

Design Exploration of Bamboo Micro House using Hyperbolic Paraboloid Structure

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Abstract. Limited land is a major problem in big cities, which has a direct impact on increasing land prices and low level of affordability. Micro house concept can be a solution to this problem. Planning a bamboo micro house with local materials can be an effort to contribute to a sustainability agenda. Bamboo is a local material that is environmentally friendly, adaptive, and widely available in Indonesia. Preserved bamboo construction with certain treatments is also affordable and durable for its high sustainability impact. This paper aims to study the exploration of bamboo materials in designing micro houses that suit the needs of urban communities. The house concept is open plan, so the spaces can be used multi-functionally by taking into account the requirements of livable micro houses. The method used is the Cyclical Design Process which consists of three stages, which are analysis stage, synthesis stage, and evaluation stage which is carried out repeatedly to produce a design that is in accordance with the design criteria that have been determined. Paraboloid hyperbolic structure system is used to produce an attractive and efficient form. The development of this micro-bamboo house is expected to be useful in solving the backlog and housing affordability problems in Indonesia.

Keywords: Bamboo; Micro House; Sustainable Local Material

1. Introduction

Scarcity land is one of the main problems in the big cities. Surabaya city as a capital city of East Java also experiences similar problems. Every year, land and property prices are increasing, and has direct impact on the low level of community affordability [1]. This problem demands innovation in accommodating housing needs, one solution is the concept of a micro house with affordable price [2][3].

The concept of a micro house has long been implemented as a solution for urban dwellings. This concept began with the emergence of the Tiny House Movement in America at 1978 [4]. The concept of micro housing is the space effectiveness according to the function and needs of its occupants. The ideal size for a small house is 18 square meters for 1-2 people (the size of one car) or 36 square meters for a family of 4 people [5]. Livable micro house are required to fulfil several aspects related to space quality, layout, space design, room capacity and multifunctional furniture, maximizing natural lighting and ventilation, and minimizing noise from outside [6].

The development of micro houses should be adjusted to the goals of the Sustainable Development Goals [7]. One of them using the local materials for construction [8]. In Indonesian context, bamboo is a local material that can be used as an alternative construction material [9], [10]. Bamboo is classified as a type of sustainable material, that widely grown in Indonesia. The characteristics of bamboo material can be studied as an initial approach to designing a building, whether to be applied as a building structure, shell, or interior. Bamboo material is widely used because it is one of the materials with the fastest growing time in the world, which is up to 60 cm or more in a day [11]. Bamboo can also be an affordable local material for building micro houses. However, in general, developers seem to be sceptical about the use of bamboo as a constructive material.

With the advancement of technology, there are various studies on bamboo materials that are cultivated to be stronger, more durable and longer lasting. These include laminated bamboo, bamboo reinforced concrete, and many others. Bamboo lamination is known as the process by which different layers of wood are used, glued and pressed together. Bamboo is more durable and has 11 different storage processes. These processes are harvesting, soaking, lime washing, painting, brine soaking, vertical diffusion (VSD) soaking with boric acid, soaking with camphor washing, filling or soaking in kerosene and waste oil solutions, and injecting with Salpeco chemical solution [12].

This study aims to conduct a study related to the exploration of bamboo as a local material to design micro houses that suit the needs of urban communities. The development of the bamboo micro house is expected to solve the housing backlog and affordability problems in Indonesia.

2. Theoretical Framework

2.1 Bamboo as a Sustainable Local Material

Bamboo is a local material that is categorized as a sustainable material because of its relatively short planting period. Compared to wood, bamboo has a stronger strength and an affordable price. Some types of bamboo have rapid growth on average 90-120 cm per day, while bamboo which is often used for construction usually takes 3-6 years to grow [13]. Bamboo grows on existing roots and therefore does not need to be replanted. Meanwhile, most other wood species die after harvesting which means it takes time to grow (figure 1), for example pine and oak trees which take 30 and 60 years to be harvested, respectively. One bamboo can be harvested 12 times more than oak. Several literatures informing the diversity of bamboo species commonly used as building materials in the local area of East Java are listed in Table 1.

