SUSTAINABLE INCREMENTAL HOUSE WITH MODULAR CONSTRUCTION

CIB2010-W110-A4022

Eunike Kristi, JULISTIONO
Lecturer
Department of Architecture, Petra Christian University - Surabaya
INDONESIA
kristi@peter.petra.ac.id

ABSTRACT

Dwelling is an essential needs of human being; unfortunately, housing development is the main contributor to the problem of climate change and environmental degradation. Thus, it is important to build a more sustainable house.

One of the sustainable models of dwelling, which has been proven over time, is the traditional architecture. Most traditional houses in Indonesia are constructed with the local wisdom of traditional people in responding to the local climate, using the local materials and influenced by their culture. Some have a flexible lay-out with easily adaptable space, others are incremental houses which expand bigger over time.

This paper proposes the new concept of sustainable house. From a study of three traditional houses with space adaptability, an incremental house is designed to accommodate the owner's changing phase of life (from single, married, up to having some children). The house uses a knock-down system and modular construction, and incorporated with many sustainable features to make it not only comfortable, but also sustainable and adaptable.

Keywords: *incremental house, adaptable, modular construction, knock-down*

I. INTRODUCTION

Every human being naturally wishes to fulfil all of their needs, not only material necessity, but also emotional and spiritual satisfaction. According to Maslow's hierarchy of needs, there are five basic needs; existential needs, safety, social needs, esteem and self-actualisation (Simons *et al*, 1987). Dwelling is important not only to house human activities, but also to protect them from natural environment and climate. It accommodates the social and cultural activities, and also a means to self-actualise and gain respect from others. Thus, it is an essential needs which can satisfy the five basic needs mentioned above. Due to social and economic differences in the world, criteria of a feasible house differ from one country to another. However, housing development has become major problem of the construction industry all over the world.

Nowadays, climate change and resource scarcity have happened globally and put the future of civilisation on jeopardy. The main reason behind this is over consumption of resources and over emission of greenhouse gasses caused by population explosion, massive urbanisation and industrialisation. Among other causes, construction industry is responsible towards 50% of natural resources used, 40% of energy used, 16% of water used and 45% of CO2 emission (Akmal, 2007), with a significant contribution from residential sector as the primary needs.

Facing the current environmental problem, global action for sustainability has emerged. In here, housing as one of the largest construction industry, should be designed in a sustainable way to ensure not only minimum consumption of energy and resources, and minimum environmental impact, but also enhancing human condition and accommodating their social and cultural needs.

Most houses in Indonesia, especially in the big cities, have been far from being sustainable. The trends show that while low-income people are still struggling to have a proper dwelling, other people are trying to build bigger and more prestigious houses. These houses are likely to be over consumptive towards resources and selfish to the surrounding. There is still lack of knowledge about the importance and how to build a sustainable house. A house is frequently designed only to accommodate the present needs of its occupants. More investment is made to achieve thermal comfort through active system such as air-conditioning, rather than to pursue a healthy house which works in integration with the local climate.

Other common issue in housing development is the needs to adapt the house according to the developing needs of its occupants. It is likely that throughout years, the activities and needs of the occupants will change, and thus the house needs some adjustments. Some examples are the needs of an extra room when a baby is born, or when the children have grown and need individual space. Changes, which are not anticipated in the design phase, will cause unplanned renovation cost or even early demolition of the house when it is no longer proper. A sustainable house should take into account space adaptability and flexibility to prolong the building lifespan. This is aligned with the concept of 4R (reduce, refurbish, reuse and recycle) (The Institution of Structural Engineers, 1999). In Indonesia, as in other developing countries, people tend to emphasis the short-term benefits. Thus, most houses are not designed to respond to the changing needs of the owner.

Consider the needs for a more sustainable dwelling, this paper presents a sustainable incremental house to be implemented in Indonesia. The research is carried out in several stages; starting with exploration of traditional houses in Indonesia, the principles coined are integrated with the sustainable strategies to produce a model of incremental house with modular construction. The research has involved literature study, case studies, design drawing and modelling.

To find a proper model of sustainable house, exploration should be carried out towards the local climate, culture and the strength of the local community. Therefore, observation has been done towards several traditional houses in Indonesia, focussing in the flexibility of a house to respond to the changing needs of its occupants. From the study, it can be seen that some traditional houses are incremental houses with flexible lay-out. Thus, an incremental house is proposed.

