# OPTIMIZED BAMBOO PANELS TECHNIQUES FOR SUSTAINABLE LIGHTING AND THERMAL SOLUTIONS

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## ABSTRACT

*This research aims to explore diverse bamboo processing techniques for panel production and their impact on indoor environmental quality, with a focus on lighting and thermal comfort. By reviewing traditional and contemporary methods of bamboo technique, we identify optimal approaches for creating bamboo panels that enhance natural lighting and thermal conditions. Laboratory testing and simulations are employed to analyze changes in optical properties and thermal performance, including light transmission, diffusion, thermal conductivity, and insulation. The findings provide architects and construction professionals with actionable insights into leveraging bamboo's sustainability to achieve superior indoor environments. This study promotes eco-friendly building practices that prioritize occupant well-being and environmental preservation.*

***Keywords:*** *Bamboo Panels, Indoor Environmental Quality, Lighting Optimization, Thermal Comfort, Sustainable Building Materials*

## INTRODUCTION

In an era increasingly focused on sustainability and indoor comfort, architectural and construction research has advanced significantly in exploring environmentally friendly solutions that enhance the quality of indoor living spaces. Among these efforts, bamboo has garnered attention as a sustainable and versatile material with immense potential for building applications, particularly as panels for secondary skin systems. Its rapid growth, high strength-to-weight ratio, and aesthetic appeal make it an attractive choice for eco-friendly construction.

Despite its widespread use in traditional architecture, the modern application of bamboo in interior spaces remains underexplored. Existing studies often highlight bamboo's environmental benefits but provide limited insight into how processing techniques can optimize its performance for specific applications like enhancing lighting and thermal comfort. This gap in knowledge forms the foundation of this research, which aims to investigate bamboo processing techniques to address these challenges effectively.

Bamboo, a member of the *Poaceae* family and *Bambusoideae* subfamily, is renowned for its renewability and adaptability. As Kumar *et al.* (2021) notes, its etymology traces back to Malay origins, highlighting its cultural significance across tropical and subtropical regions. While its ecological advantages are well-documented, the ability to optimize bamboo panels for lighting optimization and thermal regulation remains an emerging field of study. This research contributes to filling this gap by analysing and proposing innovative processing techniques for bamboo panels that improve indoor environmental quality.

To achieve this, the study delves into both traditional and modern bamboo processing methods. Techniques such as boron treatment and heat treatment are evaluated for their role in enhancing bamboo’s durability and resistance to weathering. Additionally, modern fabrication methods, including bamboo cladding and shading systems, are explored for their ability to enhance natural lighting and reduce excessive solar heat, thus improving both thermal comfort and energy efficiency.

By addressing these critical gaps, this research provides architects and construction professionals with practical insights into how bamboo processing techniques can be advanced to achieve sustainable and comfortable indoor environments. Furthermore, the study sets the stage for future research to expand on bamboo's potential as a key material for environmentally conscious building design.

## THEORY / RESEARCH METHODS

### Bamboo Processing Techniques

Bamboo processing is a multi-stage procedure designed to transform raw bamboo into a durable and versatile material suitable for various applications. This process begins with the harvesting of bamboo, typically when it reaches maturity (around 3 to 5 years old), ensuring it has optimal strength and flexibility. In Indonesia, bamboo harvesting often takes place during the dry season to minimize moisture content. After harvesting, the bamboo is cleaned by removing leaves and branches and may undergo surface stripping to create a smoother texture suitable for further refinement.

Once prepared, the bamboo undergoes drying, either through natural air-drying methods or kilns, to reduce moisture content. This crucial step not only prevents decay but also extends the bamboo’s longevity. To enhance its resistance to pests and decay, traditional Indonesian methods often include immersion in water or smoking over a fire, while modern techniques use chemical treatments such as boron solutions or heat treatments. Following preservation, the bamboo is cut into desired lengths, smoothed to remove sharp edges, and organized for specific applications.

In Indonesian architecture, cultural practices influence bamboo processing. Traditional techniques like hand-stripping or weaving reflect a deep connection to the community’s heritage, while modern methods incorporate adhesives or machinery for precision and scalability. Depending on the intended use, bamboo may also be painted or decorated to align with aesthetic and functional needs. Quality control remains critical throughout the process to ensure that the material meets the standards required for its applications.

**Bamboo Applications in Indonesian Architecture**

Indonesia's rich cultural heritage and tropical climate have shaped the way bamboo is used in construction. One of the most prevalent techniques is bamboo weaving, locally known as *anyaman bambu*. This method involves cutting bamboo into thin strips and weaving them into panels, a practice deeply rooted in Indonesian craftsmanship. The resulting panels, commonly referred to as Sasak Bambu, serve as secondary skins in traditional and modern architecture (Figure 1).

Sasak Bambu panels are widely used in Indonesian homes, particularly in rural areas, due to their ease of production, affordability, and multifunctionality. Available in standardized sizes such as 2 x 2 meters or 3 x 3 meters, these panels are primarily used as walls, roofing, and flooring. Their unique structure allows them to function as "Breathing Walls", which separate indoor and outdoor spaces while permitting natural light and airflow to pass through. This feature is especially significant in tropical climates like Indonesia's, where maintaining ventilation and reducing indoor temperatures are crucial for thermal comfort.

**Figure 1.** Waving Technique, Sasak Bambu, and Bamboo Panel
Source: Bambuyasa Workshop (2023)

Moreover, these panels exemplify a harmonious balance between functionality and cultural expression. The intricate weaving patterns not only reflect local artistry but also embody sustainable practices by maximizing bamboo's natural properties. In modern applications, Sasak Bambu panels are gaining attention for their ability to improve indoor environmental quality, aligning with contemporary architectural goals of sustainability and energy efficiency.

This study employs a quantitative method through an experimental approach, collecting both primary and secondary data. Primary data were gathered from hands-on experiences during the Bambuyasa Workshop (July 31 - August 12), where participants practiced creating bamboo panels. The process began with crafting a scaled 1:4 module and progressing to produce a full-sized 2 x 2 meter panel (Figure 2). Under the guidance of the second author, the team learned to work with bamboo materials, understanding the differences between bamboo types, and mastering the steps of bamboo processing techniques. These activities were further enhanced by a site visit to BambooLand Indonesia in Ngepring, Yogyakarta, where practical insights into bamboo's growth, harvesting, and preparation were obtained.

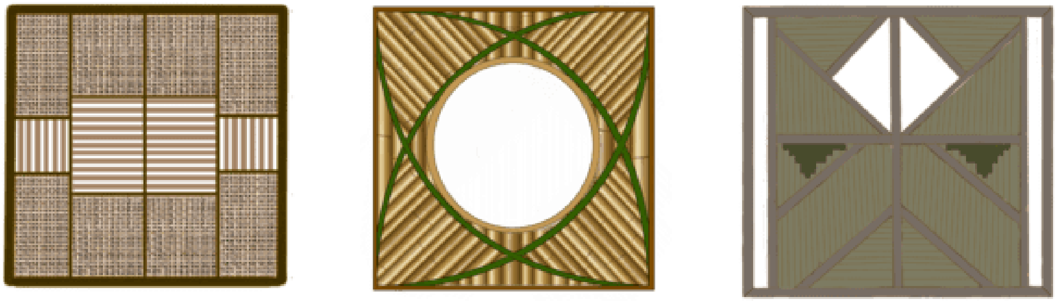

**Figure 2.** Bamboo Panel Designs
Source: Bambuyasa Workshop (2023)

To ensure practical application, the team designed three alternatives for bamboo panels, selecting the first design (Figure 3) for use as an entrance panel. Additionally, a new design was developed specifically for a kitchen ceiling, considering weight limitations and openings to allow ventilation and lighting.

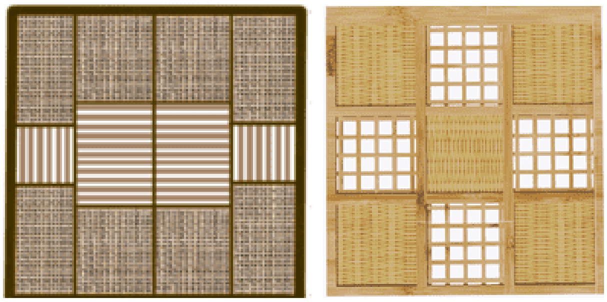

**Figure 3.** Chosen Panel Designs
Source: Bambuyasa Workshop (2023)

In terms of techniques, the research utilized:

1. *Bilah* (Figure 5a): This technique involves splitting bamboo into narrow strips, which are arranged with small gaps between them. It is a simplistic yet effective method that allows natural light to penetrate while facilitating airflow, enhancing ventilation and lighting in indoor spaces. The straightforward nature of this technique makes it ideal for applications where functionality and ease of construction are prioritized.
2. *Geprek* (Flattened Bamboo) (Figure 5b): The *geprek* technique involves flattening bamboo by splitting it and compressing it until it forms a flat, uniform surface. This process requires precise tools, such as a hammer and axe, to break the bamboo nodes and ensure an even texture. While slightly more wasteful compared to other techniques, *geprek* panels offer

excellent thermal and lighting control, making them suitable for applications where insulation and aesthetic quality are critical.

3. *Anyaman* (Weaving) (Figure 5c): This technique employs a woven pattern of bamboo strips, interlaced in a 2 x 3 configuration. The weaving not only enhances the structural strength of the panel but also adds a visually appealing texture, blending functionality with aesthetic appeal. The traditional craftsmanship involved in this technique offers a nod to cultural heritage while addressing modern design requirements.
4. Mixed *Anyaman* and *Bilah* (Figure 6a): This method combines the weaving and *bilah* techniques to achieve greater design variety and improved functionality. The combination allows for creative freedom in panel design, enabling the panels to meet diverse architectural needs. By blending the intricate patterns of *anyaman* with the simplicity of *bilah*, this technique strikes a balance between practicality and artistic expression, making it suitable for both decorative and functional applications.
5. Mixed *Anyaman* and *Geprek* (Figure 6b): This innovative combination merges the intricacy of woven bamboo patterns with the flat, clean lines of the Geprek technique. By integrating the visual appeal and structural integrity of *anyaman* with the smooth, uniform surface of *geprek*, this technique delivers panels with enhanced aesthetic diversity and performance. The mixed design is particularly advantageous for architectural projects requiring a balance between artistic expression and practical functionality, such as ceiling panels or decorative wall installations.

These techniques were selected to create panels with variations in aesthetics and performance, blending traditional craftsmanship with modern architectural needs (Figure 4).

**Figure 4.** 2 x 2 meters Panel Result
Source: Bambuyasa Workshop (2023)

This research necessitates the inclusion of case studies to assess the viability of bamboo as a construction material in buildings with organic shapes. The selected case study subject is Difour Coffee House. The research approach entails a combination of on-site investigations and extensive literature reviews. It's important to clarify that this study focuses on improving an area by using bamboo materials as secondary skin.

## RESULTS AND DISCUSSION

This study assessed the effectiveness of various bamboo techniques for panel applications in achieving thermal and lighting comfort for a 4 x 5m café while exploring bamboo's scalability in broader architectural contexts. The bamboo weaving technique proved to be the most intricate and effective. By diffusing light and reducing solar heat, it enhances indoor comfort while maintaining aesthetic appeal. The adaptability of weaving patterns (e.g., zigzag, diagonal) allows for creative designs that integrate seamlessly into contemporary and traditional architectural styles. Compared to studies by Kumar et al. (2021), which emphasized bamboo panels' role in thermal regulation and lighting, this study adds insights into specific weaving patterns that maximize these benefits. Additionally, bamboo weaving aligns with findings by Manandhar et al. (2019), highlighting its environmental, social, and economic sustainability in construction materials.

The flattened bamboo technique, despite its labor-intensive preparation, offers significant advantages in insulation and thermal comfort. Flattened bamboo panels could serve as cost-effective alternatives to synthetic materials in affordable housing projects, particularly in tropical or subtropical regions. As explored by Lou et al. (2021), advancements in flattening techniques have improved bamboo's structural reliability, making it suitable for applications such as façades and shading systems in urban environments. While less effective in diffusing light than weaving, combining flattened bamboo with other techniques, such as weaving, improved its overall performance. This combination reflects traditional Indonesian practices that successfully integrate craftsmanship and functionality.

(a) (b) (c)

**Figure 5.** Bamboo Technique: (a) Bilah, (b) Geprek, (c) Waving
Source: Bambuyasa Workshop (2023)

The *bilah* technique, with its simple yet effective design, allows for small openings that balance natural light and ventilation. This makes it suitable for buildings requiring cross-ventilation or diffused lighting, such as libraries, co-working spaces, or galleries. Its simplicity, affordability, and low material waste make it ideal for large-scale projects, especially in low-income or rural areas. Bamboo’s physical and mechanical properties, as highlighted by Nordahlia et al. (2019), contribute to its structural efficiency and ease of implementation in such contexts.

By combining techniques such as weaving and *bilah* with modern innovations like sliding mechanisms, architects can develop adaptive solutions that address varying climatic conditions and user preferences. For example, mixed designs can enable dynamic façades that optimize daylight and reduce heat gain.

(a) (b)

**Figure 6.** Bamboo Technique (a) Anyaman & Bilah, (b) Anyaman & Geprek
Source: Bambuyasa Workshop (2023)

Thermal and lighting simulations validated the effectiveness of these techniques in a case study of Difour Coffee House (Figure 7 & 8). Adding bamboo secondary skin panels (Figure 9) to west-facing walls reduced indoor temperatures by up to 3°C and improved lighting conditions by diffusing glare (Figure 10). This secondary skin acted as a thermal buffer, significantly reducing reliance on air conditioning while promoting energy efficiency. Sliding mechanisms integrated into the panels allowed for adjustable operation based on the time of day, enhancing thermal and lighting control. These findings align with Hajji et al. (2024) and Irfan et al. (2023), who demonstrated bamboo’s role in improving indoor environmental quality through passive design strategies like natural lighting and shading.

Additionally, bamboo's potential for sustainability extends beyond construction into broader applications. For instance, Silva et al. (2020) highlighted its eco-friendly properties for industries like food and biotechnology. The versatility of bamboo in modular designs or prefabricated panels, as suggested by Natanael et al. (2020), allows for faster construction timelines, lower costs, and minimal environmental impact. Such features make bamboo a valuable material for achieving sustainable development goals, particularly Goal 11 (Sustainable Cities and Communities), as noted by the United Nations (no date). Its use aligns with the Paris Agreement's focus on reducing carbon emissions and creating climate-resilient infrastructure (United Nations Climate Change, no date).

**Figure 7.** Difour Coffe House Photo and Render
Source: Field Survey and Sketchup (2023)

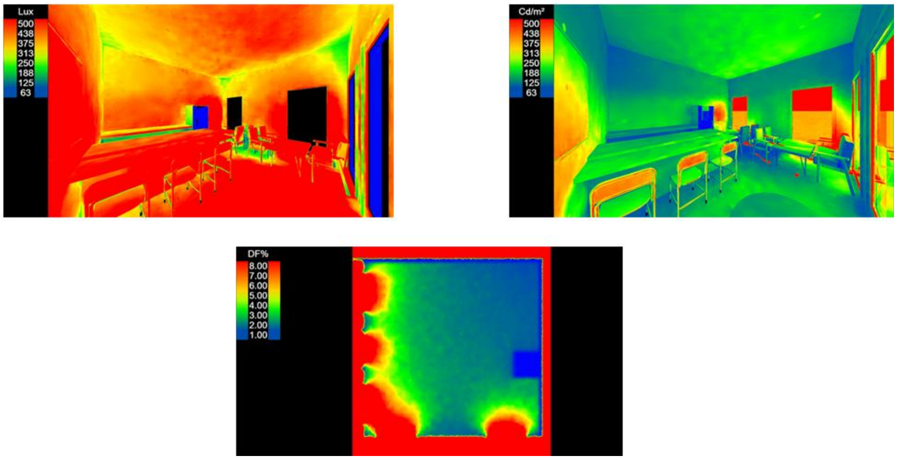


**Figure 8.** Velux Simulation Before Improvement Condition
Source: Software simulation (2023)

Economically, bamboo construction offers significant benefits to local communities. The integration of traditional techniques like weaving and *bilah* into modern applications not only preserves cultural heritage but also provides employment opportunities for artisans, as noted by Mishra et al. (2014). Moreover, innovations like embossed bamboo panels, as described by Schober et al. (2014), demonstrate how traditional materials can be adapted to meet contemporary design aesthetics and functionality.

These findings align with the principles of passive design, emphasizing materials with low thermal conductivity and adaptive features to improve indoor environmental quality. By integrating traditional Indonesian techniques with modern sustainability goals, this study bridges the gap between heritage and innovation. The results underscore bamboo's potential for eco-friendly and scalable building design, offering architects and planners an opportunity to address pressing climate challenges while achieving global sustainability targets (Huang et al., 2017; Nurdiah, 2016).

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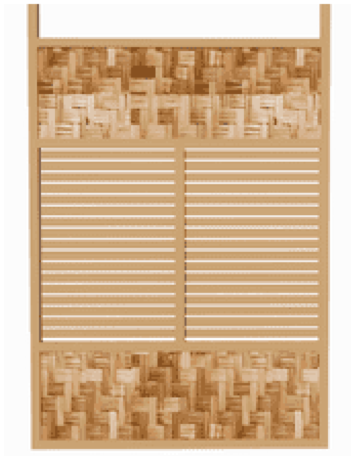

**Figure 9.** Panel Design
Source: Software simulation (2023)

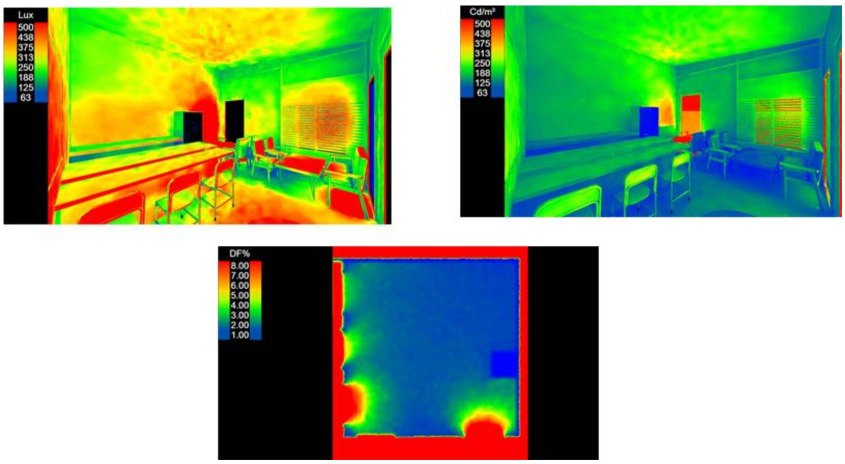


**Figure 10.** After Improvement Condition
Source: Velux Software simulation

Architects and urban planners can leverage bamboo's properties to create bioclimatic designs that respond to local environmental conditions. For instance, bamboo panels could be used to design modular, prefabricated building components, enabling faster construction timelines while minimizing environmental impact. Additionally, incorporating bamboo into architectural practices could support the global transition toward carbon-neutral construction, aligning with international frameworks such as the Paris Agreement and UN Sustainable Development Goals (United Nations; United Nations Climate Change).

Overall, the results highlight bamboo's versatility and sustainability as a material for secondary skin applications in tropical architecture. By integrating traditional Indonesian techniques with modern sustainability goals, the study bridges the gap between heritage and innovation. By linking these findings to broader architectural practices, this study underscores bamboo’s potential to drive innovation in eco-friendly and scalable building design.

## CONCLUSIONS

The study demonstrates that the weaving technique is the most effective for reducing excessive light penetration, providing significant thermal comfort benefits. Its ability to block high amounts of light makes it an ideal choice for spaces where glare and heat control are critical. On the other hand, the *bilah* technique stands out for its simplicity and practicality, offering a straightforward method to create small openings or gaps that allow controlled amounts of light to enter. This balance between natural illumination and thermal regulation makes it an efficient solution for various architectural applications.

Furthermore, combining weaving and *bilah* techniques in a mixed design, coupled with a sliding mechanism, introduces flexibility in controlling light and thermal conditions. This innovative approach provides adaptability to suit different indoor environments and user preferences. Simulations conducted using Velux Daylight Visualizer 3 confirmed the effectiveness of the proposed panel design for Difour Coffee House. The panels significantly reduced excessive light entering the space, improving thermal conditions and reducing reliance on artificial cooling systems.

While this study primarily focused on specific bamboo panel designs and techniques, future research should explore their broader applications in diverse architectural contexts. Investigating their performance in different climates, building typologies, and cultural settings could offer valuable insights into optimizing bamboo as a sustainable material. These findings contribute to the growing body of knowledge on bamboo’s potential for eco-friendly and adaptable architectural solutions.

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