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Prefabricated Bamboo Cabins: A Socio-Technical Evaluation of Modular and Relocatable Shelter Systems

Anak Agung Gede Raka Gunawarman[1,*], Wan Srihani Wan Mohamed[2], I Wayan Wirya Sastrawan[1], Ni Putu Ratih Pradnyaswari Anasta Putri[1], Nyoman Ratih Prabandari[1]

[1]Department of Architecture, Universitas Warmadewa, Indonesia
[2]Faculty of Design and Architecture, Universiti Putra Malaysia, Malaysia

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Abstract The growing demand for sustainable and rapidly deployable housing in Southeast Asia underscores the potential of bamboo as a renewable material for prefabricated construction. While steel, concrete, and container-based systems are well established, the socio-technical dimension of bamboo remains underexplored. This study develops and evaluates a prefabricated bamboo cabin using an integrated framework that combines Design Science Research, Research through Design, Participatory Design, and structured Prototyping. Bamboo served as the main structural material, reinforced with steel joints to achieve modular precision, while BIM simulations (Autodesk Revit and Forma) assessed solar gain, ventilation, and thermal performance in a tropical coastal setting. Workshop fabrication and field assembly demonstrated reduced material waste and rapid on-site erection, completing one cabin in 5 hours 15 minutes with a small non-professional team and minimal tools. Stakeholder and user feedback indicated strong cultural resonance and practical feasibility, though challenges persisted in thermal comfort, rain protection, and sanitation integration. Overall, this research positions bamboo prefabrication as a fast, adaptable, and environmentally responsible construction method, bridging design innovation with socio-technical insights for tropical housing advancement.

Keywords Bamboo Prefabrication, Modular Housing, Socio-Technical Design, Sustainable Construction, Tropical Architecture

1. Introduction

The increasing frequency of environmental disruptions, rapid urbanization, and population displacement has intensified global attention toward shelter systems that are not only fast to deploy, but also adaptable, sustainable, and culturally grounded. In response, prefabricated and modular construction has been widely promoted as a strategic solution, offering advantages in speed, scalability, and resource efficiency. However, the question of how these systems integrate material choice, cultural acceptance, and technical performance remains insufficiently addressed. Within this broader debate, bamboo emerges as a particularly compelling material: it is renewable, locally familiar in many regions, and structurally capable, positioning it as a potential bridge between vernacular building traditions and contemporary modular construction systems.

Recent studies on prefabricated and modular shelters demonstrate their versatility across emergency, transitional, and sustainable housing contexts. In bamboo-based research, deployable scissor-like element (SLE) systems highlight bamboo's capacity for compactness and transformability, enabling structures to shift from compact stowed states to predetermined configurations, and reinforcing their suitability for adaptive and deployable architectures [1]. Comparable interests in transportability and reuse are reflected in folding-roof temporary homes, where modular logic supports repeated assembly, disassembly, and relocation [2]. In Indonesia, investigations in Hargotirto Village further emphasize that material locality, craftsmanship, and community familiarity are decisive factors influencing the acceptance of modular bamboo shelters [3]. Alongside bamboo, alternative material systems continue to be explored, including prefabricated aluminum-frame structures designed for self-construction and modular expansion [4] and modular clustering strategies that attempt to balance spatial efficiency, comfort, and environmental performance [5]. Together, these studies reveal a growing interest in modularity, yet also underline divergent assumptions regarding material choice, labor organization, and cultural context.

Beyond technical performance, prefabricated housing research increasingly addresses social and economic dimensions. Reviews of affordable housing identify modular construction as a means to reduce construction time and overall cost, while maintaining acceptable levels of quality and durability [6]. Other studies examine shipping-container shelters in post-disaster scenarios, highlighting participatory and volunteer-driven construction models, while also reporting persistent challenges related to thermal comfort, social acceptance, and long-term usability [7]. Time-efficient reconstruction frameworks suggest that prefabricated modules can shorten the transition from emergency shelters to permanent housing solutions [8], while modular prefabricated components (MPC) are promoted as customizable, repairable, and recyclable systems suitable for post-disaster conditions [9]. Experimental projects, such as modular housing systems based on elliptical frames, further demonstrate how formal and structural innovation can enhance portability and resilience [10]. At a larger scale, European refugee housing studies stress that sustainability, safety, spatial quality, and aesthetics are as critical as logistics and speed of deployment [11].

Nevertheless, significant gaps persist in translating these approaches across diverse climatic and cultural settings. In Ecuador, bamboo-based housing combined with off-grid photovoltaic systems illustrates how local resources and energy autonomy can converge into integrated solutions [12]. Comparable integration remains limited in Southeast Asia, despite similar climatic pressures and strong bamboo traditions. Critics further note that many post-disaster housing models continue to operate within a linear "take–make–use–dispose" paradigm. Flatpack housing concepts designed for repair, reuse, and upgrading attempt to address this limitation [13], yet their long-term durability and cultural fit remain uncertain. Experiments in South China with bamboo eco-living units suggest that modular construction can support ecological communities and resource-efficient settlement patterns [14], but questions remain regarding the environmental costs of processing, detailing, and assembly at scale.

Transitional housing models in Colombia demonstrate how modular growth and multilayer structural strategies can support affordability and resilience [15], while engineered bamboo housing in Latin America highlights seismic performance and structural reliability, alongside persistent challenges related to maintenance, policy support, and scalability [16]. Another unresolved concern is the afterlife of temporary shelters: donor-driven housing units are frequently dismantled or abandoned due to cultural mismatch or lack of long-term planning. In response, scholars advocate strategies that allow temporary housing to evolve into longer-term assets through social and physical transformation [17]. Industrialized Building Systems (IBS) further propose modular solutions with advantages in speed and flexibility [18], yet much of the existing evidence remains based on controlled or experimental environments rather than real-world deployment. Even European timber-based prototypes, while offering valuable experimental insights [19], raise questions about transferability to tropical and resource-variable contexts.

Overall, what emerges is a field rich in technical experimentation yet lacking integrated frameworks that clearly situate bamboo within broader modular housing debates. The urgency is particularly evident in Indonesia, where rapid building must align with affordability, ecological responsibility, and cultural fit. Yet much prefabricated shelter research continues to rely on industrial materials or to focus narrowly on aesthetics and engineering performance, leaving bamboo's socio-technical potential underexplored. Rather than treating the prototype solely as a pedagogical exercise, this study frames the workshop as a controlled socio-technical experiment conducted under real-world conditions. It examines bamboo prefab cabins as modular and relocatable systems, assessing not only construction speed, material efficiency, durability, and mobility, but also cultural resonance, comfort, and sustainability. By positioning bamboo against conventional prefab models, this research demonstrates how locally embedded and renewable materials can respond to urgent housing needs while opening longer-term pathways for sustainable development.

