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DEVELOPMENT OF A PREFABRICATED HOUSE PROTOTYPE WITH DFMA AND BIM INTEGRATION

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Abstrak

Meningkatnya permintaan akan perumahan yang layak di Indonesia, didorong oleh pertumbuhan penduduk yang pesat, terus menimbulkan tantangan substansial, terutama karena inefisiensi dalam metode konstruksi konvensional. Perumahan prefabrikasi menawarkan alternatif yang menarik, dengan keunggulan dalam kualitas, efektivitas biaya, efisiensi waktu, dan pengurangan limbah. Namun, integrasi tahap awal yang terbatas sering kali menyebabkan desain yang kurang terdefinisi, sehingga menghambat adopsi yang lebih luas. Studi ini bertujuan untuk mengembangkan prototipe rumah prefabrikasi dengan mengintegrasikan DFMA dengan BIM. Metode kualitatif deskriptif digunakan, memanfaatkan data sekunder yang berasal dari literatur. Prosesnya dimulai dengan pemodelan rumah konvensional sebagai baseline, yang kemudian direstrukturisasi menjadi sistem prefabrikasi melalui prinsip-prinsip DFMA, pemodelan BIM menggunakan Autodesk Revit, dan evaluasi sistematis menggunakan perangkat penilaian DFMA yang mencakup aspek manufaktur, transportasi, dan perakitan. Studi ini menghasilkan dua model prototipe berdasarkan sistem panel modular. Pengurangan 30% dalam jumlah komponen dicapai dalam transisi dari model konvensional, sementara pengurangan 7,45% dalam jumlah panel diamati antara dua model prefabrikasi. Integrasi DFMA dan BIM secara signifikan meningkatkan efisiensi desain, memastikan organisasi struktural yang lebih baik, dan meningkatkan kesiapan implementasi yang menghadirkan strategi yang layak untuk mendukung upaya penyediaan perumahan.

Keywords: BIM, DFMA, sistem panel, prefabrikasi

Abstract

The growing demand for adequate housing in Indonesia, fueled by rapid population growth, continues to pose a substantial challenge, particularly due to inefficiencies in conventional construction methods. Prefabricated housing offers a compelling alternative, with advantages in quality, cost effectiveness, time efficiency, and waste reduction. However, limited early stage integration often leads to poorly defined designs, hindering its broader adoption. This study aims to develop a prefabricated house prototype by integrating DFMA with BIM. A descriptive qualitative method was employed, utilizing secondary data derived from literature. The process began with modeling a conventional house as a baseline, which was then restructured into a prefabricated system through DFMA principles, BIM modeling using Autodesk Revit, and a systematic evaluation using DFMA assessment tools covering manufacturing, transportation, and assembly aspects. The study resulted in two prototype models based on a modular panel system. A 30% reduction in component count was achieved in transitioning from the conventional model, while a 7.45% reduction in panels was observed between the two prefabricated models. The integration of DFMA and BIM significantly improves design efficiency, ensures better structural organization, and enhances readiness for implementation presenting a viable strategy to support housing provision efforts.

Keywords: BIM, DFMA, Modular Panel System, Prefabricated House

I. INTRODUCTION

Housing is a fundamental human necessity. As the population continues to grow rapidly, the demand for adequate housing rises correspondingly. According to the Ministry of Public Works and Housing (PUPR), Indonesia's housing backlog reached 12.7 million units in 2023, underscoring a significant national challenge in ensuring housing provision.

One major obstacle in meeting this demand is the continued reliance on conventional construction methods, which tend to be inefficient. To address this issue, prefabricated housing technology has been introduced. This approach involves manufacturing building components off-site, which are then transported and assembled on-site within a relatively short timeframe [1].

To ensure the effectiveness of prefabricated construction, it is crucial to establish the design early, as this helps prevent issues during implementation [2]. In this regard, the application of Design for Manufacturing and Assembly (DFMA) plays a vital role. DFMA facilitates early-stage integration among design, fabrication, transportation, and assembly processes, thereby minimizing the risk of errors [3]. This integration becomes more effective when supported by Building Information Modelling (BIM), a digital platform that enhances coordination throughout all design stages [4] [5].

