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To cite this article: A Z Husna *et al* 2025 *IOP Conf. Ser.: Earth Environ. Sci.* **1574** 012026

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Designing with local materials: toward sustainable temporary housing after the 2021 Mount Semeru eruption in Indonesia

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Abstract. This study proposes a modular prototype for temporary post-disaster housing using a hybrid system of bamboo, galvalume, and light steel framing (LSF), aiming to address urgent shelter needs after the 2021 Mount Semeru eruption. The design emphasizes structural efficiency, rapid construction, and environmental sustainability through the integration of renewable local materials and industrial components. Bamboo is selected for its availability, low carbon footprint, and community-based application, while galvalume and LSF are incorporated to enhance durability, prefabrication efficiency, and moisture resistance. This research adopts a Design-Based Research (DBR) methodology, which involves iterative design exploration, contextual material mapping, and prototype visualization to develop a realistic and adaptable housing solution. The prototype utilizes five modular wall panels, each tailored to specific spatial and environmental functions, allowing for flexible assembly and disassembly. This system supports low-waste construction and circular use of materials, aligning with sustainable development goals. A contextual design strategy underpins the spatial layout, enabling transition from temporary to permanent housing.

Keywords: Design-Based Research (DBR), modular system, renewable local materials, sustainable materials, temporary housing

1. Introduction

Indonesia is recognized as one of the countries with the highest vulnerability to natural disasters in the world [1]. These disasters include floods, landslides, earthquakes, tsunamis, and volcanic eruptions, each varying in scale, severity, and impact on communities [2]. The country's high volcanic risk is largely due to the fact that approximately 30% of the world's active volcanoes are located within Indonesian territory [3]. Studies have shown that Indonesia, along with the Philippines and the West Indies, accounts for the highest number of fatalities caused by volcanic eruptions globally [4], highlighting the urgent need for effective disaster mitigation strategies as part of a broader framework for sustainable development.

One of the most significant volcanic disasters in recent years was the 2021 eruption of Mount Semeru in East Java, Indonesia [5]. The disaster damaged at least 2,970 homes and displaced thousands of residents, who were forced to live in inadequate shelters or relocate to new, safer

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areas. The relocation process involved multiple stakeholders, including government agencies, NGOs, practitioners, and academic institutions [6]. This multi-stakeholder involvement resulted in various proposals for temporary housing (*hunian sementara* or *huntara*), addressing spatial layout, building function, and the use of locally available materials that could be assembled collaboratively through community participation [7].

In post-disaster contexts, the provision of temporary shelters is a top priority due to the inadequate condition of emergency shelters, safety concerns, and the urgency of physical, psychological, and economic recovery for affected populations [8]. However, temporary housing design must also overcome several challenges, including the need for rapid construction, material efficiency, environmental sustainability, and cultural and climatic appropriateness. Therefore, a design approach rooted in the use of local materials is essential to produce shelters that are not only functionally adequate in the short term but also contribute to long-term ecological and social recovery.

In this context, bamboo is recognized as a highly promising and sustainable local material for post-disaster construction. It is abundantly available in relocation areas and offers advantageous properties such as being lightweight, strong, fast-growing, flexible, and environmentally friendly [9–12]. As a renewable natural resource with low embodied energy, bamboo supports ecological goals in building design. Previous studies, including post-disaster shelter projects in Lombok, have demonstrated their effectiveness in facilitating rapid and environmentally responsible construction [13]. Bamboo-based structures have also been shown to encourage community involvement and foster a sense of ownership among disaster-affected populations [14].