2. Materials and Methods

The primary material in this study is bamboo, which functions as the main structural component of the prefabricated shelter kit. Different bamboo species were examined for strength, durability, and preservation potential. To enhance performance, treatments such as drying and pest protection were applied. Steel joints and bolts were introduced as secondary elements, making repeated assembly and disassembly possible while preserving structural stability.

In the digital environment, the study relied on Building Information Modeling (BIM) tools, particularly Autodesk Revit and Autodesk Forma, for drawings, 3D modeling, and performance simulations. The integration of BIM helped synchronize structural data with modular detailing and environmental analysis, providing accuracy in both design and prototype evaluation.

Beyond technical resources, the study also depended on contextual and human contributions. Local craftsmen and bamboo experts shared practical fabrication knowledge, while construction workers and stakeholders gave feedback on usability and cultural resonance. Field testing was carried out at Mertasari Beach, Sanur, Bali, where real environmental conditions provided a basis for evaluating the prototype's performance.

Methodologically, the research combines Design Science Research (DSR), Research through Design (RtD), Participatory Design, and structured Prototyping. This mix reflects a dual ambition: advancing theory on bamboo prefabrication while delivering a design artifact that responds to urgent housing needs.

The overarching framework is DSR, a problem-driven paradigm that develops artifacts with both practical utility and theoretical value [20]. Within it, RtD positions design and prototyping as legitimate modes of inquiry, producing situated, experiential, and technical knowledge [21–23]. The study's iterative process from digital models to physical prototypes mirrors RtD's commitment to generating insights through making.

In parallel, a Participatory Design approach was adopted to secure cultural relevance and user acceptance. Co-design with local craftsmen shaped the fabrication phase, while structured dialogues with construction workers and community representatives informed the pilot stage. Prior research shows such approaches empower participants and embed cultural practices in design outcomes [24,25].

To support this, prototyping methodologies were used to move from ideas to testable artifacts in a systematic way. The work combined full-scale bamboo modules with computational simulations for structural and environmental testing. Balancing digital and physical experiments helped reduce risks and allowed iterative refinement [26,27]. Structural tests such as load-bearing, seismic resistance, and modular stress analysis were complemented by thermal and ventilation simulations, carried out on-site at Mertasari Beach, to assess performance under tropical climates.

Together, these methods build a comprehensive process: DSR sets the problem-driven logic; RtD frames knowledge generation through making; Participatory Design anchors the work socially; and Prototyping delivers iterative testing. This integration ensures the prefabricated bamboo cabin is not only technically sound but also socially embedded and academically valuable, contributing both practical solutions and methodological lessons to sustainable modular housing. This study did not require ethical approval, as it did not involve any personal or sensitive human data, and all participants engaged voluntarily in non-identifiable design and fabrication activities. Informed consent was obtained verbally from all participants involved in the study and community engagement activities. Written informed consent to publish identifying images and other personal details was obtained from all individuals appearing in the photographs included in this study. Participants were informed about the purpose of image use for academic and publication purposes, and they voluntarily agreed to their inclusion. All identifying information unrelated to the research context has been omitted to maintain participants' privacy.

3. Results and Discussion

The results of this study are presented in relation to the design process, prototyping activities, and field assembly of the prefabricated bamboo shelter system. In line with the methodological framework, the outcomes are grouped into four categories: (i) design development and digital simulations, (ii) workshop fabrication and prefabrication logic, (iii) assembly process of the RTA system, and (iv) user perceptions and stakeholder feedback. These results highlight not only the technical feasibility but also the practical hurdles of applying bamboo within prefabricated modular systems. In practice, the process shows that while modular logic can accelerate assembly, it also requires a level of craftsmanship and familiarity with bamboo joinery that not all workers may possess. The findings provide a foundation for comparison with conventional temporary housing practices, which will later be enriched through participatory feedback from local craftsmen and other stakeholders. Finally, the combination of quantitative records such as assembly duration, labor input, and material waste with qualitative insights from workshop trials ensures that the evaluation captures both measurable outcomes and the more nuanced lessons of lived construction experience.

3.1. Design Development and Digital Simulation

The design process followed an iterative cycle that combined Building Information Modeling (BIM) with hands-on workshop trials. Initial concepts were explored using Autodesk Revit, where modular layouts, joinery details, and environmental simulations could be tested and refined. The base spatial grid adopted a standardized module of 122 × 244 cm, aligned with commercial plywood dimensions, which shaped both wall panel sizing and structural logic. This modular choice supported scalability and reduced material waste, though it also raised questions about flexibility when faced with non-standard site conditions. To ground the concept in a practical prototype, the layout was consolidated into a 244 ×244 cm cabin module that served as the primary planning unit (Figure 1).

Within the BIM environment, solar radiation studies, daylight access modeling, and ventilation flow simulations under tropical conditions were conducted using Autodesk Revit and Autodesk Forma. These analyses shaped key design choices, including window orientation, roof inclination, and panel perforation strategies to improve thermal comfort and airflow. The digital workflow also supported parametric testing of joinery tolerances and structural alignment, providing a basis for efficient on-site assembly of the prefabricated system. In parallel, workshop experiments used a trial-and-error approach to test joinery precision, module standardization, and the realities of material handling. Detailed studies of the foundation, beam-to-column connections, roof joints, and prefabricated wall/roof panels (Figure 2) revealed practical challenges, most notably bamboo's irregular geometry and the need to adjust tolerances in metal joints. The iterative loop between digital modeling and physical prototyping not only refined the design but also exposed where digital precision must yield to material reality, resulting in a more adaptable and scalable cabin system.

The integration of BIM simulations and workshop prototyping established a robust foundation for translating digital concepts into physical components. While the digital environment provided precision in modular coordination and environmental performance, the workshop trials validated assembly feasibility and exposed challenges in material tolerances. These complementary processes confirmed the viability of the modular approach and prepared the design for full-scale prefabrication. Building on these insights, the next stage focused on workshop fabrication and prefabrication logic, where standardized components were produced under controlled conditions to test efficiency, repeatability, and waste reduction prior to on-site assembly.

To further align design strategies with actual site conditions, environmental simulations for the prefabricated bamboo prototype were conducted at the designated location in Mertasari Beach, Sanur, Bali. The analysis, set on August 31, covered a total area of 17,529 m^2 (Figure 3). The sun hours distribution (Figure 4a) revealed that more than half of the surface (52 percent) receives over nine hours of direct solar exposure daily, while 16 percent experiences only about one hour, and less than 7 percent falls within the 1–5 hour range. This distribution confirms the openness of the site and the absence of natural shading from trees or adjacent structures. As a result, shading devices, cross-ventilation, and roof insulation emerged as critical design requirements to mitigate excessive heat gain and ensure thermal comfort in the cabin system.

