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Implementation of Laminated Bamboo in Pavilion Buildings As an Alternative to Substitute Wood (Case Study: Pavilion at Mertasari Beach, Sanur, Denpasar)

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ABSTRACT

Wood Construction has a lower carbon footprint compared to other modern materials. However, the use of wood materials in the long term can cause deforestation which has a negative impact on the forest ecosystem. In reducing pressure on forests and helping to combat deforestation, the development of innovative laminated bamboo materials has emerged as an alternative to wood materials. This condition raises further questions about how to apply laminated bamboo materials as an alternative to wood in building construction? This study aims to determine how to apply laminated bamboo materials to building construction as an alternative to wood materials. The research was conducted using a case study method. The case that was used as the object of study in this study was a pavilion at Mertasari Beach, Sanur, which was built with laminated bamboo materials in the structure and construction of the building. This study was conducted by observing the application of laminated bamboo materials to the Pavilion through planning drawings, modeling (design mockups), and the construction process in the field. The discussion was carried out by describing the structure of the laminated bamboo material, and comparing it with the structure of wood materials in general. As a result, laminated bamboo materials in construction can be used for building structures, such as beam and column structures. Laminated bamboo also has almost the same quality as wood, and the method of applying laminated bamboo materials is not much different

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from the application of wood materials in building construction. So that laminated bamboo material can be a substitute material for wood material as the main structure of the building. This can have the opportunity to reduce the use of wood material which is increasingly rare, and indirectly can help reduce deforestation rates.

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1. INTRODUCTION

Wood construction has a lower carbon footprint compared to other modern materials (Saputra Yupa et al., 2024). However, long-term use of wood materials can cause deforestation which has a negative impact on forest ecosystems. According to (Sulastiningsih et al., 2016), the wood processing industry in Indonesia is experiencing a shortage of wood raw materials, especially those from natural forests. This happens because the speed of wood utilization is not balanced with the speed of new development. Wood has an important role in the development of housing and residential areas. Some parts of the building structure still use wooden materials. This is because wood is relatively light, easy to work with, has a higher strength to weight ratio than several other types of building materials, and is a well-known building material for house construction, including traditional houses. When building houses and buildings, the price of wood is increasingly expensive and unaffordable (Saefudin, 2007). So far, wood is still the main material of choice in construction, especially in traditional buildings (Handoko et al., 2015) However, because the growth period for wood tends to be longer and prices are increasing, there is a need for other solutions to be used as the main construction material. In reducing this crisis, the development of laminated bamboo material innovation has emerged as an alternative to wood material. Bamboo also has a growing time of around 4 to 5 years to be harvested, so the growth of bamboo plants is faster than wood (Darwis, 2010). The types of bamboo that can be used as the main construction material are petung bamboo, santong bamboo and rembu bamboo (Bamboo Forest Survey Document, 2024). Laminated bamboo is bamboo that is processed into a composite material combined using adhesive techniques. With this technique, small building materials can be glued together to form components as needed. Apart from that, lamination techniques also allow combining raw materials that are not uniform or come from various quality levels (Suprijanto & Rusli, 2009).

The use of bamboo as a plywood material was introduced by Guisheng (1985), Bamboo Information Center (1994), and (Subijanto, 2017) Ply bamboo has high strength against abrasion and bending moments. The resistance of bamboo floors to abrasion has been studied by Mohmod and friends (1990). Laminated bamboo has been used as a building material for decades, but began to attract widespread attention in the late 1990s and early 2000s as a sustainable alternative to traditional wood and other materials. Its popularity is increasing due to its strength, durability, aesthetic appeal and environmental friendliness. The development of modern laminated bamboo products, such as panels and beams, emerged along with advances in adhesive technology and the emergence of green building practices. Bamboo's fast growth and renewal rate makes it an excellent material for construction, furniture and interior design (Nurazka et al., 2021) (Dewi, 2023). Nowadays, laminated bamboo material is still mostly applied in non-structural construction, such as materials for crafts, furniture, secondary skin, and building interiors. Laminated Bamboo developed by the Indonesian PUPR Ministry has now been implemented as a traditional house structure in Penglipuran Village, Bangli Regency, Bali. Apart from being used in building construction, Laminated Bamboo is also used as a material for handicrafts, door leaves, wall panels, parquet floors, furniture and gazebos. The material properties of laminated bamboo make it an attractive and effective choice for simple construction, with various benefits related to strength, sustainability and efficiency (Wibowo, 2005).