Table. 1 Bamboo type and function [14]

Bamboo Type	Height (m)	Diameter (cm)	Thickness (cm)	Internode Distance (cm)	Function
Petung Bamboo	20-25	>20	< 20	40-50	Columns, beams, walls
Wulung Bamboo	15-20	6-14	< 8	40-50	Wall
Apus Bamboo	22	4-15	< 15	20-60	Columns, beams, walls, floors, roofs, furniture
Ori Bamboo	25-30	5-15	10-20	20-40	Floor
Ampel Bamboo	10-20	4-10	7-15	20-45	Ornament
Ater Bamboo	22	5-10	< 8	40-50	Wall, Furniture

2.2 Micro Housing

A micro house is a dwelling that is sized according to the function and needs of its occupants. The ideal size for a small house is 18 square meters for 1-2 people (the size of one car) or 36 square meters for a family of 4 people [5]. There are four main design elements in a livable micro house, namely: (1) maximizing the quality of space by paying attention to the layout, function, and space design, (2) maximizing the capacity of the room & furniture to become multifunctional, (3) maximizing natural lighting & air, (4) minimize noise and interference from outside. The micro house should have 5 main areas, namely the kitchen, bathroom, bedroom, living room, and storage room. Several other supporting spaces can be allocated together in a public area, such as a garden, laundry room, or fitness room.

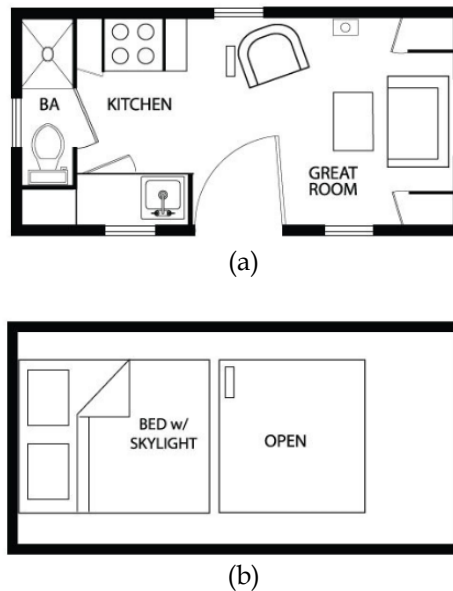


Fig. 1 Micro house layout, a) 1st floor plan measuring 3x5 m, b) 2nd floor plan measuring 3x5 m [15]

This micro house needs to be able to meet user needs and behaviors, such as sleeping, eating, gathering, and storage needs based on user behavior. The micro house should have an efficient layout to accommodate all activities. Some spaces need to be flexible to adapt to the needs of the user. Based on the theory of micro housing, the design will use the open floor plan concept and make the room of this house multifunctional [16].

2.3 Focus on Material

According to Antoniades, material is the flesh, bone and skin of architecture [17]. The varied perspectives on the art of building materials provide insight into the impact that a material has, on how buildings can be constructed and designed and their function. Sensitivity in the selection of appropriate materials, use and processing is an important issue for the success of the project. The character of a material can stimulate the creativity of the process of designing architectural buildings [18]. Focus on Materials is a channel of creativity that produces an architectural work through an in-depth understanding of materials or materials related to characteristics, durability, and technology [19]. Various aspects contained in it such as the origin of the material, how influential the material is to the surrounding environment to the production process and the treatment when installing the material on the building. An in-depth discussion of this material is the basis for this architectural work. Below are examples of buildings with different materials that will display different details, looks, and characters.

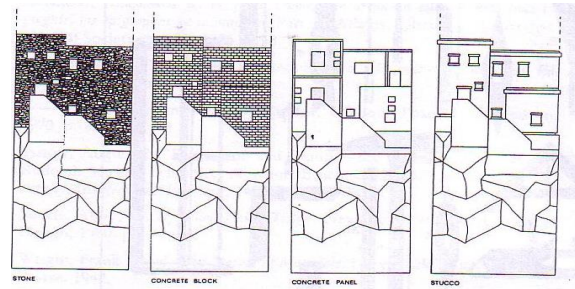


Fig. 2 Building with different material [19]

Antoniades in his *Poetics of Architecture* [17] mentions there are 2 categories of material use in architecture:

- 1) Materials that affect the structural system and spatial organization that have a relationship with the character of the building, proportion, rhythm (solid versus void), and the weight of the building.
- 2) Materials that affect details in architecture, textures on the exterior and interior, as well as on finishing and trimming details.

2.4 Hyperbolic Paraboloid Structure

Classification of structures based on basic geometry consists of two types, which are line-forming elements and surface-forming elements. The configuration of these elements is applied as a cover (surface) of the restaurant building, so that the classification of the structure that will be used is surface-forming elements. Surface-forming elements are further classified into flat surface structures and curved surface structures [20].

