The Review of Sao’s Construction Material Based on the Principles of Sustainability

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Abstract. The community of Gurusina kampong built their traditional houses by exploiting the potential of the local natural environment. Currently, timber and bamboo as Sao construction materials tend to be increasingly scarce, which leads to the extinction of Sao and entails to the unknown details by future generations. This paper aims to measure the components of Sao construction from the aspects of material strength and energy consumption based on sustainability principles. The method used is descriptive qualitative by using verbal information and numerical data through interviews and direct measurements so we used Value Engineering Analysis the formula of Kirk & Dell'Isola (1995). The results of the research highlight that the use of timber species of Oja and Fai for the construction of Sao has a longer strength life and contains low energy in terms of building process and transportation compared to other types of material. In anticipating the scarcity of these two types of material and in reviewing the types of timber to be used in spaces other than One, we suggest to use Kelapa timber and Betho bamboo as other renewable materials which are also efficient in terms of energy use and strength.

1. Introduction
The availability of natural materials for the needs of developing traditional houses is gradually scarce over time. This limitation is related to the reduction in the production forest not only due to the logging or expansion of the built environment but also due to the shift from using natural materials to fabricated one. This phenomenon has a significant impact on residents living in remote areas, who rely solely on the result of production forest to maintain the construction of their traditional houses. Likewise, for the observers of vernacular architecture, these conditions become a big concern because the scarcity of natural resources will provoke the extinction of traditional architecture in the future. One of the anticipatory steps towards this condition is conducting an inventory of knowledge about the characteristics of traditional architecture. This knowledge is crucial for the innovative needs of building traditional architecture in the future where technology will continue to grow, and natural resources will continue to decrease. This paper is a review of building materials and construction in the hope that it can contribute to the needs of the intended innovation.

Several studies on traditional architecture in Flores have been carried out by previous researchers. For example, Murti [1] measured thermal comfort to evaluate the passive system in traditional Bena dan Wogo houses in Flores (one kinship with Gurusina). The result of the study shows that important component that can reduce inner thermal space is the use of sun-shading and insulation system. Air
cooling of that space with a passive system works optimally at night. Juwono [2] [3] conducted measurements on the temperature and humidity of the space related to the use of reed-roof covering at Wae Rebo traditional house in Flores. The results of measurement indicate that the reed-roof is 1-2 degrees lower during the day while at night, it is 1-2 degrees higher than the room temperature. Susetyarto [4] [5] states that there are five factors in understanding the concept of sustainability in the Ngadha community, i.e., 1) natural environment, 2) indigenous community, 3) vernacular architecture, 4) economy and 5) culture.

This study is a supporting evidence to the previous research that emphasizes the aspects of efficiency, strength and energy consumption of the material based on the measurement from the principle of sustainability in Gurusina Sao. The results of this study are focusing on: 1) the selection of an appropriate type of material as a component of traditional Sao construction or the use of other materials as a substitution; and 2) the choice of material-type related to energy consumption.

Theoretically, physical sustainability is related to how strong the building components are constructed and whether its materials can be reduced, recycled, and reused as well as how much energy can be consumed due to the use of these materials [6] [7] This paper aims to measure the components of Sao construction from the aspects of material strength and energy consumption, which based on the concepts of Edward, the guidelines of Greenship which leads to the subsequent theoretical framework.

Based on the sustainability principles [6], materials that can be categorized as cycled and efficient comprise the following characteristics: (a) reuse of used materials, either from old buildings or from other places at the minimum of 10-20% or more of the building material as a whole (p. 4-6), (b) recycled as a building material of at least-10% of the materials (p.11), (c) reduce material in an efficient way through Value Engineering (VA) analysis, with an appropriate dimension, as well as load and strength of construction (p.38), (d) use primary raw materials derived from renewable resources with short-term harvesting period (<10 years) of at least 2-5% of the materials (p. 4-15), (e) the use of local or regional materials by reducing carbon footprint and by conserving energy i.e., the transportation of materials is not exceeding 1000 km and the use of materials is at least 10% (p. 34-34).