Concerns about the durability of bamboo and its resistance to weather, especially in humid areas without proper treatment, remain. To address these challenges, combining bamboo with industrial materials such as galvalume and light steel framing can enhance structural stability, moisture resistance, and construction speed, particularly within a modular system. Industrial materials offer distinct benefits, including quick construction, ease of installation, structural strength, and high recyclability [15,16]. The light steel frame (LSF) system enables the prefabrication of building components off-site, allowing for rapid assembly on-site, which helps to significantly reduce construction time in emergencies. Despite the increasing interest in hybrid materials for post-disaster housing, there is still a notable gap in research regarding the integration of local materials like bamboo with industrial materials such as galvalume and light steel framing within a modular design framework. Most studies focus on these materials in isolation, overlooking the potential advantages that such combinations could offer in terms of construction efficiency, environmental sustainability, and contextual relevance.

This study aims to fill this gap by introducing a bamboo-galvalume hybrid system within a modular architectural framework, developed using a Design-Based Research (DBR) approach. The originality of this research lies in its integration of local and industrial materials and its specific application to the context of the 2021 Mount Semeru eruption—an area that has not been explored in previous modular housing studies. This integrative strategy seeks to advance knowledge in adaptive post-disaster architecture and provide practical insights to support resilient housing policies in high-risk regions like Indonesia.

2. Methods

This study adopts a Design-Based Research (DBR) approach to explore the integration of local materials (bamboo) and industrial materials (galvalume and light steel framing) in the design of sustainable temporary housing following the 2021 eruption of Mount Semeru in Lumajang, Indonesia. DBR was selected due to its suitability for addressing real-world problems through iterative cycles of design, testing, evaluation, and refinement in real-life contexts. Previous studies have demonstrated the effectiveness of DBR in post-disaster architectural reconstruction, as it enables collaboration between researchers, end-users, and stakeholders to develop adaptive and context-sensitive design solutions [17–20]. The DBR implementation in this study consists of the following five stages:

1. Problem identification. This stage involved analysing post-disaster conditions, including the extent of housing damage, the availability of bamboo as a local resource, and the role of government and NGO initiatives in temporary housing provision. Data were gathered from field reports, interviews, and official documentation.
2. Initial design development. Based on the contextual findings, a modular housing prototype was developed using a hybrid material strategy: bamboo for wall infill, galvalume for roofing and moisture protection, and light steel framing as the main structural system. The design process was visualized using SketchUp to simulate spatial layout, structural configuration, and environmental performance.
3. Evaluation and feedback. The prototype was assessed through Focus Group Discussions (FGDs) involving practitioners, academics, and local stakeholders. Evaluation criteria included material efficiency, ease of assembly, thermal comfort potential, and cultural appropriateness within the local setting.
4. Reflection and design refinement. Based on the feedback received, the design underwent several modifications, including improvements to joinery systems, cross ventilation, and roof insulation. The revised prototype was visualized and documented as a refined design outcome.
5. Generalization of design principles. The final stage involved formulating modular design principles that can be adapted and replicated in similar post-disaster contexts. These principles emphasize hybrid material strategies, community involvement, and modular flexibility adaptable to diverse geographic and climatic conditions.

3. Results and discussion

3.1 Contextual needs and material mapping

The 2021 eruption of Mount Semeru resulted in a complex emergency characterized by widespread destruction and severe logistical challenges. According to Indonesia's National Agency for Disaster Management (BNPB), approximately 2,970 houses were heavily damaged, volcanic deposits buried hundreds of hectares of agricultural land, and numerous public facilities were destroyed [5]. Additionally, extensive damage to road infrastructure in several areas restricted access to disaster zones. These conditions not only disrupted evacuation efforts and the distribution of aid but also delayed the urgent initiation of temporary housing development. Under these conditions, the utilization of local materials became a practical and efficient solution, as it minimized reliance on disrupted external supply chains.

The Lumajang region and surrounding areas offer a variety of local materials suitable for post-disaster construction. These include timber species such as *sengon* and *albasia*, volcanic sand from Mount Semeru's slopes, river stones, and clay, which can be processed into handmade bricks or compressed earth blocks. In addition, agricultural waste, such as coconut husks and rice straw can be repurposed as natural fibre insulation. However, many of these materials face technical limitations, including long processing times, the need for additional energy inputs, and relatively low durability against moisture and extreme weather conditions.