In the structural and construction aspects, this laminated bamboo material is usually applied as a structural and construction material for ships. Khotimah (2014) has technically tested the use of laminated bamboo material as a construction material for fishing boat keels

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as a substitute for wooden material. The use of laminated bamboo material in shipping construction was also discussed by (Zanki dan Pribadi, 2016), especially in the use of laminated bamboo for deck covering, ceiling and ship lining as an alternative to wood. So that the economic value of laminated bamboo will be obtained which can later be used as a reference in choosing alternative materials to replace wood and can save on shipbuilding costs. The application of laminated bamboo material can be used in ship construction, as well as building construction. It's just that laminated bamboo material is not yet commonly used in building structures and construction. Research regarding technical testing of this material has begun to be developed. (Eratodi et al., 2008) states that laminated bamboo is able to fulfill various dimensions usually found in wood, and can be adapted to construction needs. Through various research that has been carried out, a lot of potential can be realized by using laminated bamboo as a building material. (Suprijanto & Rusli, 2009) in his article regarding the standardization of laminated bamboo as an alternative to construction wood, stated that one material that can be used as an alternative to wood is bamboo. Bamboo has several advantages in being able to be used as a substitute for wood as a construction material and furniture. In the 2008 and 2009 fiscal years (FY), laminated bamboo technology was developed by the Denpasar Traditional Housing Technology Development Center. With the use of increasingly advanced technology, bamboo can be used as a laminate which can be used as columns or beams by planning the dimensions and shape you want to use (Sharing Session Bauhaus, 2024).

Looking at existing research developments, this laminated bamboo innovation has a great opportunity to be developed as a structure and building construction. This opportunity was followed by further questions about how to apply laminated bamboo material as a building construction material? The study was carried out to determine the application of laminated bamboo material in building construction and to compare the application of the laminated bamboo material structure with the structure of ordinary wooden structures. It is hoped that this research can contribute to reducing dependence on wood materials in building construction and begin to open up views on new alternative materials that are more applicable. Bamboo has unique characteristics and high flexibility, as well as good sustainability thanks to its fast growth cycle. Technological innovations such as laminated bamboo increasingly prove that bamboo can meet construction needs, and can even replace wood in various structural applications.

2. METHODS

The study regarding the implementation of laminated bamboo in this building was carried out using a case study approach. The case study chosen is the Pavilion building designed by Bauhaus, which is an implementation of laminated bamboo material technology developed based on research results from Bauhaus, Bamboo Village Trust (BVT), and PT Indobamboo Lestari. This pavilion building is a pilot project for the application of laminated bamboo materials used as public scale building structures at Mertasari Beach, Sanur. This pavilion building is used for various kinds of public activity needs at Mertasari Beach, Sanur, such as a gathering place, accommodating exhibitions, performances, or other public activities. The planning for this pavilion building also aims to introduce renewable natural materials in the form of laminated bamboo to the general public in a more inclusive manner (Bondan, in Sharing Session with Bauhaus & BVT, 2024).

The Mertasari Sanur Pavilion building has a span of 4 m x 15 m, and a height of 8 meters. This is what makes this pavilion building an interesting case study for further study. This pavilion building was designed with a fairly large volume, and was built using almost 90%

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bamboo material, especially from the body of the building to the head of the building. This research was conducted to describe the extent to which laminated bamboo materials are used in the structure and construction of public buildings with quite large building volumes.