VE is a systematic functional evaluation by applying a particular technique for the efficiency of building construction element [8]. The VE covers several steps, which consist of Identifying the necessary function of the structural elements, beam, and roof-frame, and other non-construction elements.

(1) Using Mechanical engineering calculation analysis towards the structural elements by using the formulas of $W_x = M/\sigma_{wd}$, ($W_x$=Prisoner’s moment, $Max$= Maximum Moment by loading, $\sigma_{wd}$= wooden-stress), to determine the dimension of beam section ($B$) = $Max/\sigma_{wd}$. The elements of vertical structure with the approach of $\sigma_{wd} = P/F$ ($P$ is load and $F$ is area of load), so the dimension column (column area) = P column/$\sigma_{wd}$ m² [16]. The tension stress of timber is the burden borne by the column that is dead load and live load for a wooden house [17].

(2) Finding new efficient dimension aiming at fulfilling the function of construction.

The mechanism of sustainable development takes place if the selection and procurement of materials are in line with several aspects in the concept of green building, among others are: (a) the use of local materials less than 1000 km with the aim of reducing the carbon footprint of transportation, (b) the material is from renewable resources with a short or less short-term harvesting time (≤10 years), (c) the minimal energy consumption in the process of building materials minimize the use of CO₂ (Table 4) [6] [9].

2. Method
The administering of this study uses field measurements of the relevant aspects together with the interviews to the occupants of Gurusina Sao and other significant figures of the traditional village about the concept of sustainability in building the house [10] [11]. The focus of this study was
Manumillo Sao. This traditional house belongs to one family/clan who shares a close relationship with that of the family/clan from Bena. Bena Sao, as a traditional house, is older than the traditional house in Gurusina. Gurusina Sao is the expansion of Bena Sao whose inhabitants are from the same clans/relatives.

We gathered data through (1) direct measurement of the structure of Sao, (2) direct measurement of the use of materials (3) direct measurement of the dimension of structural elements (4) classification of the quality of bamboo and timber. The four kinds of data were analyzed to obtain material efficiency (reduce) and renewable material of energy consumption on the building. The measurement data employed simple VE analysis to assess the energy consumption which support the concepts of sustainability of Gurusina Sao. We administered data and information about each material and construction behavior of building components through interviews and direct measurements. To measure the strength of material and its energy efficiency, we calculated the numerical data by using VE analysis, the formula of Kirk & Dell'Isola [8]. The method, analysis, and finding of this study (Figure 1).

![Focus](Focus.png)

**Figure 1.** Framework of analysis and research findings

3. Result and Discussion

Results of this study highlight that the development practices in Sao that indicate sustainability actions include 3 principles based on Greenship concept [6]: (1) reducing the use of material in an efficient way; (2) replacing an un-renewable into renewable materials considering the harvesting period; (3) using low energy in terms of transportation and construction process.

3.1. Reducing Sao’s construction material efficiently

The measurement of material efficiency employs VE analysis. The VE analysis includes: (1) identifying the functions of each building structure component; (2) analyzing mechanical engineering elements and behavior of building construction; and (3) calculating material efficiency based on the dimensions of construction elements. The following is the explanation of each measurement of Sao.

The necessary function of structural components of Sao’s materials

The construction of Gurusina Sao (Figure 2) is a stilt house built to respond to micro environment and to function as a safe and comfortable protection from dangerous animals. The materials used are mostly of local materials, i.e. fibers as roof coverings, timbers, and bamboos as roof constructions, wood-frames as wall constructions and wooden planks as floor coverings [12]. As for the foundation, timber and stone are mainly used as the construction to support the building [12].

Sao in Gurusina has the composition of space that is the core as the sacred space, One. The supporting area of One is Teda One as the living room and Teda Wewa as the front porch, as well as Wewa as the transition space from the outside into the inside of Sao [13]. The original hierarchy of space in Gurusina Sao is composed horizontally from the outside to the inside, which consists of Loka.
(yard), Wewa (transitional area from outside to the inside), Teda Wewa (terrace), Teda One (living room), and One (main room or private). All of these spaces are used to accommodate all activities of the owners of Sao [13] [14].

Figure 2. The division of concept and element of construction at Gurusina Sao [13]

The roof construction of One is in the form of high pyramid-shaped as in Figure 2. The roof material of One is Fai timber as the frame and bamboo as common rafters, a batten or anchoring and the braided of reeds (Imperata cylindrical) as roof covering [15]. The efficiency of the large diameter of bamboo, which is on the Lenga construction of Teda One can be merged with the roof covering of One space.

Vertically, the component of Sao as part of space structure is divided into three parts i.e., roof (Zeta ulu), wall (Zeta wekki), stilt floor (Zale wekki) and the foundation and the wood column (Zale wa’i). The vertical and horizontal structural systems of Teda One and Teda Wewa are separated from One. One is constructed first elsewhere, resembling a cube-shaped. After the construction, the people of the traditional kampong assembled One on top of the stage construction, i.e. column (Leke) and beam (Ledha) which stands on the foundation of a stone pedestal (Ture).

Static mechanical engineering and dimension analysis towards Sao’s structural elements Function analysis of structural elements as the basis of the VE method to reduce the use of beams (horizontal) and columns (vertical) to obtain the efficient dimensions, and to fulfill the necessary functions as Sao buffer on top [8]. The existing data show that all beam dimensions are 10x16 cm, and all of the column are 16x16cm. Therefore, based on the result of VE analysis, the dimensions of existing beams and columns which are of equal dimensions will require large volume of timber.

Based on the result of mechanical analysis by using the formula \( \sigma_{wd} = \frac{P}{F} \) (P is load and F area of load), so the column dimension (column area) = P column/\( \sigma_{wd} \) [16]. The tension of wood is the burden borne by the column that is dead load and lives load for the wooden house. The result of analysis by using the formula at One, Teda One, Teda Wewa spaces, the dimensions of the beam should be of 8x16cm. Whereas the middle column dimension is of 16x16cm, it is larger because the dimension is larger. The dimension of the border column is of 10x10cm because the load is half of the middle column; the dimension of the angle column is of 8x8cm because the load is a quarter of the middle column. The above calculation can reduce the volume of Oja timber as column (Leke) and as the foundation to up to 17, 2% [16] [17].

There are materials of stage construction other than beams and columns which are on the horizontal force-retaining element i.e., wind bond. At the existing of wind bond, the beam is made of Oja, yet the
behavior of the wind-bond does not require high compressive strength of the timber. Then, the short segment of bamboo can replace the construction of wind-bond. The results of both efforts of material efficiency were obtained through replacement of renewable materials is 12.73% and re-dimension through the VE is 6.76% of all Fai timber used. Therefore, the total efficiency is 19.59% in which the value is meaningful for the un-renewable material.

3.2. Replacing un-renewable into renewable through harvesting period of used material

Hard-timber dominates the use of materials in Sao, i.e. Fai and Oja, as classes II in terms of strength and durability. Atlas Kayu Indonesia [18] classifies timber into five classes (Table 1).

| Timber Classification | Type of Timber | Density (kg/cm²) | Flexibility (kg/cm²) | Strength (kg/cm²) | The use in the construction |
|-----------------------|----------------|------------------|----------------------|------------------|-----------------------------|
| I                     | Ulin, Jati     | > 0.30           | >1100                | >650             | Foundation, column, beam, dock |
| II                    | Berghiral, Merbau, Fai, Oja | 0.60-0.90 | 725-1100            | 535-650          | Stage foundation, column, beam, main frame of roof |
| III                   | Kamper, Krung  | 0.40 - 0.60      | 500-725             | 300-425          | Wall, frame window |
| IV                    | Meranti, Coconut wood | 0.30-0.40 | 360-500            | 215-300          | Wall, Wind bond element |
| V                     | Sengon wood    | < 0.30           | <360                | <215             | Furniture |

The class, I and II timbers, can be used as construction materials if they can reach the productive period of 40-50 years with a thickness growth of 0.75-1cm/year and with a height of 1m/year. Radial growth reaches 35-50 cm with a height of 40-60 meters, the addition of thickness/diameter of timber after the age of 50 years experiencing a slowdown of 0.5 cm per year. To reach the diameter of 60-70 cm, it needs 70-80 years [19]. The condition of location influences the durability of timber as a construction material, for example, wooden construction which is always submerged in water, and mud, or moist soil. These can be used for protection by a roof or by paint-protected construction (Table 2).

| Condition of Construction | Durability/class |
|---------------------------|------------------|
| Submerged                 | Class I: 10-20 years, Class II: 5-10 years, Class III: 3-5 years, Short time, Short time |
| Wet land                  | Class I: 20-30 years, Class II: 15-20 years, Short time, Short time |
| Frame under Roof with Layer of paint | Not limited, Not limited, Long time, Several years |
| Attack land termites      | Not limited, Rarely, Quickly, More short time, More short time |
| Attack powder dry wood    | Not limited, Not, Hardly, More short time, More short time |

The construction material in Sao other than timber is bamboo. There are six types of bamboos growing in Indonesia namely [Apus (Gigantochloa apus Kurz), Petung (Dendrocalamus asper), Ori (Bambusa arundinacea), Wulung (Gigantochloa atrovioleacea), Batu (Dendrocalamus structure), and Ampel (Bambusa vulgaris Schard.) (Table 3). Bamboo as a construction material has the same bending strength as timber. However, the compressive strength of bamboo is lesser than that of timber so people can use bamboo as a replacement material (Table 3).

| No | Type of bamboo | Harvesting time | Density (kg/cm²) | Bending strength (kg/cm²) | Compressive strength (kg/cm²) | Benefit in construction | Branch productivity (ha) |
|----|----------------|-----------------|------------------|--------------------------|-----------------------------|------------------------|--------------------------|
| 1  | Ori            | 6-8 year        | 0.744            | 880                      | 450                         | Building material      | 2250                     |
| 2  | Petung/ betho. | 5-6 year        | 0.717            | 939                      | 471                         | House, roof, and wall construction | 4500-4800                |
| 3  | Legi/batu     | 3-4 year        | 0.613            | 736                      | 390                         | Chopsticks             | 4000                     |
| 4  | Apus           | 1-3 year        | 0.590            | 818                      | 371                         | Fence                  | 1000                     |
| 5  | Ulung          | 2-3 year        | 0.685            | 838                      | 384                         | Musical instrument     | 4000                     |
| 6  | Ampel          | 4-5 year        | 0.769            | 991                      | 458                         | Building material      | 1650                     |
3.3. The low consumption energy of Sao’s construction material

The mechanism of sustainable development occurs if the selection and procurement of materials adhere to several aspects in the concept of green building, among others are: (1) the local materials is less than 1000km to reduce the carbon footprint, (2) the renewable resources is short or less short-term harvesting time (≤10years), (3) the minimal energy consumption can minimize the use of CO₂ [6] [9].

Based on the green building criteria above, Sao meets the requirements as a green building by the following facts.

First, Sao uses material from the locations that are relatively close to the construction site so that it can reduce carbon emissions as a result of transportation use. The first criterion of the green building concept is the use of material must be less than 1000km. The use of bamboo material as a roof and as a floor tile gathered from the nearest natural resources in which the distance of transportation is not more than 5-10km, as with timber it is around 10-25 km [20]. All of these materials can only use carts or motorized vehicles. This relatively short distance of transportation resulted in a reduced carbon footprint. If the transportation employs human power, the building process of Sao equals to carbon zero.