Among these materials, bamboo emerges as a particularly promising option in terms of sustainability, construction efficiency, and compatibility with local knowledge and resources. It is widely available in the relocation zones of Lumajang, affordable, and fast-growing, making it an environmentally responsible and renewable resource [9–12]. Bamboo also possesses excellent mechanical properties, including being lightweight, strong, flexible, and earthquake-resistant, and supports the principles of low-carbon and low-impact construction. Previous studies have demonstrated its effectiveness in temporary housing, such as in the post-earthquake reconstruction in Lombok, where bamboo provided a fast and eco-friendly solution [13]. Furthermore, bamboo-based construction fosters direct community involvement, drawing upon local traditions and generational knowledge, thereby accelerating the building process while strengthening social ownership and sustainability [14].

The use of bamboo also represents an adaptive response to logistical constraints on the ground. With transportation routes severely disrupted and the delivery of industrial building materials impeded, bamboo offers a strategic alternative that can be harvested, processed, and applied directly on-site. Thus, bamboo is not only technically and ecologically viable but also contributes to an efficient and locally grounded post-disaster recovery strategy.

Nevertheless, bamboo has inherent limitations, particularly in terms of its vulnerability to moisture, pests, and limited durability if not properly treated. To overcome these challenges, an integrative approach is required that combines bamboo as a local material with industrial materials such as galvalume and light steel framing within a modular construction system. This strategy aims to deliver temporary shelters that are rapidly deployable, structurally resilient, resource-efficient, and scalable across other disaster-prone contexts.

3.2 Environmental performance of bamboo and galvalume

Bamboo is recognized as a sustainable and eco-friendly material, particularly in tropical and subtropical regions. It grows rapidly and abundantly, maturing in just three to five years. This rapid growth makes bamboo a potential renewable resource thar does not require replanting or extensive land conversion. As a lightweight material, bamboo has an excellent strength to weight ratio making it suitable for various applications, especially in remote or logistically challenged areas [23]. The manufacturing process for bamboo is simple and low-energy consumption, typically involving manual cutting, air-drying, and mechanical fastening. The previous studies have shown that bamboo can consume up to 60% less energy compared to conventional materials like steel and concrete, which further emphasizes its environmental benefits. Moreover, bamboo processing generally avoids the use of hazardous chemicals, contributing to its low embodied carbon footprint [24]. Thus, bamboo represents a material alternative that supports sustainable environmental practices, mitigates carbon emissions, and enhances ecological resilience in construction.

Bamboo adaptability extends to both structural and architectural applications. It can be transformed into durable components using self-bonding techniques that utilize the materials natural lignin under heat and pressure, or trough low emission, bio-based adhesives that minimize volatile organic compound (VOCs) release [25]. This promotes healthier indoor environments. Bamboo's versatility allows it to be used in a wide range of building components, such as flooring, wall panels, roofing, ceiling boards, doors, windows, and modular partitions. Real-world examples include the Assam-type house in Northeast India and the modular bamboo shelters built following the Lombok earthquake [13,26]. Additionally, bamboo is biodegradable and compatible with circular economy principles, ensuring its environmental impact is minimal throughout its lifecycle. These qualities position bamboo as a technically and economically viable

IOP Conf. Series: Earth and Environmental Science **1574** (2025) 012026 doi:10.1088/1755-1315/1574/1/012026

construction material and as a scalable, strategic solution for sustainable, low-impact, and community-driven development, especially in vulnerable or disaster-prone areas.