This study aims to develop a prefabricated housing prototype by integrating DFMA and BIM to support the provision of housing with a design that is simple, easy to manufacture, and assemble. However, in Indonesia, the integration of DFMA and BIM in the design of prefabricated houses is still rarely implemented; hence, the potential for construction efficiency has not been fully optimized. This research is limited to the design scope of a simple house type of 36 m^2, utilizing data derived from literature studies and BIM simulations without direct field observation. For large scale implementation, the design requires further refinement through subsequent research involving field observations, assessments of design readiness, market acceptance analyses, and evaluations of technical and logistical factors to ensure both success and sustainability. The integrated prototype developed in this study is expected to provide an applicable solution for the housing industry, particularly in addressing the national housing backlog.

II. LITERATURE REVIEW

A. Prefabricated Construction

Prefabricated construction is an innovative approach that relocates the majority of construction activities from the project site to a controlled factory setting, thereby ensuring higher quality outcomes [6]. Compared to conventional methods, this approach is regarded as more environmentally sustainable and operationally efficient. Moreover, it offers several advantages, including reduced construction costs, shorter project durations, enhanced health and safety conditions, and a significant decrease in construction waste [6].

B. Prefabricated Systems

Prefabricated systems are classified into four main types [7] :

1) Pre-cut System

The pre-cut system represents the earliest form of prefabrication. Materials such as wood, steel, and laminated timber are processed in the factory to meet specific lengths and cutting requirements, then transported to the construction site for assembly.

2) Modular Panel System

This system involves the production of standardized and simplified panels within a factory environment. It facilitates easier transportation and minimizes the need for heavy construction equipment.

3) Large Size Panel System

While similar to the modular panel system, this approach utilizes full-sized panels that function as complete structural elements and are not divided into smaller segments.

4) Volume Element System

The volume element system entails the fabrication of entire building modules or units in the factory, each pre-formed as a room, and delivered to the site for installation.

C. Prefabricated Houses

Prefabricated houses are constructed using modular systems designed to enhance efficiency [8]. This form of housing is widely favored for its practical and functional design. Furthermore, the construction process is significantly faster, as the assembly typically involves arranging factory-produced modules according to a predetermined architectural plan [9].

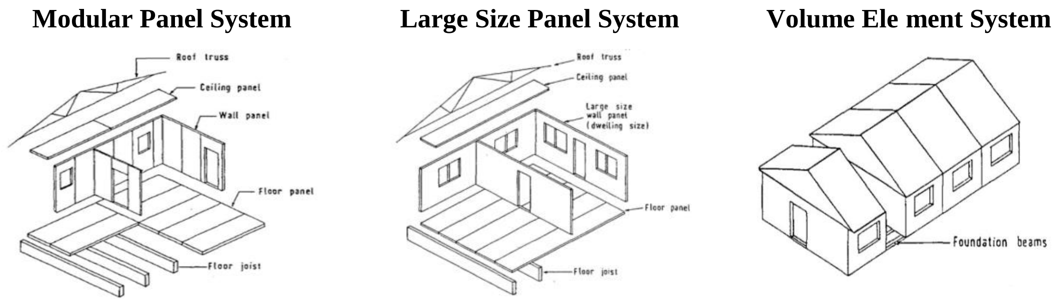

Figure 1. Prefabricated Systems

D. Building Information Modelling (BIM)

BIM is an advanced digital design technology that integrates all information related to a construction project within a single virtual model [12]. It enables project stakeholders to collaborate effectively across disciplines and phases throughout the entire project lifecycle. BIM shifts design from fragmented methods to a more coordinated and integrated system, improving communication, reducing potential errors, and supporting better and faster decision making [13].

E. BIM and DFMA

BIM is widely recognized as a construction design technology that facilitates the implementation of DFMA across various stages of a project [10]. It seamlessly integrates downstream DFMA activities such as procurement, fabrication, transportation, and installation with upstream processes including design development, conceptual planning, and evaluation. This integration enhances communication, fosters collaboration, and improves overall project comprehension among stakeholders.

III. RESEARCH METHODOLOGY

This study employed a descriptive qualitative approach, utilizing secondary data obtained through an extensive literature review. The research process commenced by defining an initial design to serve as the foundation for further development. This baseline model was then analyzed to identify and evaluate components suitable for enhancement using the DFMA approach. The modified design was subsequently modeled using Building Information Modelling (BIM) software, specifically Autodesk Revit. Finally, the design was assessed using DFMA evaluation tools, which were developed based on a Systematic Literature Review (SLR) method. The DFMA assessment criteria are presented in Table 1.

