The design concept of bamboo in micro housing as a sustainable self-building material

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Abstract. Bamboo is building material that is well known in Southeast Asia, which is renewable, environment-friendly, widely available and fast-growing, as other materials resource such as timber is diminishing and restricted due to deforestation. While timber demand is rapidly increasing, unfortunately, the supply is depleting. Therefore, bamboo can be suitably replacing timber and other materials in construction and other works—moreover, bamboo grown abundantly in Indonesia and easily found in each district as local material. Using local materials is essential in this fast-growing world. Local materials can reduce carbon footprint and support sustainable development efforts. Also, bamboo construction also technically eco-friendly and cost-effective with durable and have high sustainability impact. Besides, the land available for residential housing is currently running low. This problem requires innovation in terms of space effectiveness in design. As a two- or three-story compact bamboo house concerning sustainable local material. This research analyses the user configuration to proceed bamboo as local material to construct a compact house model that is green and durable. These works initiate nature sustainability buildings to fit into natural surroundings.

1. Introduction
Land extinction is one of the main problems in the urban world, including Surabaya city, which is known as a metropolis area. Land for housing is minimal, resulting in high land prices that are no longer affordable for low to middle-class society. Innovations are necessary to accommodate urban housing needs which continues to increase. One of them is a compact house concept that has an affordable price. The compact house concept has been applied for a long time in residential design in Indonesia, starting with the emerging phenomenon of the Tiny House Movement in America around 1978. There are four aspects of compact house concept, namely space diversity, furniture, color, and insulation [1].

Besides, the use of local materials and resources in construction is essential to perform a sustainable development [2]. Bamboo is local material that can use as an alternative material for construction which is considered as one of the most sustainable building materials. The characteristic of bamboo material can be explored as an initial approach to design a building, whether to be applied as a building structure, shell, or interior [3, 4]. Bamboo is widely used due to possesses a vast advantageous usage scheme which is environmentally friendly, in respect to timber which is gathered within 10–30 years, bamboo can be collected within 3–5 years, which are the fastest-growing plants in the world has grown up to 60 cm or more in a day [5]. The use of natural materials to be environmentally friendly in addition to the
use of bamboo is also carried out by other researchers by seeking fuel from plants [6–10], making activated carbon from various plants [11–14] and making Fashion products from used paper [11]. In this term, bamboo can be a local material that is suitable for developing compact houses with affordable prices. Though, the market seems to be sceptical about its use for constructive materials. This might be explained by the fact that some structural evaluations still need to be proven. On the other hand some local products such as cabinetmakers and handicrafts makers have already adopted bamboo (laminated) as a valuable material to make their products and its proven durable. These issues mainly apply in Indonesia whereas needs to take a fundamental different approach to Bamboo which is normally know as a temporary structures. As a consequence, this research needs to clarify technical data and comply with structural standards as well as to illustrate the bamboo as a main structural building material.

There are various study about bamboo-based construction materials that were cultivated, such as laminated bamboo, bamboo-reinforced concrete, and many others [12, 13]. As the history of bamboo in laminated uses traces back only 10 to 15 years and development are still going on [14]. Laminated is known as a process to make a use of different layers of wood, glued and pressed together. This principle is applied to bamboo to turn out to be a more labour intensive process regarding the assemblage of multiplicity of strips [2]. Bamboo is more durable, with 11 types of curing processes. The processes are Harvesting, Soaking, Washing Lime, Painting, Soaking with a salt solution, Vertical Soak and Diffusion (VSD) with boric acid, Soaking with camphor detergent, filling or immersing in kerosene and used oil solutions, and injection with Sarpeco chemical solutions [15].

Due to early studies, additional studies are required to better understand the socio-economic aspects of bamboo-based construction materials as well as the development study on bamboo material application in a built environment [16]. Hence, this research conducts the exploration of bamboo as local material to design a compact house that suits the needs of the urban community at affordable prices to adjust the socio-economic aspects of developing country. Bamboo building needs to be developed with a compact house concept to overcome the scarcity of land in urban areas where land is not widely available and has extremely overpriced. Bamboo is sustainable local material that can easily found in the Surabaya area, environmentally friendly, and has a low price. The development of this bamboo house model also can solve the housing backlog problem Indonesia as well as the affordability issues. Further, starting to grow bamboo locally could both improve air and soil quality striving for a sustainable future which conclude, growing, harvesting, processing and constructing bamboo has to be intensified locally.