In contrast, industrial materials like galvalume and light steel framing (LSF) offer certain advantages in modular construction systems, particularly regarding accelerated construction and structural efficiency. Galvalume boasts high corrosion resistance—up to twice as good as conventional galvanized steel when coated appropriately for environmental conditions [27–30]. It also features a reflective surface that aids in passive thermal control, significantly reducing heat gain in tropical climates and improving indoor thermal comfort [31]. However, it is important to note that galvalume has heat-conducting properties when used on roofs, necessitating the addition of thermal insulation for optimal comfort [32].

Meanwhile, Light Steel Framing (LSF) is characterized by high dimensional precision, structural stability, and light weight. Several life cycle assessment (LCA) studies have indicated that LSF can greatly reduce environmental impacts due to its material efficiency, rapid installation, and minimal construction waste. For instance, using LSF decreases the amounts of concrete and wood needed in construction, which in turn reduces the carbon footprint. The prefabrication potential of LSF also shortens project time on-site, improves labour efficiency, and reduces logistics impacts. Additionally, LSF is reusable or recyclable.

In the context of temporary housing (*huntara*) after the Mount Semeru eruption, combining LSF, galvalume, and bamboo materials can enhance the durability and efficiency of the modular system while maintaining sustainability. The integration of LSF and galvalume in these temporary housing structures enables material reuse once the buildings are converted to permanent housing. This approach aims to strike a balance between construction speed, structural strength, and environmental performance, while supporting the development of adaptive and context-sensitive temporary housing solutions after the Mount Semeru eruption. Such adaptability ensures that the housing can be tailored to the specific conditions in post-disaster areas, providing reassurance of the system's flexibility.

3.3 Modular prototype development

The development of this prototype study addresses the urgent need for temporary housing following the Mount Semeru eruption. The goal is to create a structure that is not only quick to build but also robust and environmentally friendly. The designed temporary housing has a basic size of 4.5 x 4.5 meters. It includes essential living spaces: one bedroom, one living room, one bathroom, one kitchen, a terrace, and a small garden area that serves as a transitional green space (Fig. 1). This layout is designed to provide basic comfort and minimal privacy while also being adaptable for future needs, ensuring a sense of reassurance regarding its long-term viability.

The temporary housing is designed using a modular system based on wall panels and structural components of specific sizes that have been adjusted to facilitate the construction process, either through prefabrication or on-site assembly. These modules include 75 cm, 150 cm, and 225 cm walls with a standard height of 250 cm, which can be combined according to spatial requirements. This modular approach aims to reduce carbon emissions through material and energy savings during construction, as well as minimize building waste due to the components being designed with precision and efficient material utilization. Furthermore, the modular system facilitates the dismantling and reuse of components during the transition from temporary to permanent housing, in line with the principles of a circular economy and sustainability.

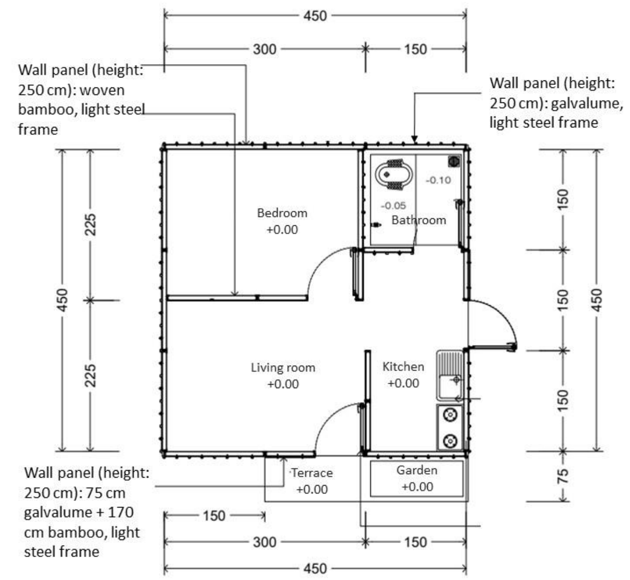
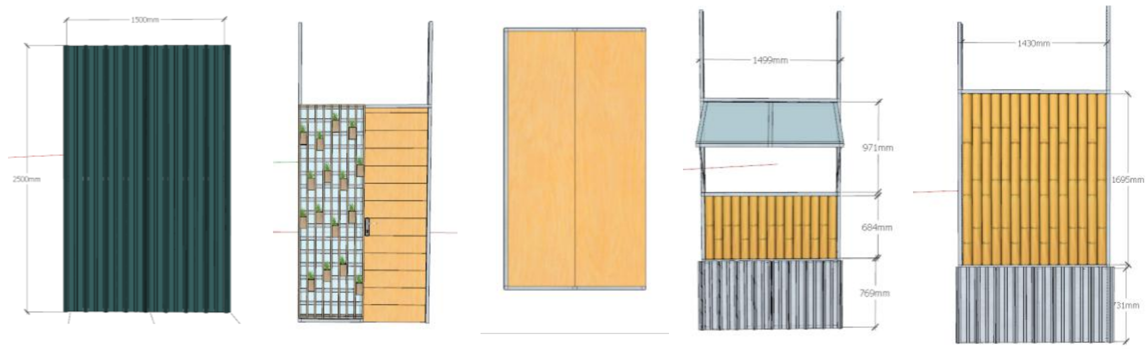