Microclimate analysis further emphasizes this concern. At the ground level, 94 percent of the area falls under strong heat stress, 5 percent under moderate stress, and only 1 percent within a comfortable range, while the roof level records 100 percent strong heat stress (Figure 4b). These results suggest that the site inherently exposes occupants to extreme thermal discomfort, primarily driven by direct radiation and reflected heat from sandy coastal conditions. Without passive interventions, such as ventilated roofing systems or reflective finishes, indoor comfort would remain severely compromised.

Air temperature analysis reinforces these findings. Although the average air temperature during midday (12:00) is measured at a moderate 26 ℃, ranging between 23 ℃ and 28 ℃, the Universal Thermal Climate Index (UTCI) categorizes the site under strong heat stress. This discrepancy highlights that thermal discomfort is not solely determined by air temperature but rather emerges from the combined influence of solar radiation, surface reflection, and humidity typical of tropical coastal zones.

To complement the solar and microclimate studies, additional simulations were performed to assess daylight potential and wind comfort at the proposed prototype site in Mertasari Beach. The daylight analysis (Figure 5a) shows that 81 percent of the prototype surface achieves very high daylight potential, scoring above 37 on the daylight index scale. This confirms that the cabin can rely on abundant natural light throughout the day, minimizing dependence on artificial lighting. At the same time, the intensity of daylight reinforces earlier findings on solar exposure, pointing to the need for shading strategies, adjustable openings, or perforated wall panels to reduce glare and overheating while preserving indoor visual comfort.

Wind simulations using the Lawson comfort scale (Figure 5b) demonstrate that 93 percent of ground-level conditions fall within the "comfortable" range for outdoor activity, while the remaining 7 percent are slightly uncomfortable due to higher wind exposure. The results indicate that the site benefits from prevailing coastal breezes, which can be harnessed through carefully positioned openings and roof overhangs to optimize natural ventilation. However, the irregular geometry of bamboo and the requirement for airtight prefabricated joints introduce a design paradox: maintaining structural stability through tight joinery while still enabling permeability for airflow. Balancing these two demands becomes a critical task in refining the cabin's passive environmental strategies.

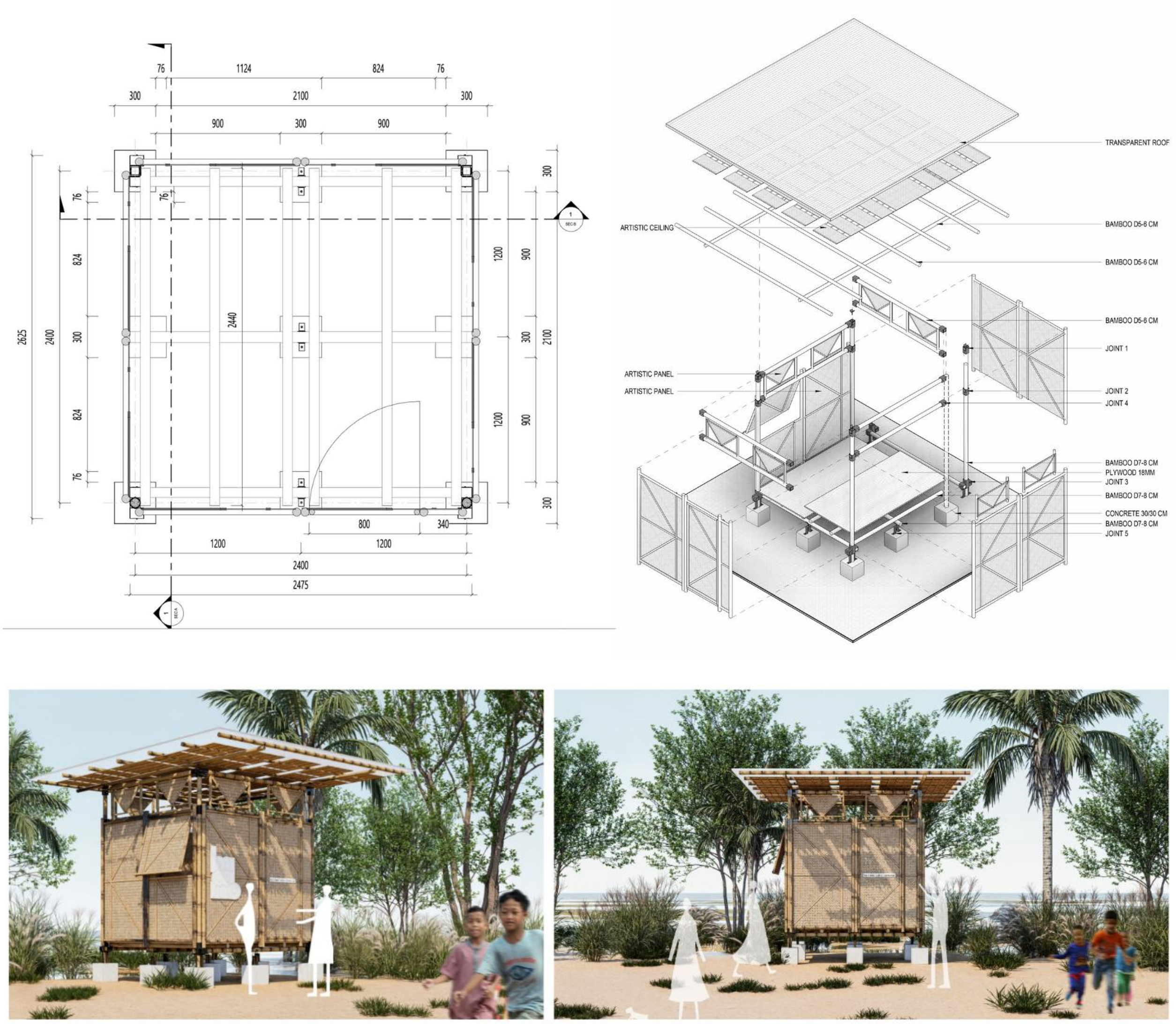


Figure 1. Modular size planning (244 × 244 cm), axonometric view of the Ready-to-Assemble (RTA) modular model and rendering image

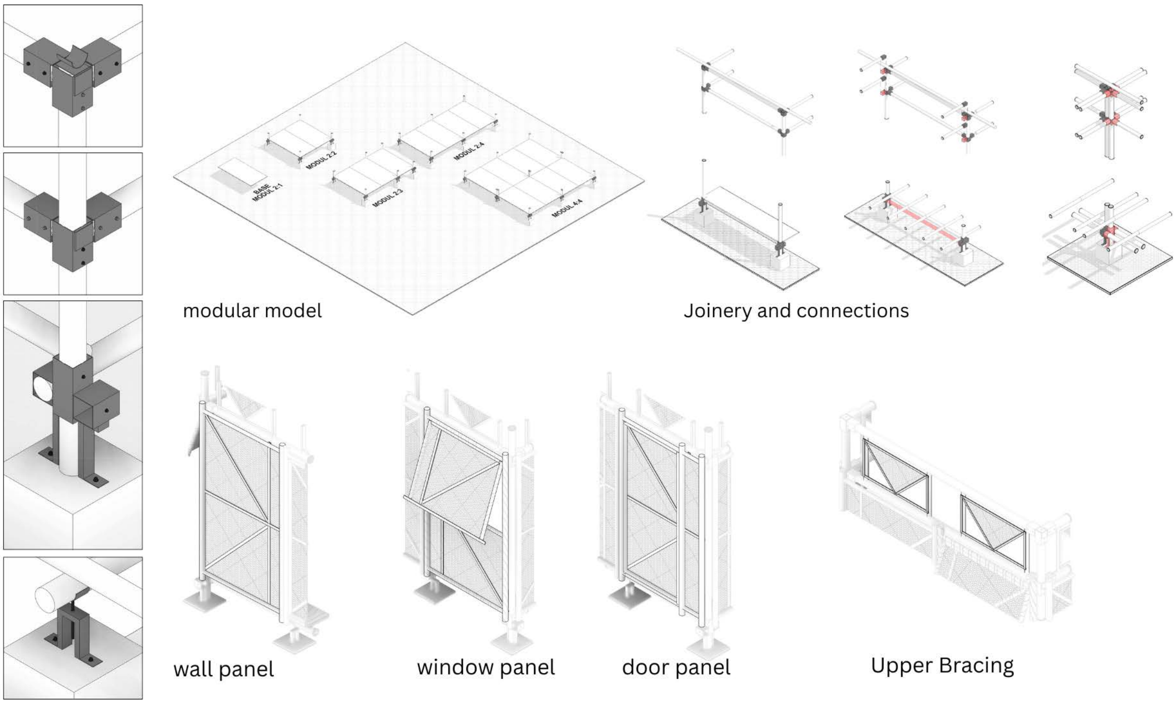
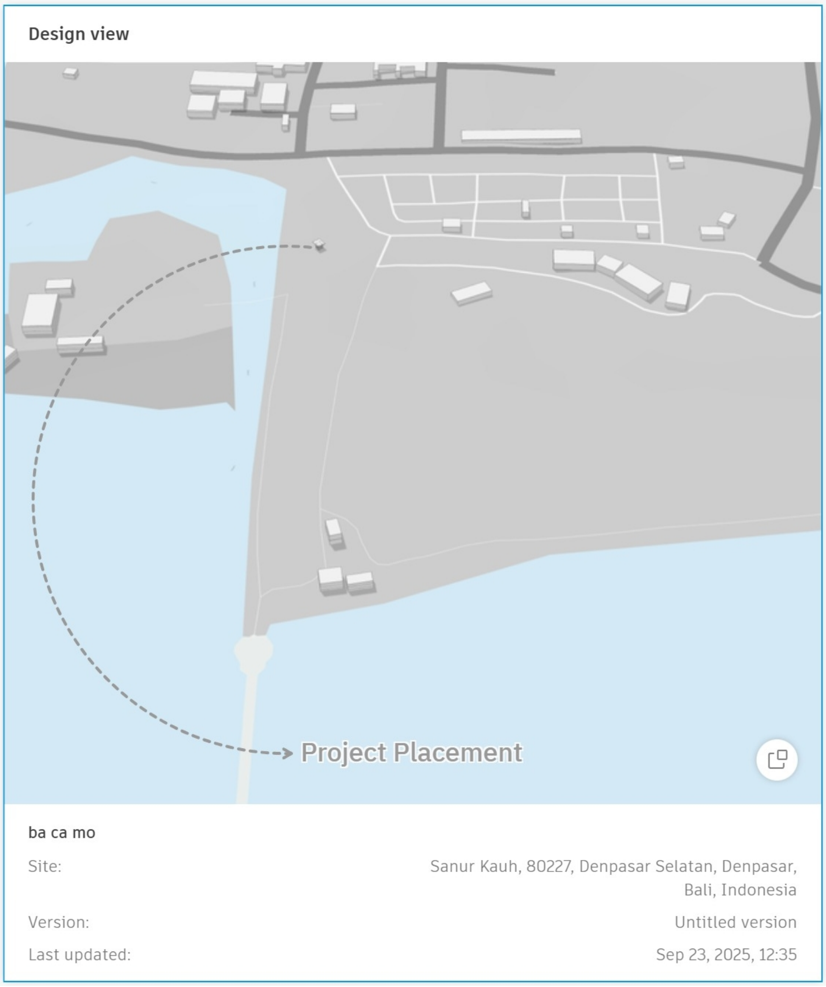


Figure 2. Detailed joinery of the foundation, beam-to-column connection, and roof joint, along with prefabricated wall and roof panels configured using 122 × 244 cm plywood modules

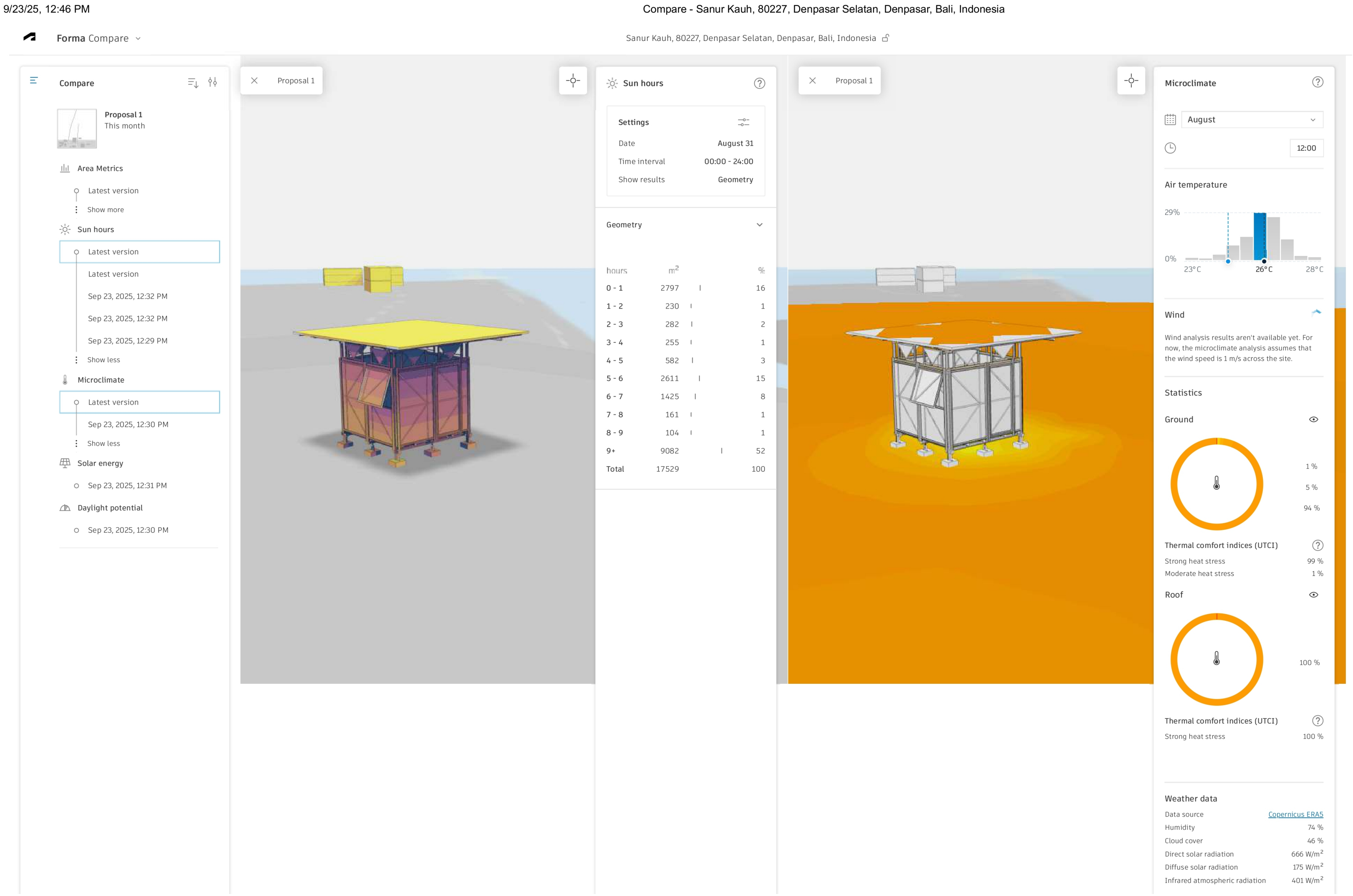


Design view

ba ca mo

Site:	Sanur Kauh, 80227, Denpasar Selatan, Denpasar, Bali, Indonesia
Version:	Untitled version
Last updated:	Sep 23, 2025, 12:35

Figure 3. Project placement and cover area Mertasari Beach, Sanur-Bali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Compare - Sanur Kauh, 80227, Denpasar Selatan, Denpasar, Bali, Indonesia

Sanur Kauh, 80227, Denpasar Selatan, Denpasar, Bali, Indonesia

Sun hours

Settings

Date: August 31

Time interval: 00:00 - 24:00

Show results: Geometry

Geometry

hours	m^2	%
0 - 1	2797	16
1 - 2	230	1
2 - 3	282	2
3 - 4	255	1
4 - 5	582	3
5 - 6	2611	15
6 - 7	1425	8
7 - 8	161	1
8 - 9	104	1
9+	9082	52
Total	17529	100

Microclimate

August

12:00

Air temperature

Wind

Wind analysis results aren't available yet. For now, the microclimate analysis assumes that the wind speed is 1 m/s across the site.

Statistics

Ground

Thermal comfort indices (UTCI)

Strong heat stress	99 %
Moderate heat stress	1 %

Roof

Thermal comfort indices (UTCI)

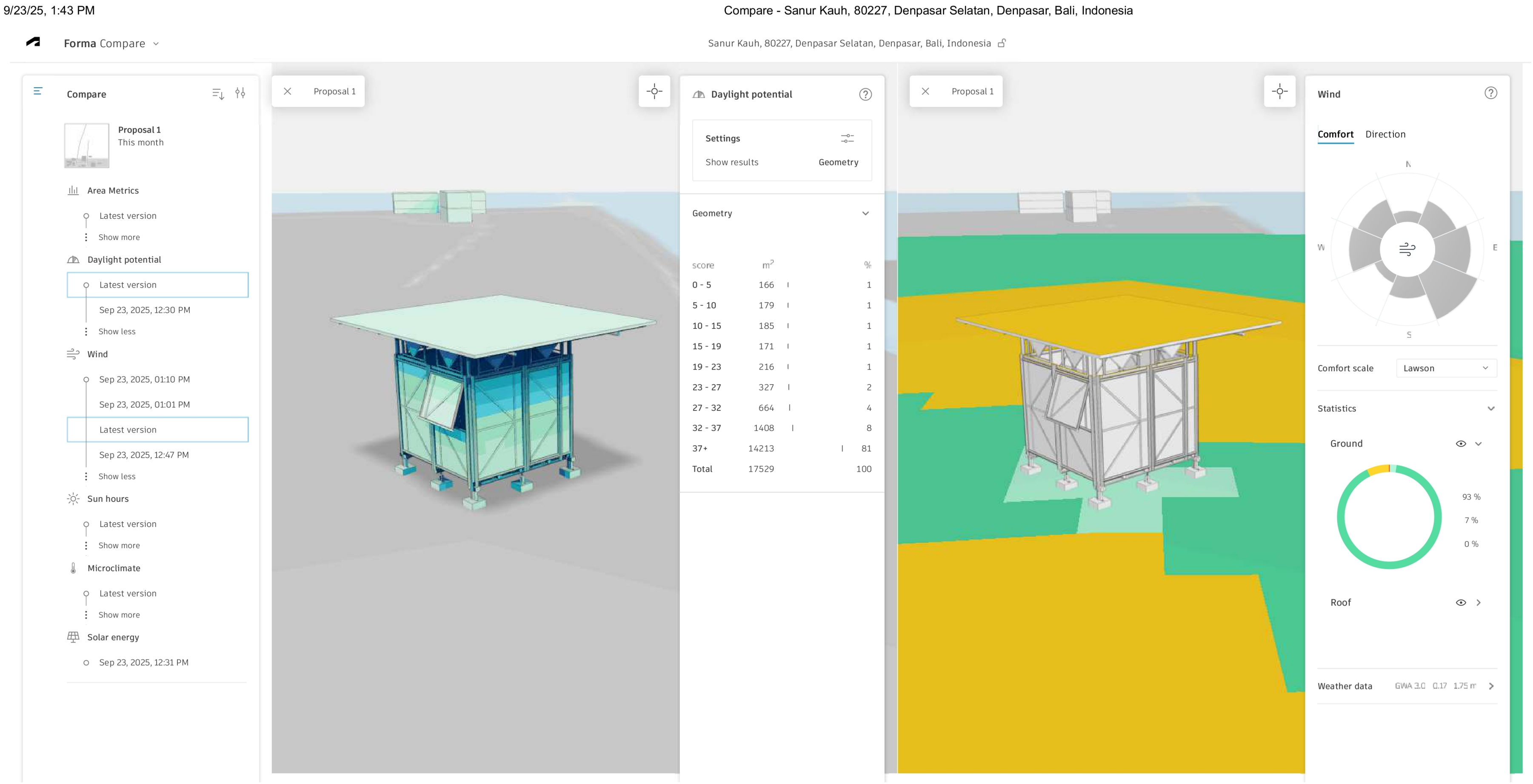
Strong heat stress	100 %

Weather data

Data source	Copernicus ERA5
Humidity	74 %
Cloud cover	46 %
Direct solar radiation	666 W/m^2
Diffuse solar radiation	175 W/m^2
Infrared atmospheric radiation	401 W/m^2

(a) (b)

Figure 4. (a) sun hours distribution, (b) microclimate analysis



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Compare - Sanur Kauh, 80227, Denpasar Selatan, Denpasar, Bali, Indonesia

Sanur Kauh, 80227, Denpasar Selatan, Denpasar, Bali, Indonesia

Daylight potential

Settings

Show results: Geometry

Geometry

score	m^2	%
0 - 5	166	1
5 - 10	179	1
10 - 15	185	1
15 - 19	171	1
19 - 23	216	1
23 - 27	327	2
27 - 32	664	4
32 - 37	1408	8
37+	14213	81
Total	17529	100

Comfort scale: Lawson

Ground: 93 %, 7 %, 0 %

Weather data: GWA 3.0 0.17 1.75 m

(a) (b)

Figure 5. (a) daylight analysis, (b) Wind simulations

3.2. Workshop Fabrication and Prefabrication Logic

The prefabrication stage was conducted in a workshop environment to evaluate the efficiency, repeatability, and material performance of the modular bamboo system (Figure 6). The process followed a structured two-day schedule, during which structural frames, wall partitions, and modular panels were fabricated under controlled conditions. On the first day (8 hours), the primary structure and wall partition frames were assembled, testing the dimensional accuracy of bamboo components alongside the precision of custom-designed metal joints. On the second day (8 hours), wall partition panels, door and window frames, and ceiling modules were produced, resulting in a complete set of components ready for delivery. In total, the prefabrication required 16 hours of labor, carried out by lecturers and students rather than professional craftsmen. This not only highlighted the accessibility of the system but also revealed areas for improvement in accuracy and efficiency.

An important component of the workshop phase was waste management. By adhering to standardized plywood dimensions (122 × 244 cm), cutting patterns were optimized to minimize offcuts, while bamboo's irregularities continued to challenge the consistency of modular elements. Each prototype cycle generated measurable waste, which was systematically documented to enable comparison with conventional on-site construction. This record will serve as a basis for future refinements aimed at reducing waste and enhancing material efficiency, reinforcing the sustainable objectives of the prefabrication approach.

The prefabricated components were designed for a Ready-to-Assemble (RTA) system, sized to fit a single pickup vehicle for transportation. This strategy simplified logistics and reduced the risk of damage during delivery. Once on-site, the components could be assembled rapidly, underscoring the practical benefits of prefabrication compared to conventional worker housing. The details of the workshop process are summarized in Table 1, which outlines the sequence of activities, duration, labor input, and outputs across the two-day prefabrication phase. Building on these outcomes, the following section discusses the assembly process and efficiency evaluation during the field installation stage.

In Figure 7, the workshop process inevitably generated several categories of material waste, primarily from bamboo cutting and panel fabrication. Offcuts from round bamboo used in the structural frame and panel skeleton accounted for approximately 12–15% of the total bamboo volume, consisting mostly of short pieces unsuitable for reuse. The splitting of bamboo for infill panels created additional waste of around 8–10%, largely in the form of irregular strips that could not be woven effectively. Drilling circular openings for joints and connections resulted in small bamboo plug remnants, estimated at 0.5–1 kg in total. Meanwhile, weaving panels produced leftover strips amounting to roughly 5% of the woven bamboo stock, often due to breakage during handling.

While each category of waste may appear minor in isolation, its cumulative volume represents a significant share of the overall material input. This finding underscores the need for further refinement in cutting patterns, joint detailing, and weaving techniques to minimize inefficiencies in future prefabrication cycles. The detailed documentation of these waste streams also provides a baseline for comparison with conventional on-site construction practices, positioning the prefabricated bamboo system as a continuously improving framework that integrates environmental responsibility into its design and fabrication logic.

Figure 6. Workshop Fabrication and Prefabrication Logic

Table 1. Workshop Prefabrication Process

Day	Main Activity	Duration	Labor	Output
Day 1	Structural frame assembly (columns, beams, floor) and wall partition structure	8 Hours	4 persons (lecture & students)	Completed frame + partitions frame
Day 2	Fabrication of wall panels, door & window frames, ceiling modules	8 Hours	4 persons (lecture & students)	Prefabricated panels & modules ready for transport
Total		**16 Hours**		**Complete set of RTA modules**

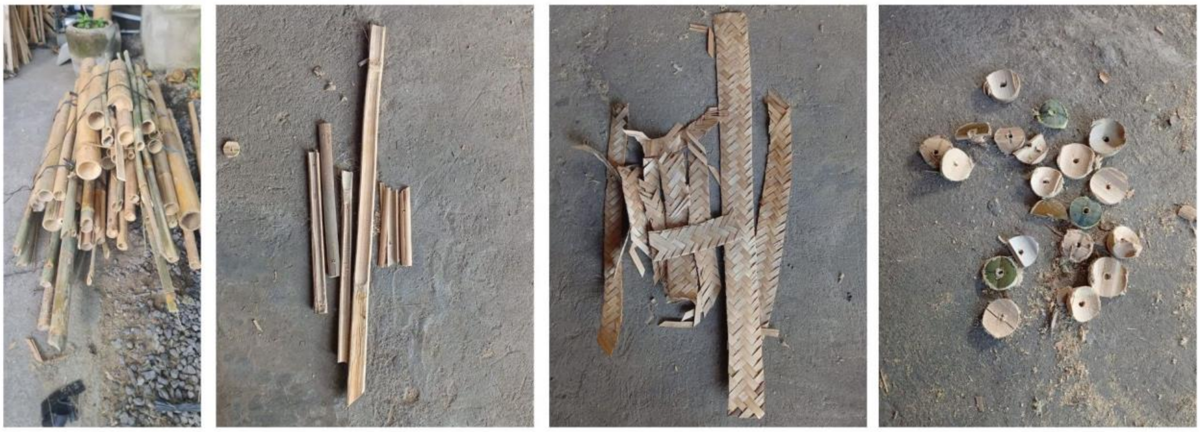

Figure 7. Waste material sample in the prototyping process

3.3. Assembly Process of the RTA System

The field assembly of the prefabricated bamboo cabin prototype took place at the coastal site of Pantai Mertasari, Sanur, Bali, applying the Ready-to-Assemble (RTA) strategy refined during the workshop stage (Figure 8). All prefabricated components were transported using a single pickup vehicle, with one full set of modules accommodated per trip, demonstrating that the logistics of moving the system can be kept simple and low-cost. Once delivered, the assembly followed a stepwise sequence: first erecting the structural frame, then installing floor, wall, and roof modules, before concluding with detailing to secure stability and achieve a coherent finish.

The on-site work was carried out entirely by a small team of lecturers and students, without professional craftsmen, yet the cabin could still be assembled efficiently. The structural frame and wall partitions were completed within 2 hours and 15 minutes by four workers. Roofing and ceiling modules required a further 2 hours, while the electrical installation, limited to basic lighting, took 1 additional hour. In total, the cabin was fully assembled in 5 hours and 15 minutes, including both structural and finishing tasks. This outcome illustrates not only the practicality of the RTA system but also its accessibility: even a non-specialist team could achieve rapid assembly under real field conditions, highlighting its potential for broader application in emergency or temporary housing contexts.

This outcome highlights the advantages of prefabrication over conventional worker housing construction, where assembly typically requires longer timeframes, larger crews, and a broader set of tools. By contrast, the RTA system operated with only a small team and minimal equipment, yet was able to complete the cabin in just over five hours. This efficiency reduced both labor intensity and logistical demands, while also minimizing disturbance at the site during construction. Importantly, the straightforward process showed that the system does not depend on highly skilled labor, broadening its potential applicability across diverse contexts.

Beyond the single prototype, the findings suggest opportunities for scalability and replication in other tropical settings where rapid deployment of worker housing is urgently needed. The ease of transport, quick assembly, and adaptability to local site conditions position the prefabricated bamboo cabin as a viable alternative to conventional approaches. Still, the experience also revealed areas for refinement—particularly in aligning digital precision with field variability—pointing to the value of continued iteration as the system moves toward larger-scale implementation.

3.4. User Perceptions and Stakeholder Feedback

The prototype cabin was tested through public use and stakeholder interviews with students, researchers, local craftsmen, and community members who stayed overnight in the shelter (Figure 9). The responses revealed a mix of appreciation and critique, reflecting the socio-technical realities of prefabricated bamboo housing in the Balinese context.

Figure 8. The field assembly of the prefabricated bamboo cabin prototype

(a) (b) (c) (d)

Figure 9. User Perceptions and Stakeholder Feedback: (a) craftsmen discussing joinery precision and structural strength, (b) tourists providing visual and functional impressions, (c) students reflecting on comfort and learning from prototyping, (d) local community members sharing experiences of ventilation, rainwater, and heat

Overall first impressions were positive. Many respondents described the cabin as visually appealing and eco-friendly, fitting naturally into the coastal tourism setting of Sanur. The lightweight, modular character was seen as both practical and sustainable, while the use of bamboo resonated strongly with Bali's cultural identity. Functionally, the cabin was viewed as a creative alternative to conventional worker housing, demonstrating efficiency and adaptability in its design.

Craftsmen, however, paid closer attention to technical details. They noted that the use of screws made some joints look less refined, and transitional gaps between modules occasionally disrupted the precision of assembly. Yet, despite these imperfections, they praised the overall robustness of the structure and acknowledged its potential as a reliable building system.

Overnight users provided more experiential feedback. They appreciated the comfort during early mornings and evenings, when coastal winds improved air circulation. However, from late morning to afternoon (10 a.m.–4 p.m.), the interior became uncomfortably hot, a problem traced to roof design and window orientation. Rain also proved challenging: water seeped through woven bamboo wall panels, leaving them damp and reducing their effectiveness. Still, many users emphasized the benefit of natural nighttime ventilation, while recommending stronger weatherproofing and shading strategies for long-term use.

Researchers and visitors, including foreign guests, added another layer of reflection. They welcomed the sustainable design direction but encouraged expanding the programmatic functions of the cabin. The most consistent suggestion was the integration of sanitary facilities, such as a dry toilet, to make the shelter more autonomous and versatile.

Taken together, the feedback illustrates both the promise and the current limitations of the prototype. Stakeholders recognized its cultural fit, structural soundness, and ecological value, but also underscored urgent needs in thermal comfort, waterproofing, and joinery refinement. These insights not only validate the prototype as a step forward but also guide its next design iterations, ensuring that the prefabricated bamboo system grows into a more resilient, comfortable, and widely accepted housing solution.

To further clarify the diverse perspectives collected during the prototype testing, Table 2 summarizes the feedback from different stakeholder groups. The table highlights both positive impressions and constructive critiques, offering a comparative view of how users, craftsmen, researchers, and the public perceived the prefabricated bamboo cabin.

Table 2. Summary of Stakeholder Feedback on the Prefabricated Bamboo Cabin Prototype

Stakeholder Group	Positive Impressions	Critical Feedback/Suggestions
Local craftsmen	Recognized cultural fit of bamboo; praised robustness of the structure; saw potential for replication.	Joinery detailing less neat due to screws; small gaps between modules reduced precision; suggested refinement in metal joints.
Overnight users (community members, students)	Comfortable in mornings/evenings due to natural ventilation; appreciated strong coastal airflow during windy season.	Interior became hot at midday (10 a.m.–4 p.m.); rain penetrated woven bamboo walls; recommended shading, improved roofing, and better waterproofing.
Researchers & visitors (including foreign guests)	Supported sustainable and modular design direction; valued eco-friendly image in the tourism context.	Recommended expanding functions, especially sanitary facilities (e.g., dry toilet), to increase autonomy and usability.
General public	Found the design visually appealing and eco-friendly; noted that it blended well with the Sanur coastal setting.	Highlighted need for improved thermal comfort and long-term durability.

3.5. Cost Comparison between Prefabricated and Conventional Bamboo Construction

To address concerns regarding affordability and construction efficiency, this study conducted a comparative cost analysis between a prefabricated bamboo cabin model and a conventional on-site construction approach, using the same design specifications and material standards. The comparison focuses on material consumption, labor input, and total production cost, under a controlled assumption of four workers (*tukang*) in both scenarios, allowing cost differences to be attributed primarily to construction logic and time efficiency rather than workforce scale.

Table 3 presents the detailed cost breakdown for the prefabricated construction model, including structural components, enclosure systems, finishing elements, and labor, calculated based on a total of 84 working hours. This table reflects the workshop-based production process combined with rapid on-site assembly, highlighting how prefabrication compresses construction time and reduces labor dependency.

In contrast, Table 4 summarizes the cost structure of the conventional construction model, in which the same cabin is built entirely on-site by four craftsmen working full-time over eight days. This scenario captures the cumulative effects of longer construction duration, higher labor costs, and less controlled material handling, which are typical of traditional building practices.

The cost analysis compares two construction scenarios for the bamboo cabin: a prefabricated (workshop-based) approach and a conventional on-site construction method, under the same assumption of four workers (tukang) in both cases. This clarification ensures that cost differences are attributed to construction logic and time efficiency rather than workforce size.

In the prefabricated scenario, the cabin components were produced and assembled using a total of 84 labor-hours, equivalent to four workers working intermittently across the prefabrication and on-site assembly phases. This workload includes structural preparation, enclosure installation, roofing, finishing, and basic electrical setup. The total construction cost reached IDR 10,758,000 (USD 672.38). Labor efficiency was achieved through task parallelization, reduced rework, and shorter on-site assembly time enabled by prefabrication.

In contrast, the conventional construction scenario assumed four full-time craftsmen working on-site for eight consecutive days, with an average of eight working hours per day. This results in approximately 256 labor-hours, more than three times the labor input required in the prefabricated approach. The extended construction duration directly increased labor costs and necessitated additional temporary structural elements, leading to a total cost of IDR 13,893,000 (USD 868.31).

Overall, the prefabricated approach achieved a cost reduction of IDR 3,135,000, corresponding to approximately 22.6% lower total cost compared to conventional construction. From a labor perspective, prefabrication reduced effective working time by roughly 67%, demonstrating that time compression—rather than material substitution alone—was the dominant factor driving cost efficiency.

Nevertheless, this economic advantage is context-dependent. The reduced labor input relies on access to prefabrication facilities, coordinated workflows, and proximity between workshop and site. Without these enabling conditions, conventional construction may remain competitive. Even so, the findings confirm that prefabricated bamboo systems offer a measurable, low-cost and time-efficient alternative, particularly suitable for rapid-deployment housing and small-scale modular shelters in tropical environments.

Table 3. Cost of production with the prefabrication model

Component	Material	Quantity		Unit Price (IDR)	Total (IDR)	Unit Price (USD)	Total (USD)
Structure	Bamboo Tali (treated) (6cm, long 4m)	10	btg	25,000	250,000	1.5625	15.625
	Steel Joints/Bolts	16	set	175,000	2,800,000	10.9375	175
Enclosure	Plywood / Woven Bamboo	2	layer	210,000	420,000	13.125	26.25
	Bamboo Woven panel	8	panel	200,000	1,600,000	12.5	100
	Bamboo Split	100	btg	4,000	400,000	0.25	25
	Roofing	22	pcs	80,000	1,760,000	5	110
	Lighting	8	set	76,000	608,000	4.75	38
Finishing	Varnish/Coating	1	can	400,000	400,000	25	25
Labor	Student/Tukang (4 men-21 hours)	84	hours	30,000	2,520,000	1.875	157.5
TOTAL					**10,758,000**		**672.375**

Table 4. Cost of production with the conventional model

Component	Material	Quantity		Unit Price (IDR)	Total (IDR)	Unit Price (USD)	Total (USD)
Structure	Bamboo Tali (treated) (6cm, long 4m)	15	btg	25,000	375,000	1.5625	23.4375
	Long drats (1m)	10	set	33,000	330,000	2.0625	20.625
Enclosure	Plywood / Woven Bamboo	2	layer	210,000	420,000	13.125	26.25
	Bamboo Woven panel	8	panel	200,000	1,600,000	12.5	100
	Bamboo Split	100	btg	4,000	400,000	0.25	25
	Roofing	22	pcs	80,000	1,760,000	5	110
	Lighting	8	set	76,000	608,000	4.75	38
Finishing	Varnish/Coating	1	can	400,000	400,000	25	25
Labor	Tukang (at least 4 men, 8 days)	32	days	250,000	8,000,000	15.625	500
TOTAL					**13,893,000**		**868.3125**

4. Conclusions

This study demonstrates that prefabricated bamboo cabins can function as modular and relocatable shelter systems when design development, prototyping, field assembly, and user evaluation are integrated within a coherent socio-technical framework. By structuring the investigation across digital simulation, workshop-based prefabrication, Ready-to-Assemble (RTA) field deployment, and stakeholder feedback, the research moves beyond purely technical validation and situates bamboo prefabrication within real construction practices and lived user experience.

From a design and simulation perspective, the iterative use of BIM tools alongside physical prototyping proved essential. Digital models enabled precise modular coordination, environmental simulations, and joinery planning, while workshop trials revealed the limits of digital precision when confronted with bamboo's natural irregularity. This finding reinforces earlier research showing that bamboo's structural potential depends not only on engineered connectors [28,29] but also on adaptive tolerances that respond to material variability [30]. The study confirms that standardized modular dimensions can reduce waste and support scalability, yet must remain flexible enough to accommodate non-uniform natural materials.

The prefabrication phase highlighted both the strengths and constraints of workshop-based production. Consistent with prior studies emphasizing the role of craftsmanship in reducing material waste [31], the results show that bamboo offcuts and panel inefficiencies remain significant when fabrication is carried out by semi-skilled participants such as students. While digital and parametric approaches have been proposed to mitigate these issues [32], this research underscores that technological optimization alone is insufficient without parallel investment in skill development and tacit knowledge transfer. In this sense, bamboo prefabrication emerges not as a fully industrialized system, but as a hybrid process that relies on both modular logic and human expertise.

Field assembly results provide strong evidence of the practical advantages of the RTA system. The complete cabin was assembled on-site in 5 hours and 15 minutes by a small, non-professional team using minimal tools, confirming that modular bamboo systems can significantly compress construction time compared to conventional practices. This finding aligns with broader modular housing research that identifies speed and logistical simplicity as key advantages of prefabrication [6]. At the same time, the study reveals that assembly efficiency does not eliminate the need for careful detailing, particularly at joints and panel interfaces, where precision directly affects durability, waterproofing, and perceived quality.

User perceptions and stakeholder feedback further emphasize the socio-technical nature of bamboo prefabrication. The material was widely appreciated for its cultural familiarity, ecological image, and visual compatibility with the Balinese coastal context, echoing findings from earlier bamboo housing studies [28]. However, experiential feedback also exposed critical shortcomings, especially thermal discomfort during peak daytime hours and rainwater penetration through woven bamboo panels. These issues mirror observations in vernacular bamboo research, where passive cooling often relies on permeability and informal detailing [33], suggesting that future iterations must better reconcile modular precision with environmental responsiveness.

The inclusion of a comparative cost analysis strengthens the study's contribution by translating qualitative claims of affordability into measurable evidence. Under equivalent labor assumptions, the prefabricated model reduced total construction cost by approximately 22.6% compared to conventional on-site construction, primarily due to labor time compression rather than material substitution alone. While previous modular housing literature frequently asserts cost efficiency in general terms [6,34], this study provides concrete data showing how prefabrication can reduce labor input by nearly two-thirds. Nevertheless, this advantage remains context-dependent, relying on access to workshop facilities, coordinated logistics, and proximity between fabrication and site.

Overall, this research situates bamboo prefabrication within contemporary debates on modular housing systems that often face barriers related to cost, skill availability, and regulatory acceptance [35]. By combining Design Science Research, Research through Design, participatory workshops, and structured prototyping, the study demonstrates how bamboo can act not only as a structural material but also as a cultural and social mediator within prefabricated construction. The findings suggest that prefabricated bamboo cabins offer a promising pathway for fast, affordable, and environmentally responsible housing in tropical contexts, while also revealing clear priorities for future development—namely improved thermal strategies, refined joinery precision, integrated sanitation modules, and professional training in bamboo craftsmanship.

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