Modular construction is cost and work-saving, and due to this benefit, it is more likely to be implemented to achieve a sustainable construction. With modular construction, the construction components can be standardise and produced with fabrication and thus the construction becomes faster and cheaper. Moreover, if the joints between modules are not fixed, the construction can be easily dismantled and hence it means an increase of reuse potential of construction materials.

II. LEARNING FROM TRADITIONAL ARCHITECTURE

From exploration of traditional houses in Indonesia, it is found that most houses have a flexible lay-out. These houses use only limited partitions between rooms, so that the rooms are easily adjusted according to the needs of the occupants. Some houses are incremental, they grows bigger/longer over time to satisfy the addition of the family member. Three traditional houses with adaptability towards functional changing are taken as the case studies to be examined - The Bornean Longhouse, Kampung Naga House, and The South Sumatran House.

2.1 The Bornean Longhouse

The Bornean Longhouse is a typical house of Dayak communities in Borneo Island, known now as Kalimantan Island between 1850-1990. Different with a single-family house, which one family usually lives in a house, one village of Dayak communities used to stay in a single longhouse. The longhouse can be 20 to 200m in length, 8 to 20m in width, with the floor raises between 2 to 5m from the ground (Guerreiro, 2004). It is a raised-floor construction with a simple rectangular plan which grows longer along with an addition of the family members. By raising the house from the ground, the occupants get a large platform to dry crops, cloth, etc. It is also protected from humidity, wild animals and flood.

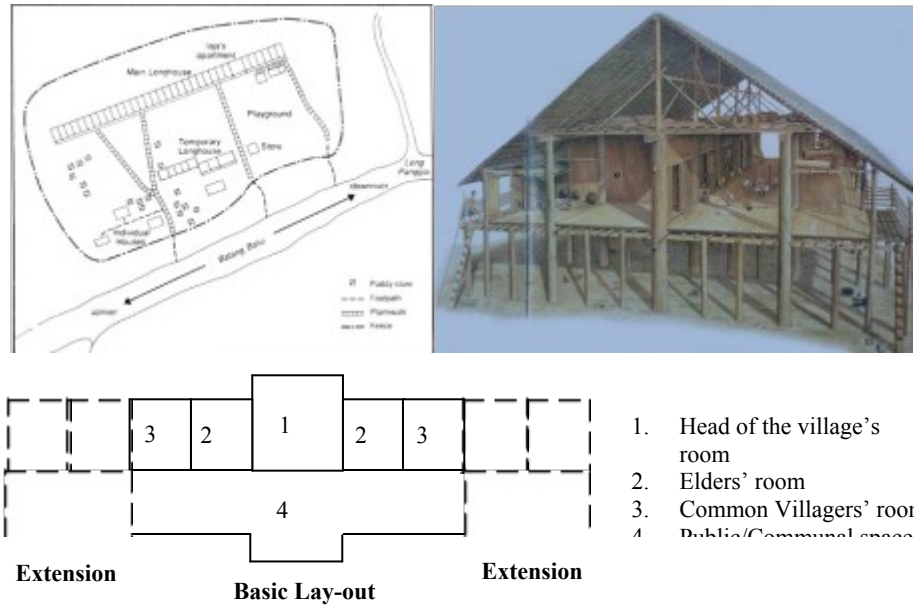


Figure 1. Typical Dayak Settlement and House
Source: Millet (2002)

Longhouse has a simple and flexible lay-out. Along its width, the lay-out is divided between private rooms for families and public spaces, consisting of passages, corridors, halls, platforms and stairs. Each private room belongs to each family, and it is a single flexible room without any partitions inside. Meanwhile, the public spaces accommodate social interaction between families. This place is used regularly for social, agricultural and ritual activities of the community (Figure 1).

The construction is made majority of local hardwoods and shingles. The main structural elements - posts, beams, rafters, cross-beams and floorboards, are all made of the local hardwoods joined with mortise-and-tenon joints, so they could be reused several times (Guerreiro, 2004). The simple gable roof and the timber construction make the longhouse is possible to be lengthen according to the occupants' needs.

2.2 Kampung Naga House

Kampung Naga is located in Neglasari Village, 30 kilometres from Tasikmalaya, West Java. In here, more than 100 families live in a typical house. From 10 hectares area of Kampung Naga, only 1.5 hectares is used as housing area, while others are forest, farms and open spaces (Hermanto & Malangjudo, 1987).