Figure 1. The spatial layout of temporary housing



wall panel 1 wall panel 2 wall panel 3 wall panel 4 wall panel 5

Figure 2. Five types of wall panels

Temporary housing prototype development utilizes a modular wall panel system with five types of wall panels designed to suit the spatial functions and contextual environment (Fig. 2). The panel dimensions are designed with a standard height of 250 cm and widths that vary based on their position and function. The wall panel types are as follows:

a. Wall panel 1: Galvalume (150 cm x 250 cm), used in the bathroom and kitchen areas to protect against high humidity and maintain user privacy.
b. Wall panel 2: A combination of galvalume, bamboo, and vertical gardens (75 cm x 250 cm), installed in the front terrace area to provide shade, an aesthetically pleasing facade, and natural air circulation and filtration through the vertical plants.
c. Wall panel 3: Woven bamboo (225 cm x 250 cm), serves as an internal partition wall separating the bedroom and kitchen from the living room, providing local texture and adaptability.

d. Wall panel 4: A combination of galvalume, bamboo, and glass (150 cm x 250 cm), used in the living room and bedrooms to maximize natural lighting and cross-ventilation, while enhancing occupants' visual comfort.
e. Wall panel 5: A combination of galvalume and bamboo (150 cm x 250 cm), used extensively throughout the building. The use of galvalume on the underside of this panel aims to reduce soil moisture and minimize the effects of rainwater splashes during the rainy season.

Each panel is designed to be prefabricated or assembled directly on-site using a knock-down system, allowing for time efficiency, quality control, and ease of disassembly and assembly when needed.

The application of a modular wall panel system in this temporary housing prototype development reflects a design strategy that considers the tropical context, construction efficiency, and material sustainability. Each wall panel is specifically designed to meet the functional needs of the space, taking into account privacy requirements, local climate conditions, and the principle of modularity, which allows for flexibility in installation and disassembly.

The combination of materials used in the wall panels—such as galvalume for moisture resistance, bamboo as a sustainable local material, and transparent elements like glass—ensures effective natural lighting within the building. For instance, wall panels 1 and 5 emphasize resistance to moisture and rainwater, which is particularly crucial in disaster-prone and high-rainfall environments. In contrast, wall panel 2, which integrates a vertical garden, contributes to improved air quality and a micro-cooling effect. Wall panel 3, made from woven bamboo, reflects local wisdom while also serving as a lightweight and easy-to-install space divider. These panels are designed in consistent modular dimensions, facilitating efficiency in mass production and on-site assembly while also minimizing potential construction waste.