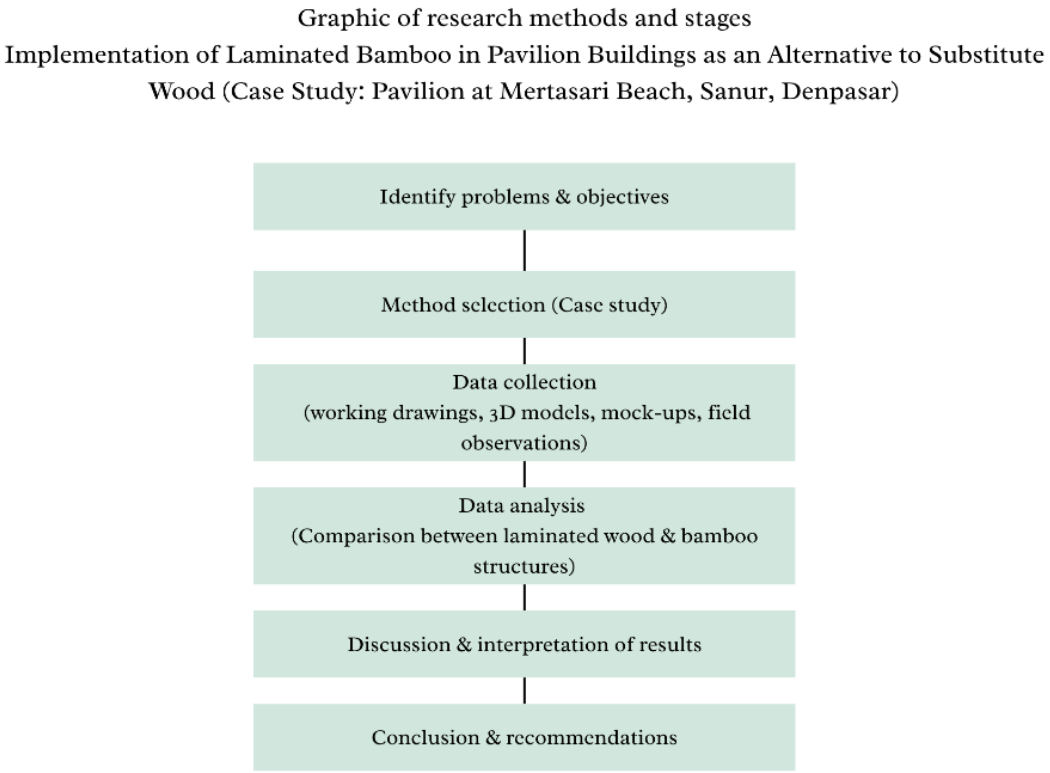

Figure 1. Research method and stages of the case study on the application of laminated bamboo material in the Mertasari Beach Pavilion building.
(Source: Author, 2024)

Figure 2. Location of the Bamboo Pavilion
(Source: Google Earth, 2024)

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Figure 3. Pavilion Building 1 : 1
(Source: Field Survey, 2024)

This study began by collecting data regarding the application of laminated bamboo materials in buildings through planning documents in the form of working drawings, 3D modeling drawings, model mockups, and the construction process in the field which has been running since October 2024 until now (December 2024). This data collection was also carried out by observing documentation drawings and photos from the field, and comparing them with data obtained from studying design documents. Data related to design document images was obtained directly from the design team.

This study approach begins by comparing the application of structural and construction systems for buildings made from laminated bamboo with systems for wooden buildings in general. The results of this comparison were then analyzed descriptively qualitatively, using existing studies of wooden building systems and research developments related to the application of laminated bamboo material technology.

3. RESULTS AND DISCUSSION

This research departs from a case study of pavilion construction on Mertasari Beach, which is a concrete example of the application of laminated bamboo as a construction material. This pavilion is the first project in Bali to use laminated bamboo as the main structure, making it an important milestone in the innovation of environmentally friendly materials in the fields of architecture and construction. The process of applying laminated bamboo to the construction of this Pavilion building will be discus sed further in this discussion.

3.1 Application of Laminated Bamboo Material in Pavilion Buildings at Mertasari Beach, Sanur

The pavilion building at Mertasari Beach was designed by adapting the Jineng form, which is one of the traditional buildings of the Balinese people. This building is made with a wooden structure and construction material, and has interesting tectonic features in the attic or under the curved roof. The shape of this building was the inspiration for the design of the Mertasari Beach Pavilion building. This project uses laminated bamboo material as a substitute for wood material which is usually used for Jineng structures and construction. Based on the results of the design document study, the laminated bamboo material in the Pavilion Building at Mertasari Beach is applied to the parts that function as load-bearing uses for the building, namely elements **upper-structure** And **super-structure**, including the roof frame structure,

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beams and building columns. Around 90% of the building structure of the Mertasari Beach Pavilion uses laminated bamboo, namely from the body structure to the roof of the building. The foot of this pavilion building uses a footplate foundation system with the base of the building using river stone material which is covered with a cement mortar finish as the floor.

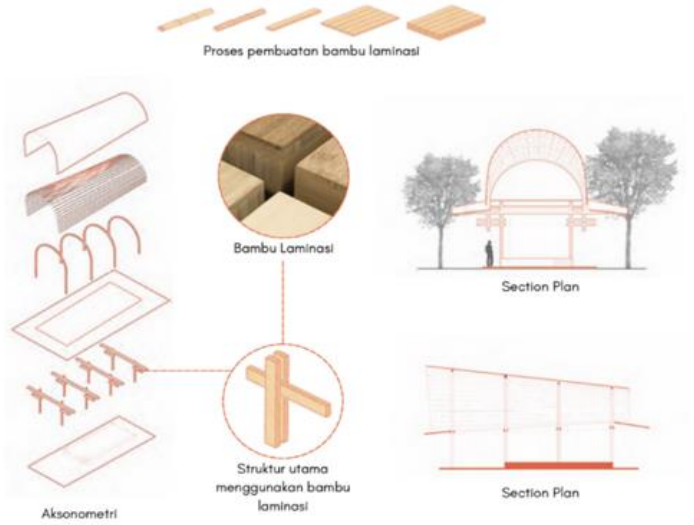

Figure 4. Application of Laminated Bamboo Material to The Main Structure of The Building at Mertasari Beach
(Source: Bamboo Village Trust, 2024)

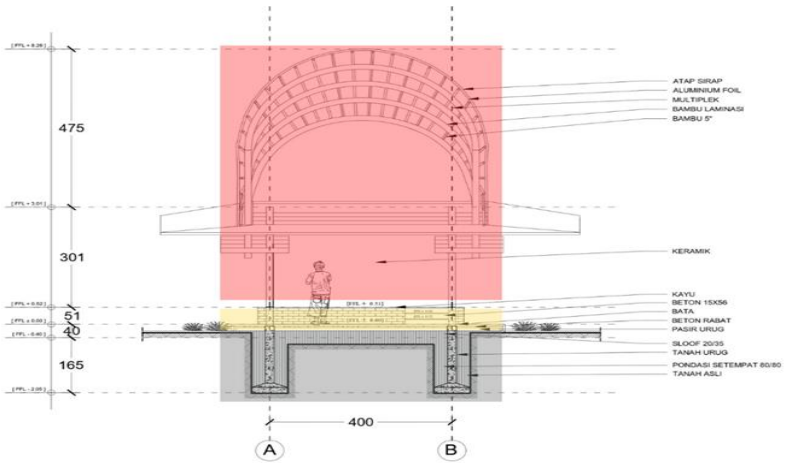

Figure 5 The Proportion of Material Used in The main Structure of The Pavilion Building at Mertasari Beach, The Red Color is The use of Laminated Bamboo Material As The Main Structure
(Source: Processed from Bamboo Village Trust, 2024)

Architectural details of the use of materials in the main structure of the pavilion building at Mertasari Beach can be explained as follows.

a. Upper Building Elements

Laminated bamboo is used in roof frame structures to support the roof load and protect the building interior from various weather conditions. This material has high tensile strength, thus providing good resistance to wind loads and changes in weather conditions that often occur in coastal areas.

b. Building Body Elements Beam System

As a load-bearing element, laminated bamboo functions to distribute horizontal loads from the roof to the columns. Laminated bamboo that has gone through the lamination process has high resistance to bending loads, making it the right choice for long-term loads and temperature variations.

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c. Building Columns

Columns from laminated bamboo support vertical loads from the roof and structures above it. The use of these columns provides flexibility in design as well as sufficient strength to support one-story buildings, such as pavilions.

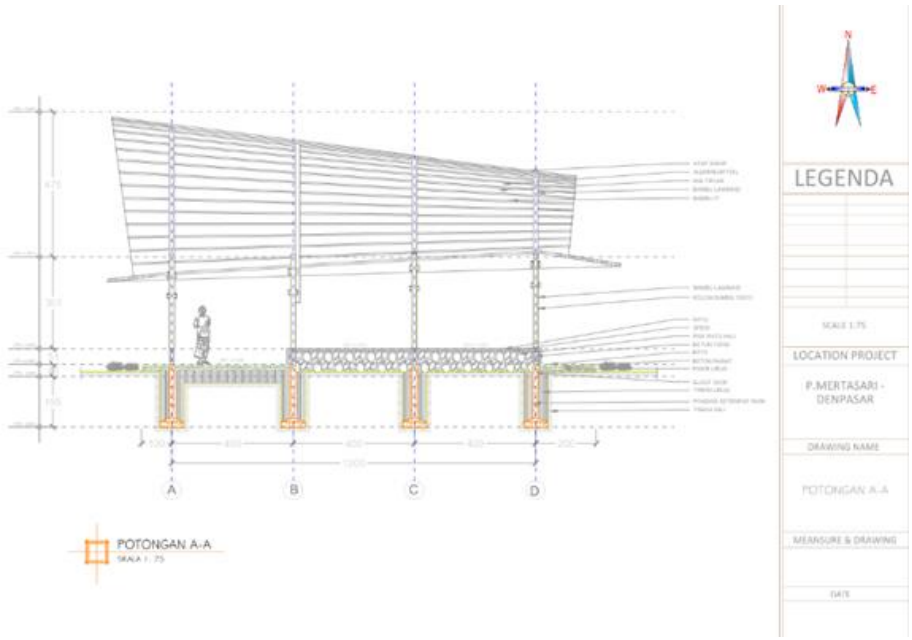

Figure 6. 2D Image of Structure Section
(Source: Work Image, 2024)

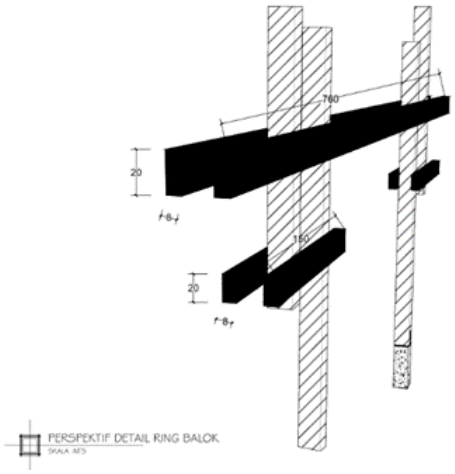

Figure 7. 2D Beam Image
(Source: Work Image, 2024)

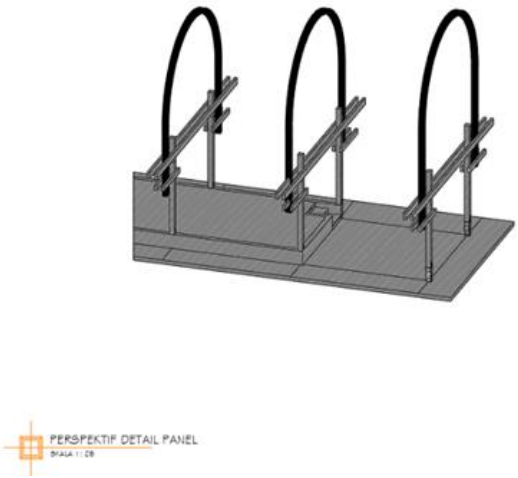

Figure 8. 2D Roof Frame Panel
(Source: Work Image, 2024)

3.2 Comparison of Practices for Applying Laminated Bamboo Materials to Wood Materials in General in Building Structure and Construction System

Previous research revealed that the laminated bamboo system can refer to a technical system that is almost the same as that applied to wood. This shows that although bamboo has its own characteristics, the approach to connecting its structural elements can follow the same principles as those used in wooden construction. This makes it easier to apply existing techniques and methods.

Application in the field proves that laminated bamboo really uses an application system that is almost similar to wood joints. This also proves that what previous research said is true

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is that its application is similar to wood. So it has a big chance of being a substitute for wood. with more sustainable material conditions.

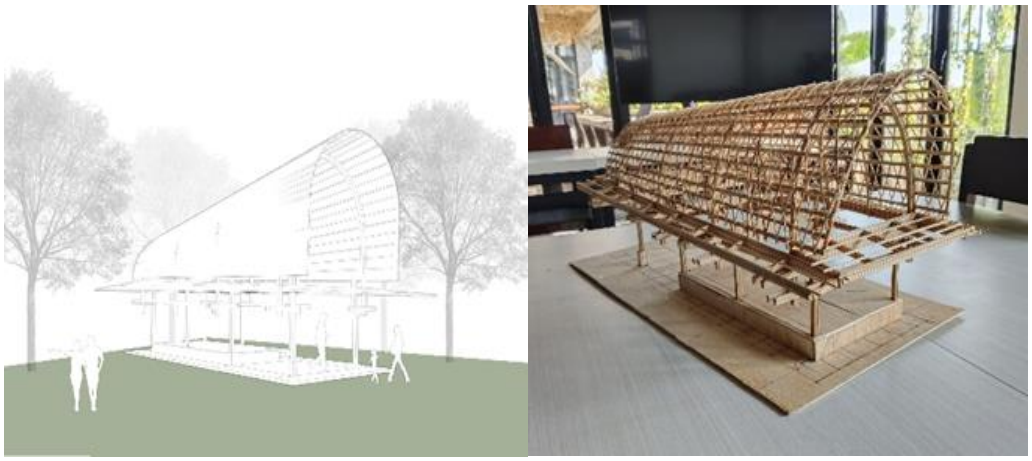

Figure 9. 2D and Pavilion Maquette Bamboo Laminate
(Source: Work Document, 2024)

The image above will be an illustration of a laminated bamboo building when the building is already standing. This pavilion uses laminated bamboo in the superstructure and superstructure. In the superstructure, laminated bamboo is used as columns and beams which function to distribute and support the main load of the building towards the foundation. Meanwhile, the upper structure is in the curved part of the roof structure which is the main point highlighted by this building model.

In the lower superstructure, the connection between the concrete column and the laminated bamboo column uses a T-shaped plate (Figure 10). The installation process starts with cutting the laminated bamboo and trimming the axle to prepare for installing the plate. The T-shaped plate is attached to a long iron thread installed in the concrete column. The T plate is then installed on laminated bamboo which has been hacked and drilled, so that it blends with the long threaded iron. This connection section functions as the main structure of the pavilion building as well as supporting the main load. This condition is not much different from the joint foundation system on traditional architectural wooden columns(Sulistiyono & Mulyono, 2019).

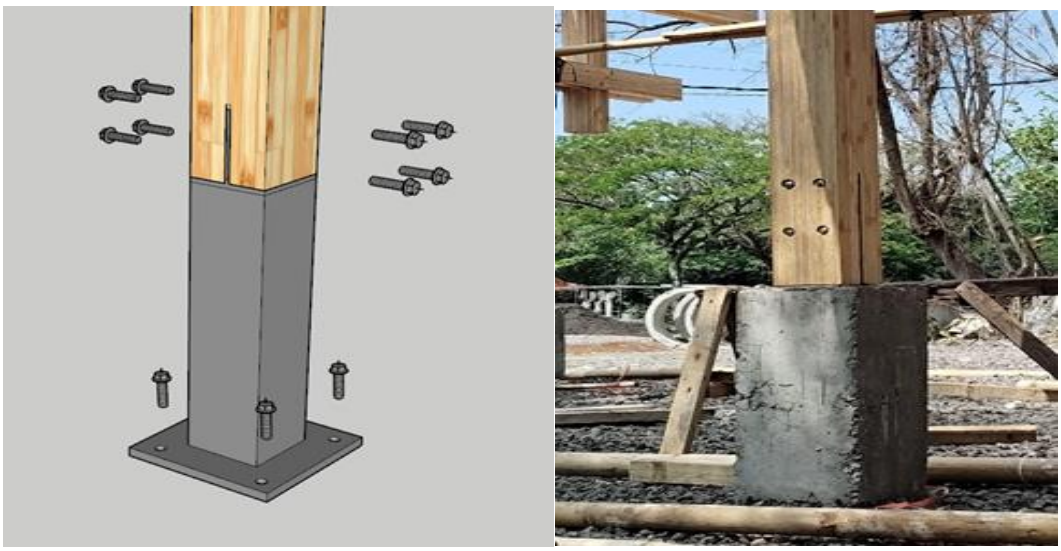

Figure 10. Perpendicular Longitudinal Wood Joints
(Source: Alilah, 2016)

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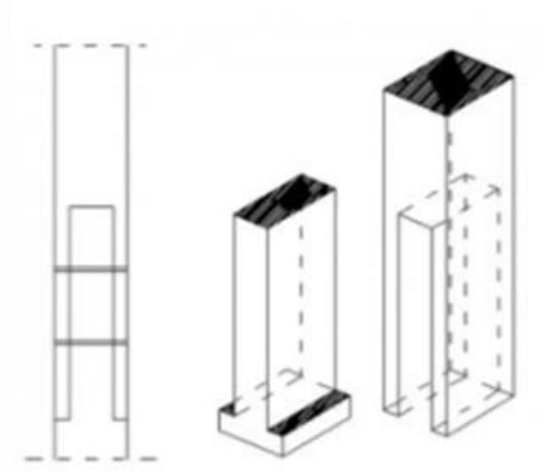

Figure 11. Laminated Bamboo Foundation Connection
(Source: 3D Sketchup and Connections documents in 1:1 Buildings, 2024

According to (Andri, 2023), this type of connection is also used in wooden construction in the longitudinal direction. This type of connection is used by working straight or upright. Wooden joints in the vertical longitudinal direction have protruding ends and grooved ends, so their use is suitable for straight or upright installation. This type of wood connection can be used as tall posts or columns, and is an alternative when the required wood dimensions are not available (Egatama dan Lisantono, 2022).

Judging from the connection between laminated bamboo and wood, it has quite a significant similarity to the T-shaped plate connection, only the laminated bamboo uses long-dense steel as the connection to make it stronger(Mulyono, 2021).

Figure 12. Connection of Laminated Bamboo Colums and Beams
(Source: 3D Sketchup and Joint Documents on 1:1 Buildings

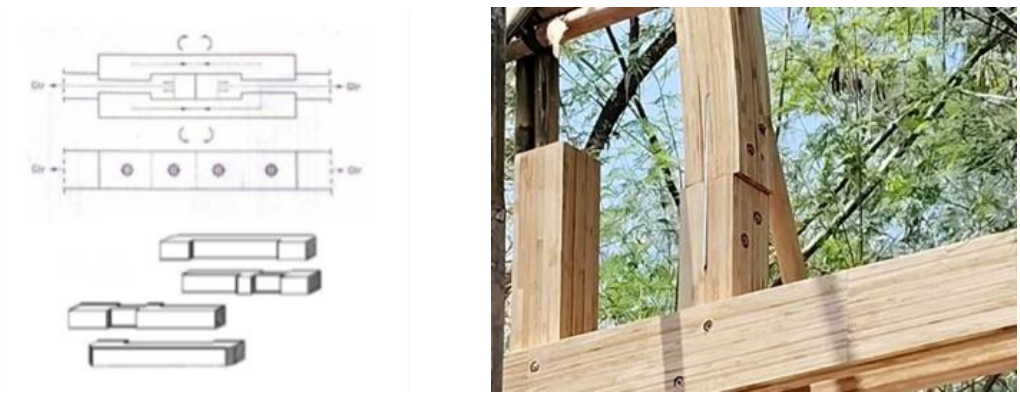

Figure 13. Connection of Pavillion Rood Frame
(Source: Pavilion Building Survey, 2024)

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The upper structure is found in the arch of the pavilion roof. This part uses a connection with a clamped installation system. Laminated bamboo will be drilled and bolted using a long thread. At the top of the laminated bamboo frame, intact laminated beam material is used to support the roof covering. This section does not have special connections used, but instead focuses on connections that use drilling with long thread iron as roof frame connections to make it stronger and sturdier.

4. DISCUSSION

Based on the results of the comparison carried out, it can be seen that laminated bamboo material has significant similarities with wood in terms of the method of application and the connection system. The installation process for laminated bamboo, from cutting to joining, can follow the method currently applied to wood without requiring major adjustments. This makes laminated bamboo a very practical and efficient alternative to wood. With almost equal capabilities in structural function, laminated bamboo not only offers ease of use, but also provides a solution to sustainability challenges in the construction industry. As a renewable and more environmentally friendly material, laminated bamboo has the potential to replace wood without sacrificing quality or aesthetics. In fact, in some conditions, this laminated bamboo material allows building designs to be realized in more flexible and dynamic forms.

The use of laminated bamboo in these load-bearing elements has advantages in terms of strength. The lamination process in bamboo can increase the mechanical strength of bamboo, making it able to withstand heavy loads and is ideal as a structural material. The application of laminated bamboo in the Pavilion project at Mertasari Beach shows the application of an innovative material that has superior mechanical strength as a load-bearing element. The lamination process not only increases the strength of bamboo, but also overcomes dimensional variations and fiber irregularities in natural bamboo. Based on research by (Suprijanto & Rusli, 2009), laminated bamboo with polymer isocyanate adhesive has flexural strength and compressive strength values that comply with structural quality standards E25 and E22, indicating that this material is able to withstand heavy loads optimally. Apart from that, the characteristics of bamboo which is light, flexible and has a high tensile strength of up to 370 MPa (Pradana, 2018) further strengthens the reasons for its use in the main structure of pavilion buildings. Research by (Hong et al., 2021) also confirms that high strength compared to specific gravity makes laminated bamboo an efficient material, especially for construction that requires dimensional precision and high bearing capacity. With this implementation, the pavilion at Mertasari Beach becomes a clear example of how laminated bamboo can be used as an alternative structural material that is strong, environmentally friendly, and has great potential for the development of sustainable construction in Bali. The application of a similar structure was also found in office buildings in Guangzhou, China, as explained by (Hong et al., 2021). This project, which was built in 2019-2020, uses laminated bamboo not only as the main structure, but also on walls, partitions, roofs, stairs and decorative elements. Significant differences lie in building scale and function; Guangzhou buildings implement laminated bamboo in office complexes and showrooms with strict construction standards, demonstrating the flexibility of laminated bamboo not only for small or semi-permanent buildings, but also for large-scale multi-functional buildings. Thus, in both the Pavilion project in Mertasari and the building in Guangzhou, laminated bamboo has proven capable of acting as the main structural material.

In the case study of the laminated bamboo pavilion at Mertasari Beach, the design approach not only focuses on material strength, but also adopts structural principles *grid shell*

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on building roof elements. This curved roof design aims to create new tectonics that push the limits of the bending capabilities of laminated bamboo material. This approach not only produces a unique and dynamic architectural form, but also provides a different spatial experience for its users, with a light, open and organic feel that blends with the coastal environment. This is in line with research conducted by (Elnagar & Sharma, 2017), which states that laminated bamboo is an ideal material for structures. *grid shell* because of its high bending power, good compressive strength, and the ability to be formed into components with uniform dimensions and curves. Structure *grid shell* itself is a type of lightweight structure designed to cover large spans efficiently, utilizing curved geometry to distribute loads evenly. The application of this structure is generally found in large-scale public buildings such as pavilions, stadiums and exhibition halls. In the context of the Mertasari pavilion, inner laminated bamboo is used *grid shell* not only demonstrated the mechanical strength of this material in withstanding heavy and uneven loads, but also proved its flexibility in conforming to challenging organic shapes.

Apart from being superior in terms of strength, the application of laminated bamboo to the structure of this pavilion also has a good impact on the durability of the material. The preservation process and special treatment of bamboo material makes laminated bamboo more resistant to attacks by termites, fungi and weather changes. (Khotimah et al., 2014) explains the results of his research regarding the technical analysis of laminated bamboo material that the average density of laminated bamboo with a horizontal arrangement is 0.78225 and with a vertical arrangement is 0.76495. The average moisture content for both arrangements was 13%. These results indicate that laminated bamboo has physical properties comparable to teak wood, being included in the Strong Durability II class of BKI Wooden Ships. This shows that apart from having high mechanical strength, laminated bamboo also has a good level of durability, so it has great potential for application in construction in coastal environments, such as the pavilion on Mertasari Beach. Coastal environments that tend to be damp and have the potential to accelerate material damage due to extreme weather require the use of materials that are resistant to these conditions. With the right treatment and lamination process, bamboo not only functions as a strong structural material, but is also durable and dimensionally stable. Therefore, choosing laminated bamboo for buildings in coastal areas is the right decision, as well as showing the potential of this material to continue to be developed as an environmentally friendly alternative construction material that is resilient in various climatic conditions.

Apart from its strength, flexibility and durability, another advantage of laminated bamboo is its relatively light weight compared to conventional materials such as concrete or steel. These characteristics provide significant advantages in logistics, distribution and installation processes on construction sites. Light materials not only speed up processing time, but also reduce the need for heavy equipment, making it more efficient and environmentally friendly. In the case study of the Pavilion at Mertasari Beach, this advantage is very helpful in the construction process in coastal areas that have limited access. With light weight but high strength, laminated bamboo is a practical and sustainable structural material solution.

5. CONCLUSION

This research shows that the application of laminated bamboo as the main material in the Pavilion building at Mertasari Beach is an innovative step in using environmentally friendly and sustainable construction materials. Laminated bamboo has been proven to be able to replace wood, both in terms of structural strength, flexibility, and connection methods that are similar to wood construction. The lamination process increases the mechanical strength,

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bending durability, and overcomes the irregularities of bamboo's natural fibers, making it ideal for load-bearing elements such as columns, beams, and roof trusses. Other advantages include durability against extreme weather and pest attacks, with physical characteristics equivalent to durable class II wood. Its light weight also supports logistics efficiency, installation, and reduces the use of heavy equipment, especially in coastal areas where access is limited.

This case study not only shows the strength and durability of laminated bamboo, but also confirms its potential as an alternative primary structural material for buildings of various scales. Quality-wise, laminated bamboo is almost on par with wood, making it a reliable alternative in a variety of construction applications. The application process is similar to wood, so it does not require significant changes in construction work methods. Using laminated bamboo as a substitute for wood can help reduce dependence on wood materials, the availability of which is increasingly limited. Thus, widespread use of laminated bamboo can be a strategic step in reducing deforestation rates and supporting environmental sustainability.

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