Each house is typical and has a standard dimension of 7.5m by 4.8m. It is rectangular in plan with a single gable roof, with construction made of wood and bamboo. This modular house is proven to have an earthquake resistance. The flexible joints make the house able to withstand a 7.3 Richter scale of earthquake in Tasikmalaya, while the knockdown system makes the house easy to be fixed and moved to a new location after the catastrophe (Rambay, 2009).

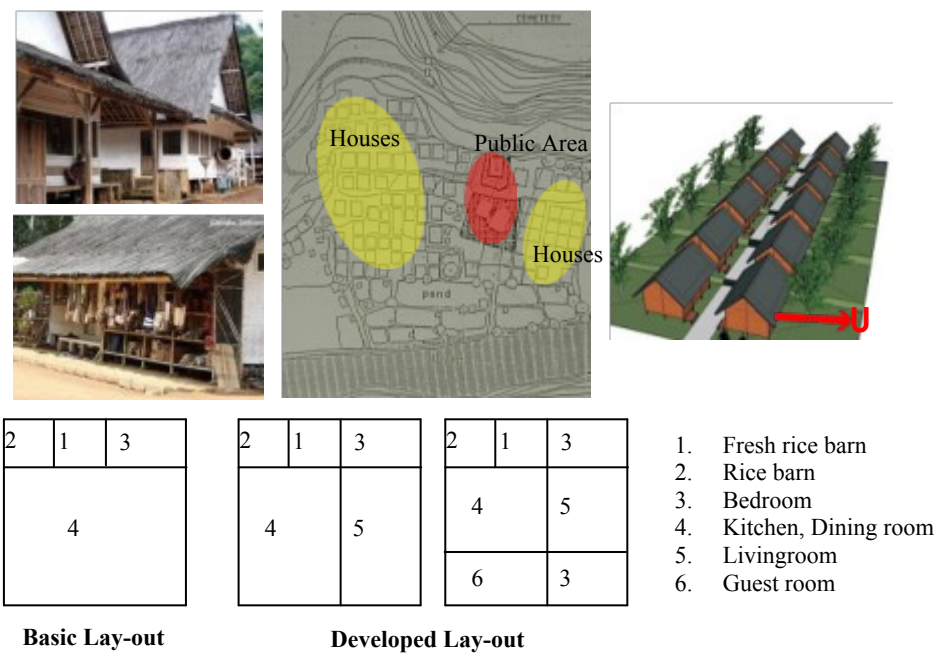


Figure 2. Kampung Naga Settlement and House
Source: Hermanto & Malangjudo (1987) and Indartoro (1987)

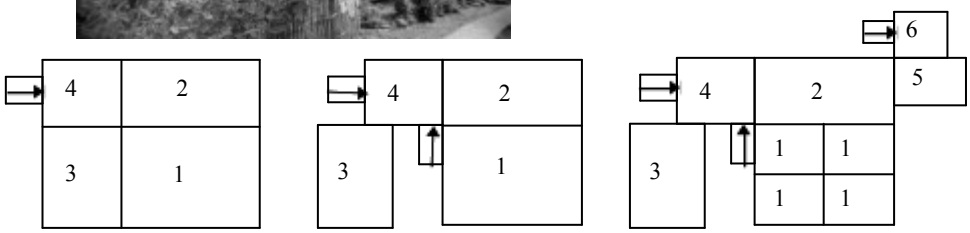
With a standard dimension, the house is prohibited to have an enlargement. This is done to preserve the quality of outdoor spaces in the neighbourhood, since the houses are arranged in a linear organisation with 2-3m distance between houses. However, the house has a flexible lay-out, so that the lay-out can be adjusted with the occupants' needs by addition of partitions (Figure 2). As in any traditional houses, the house also uses a raised floor construction and has no underground foundation. Its posts are simply supported on stones.

2.3 The South Sumatran House

A typical South Sumatran House is largely found in the South Sumatra regions of Bengkulu, Jambi and Lampung. As in Kampung Naga, each house is inhabited by a family. This traditional vernacular house is a square, raised box-frame construction with gable roofs, which sits on six to nine main posts stands on river stones.