Table 1. DFMA Assessment Tools Criteria

Stage	Criteria	References
Manufacturing	Minimize the number of components	[5], [11], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24]
	Configure component size and weight	[14], [15], [16], [17], [18], [20], [21], [24]
	Consider fabrication complexity	[11], [14], [15], [16], [17], [18], [21], [22], [24]
Transportation	Minimize the use of specialized transportation equipment	[15], [18], [20], [21], [24]
	Minimize the types of transportation equipment	[15], [18], [20], [21]
Assembly	Simplify component assembly	[5], [11], [14], [15], [16], [17], [18], [19], [22]
	Minimize the types and quantities of connectors	[5], [11], [14], [15], [16], [17], [18], [19], [20], [21], [24]
	Simulate the assembly sequence	[16], [18]

IV. RESULTS AND DISCUSSION

A. Establishing the Initial Design

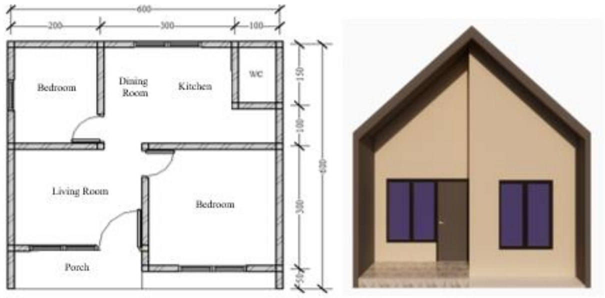

Figure 2. Initial Design from Independent Modeling

The initial design adopted in this study is a 36 m^2 simple house constructed using conventional methods. This housing type was selected as it is part of a government-subsidized program aimed at providing decent and affordable homes for low-income communities [25]. Figure 2 illustrates the floor plan and elevation of the initial design, which was independently modeled as a foundation for the prefabricated house development. The components used in the initial design model are listed in Table 2.

Table 2. Components of a Simple House

Component	Type	Material
Foundation	Structural	River stone
Sloof beam	Structural	Concrete
Column	Structural	Concrete
Ring beam	Structural	Concrete
Roof frame	Structural	Light steel
Wall	Non-structural	Brick
Doors and windows	Non-structural	Aluminum
Roof covering	Non-structural	Metal roofing tile
Floor	Non-structural	Ceramic
Ceiling	Non-structural	Gypsum

B. Initial Design Identification

1) Initial Design Analysis of the Simple House

The initial design employed a conventional construction method, in which all construction activities were carried out sequentially on-site. This approach presents several drawbacks, including diverse component shapes and sizes, high time and cost requirements, weather dependency, and substantial construction waste. To address these challenges, a prefabrication approach specifically the modular panel system was adopted. This system facilitates the integration of multiple structural elements into prefabricated panels. The selection was supported by previous studies on prefabrication in small-scale projects, which reported high adoption rates for wall components 30% in private housing and 60% in public housing developments [26].

2) Identifying Components for Development

This stage aims to identify components of the simple house that are suitable for development using a modular panel system. The selected components include the sloof beam, columns, walls, and ring beam. These elements serve interconnected structural functions, enabling their integration into a single prefabricated wall panel.

C. Application of DFMA Principles

Figure 3 illustrates the DFMA implementation framework, outlining the systematic and structured stages involved in the design development process [27].

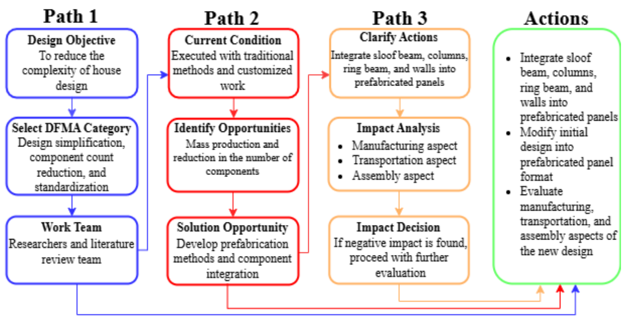

Figure 2. DFMA Implementation Framework

The following three DFMA principles were applied during the design development phase:

1) Design Simplification

The objective of design simplification is to minimize complexity by consolidating multiple building components into a single, streamlined panel, as depicted in Figure 4.