Figure 3. The structure plan of temporary housing

Additionally, the use of Light Steel Framing (LSF) as the primary structural material for the middle and roof structures offers significant advantages for temporary housing that may transition to permanent housing (Fig. 3). LSF demonstrates high resistance to tropical weather and corrosion, along with precise dimensions that support efficient integration of modular components [33,34]. Its durability makes it suitable for buildings intended for longer lifespans, eliminating the need to replace the main structure when the dwelling is converted to a permanent one. Moreover, LSF has an excellent strength-to-weight ratio, which helps reduce foundation loads without compromising structural integrity. Its fast, clean, and waste-free fabrication and assembly processes also make LSF an appropriate choice in post-disaster situations where time and resources are limited.

Overall, the development of this temporary housing prototype demonstrates that a modular system based on a combination of local and industrial materials can provide an effective solution to address post-disaster needs (Fig. 4). The modular design allows for high speed in construction and dismantling processes, as well as efficiency in terms of time, labour, and resources. The integration of five types of wall panels with tailored functions demonstrates the application of function-based design principles, where each component is designed to address specific issues such as humidity, air circulation, natural lighting, as well as aesthetics and visual comfort. The use of local materials such as bamboo not only reduces carbon emissions and construction waste but also enhances community involvement in the construction process.

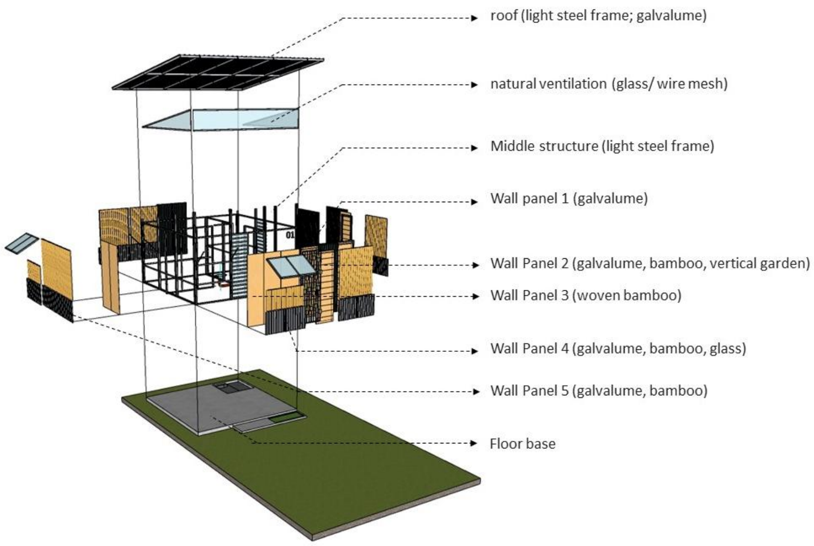


Figure 4. The axonometry of temporary housing

Furthermore, the use of LSF as the primary structure offers advantages in terms of strength, precision, and durability. Its resistance to corrosion and extreme weather conditions makes LSF ideal for the transition from temporary to permanent housing. The LSF fabrication process, which supports prefabrication, also accelerates project duration and reduces logistical burdens, which are crucial in emergencies. The synergy between LSF and flexible modular panels creates a hybrid construction system that is not only strong and fast but also has a low environmental impact.

This modular prototype model offers a contextual, efficient, and sustainable approach to post-disaster temporary housing construction. By implementing a wall panel system based on a combination of local and industrial materials and utilizing LSF as the primary structure, this plan not only addresses technical and logistical challenges but also opens up the possibility of replication and adaptation in other areas with similar conditions. This design strategy supports the principles of sustainability, adaptation, and transitional readiness for long-term housing. Therefore, this prototype can be a significant contribution to the development of a resilient, inclusive, and environmentally friendly disaster-responsive housing system.