2. Theoretical Review

2.1. Bamboo in the application of construction

2.1.1. Bamboo materials and products

Bamboo is one of the local materials which is categorized as a sustainable material due to the rapid spread and fast-growing time. Compared with timber, bamboo has stronger strength and affordable prices. Some types of bamboo have rapid growth on average 90-120 cm per day, while bamboo’s nature that often used as construction usually takes 3-6 years to grow [5]. It has to be taken into account that bamboo grows on its existing roots and therefe has no need to be replatend. Most other wooden species will die after being harvested which means need time to grow (See Figure 1). The time for bamboo to fully grow is 3 to 6 years. That is different from pine and oak trees respectively need 30 and 60 years. Within the same bamboo can be harvested 12 times more than oak [17]. Some literatures inform variety of bamboo’s type which commonly used as structural materlas in the local area of East Java region, listed in Table 1.

Figure 2 illustrates an overview of a modernized bamboo by biobased composite materials that usually constructed nowadays. The use of all biodegradable product provide a great potential for further development especially in local construction.
Figure 1. Growth graph of varieties of trees

Figure 2. Modernized bamboo product as composites

Table 1. Bamboo types [18]

| Bamboo Type         | Height (m) | Diameter (cm) | Thickness (cm) | Internode Length (cm) | Utility                                      |
|---------------------|------------|---------------|----------------|-----------------------|----------------------------------------------|
| Petung Bamboo       | 20-25      | >20           | < 20           | 40-50                 | Column, beam, batt, rinse                     |
| Wulung/ Black Bamboo| 15-20      | 6-14          | < 8            | 40-50                 | Wall                                         |
| Apus Bamboo         | 22         | 4-15          | < 15           | 20-60                 | Columns, beams, floors, walls, roofs, furniture |
| Ori Bamboo          | 25-30      | 5-15          | 10-20          | 20-40                 | Stucco construction, floor                   |
| Ampel Bamboo        | 10-20      | 4-10          | 7-15           | 20-45                 | Ornament                                     |
| Ater Bamboo         | 22         | 5-10          | < 8            | 40-50                 | Wall, furniture                              |

Table 2. Structural properties of bamboo compared to other materials [19]

|                   | kN/cm² | Spruce | Bamboo | Steel |
|-------------------|--------|--------|--------|-------|
| Elastic modulus   | 1100   | 2000   | 2100   |       |
| Compressive       | 4.3    | 6.2–9.3| 14     |       |
| Tension           | 8.9    | 14.8   | 16     |       |
| Bending           | 6.8    | 7.6–27.6| 14    |       |
| Shear             | 0.7    | 2.0    | 9.2    |       |
2.2.2. Structural Properties and processing techniques
To support the capacity as a building materials, the performance of bamboo is enhanced e.g., compression 1/3 of tension strength, tension which needs 3 times as strong as in compression, splitting easily along the length, easy to work and construct, ability to laminate and lastly can be modified into different appearances (see Table 2) [19–21]. However, the weakness has to be concerned such as low bending capacity if no laminated, weather sensitive (the special treatment needed) and hard to make nail joints since the splitting easily along the length. In addition, to support the better natural durability, a certain chemical treatment needs to be given, i.e., treated in submerged water or adding chemical compound in the process of curing, resurfacing, soaking or boiling. The process of treatment more tricky than steel where the simply conceptual process is created, e.g., strengthen the connection [22, 23].

For applications in buildings, bamboo with intact conditions will last longer than cleaved bamboo. This is because, in cleaved bamboo, fungi and pests can quickly enter into bamboo pores. As to avoid the entry of fungus and parasites, the preservation process is necessary before the bamboo usage. There are two kinds of bamboo preservation process, which are natural processes and chemicals. According to the paper theme about sustainability, natural preservation is chosen. The natural way of preservation [24] includes:

- Curing: this method is done by cutting bamboo stems at the bottom but remain the leaves and branches. Then the bamboo clump is stored in a particular room within a specific time. Because of the assimilation process, the leaves still survive, the starch content of bamboo segments is reduced.
- Resurfacing: this method is done by sprinkling bamboo sticks with lime. The aim is to slow down the absorption of water so that the resistance of bamboo to mold is higher.
- Bamboo Soaking: this method is done using bamboo stems soaked for one month in freshwater, brackish water, calm seawater, or flowing water so that the starch in bamboo is reduced. Bamboo soaking should be done after the bamboo is dried in a standing condition, then soaked entirely. Bamboo that has been immersed in the water must be pale (not yellow-green or black) and sour.
- Boiling: boiling bamboo at a temperature of 55-60 degrees celsius for 10 minutes will cause the starch to undergo complete gelatinization that is amylose insoluble in water. Boiling at 100 degrees Celsius for 1 hour is effective enough to reduce attacks from pests.

From the literature, we can conclude that with the correct preservation process, bamboo buildings can last up to 40 years. As for the joints in bamboo construction, it is better to avoid using nails. And for sustainability reason, it is better to use natural material and methods such as rope, nut, and bolt techniques, so it does not cause damage to the bamboo material itself. It is also important to minimize the danger of fire. To slow the spread of the light that burns vertically, the bamboo arrangement can be made by arranging bamboo horizontally or diagonally.

2.3. Micro housing
The micro housing is a dwelling that is sized to meet its context, and its occupants need with little excess space. This concept is also popular as a small house, tiny house or micro apartment. The ideal size for a small home seems to be 18 square meters for 1-2 people (the size of a one-car) or 36 square meters for a 4-person family. Four key design elements in a small house that influence liveability [25], which are:

- Trade space for a place, maximize the quality of space by paying attention to the layout, function, and design of space.
- Durability, maximize the capacity of space & furniture to be multifunctional.
- Air and light, maximize lighting & natural air.
- Privacy and noise reduction, minimize noise and interference from outside.
This concept was derived from research conducted in North America, which used a mixed-method between literature reviews, interviews, and direct survey observation in several samples of small houses. From this literature review, it can be concluded that the small house has some prime functional areas which are kitchen and dining area, bathing area, sleeping area, living area, and storage area. Some spaces can be designed as public or shared spaces, such as parks, laundry, fitness rooms, etc.

3. Result and discussion

3.1. Design concept

Figure 1 shows the diagram design for the bamboo house. This bamboo house is designed according to the standard size of a small house which is 36 square meters (figure 3.a) [26]. Ground floor modules adapted to the size of a carport, which is 4.5 meters x 4.5 meters (figure 3.b). As a response to the scarcity of land in urban areas, design development is made vertical (figure 3.c). The base of the building is designed elevated to maximize open space and rainwater absorption. The shape concept of this building is dominated by triangular geometry, where triangles are known as the sturdiest in forming a space frame (figure 3.d). The last figure (figure 3.e) explains the position of vertical circulation in the bamboo house. The complementary elements such as window, wall, and door are designed to adjust to triangle shape to fit in.

Figure 3. Design diagram for the bamboo house, (a) small house standard size 36 square meters, (b) ground floor modules, (c) vertical development, (d) triangular geometry concept, (e) vertical circulation position of bamboo house

This small house has to accommodate behavior setting of the user, which are include some domestic activity such as eating, sleep, gathering, and the need of storage based on user’s action [27]. The small house must have an efficient layout to accommodate all activities. Some multifunctional rooms are also needed to be flexible spaces that can adjust to the user’s needs. Due to the small house theory, the floor plan concept used in this building is open plan; thus, the spaces in this house can be used multi functionally [28].

3.2. Plan design: a small house

This bamboo house plan applied the small house theory, where the open-plan plan concept is used to make some multifunctional room and space. Figures 4 and 5 depict the ground floor, which consists of a carport, bathroom, and foyer room that can be used as a terrace, living room, or an intermediate room. Carport design is designed with minimal pavement by selecting paving grass material to maximize the open space and rainwater absorbing.
Moreover, figures 6 and 7 show the second-floor design, which consists of a service area and multifunctional area. Kitchen area is made vertically parallel to the bathroom in ground floor to facilitate the shaft, and plumb the multifunctional space is quite broad; thus, it can be used as a living room during the daytime and change its function as an additional bedroom in the night time.

Figures 8 and 9 show the third floor is a mezzanine that functioned as the main bedroom area. According to small house theory, custom furniture that fits in with house design is needed. The furniture in this room is a bed and wardrobe, which is made custom to adjust to a compact size. All this three-level house is 36 m² in total, thus comply with the minimum size standard of a small house (figure 10).
3.3. Structure design
Figures 11 and 12 show the structure concept of the house design. The first level is designed elevated to minimize the footprint and maximize rainwater absorption. It uses bamboo as the main construction, including primary beams and column, while the joints are using palm fiber lashing—the foundations using a concrete base which joined with bamboo’s column. Meanwhile, the shape concept applied triangle geometry because the triangle is the most sturdy and stable in forming a space frame structure.

4. Conclusions
A micro housing with bamboo material has been designed in this study. The design concept proposes a sustainable construction using local content and compact design to solve the scarcity of land in an urban area. The design applied small house theory which is the efficiency of layout design, the use of a multifunctional room and furniture, good air conditioning and lighting, and protection from outside disturbances such as noise. However, this bamboo house consists of three-level which comply with the
minimum size standard of a small house. This house uses bamboo as the main construction is emerging with triangle geometry shape, though not widely accepted yet.

5. References

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