The house usually consists of one main room with two difference floor heights. The lay-out of the house is very flexible with minimum partitions between rooms. The core of the house is called *luan*, is usually built first and then *tempuan* is built later with a lower level floor. *Luan* is the core of the house, used as bedroom and sitting room, while *tempuan* is the dining room and kitchen (Barendregt, 2004). In its development, the lay-out of the house can be adjusted according to the occupants' needs through addition of extra building as in an incremental house, or by adding more partition to create more rooms (Figure 3).

1. Luan (Bedroom & sitting room)
2. Tempuan (Dining & kitchen)
3. Front gallery
4. Entrance
5. Kitchen (separate from Dining room)
6. Back terrace



Basic Lay-out **Developed Lay-out**

Figure 3. South Sumatran House
Source: Barendregt (2004)

From the study of three houses above, some sustainable feature coined are:

- The space flexibility and adaptability is produced through either addition/adjustment of indoor partitions or addition of a new structure outside the house (incremental house). The second strategy is possible since these traditional houses are timber construction with flexible joints and have no fixed foundation below ground surface.

- The raised-floor construction is used as a protection from nature – humidity, floods and wild animals.
- All houses are tripartite house with simple gable roofs, reflecting the characteristic of tropical house with high rail fall.
- Constructing using local materials such as wood and bamboo, the house is designed with passive system to ensure a comfortable indoor environment by maximising natural ventilation and daylight.

These three houses are indeed sustainable; however, not all of their features can be implemented in today's housing development. Therefore, to design a new model of sustainable house, the sustainable characteristics of these houses are taken and combined with the development of construction industry and the availability of resources at the moment.

III. THE PROPOSED MODEL

The sustainable house presented in this paper is an incremental house which grows larger along with the extension of the family member. The house is designed to maximise natural ventilation and daylight, to minimise the energy use. The knock-down system is applied to make the house easily dismantled to increase the adaptability of the house and its reuse potential, while modular construction is used so that the occupants can easily purchase the additional components needed for the refurbishment in the maintenance office inside the development area.

In designing the sustainable house, 2.2 hectares site in Citra Raya housing complex in West Surabaya was chosen. This complex offers an independent city concept with complete facilities so that the occupants can live, work and study near their house. Many young families and young professionals live here, since the Central Surabaya area has become too dense and the price of land is very expensive. It is expected that this sustainable house does not only satisfy the growing needs of the young families and professionals, but also influences and teaches the surrounding neighbourhood about the concept of sustainable living.

The house is designed with the principle of sustainable housing (AIJ, 2005);

- Working with nature
  The use of natural ventilation and daylight, and the creation of open spaces around the house show that the house is designed to work integrated with the natural environment.
- Conserving energy
  Energy conservation is achieved by reducing the use of energy for lighting & AC through the use of the passive system. In addition, the roof angle and orientation are designed to provide an additional option of solar photovoltaic cells and rainwater harvesting.
- Resource management
  To minimise the use of resources while increasing the possibility of the space adaptability, this incremental house is designed with a modular construction and a knock-down system. This automatically increases the space flexibility and possibility for the house to be refurbished and reused in the future.
- Human comfort
  Occupants' comfort and health is achieved by ensuring adequate ventilation inside the house and the use of non-toxic materials.

Although emphasis of the research is to design a single family house which can increment through out time, a sustainable house can not be designed apart from its environment. Thus, the communal spaces are also planned, such as public facilities (club house, eating area, repair, maintenance and management office), open spaces for each cluster, and centre for waste and water management.

A. Club House & Commercial Area
B. Management Office
C. Maintenance/Re-pair Management Office
D. Waste Management
E. Water Management
F. Swimming Pool & Recreation Area
G. Houses (arranged in cluster with open space in the middle)

Figure 4. Lay-out of Three Clusters Sustainable Housing with The Public Facilities

3.1 The Incremental House

In traditional houses, space adaptability is produced by the flexibility of indoor lay-out and the possibility to enlarge the house with additional structure. In here, a flexible timber construction allows the house to be easily expanded or dismantled.

Currently, with the extinction of natural forest, using timber is not always sustainable. Concrete, the most usable structural material, is heavier and less flexible. It is less ductile and do not have reuse and recycle potentials (Lawson, 1996). Besides, different with traditional structures which are simply located on the ground, today's structures are usually supported by substructure below the ground. These are some issues dealt in designing an incremental structure. Addition of a new structure attached to the primary one is difficult to be performed several years after the initial structure due to the issue of differential settlement and the joints.