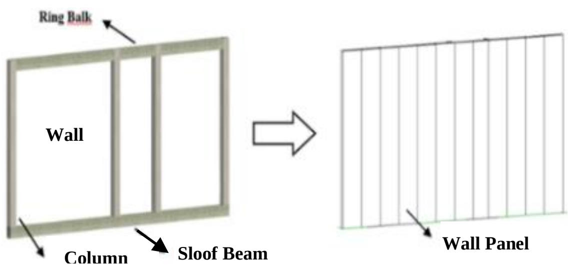

Figure 3. Design Simplification from Independent Modeling

2) Component Reduction

The reduction of components is intended to streamline the construction process, lower the risk of assembly errors, and accelerate project completion. Figure 5 compares different panel segmentation methods, indicating that fewer panels contribute to improved handling, greater efficiency, and enhanced structural stability.

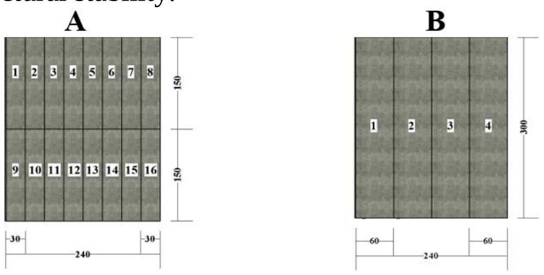

Figure 4. Component Reduction from Independent Modeling

3) Component Standardization

Standardization is a core principle of DFMA. This study utilized a base panel measuring 60 x 10 x 300 cm and a door panel measuring 120 x 10 x 300 cm, featuring a 90 x 200 cm door opening. The base panel was selected due to its availability in the market and compliance with industry standards, while the door panel was custom developed by the researchers. Both panels can be cut as needed to accommodate specific design adjustments.

D. BIM Modeling with Autodesk Revit

1) Component Modeling with Family Templates

Figure 6 illustrates the process of modeling prefabricated panel families. The initial steps involve conducting a DFMA analysis, determining the family type, selecting the appropriate template, and constructing both 2D and 3D geometry. Subsequently, parameters for material and visibility are specified. The final stage includes evaluating the model, saving the family, and loading it into the main project environment.

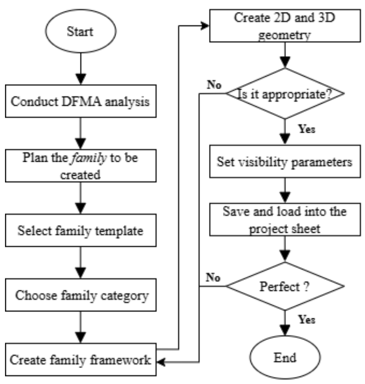

Figure 5. Independent Family Modeling Process

Figure 7 displays the resulting family models for the base panel and the door panel.

Base Panel **Door Panel**

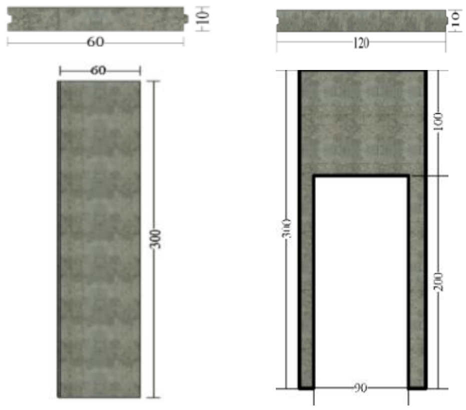

Figure 6. Independent Modeling Results of Panel Family

2) Prefabricated House Modeling

In the house modeling stage, two prefabricated house prototype models were developed. The first model consists solely of base panels, while the second integrates both base panels and door panels. The modeling process adheres to standard Revit procedures. Figure 8 presents the resulting prefabricated house models, with Model 1 comprising 94 panels and Model 2 comprising 87 panels.