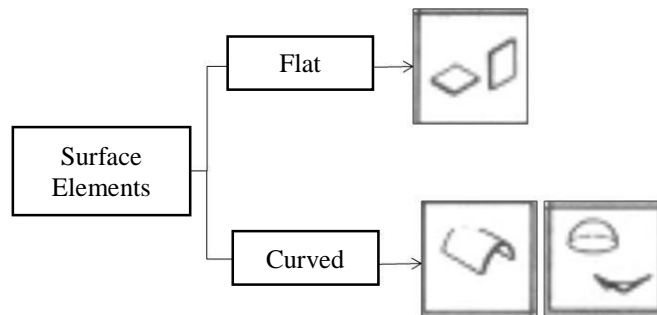


Fig. 3 Structural classification of surface-forming elements [20]

The curved surface structure is further classified into two types, namely single curved and double curved [20]. A single curved surface structure is a structural plane curved in one direction. An example of a single curved surface structure is the barrel shell. Double curved surface structure is a structural plane curved in two directions. Examples of double curved surface structures are hyperbolic paraboloid and conoid shell.

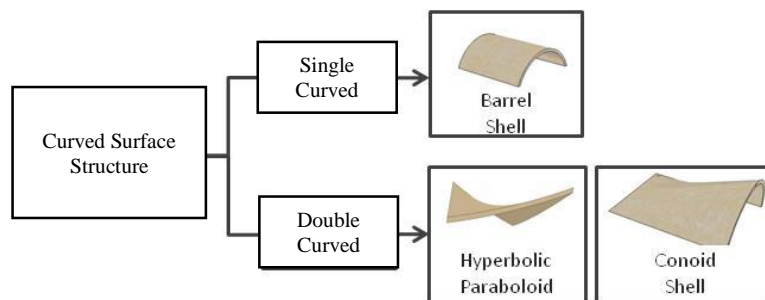


Fig. 4 Curved surface structure classification [20]

3. Methods

The method used is the Cyclical Design Process by Donna Duerk which consists of three stages, namely the analysis stage, the synthesis stage, and the evaluation stage which is carried out repeatedly to produce designs that comply with predetermined design criteria [21].

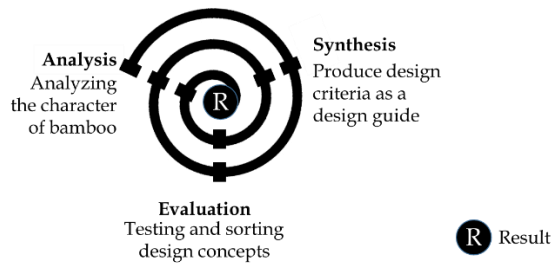


Fig. 5 Methods used in this research

The analysis stage includes the stage of analyzing the character of bamboo to formulate design criteria for bamboo as a material that will be applied to buildings as structures, facades, and furniture. The synthesis stage includes a design exploration stage to produce a design concept with design criteria as a design guide. The evaluation stage is the stage of testing and sorting several alternative design concepts using design criteria to produce the most suitable design concept. While the method to explore the characteristics of bamboo material is a channel of creativity, focus on material [18]. The character, potential, and limitations of bamboo will be used as the main strength in designing buildings through several stages of geometric transformation. The basic geometric shapes can be processed with the principles of geometric arrangement to create new geometric shapes in architectural compositions and facades.

4. Result and Discussion

4.1 Conceptual Design

This bamboo micro house is designed according to the standard size of a small house for 3-4 people, which is 36 square meters [5]. The ground floor module is adjusted to the standard size of a two-story micro house, which is 4.5 meters x 4.5 meters (figure 6.a). In response to the scarcity of land in urban areas, the design development was made vertical (figure 6.b). Due to its flexibility, strength, and versatility, bamboo is a suitable material for structural and engineering material [22]. The concept of this micro house shape uses a hyperbolic paraboloid structure to adjust the character of the bamboo material. The use of this type of structure can maximize the character of bamboo material as a constructive material as well as forming buildings and facades (figure 6.c). The arrangement of bamboo materials using the hyperbolic paraboloid space frame method creates the impression of a dynamic building form. Complementary elements such as windows, walls, and doors are designed to match the geometry formed by the space frame.