In this research, steel is utilised as the main structural materials with secondary components made of light steel, due to its reuse and recycle potentials, especially when it is assembled with a pinned joints. The main structural frame is planned to be fixed and do not have to be added if the house is enlarged. Thus, an incremental space is created by designing modules of rooms between the main structures.

Four basic configurations are designed, to accommodate occupants' changing phase of life - one-bedroom plan for single occupant, two-bedroom plan for married couple, three and four-bedroom plans for families with child/children (Figure 5). The dimensions of each room required for all configurations are studied and standardised to determine the structural frame module. With a standardise dimensions, a modular construction is produced. Thus, the occupants can easily

purchase an additional room in the maintenance office, so that the renovation cost and time can be minimised.

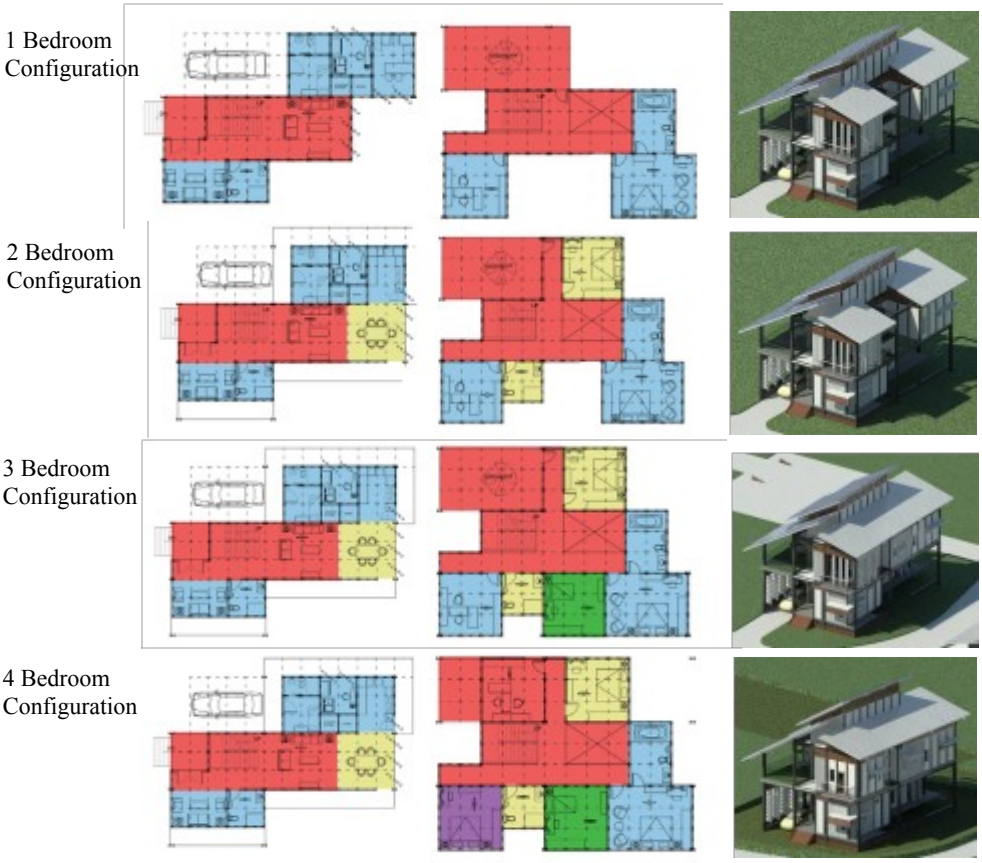


Figure 5. 4 Development Phases of The Incremental Houses

The four configurations above are designed by applying the sustainable features coined from the traditional houses studied and the sustainable design principles. The house uses a raised-floor construction to avoid humidity, minimise the building footprint and maximise the water absorption in the ground. The house position and orientation are arranged to allow every house has an adequate wind flow. The lay-out is designed to maximise natural ventilation and day lighting for each room to ensure a healthy and comfortable house. Instead of a simple gable roof, the roof is cut in the middle and elevated to create additional openings as hot air outlets and additional day lighting. The roof is also designed for additional option to use solar photovoltaic panels and rainwater harvesting. Two separate voids are designed in the core of the house as the light wells. The materials used are all sustainable and non-toxic, some are local materials, some are not.