Model 1 **Model 2**

Figure 7. Prefabricated House Modeling Results from Independent Design

E. Manufacturing Evaluation

1) Minimizing the Number of Components

The initial simple house model consisted of ten components, whereas the prefabricated model reduced this to seven. The first prefabricated model included 94 panels, while the second featured 87. Based on calculations using Equation 1 [28], this transition resulted in a 30% reduction in the number of components and a 7.45% decrease in the number of panels.

$$\text{Reduction} = \left(\frac{N_{Initial} - N_{Final}}{N_{Initial}}\right) \text{x } 100\% \qquad (1)$$

Description :

$N_{Initiall}$ = Initial number of components/panels

N_{Final} = Final number of components/panels

2) Configuring Component Size and Wight

The components were designed in consideration of technical constraints such as production feasibility, distribution logistics, and installation methods. Consequently, the panel dimensions and weight were optimized to facilitate handling. Lightweight concrete mixed with styrofoam was selected, featuring a density of 830,9 kg/m^3 [29] and a reinforcement ratio of 1%. Table 3 presents the panel dimensions and corresponding weights, calculated based on material volume and density.

Table 3. Size and Weight Configuration

Component	Dimensions (cm)			Wight (kg)
	P	L	T	
Base panel	60	10	300	154
Door panel	120	10	300	157

3) Considering Fabrication Complexity

The panels were intentionally designed with simplified geometry to streamline the fabrication process. This was further supported by the application of standardization principles in the design of panels, reinforcement, and formwork, as illustrated in Figure 9. Such an approach enhances production efficiency and ensures consistency in manufacturing outcomes.

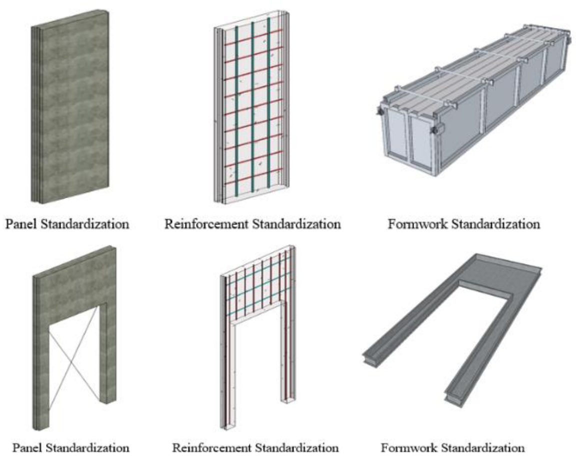

Figure 8. Panel Standardization from Independent Modeling

F. Transportation Evaluation

1) Minimizing the Use of Specialized Transportation

Transportation is a critical component in prefabricated construction, often accompanied by challenges such as scheduling constraints, permit requirements, road accessibility, and safety concerns. To mitigate these issues and reduce dependency on specialized vehicles, the panel transport was planned using a Cold Diesel Double (CDD) truck with a cargo volume of 26.36 m^3 and a maximum load capacity of 8,250 kg. This type of truck was chosen for its broad availability, suitable carrying capacity, and adaptability to on-site conditions, thereby enabling efficient and flexible delivery in diverse project environments.

2) Minimizing the Number of Transportation Equipment Types

Utilizing multiple types of transportation equipment can complicate logistics due to differences in handling procedures, costs, and scheduling. To streamline operations, only one type of vehicle the Cold Diesel Double (CDD) truk was employed. The number of panels transportable by this truck was calculated using Equation 2.

$$\text{Number og panels} = \frac{\text{Truck load capacity}}{\text{Panel wight}} \qquad (2)$$

The calculation indicated that a CDD truck can accommodate up to 53 panels. However, this figure must be adjusted based on the physical dimensions of the truck bed to ensure compatibility with the vehicle's actual loading capacity.

G. Assembly Evaluation

1) Ease of Component Assembly

The panels were specifically designed to be installed manually, eliminating the need for heavy machinery. In accordance with the guidelines from the International Labour Organization (ILO), the maximum recommended lifting capacity for adult males is 40 kg per individual. Given the weights of both panel types, manual handling and installation are feasible with a four-person crew. Moreover, site accessibility must be considered, as not all construction locations provide adequate access for heavy equipment. Figure 10 illustrates the manual installation process performed by four workers.

Figure 9. Panel Installation Method from Independent Modeling

2) Component Joint Configuration

Panel connections are designed to include vertical joints using a male–female interlocking system, and horizontal joints employing a mechanical fastening system with plates and anchor bolts, as depicted in Figure 11.