Second, in the process of development, timber and bamboo as construction materials consume carbon that is low. In the material processing other than the energy needed, the production of carbon (CO₂) releases the negative impact as shown in Table 4. The smallest carbon-producing (CO₂) material is concrete, timber, and bamboo. Concrete as the construction material represents low carbon consumption, but it will have higher bending strength when it is combined with iron or other material, so that it has the same quality as timber and bamboo. Concrete and steel, if combined, can become reinforced concrete. Hence the energy consumption and CO₂ producer are 25.67 MJ/kg and 2.07 CO₂/kg. Therefore, this material is the highest energy consumption and as a CO₂ producer compared to other building materials.

Table 4. Energy Consumption of Building Materials [9]

| Material  | Energy consumptions MJ/kg | Density kg/cm³ | Carbon: CO₂/kg |
|-----------|--------------------------|----------------|----------------|
| Concrete  | 0.8-1.12                 | 2400           | 0.159          |
| Steel     | 25-30                    | 7800           | 1.91           |
| Timber    | 1-2                      | 600            | 0.46           |
| Bamboo    | 0.5-1                    | 600            | 0.32           |
| Ceramic/tile | 12                  | 2000           | 0.74           |
| Glass     | 15                       | 2500           | 0.85           |
| Brick     | 3                        | 1700           | 0.24           |

People can easily find timber and bamboo as local materials in Gurusina. Oja and Fai timbers are local materials, but bamboo species, i.e. Betho is the first-class quality of bamboo. Therefore, people can use Betho as a substitute for timber construction materials, among others as rafters, column, beams, and roof frame in Teda One (Ledha lewa, Paja soku). The procurement and process of timber and bamboo construction at Sao, which is processed through the local wisdom will require less energy than other construction materials (Table 4).

Third, building material consumes energy, which is low compares to others. The construction material of Gurusina Sao is from local material both for the roof (Zeta ulu), floor, wall (Zeta weki), and for stage foundation as column (Zale wa’i). In building Sao, the Gurusina community uses simple technology. The process of procurement of timber and bamboo represents low energy consumption as in Table 4. The energy consumption as building construction and as furniture material among others, timber is 1.5 MJ/kg, bamboo is 0.5 MJ/cm² and concrete is of 0.67 MJ/kg and steel is 25 MJ/kg, ceramic tile is 12 MJ/kg, glass is 15 MJ/kg and brick is 3MJ/kg. The value of timber and bamboo as energy consumption is relatively small compared to the process of other building materials [9].

4. Conclusion

Gurusina Sao signifies the practice of sustainability principles and green building through:

(1) Material reduction and regulation efficiently in terms of:
(a) The allocation of structural elements is adjusted to the hierarchy of space values (the level of the sacredness of space), One is perceived as sacred in value, whose structural elements take precedence and priority over others.

(b) Adjustment/reduction of dimensions of columns according to the load capacity carried by comparison of the middle column, boundary column, and corner column (1:1/2:1/4) to reduce the foundation load by 17.2%.

(2) Replacing un-renewable into renewable structural materials based on the strength, durability, quality, and productive period of local one (timber and bamboo).

(3) Sao’s construction material is relatively consuming low energy that can be confirmed by:

(a) Relatively low carbon emissions of transportation concerning the location of material resources somewhat close to the surrounding construction sites which are 10-25 km (less than 1000km)

(b) Relatively low carbon of the used timber and bamboo building materials compared to other materials.

(c) Relatively low energy consumption in the process of timber and bamboo as building materials compared to other materials.

(4) In an effort to continue the product legacy of traditional architecture while overcoming the limitation of natural materials, in the future, it is necessary to innovate new building materials with similar characteristics, such as: structurally adjustable according to the load capacity, strength, durable, low energy, low carbon emission, and low energy consumption.

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