3.4 Environmental implications of material choices

The selection of materials for post-disaster housing is vital in achieving a balance between the urgent need for rapid construction and the imperative of environmental sustainability. Local materials, such as bamboo, provide substantial ecological benefits, including rapid renewability, low carbon emissions, minimal energy consumption during processing, recyclability, and affordability [23–26]. These features make bamboo particularly well-suited for emergencies where speed, cost-effectiveness, and environmental considerations are of paramount importance.

In contrast, industrial materials like Light Steel Framing (LSF) and galvalume present unique environmental trade-offs. While they require more energy during production, resulting in higher embodied energy, they offer long-term advantages in terms of structural precision, durability, and recyclability. For instance, galvalume exhibits excellent corrosion resistance, which prolongs the lifespan of building components and reduces the need for frequent replacements or extensive maintenance. Meanwhile, LSF facilitates prefabricated construction methods that help minimize on-site waste, shorten construction timelines, and lower emissions generated during the building process [28,31,33,34].

This study advocates for a hybrid material strategy that combines bamboo with galvalume and LSF within a modular design framework. This approach not only addresses the immediate needs of post-disaster response but also integrates sustainability into the core construction process. The modular design enables easy disassembly and reuse of components, aligning with the principles of the circular economy and mitigating the environmental impact of repeated rebuilding. Ultimately, this strategy enhances resilience, accelerates shelter deployment, and reduces both material waste and long-term ecological effects.

4. Conclusion

This study illustrates the significant potential of a modular design approach that integrates local and industrial materials—namely bamboo, galvalume, and light steel framing (LSF)—for creating resilient, efficient, and environmentally responsible temporary housing in post-disaster scenarios. The conceptual prototype developed in this research addresses the urgent shelter needs that arose following the 2021 Mount Semeru eruption, meeting essential criteria such as rapid construction, resource efficiency, community involvement, and future adaptability for transformation into permanent housing systems.

Bamboo, a renewable and low-carbon local material, not only provides ecological benefits but also encourages community engagement in the construction process. In contrast, galvalume and LSF contribute structural precision, dimensional stability, and long-term durability, making them compatible with prefabrication techniques. The proposed modular system features five function-specific wall panel types, enabling rapid on-site assembly, minimizing construction waste, and facilitating future disassembly and reuse. These characteristics align closely with circular design principles and support Sustainable Development Goal 11, which emphasizes the need for inclusive, safe, resilient, and sustainable human settlements.

It is important to note, however, that this prototype is still in the conceptual design stage, with no physical testing or field implementation conducted to date. Consequently, follow-up studies are essential to validate its performance. Such studies should include computational simulations to evaluate thermal comfort under various tropical conditions, life cycle assessments (LCA) to quantify embodied carbon and environmental impacts, and pilot-scale construction projects to assess feasibility in real-world settings. Moreover, this study advocates for the incorporation of modular and hybrid material systems into national and regional post-disaster housing policies. Adoption by government-led reconstruction initiatives could significantly enhance the speed, sustainability, and community relevance of housing responses during future disaster events. By bridging ecological design, construction efficiency, and local adaptability, the proposed system represents a valuable contribution to disaster resilience and long-term recovery planning in Indonesia and other vulnerable regions.

Acknowledgements

This research was supported by the Institute for Research and Community Service (LP2M) of UIN Maulana Malik Ibrahim Malang through the Litapdimas (Research, Scientific Publication, and Community Service) Program in 2022.

AI Use Acknowledgements

To ensure linguistic clarity and consistency, this manuscript utilized the assistance of artificial intelligence (AI) tools—specifically ChatGPT (OpenAI) and Grammarly—for the purposes of translation from Bahasa Indonesia to English and for language refinement. The AI-assisted process was employed to improve grammatical accuracy, coherence, and academic tone while maintaining the originality and integrity of the research content. All technical terms, conceptual frameworks, and data interpretations were reviewed and verified manually by the authors to ensure that the final manuscript accurately represents the intended meaning and scholarly standards.

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