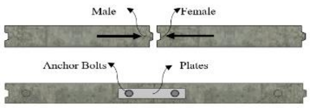

Figure 10. Vertical and Horizontal Connections from Independent Modeling

To enhance structural stability, corner joints are reinforced with steel anchors positioned at opposing angles. Additionally, connections between the panels and the foundation are secured using steel anchors spaced at 120 mm intervals. Figure 12 illustrates the configuration of the corner joint and the panel-to-foundation connection.

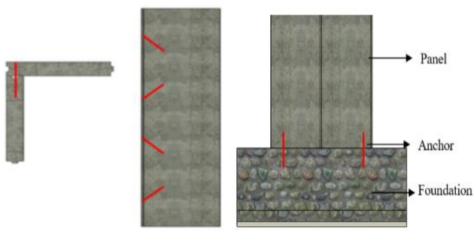

Figure 11. Corner and Panel to Foundation Connections from Independent Modeling

3) Assembly Sequence Simulation

The assembly process begins with site preparation and the installation of bouwplank, followed by foundation construction and the placement of steel anchors to secure the panels to the foundation. Subsequently, panel installation is carried out, as illustrated in Figure 13. The final stage involves the installation of the roofing system, architectural components, mechanical, electrical, and plumbing (MEP) systems, and concludes with the finishing works.

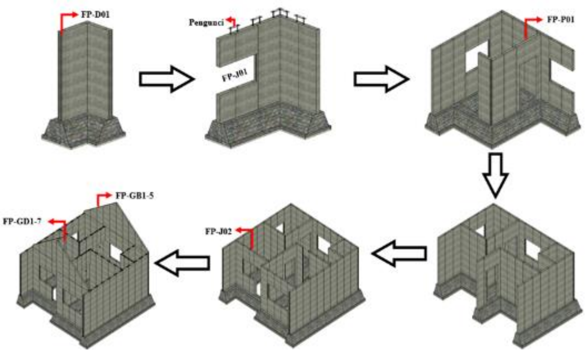

Figure 12. Panel Installation Stages from Independent Modeling

H. Discussion

Based on the DFMA evaluation, the original simple house design was transformed into a prefabricated modular panel system, yielding a 30% reduction in component count. This was accomplished by merging the sloof beam, columns, walls, and ring beam into two prefabricated panel types: base panels and door panels. Comparing the two models revealed that integrating both panel types in the second model reduced the total panels by 7.45%, thereby minimizing on-site adjustments.

Both panel types were dimensioned and weighted to allow manual handling without heavy equipment. Panels were transported using a CDD truck and loaded manually. Panel connections incorporated both interlocking and mechanical systems, while corner joints and panel-to-foundation interfaces were reinforced with steel anchors to enhance structural stability. The construction sequence was divided into three phases: site preparation, panel installation, and installation of remaining components, including finishing.

The integration of DFMA and BIM rendered the design process more efficient and organized. From the preliminary design stage, manufacturing, transportation, and assembly considerations were addressed through digital modeling. Consequently, each component was optimized for fabrication, transport, and installation. Prefabrication also shortened construction time, as fewer components reduced on-site work duration. Additionally, the panel design is adaptable to various house types, making it a promising solution for addressing housing demand.

V. CONCLUSION

A. Summary of Findings

Based on the research conducted, the following conclusions were drawn :

1. The development process included defining the initial design, identifying key components, applying DFMA, executing BIM modeling, and evaluating outcomes using DFMA assessment tools.
2. DFMA effectively simplified the conventional house design into a modular panel system, resulting in a 30% reduction in component count.
3. BIM modeling was conducted in two phases: component family modeling and prefabricated house modeling. Model 1 comprised 94 panels, while Model 2 had 87, reflecting a 7.45% reduction.

4. Two prefabricated panel types were produced: a base panel 60 x 10 x 300 cm, 154 kg and a door panel 120 x 10 x 300 cm, 157 kg with a 90 x 200 cm opening.
5. The panels were constructed from lightweight concrete, suitable for transportation using a CDD truck and manual assembly without heavy equipment, employing interlocking and mechanical joint systems.

B. Recommendations

Based on the findings and identified limitations, several recommendations for further development are proposed as follows :

1. Refine the design to be adaptable for various housing types and site conditions.
2. Conduct direct field observations to ensure the design aligns with actual construction conditions.
3. Carry out a market acceptance study to assess interest and perceptions toward the prefabricated housing concept.
4. Evaluate the readiness of the supply chain, including materials, production facilities, and distribution systems, to support sustainable implementation.

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