3.2 The Modular Construction

Modular construction has grown enormously at the moment, especially in industrialised countries. It is work and cost-saving construction, since the construction elements are pre-fabricated in modular sizes and can be easily assembled on site with simple joints.

Some modular constructions use a knock-down system, so that that they can be easily assembled and dismantled, means possibility for refurbish and reuse. In a knock-down system, the construction flexibility is determined by the flexibility of the joints. Thus, in this house, instead of welded and fixed connections, the structural frames and the secondary members are all joined with bolts.

In designing the house as a modular construction, it is important to find a minimum variation of modular components without limiting the possibility of module combinations. Through the study of various room dimensions, five standardise construction modules which can be combined to produce diverse lay-out configurations are obtained (Figure 6). Using only these five modules, owner can build his house in four different configurations offered or even create his own design. Moreover, the house can be easily enlarged and dismantled by addition and subtraction of certain modules with a knock-down system.

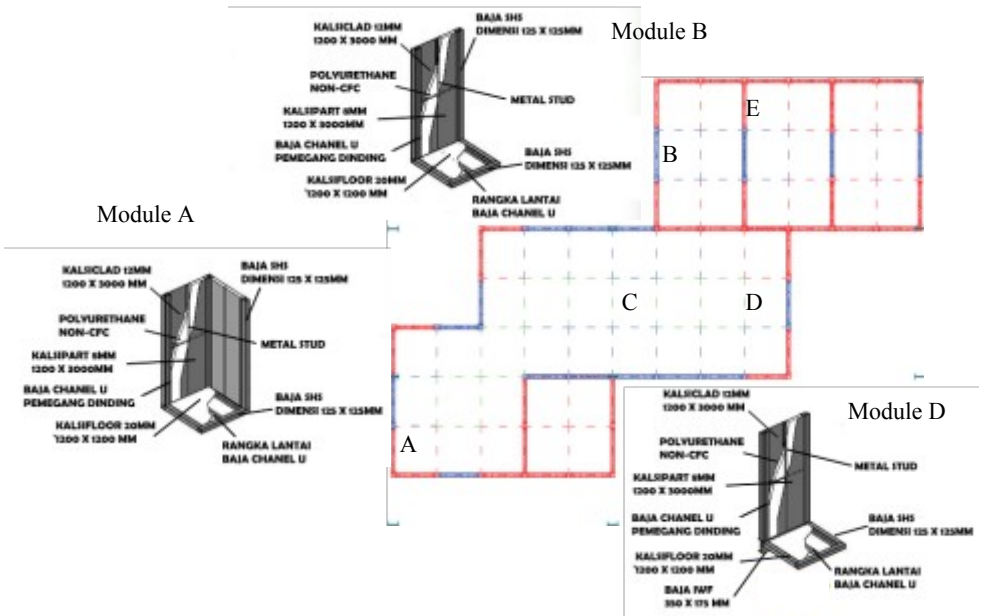


Figure 6. Lay-out of Modules for 1 Bedroom Configuration & Details of Some Modules

IV. DISCUSSION

Realising the necessity for a more sustainable house at the moment, especially to anticipate the continual growing needs of housing and the global environmental problem, this paper presents the concept of sustainable incremental house with modular construction. This concept was developed by integrating the sustainability of traditional houses with sustainable design principles and today's development of the construction industry. The result is an incremental house which can adapt to the changing needs of the occupants, while incorporating sustainable features to reduce the energy and resource usage, and maximize the occupants' comfort.

Several advantages of this sustainable incremental house are:

- Its adaptability towards the occupants' changing phase of life.
- Reduction of energy usage and carbon emission by designing the house to work integrated with the climate.

- Efficient use of resources through the use of modular construction and knock-down system.
- Healthy and comfortable house is ensured by the use of non-toxic materials and adequate air flow and lighting in the house.
- Maximise water absorption on the ground and avoid humidity by a raised-floor construction.

It is realised that the research has some limitations. Thus, some possible future works are finding alternative materials to develop more economical modular components and studying the issues related to the joints between each module more thoroughly, such as the issue of insulation and acoustic.

V. ACKNOWLEDGEMENT

Some parts of this paper are taken from an undergraduate architectural final project of Steven Junius Irawan, supervised by the author.

BIBLIOGRAPHY

Akmal, