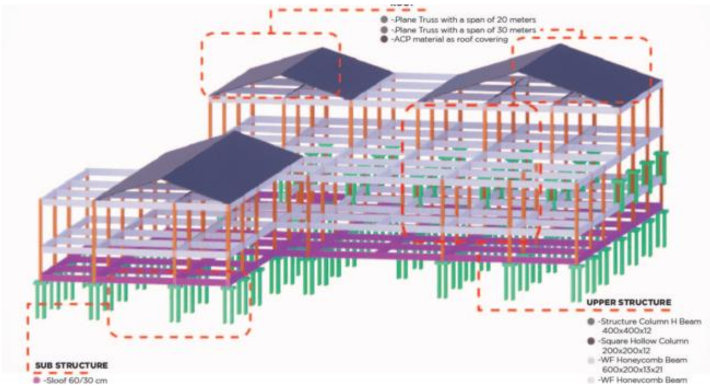

Figure 4 Application of Steel Material in Mocaf Factory Design

In addition to the principle of stability and strategy (benefit), the permaculture architecture approach also incorporates the principles of observation and interaction. This is exemplified by the use of automatic room temperature sensors in the warehouse area to ensure that the warehouse temperature remains constant, thus guaranteeing the hygiene and quality of the mocaf products (Figure 5).

Figure 5. Use of Automatic Sensors in the Warehouse

In line with the sustainability concept in the design of the mocaf factory in Banjarnegara Regency [18] examines the application of the principles of the New European Bauhaus in sustainable architecture education. This research emphasizes the importance of reducing greenhouse gas emissions, increasing building energy efficiency, and using renewable energy.

C. Topography Utilization

The aspect of topography utilization in the construction of the mocaf factory involves the application of the principle of natural pattern design by preserving the existing land topography. The factory is built using a stilt system, raising the building away from the ground and supported by columns and tie beams for structural stability, as shown in Figure 7.

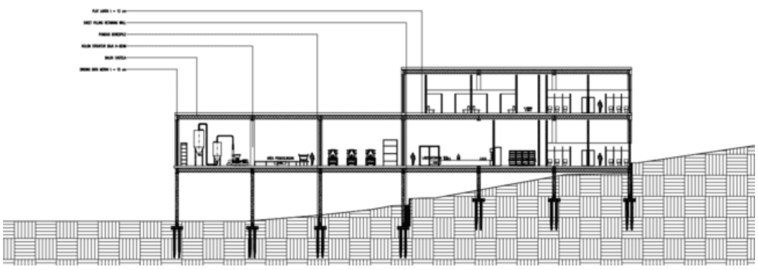

Figure 6 Stilt Construction System to Minimize Topography Changes

Vegetation is planted around the perimeter of the site to control wind paths so that air circulation within the site can establish a microclimate suitable for the building's function, as seen in Figure 8. This vegetation also serves as a noise control measure for the site. The selection of vegetation types is based on the land topography, using deep-rooted vegetation that acts as a landslide prevention measure (soil movement damper).

The design of the vegetation arrangement in this location is derived from the idea of permaculture which emphasizes plants that produce. Therefore, the choice of plants should not only consider their function and beauty, but should also be in line with the principles of permaculture. The vegetation arrangement plan developed earlier categorizes vegetation into three roles, namely producing plants, protective plants, and supporting plants [19]. The vegetation was selected based on the climatic conditions in the Banjarnegara region, such as Chinese petai trees, ketapang trees, mahogany trees, avocado trees, and vetiver grass. According to the National Disaster Mitigation Agency (BNPB), the leaves of vetiver grass can absorb carbon, and its roots act as a landslide and flood prevention measure, as well as improving water quality.

Figure 7 Application of Vegetation to Create Comfort on the Site

D. Facility Integration

To integrate spatial functions, the factory is designed with a zoning division that separates the management area, production areas for both dirty and clean processes, and waste treatment to streamline workflows and minimize negative environmental impacts, as shown in Figure 9. This strategy is also applied in the design of organic dairy factories by applying permaculture principles [20]. This study demonstrates permaculture principles, including the zoning system, and how they are applied in the context of agroecology.

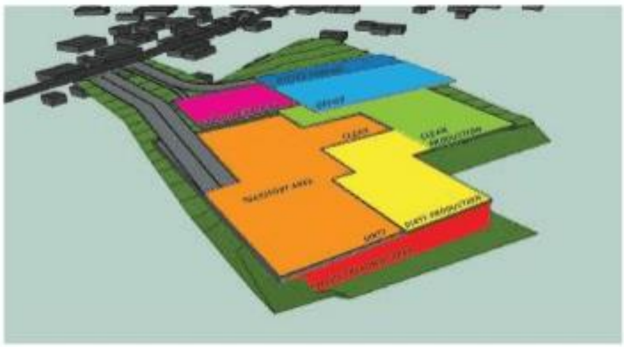

Figure 8 Function Grouping (Zoning) to Streamline Workflow

E. Energy Efficiency

In terms of energy efficiency, the factory is designed to optimize the use of solar energy (sunlight) that can be converted into electrical energy, as shown in Figure 10. The use of solar panels as an application of the energy and renewable resource capture and storage principle is an effort to manage and maintain systems aimed at energy efficiency and empowerment. Solar panels are used to assist in the drying process of mocaf chips in solar dryer domes. Making the most of the energy and materials available to you, starting with what is on-site and then seeking external sources as efficiently as you can. On-site energy sources encompass natural elements like gravity, wind energy, and hydropower [21].

The drying process of mocaf chips using solar panels will be faster compared to the direct sun drying process. In the design of the mocaf factory, a wastewater treatment plant is also designed to produce biogas from the fermentation wastewater treatment process. The energy generated is used for cooking in the employee canteen. The use of wastewater treatment plants as a self-sufficient system is a process to maintain purity in the permaculture concept [22]. Wastewater treatment plants produce biogas and residues that can be reused by managers and local farmers. The biogas produced can be used as fuel for electricity generators, and the residues can be used by local farmers as organic fertilizer. Organic fertilizers are beneficial for increasing agricultural production in terms of both quality and quantity, reducing environmental pollution, and improving land quality sustainably.

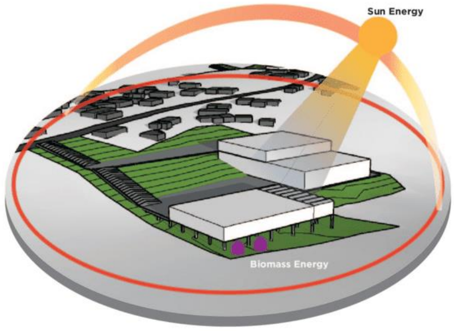

Figure 9 Illustration of the Use of Natural Energy

The design of a mocaf factory incorporates energy conservation and waste management practices, aligning with the principles. Their work explores the pentential of waste-to-energy technology to address global waste management challenges and reduce greenhouse gas emissions [22].

F. Waste Management

In addition to the self-sufficient system principle, the installation of a wastewater treatment plant also reflects the zero-waste and zero-residue principle. The gathering, keeping, and moving of this garbage poses many difficulties for managing solid waste[23]. This principle establishes a connection between inputs and outputs. Waste from the fermentation process is converted into biogas by collecting mocaf chip soaking water in a digester. Within the digester, anaerobic bacteria decompose the organic matter in the waste into methane (CH_4), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and water vapor.

Biogas generated from mocaf fermentation waste typically comprises 50-70% methane, with the remaining constituents being carbon dioxide, hydrogen sulfide, and water vapor. Other waste streams from mocaf production include unprocessed cassava that fails to meet sorting criteria and cassava peels from the peeling process. These unprocessed cassava and cassava peels can be utilized as animal feed for livestock such as cows and goats. Therefore, dedicated waste storage areas and warehouses should be established within the factory premises to accommodate these waste materials, which can then be repurposed by local farmers and factory operators.

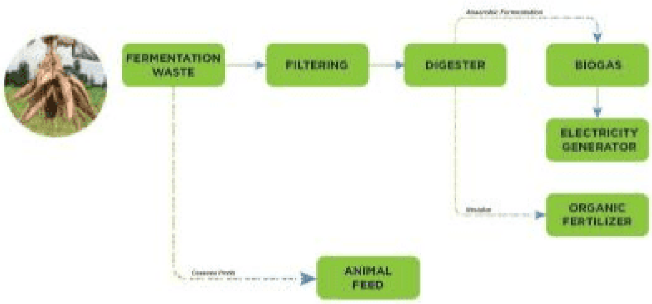

Figure 10 Production Waste Flowchart

Similar strategies were also employed in the design of a wastewater treatment plant in an urban setting using a permaculture approach [24]. The primary focus of this research is to explore waste management methods through the gasification of municipal solid waste combined with biomass for energy production and resource recovery. It highlights the importance of facilities that support advanced technology in efficient waste management [24].

G. Workplace Comfort

The design of a mocaf (modified cassava flour) factory using a permaculture approach focuses on implementing sustainable agricultural technologies. This approach integrates humans and nature in a harmonious unity. One of the main goals is to facilitate education for farmers and flour craftsmen so that they can produce high-quality products in an efficient and environmentally friendly way. The size of the space is designed according to needs and activities to provide optimal work comfort. The aspect of work comfort is an implementation of the scale principle where the space in the mocaf factory is designed to provide functions from the smallest to the largest scale that are practical and efficient. The size of the space in each workspace is adjusted to the needs, capacity, activities, and size of furniture and/or machinery. The results of developing space requirements in the mocaf factory design can be seen in Table 4.

Table 1 Space Dimensions

Space Requirement	Space Dimension
Office	1800 m²
Production Plant	4200 m²
Service	730 m²
Wastewater Treatment Plant (WWTP)	1040 m²
Parking Lot	900 m²
Total Area	**8670 m²**

Comprehensive space planning with adequate dimensions is crucial for the success of a design in accommodating functions and activities, and it will undoubtedly determine the comfort of using the space and building. This aligns with the views of Hathaway [25], who suggests that permaculture offers solutions to major ecological issues through a design approach that considers the entire agricultural system and its interaction with the environment. This approach also focuses on creating a comfortable and productivity-supporting work environment through efficient and functional space design.

IV. CONCLUSION

In response to the various environmental issues found and the aspirations of Banjarnegara Regency to develop alternative food sources, the design of the mocaf factory is developed using a permaculture approach that is believed to be able to make a positive contribution to environmental sustainability. The permaculture architecture approach provides advantages to the building design so that it can harmoniously contribute to the environment. Furthermore, this approach also provides benefits for social community development through the development of educational functions in the design. The strategies for developing the mocaf factory design in Banjarnegara Regency are to use the following principles: 1) Sustainable Design, 2) Topography Utilization, 3) Facility Integration, 4) Energy Efficiency, 5) Waste Treatment, and 6) Workspace Comfort. Each strategy emphasizes permaculture principles that aim to create a balance between human and nature's needs, and to ensure that mocaf industry development can be sustainable and provide long-term benefits to society and the environment.

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