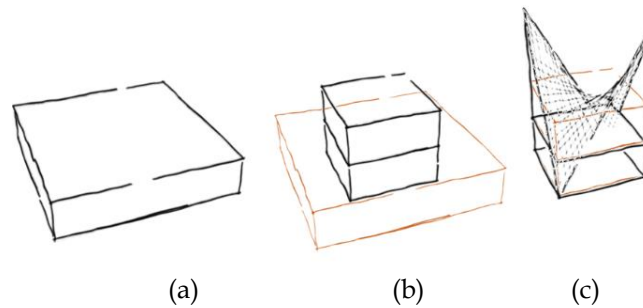


Fig. 6 Conceptual diagram concept

4.2 Plan Design

This bamboo house plan applies the micro house theory, where the open plan concept is used to create several rooms and multifunctional spaces [5]. Figure 7 and 8 shows the design of the first floor, which consists of a living room area, kitchen and dining area, and a bathroom area. The living room area is designed to be quite spacious and used as a multifunctional room, so it can be used as a living room during the day and change its function as a family area or an additional bedroom at night.

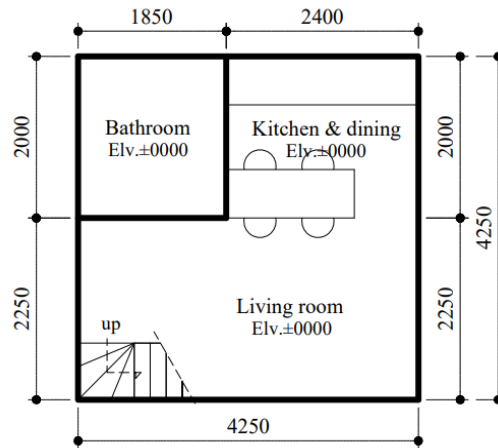


Fig. 7 Floor plan of the bamboo micro house

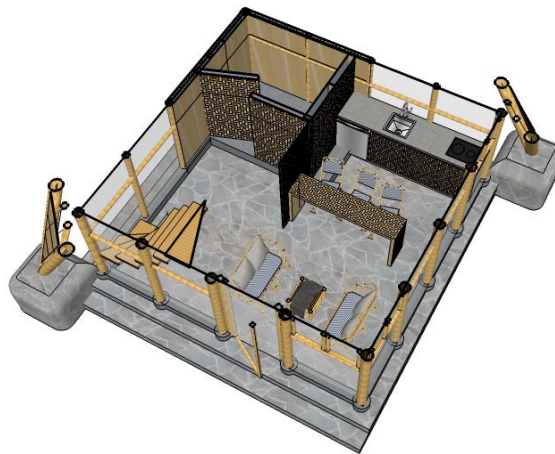


Fig. 8 Axonometry floor plan one bamboo micro house

Figure 9 and 10 shows the second floor which is used as the main bedroom area and the children's bedroom. Temporary wall panels are used to define the space and can improve functionality [5]. This area uses custom furniture made according to the size and design of the house. Custom furniture is made specifically to suit the small size of a micro house [16]. All of these three-story houses are 36 m² in total, thus meeting the minimum size standards for micro houses [5].

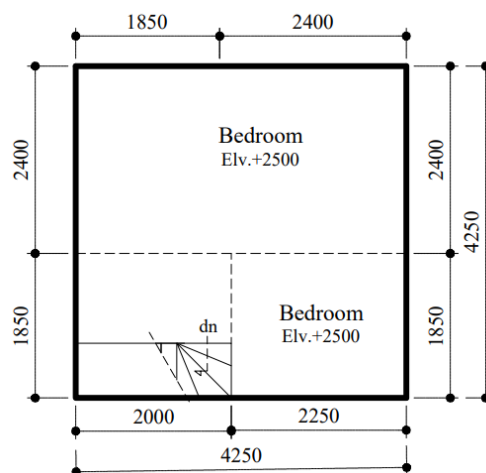


Fig. 9 Second floor plan of bamboo micro house

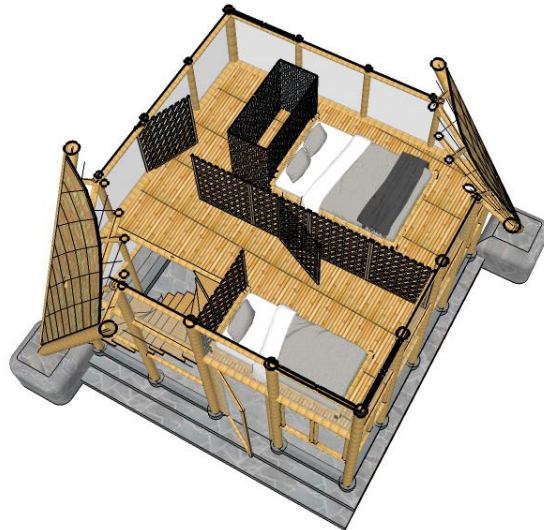


Fig. 10 Axonometry of the second-floor plan of the bamboo micro house

4.3 Structure Design

The structure used in the design of this micro bamboo house is a hyperbolic paraboloid double curved surface structure (figure 11). The use of this type of space frame structure can maximize the character of bamboo material as a constructive material as well as forming buildings and facades [22]. The use of a hyperbolic paraboloid frame structure system can optimize the flexibility and tensile characteristics of bamboo. The two long sides add to the shade offered by the structure, while the sides formed from the structure can be used as a facade area for laying windows and doors. The shape created by the roof can efficiently protect the house from rain, with water rolling off its sides. Using bamboo as the main construction, including the main beams and columns, while the connection uses a combination of iron anchors and fiber binding, the foundation uses a concrete base connected to bamboo poles. The main structural frame of thick bamboo beams is used to set the outer edge of the roof plane with a secondary frame that forms the lattice.

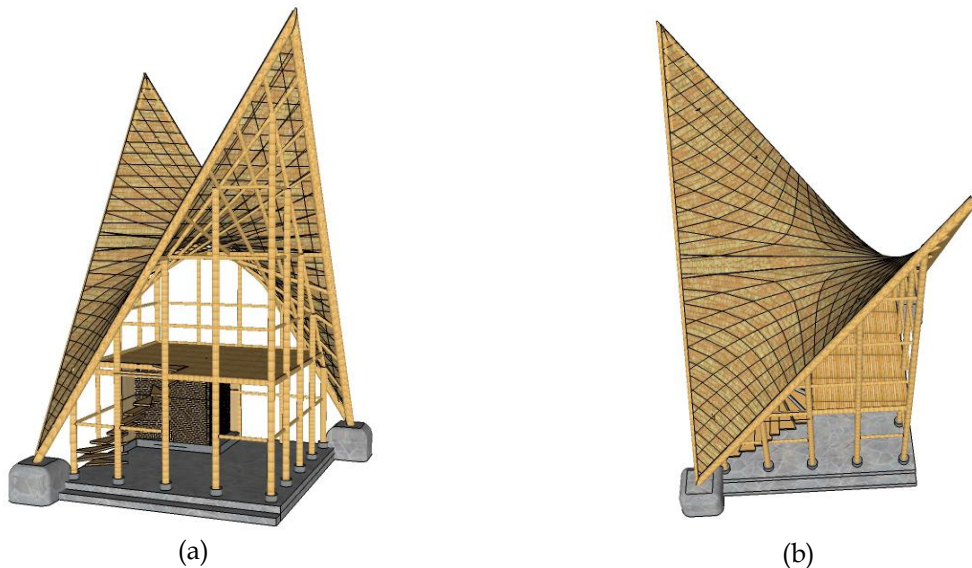


Fig. 11 Hyperbolic paraboloid frame as a bamboo structure, (a) normal view, (b) bird eye view

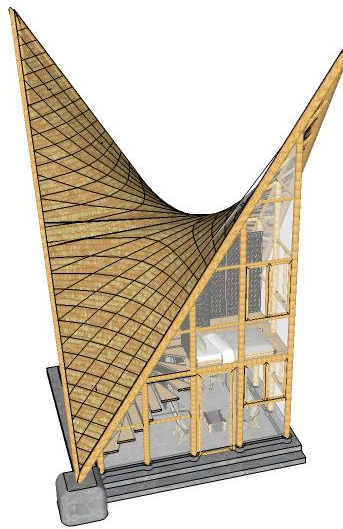


Fig. 12 Bamboo micro house perspective with furniture (top view)

5. Conclusion

This study aims to study the exploration of bamboo materials in designing micro houses that suit the needs of urban communities. The concept of setting the floor plan used is an open plan, so that the spaces in this house can be used multi-functionally by taking into account the requirements of liveable micro houses. Aspects that are considered in the design of this micro house include the efficiency of spatial design, the use of multifunctional rooms and furniture, good air conditioning and lighting, and protection from outside disturbances such as noise. The use of a paraboloid hyperbolic structure system is used to produce an attractive and efficient form. The design of this micro-bamboo house is expected to be useful in solving the backlog and housing affordability problems in Indonesia.

Acknowledgments

Thanks are conveyed to YPTS ITATS and LPPM ITATS for funding independent research for the 2020/2021 period so that this research can be completed properly.

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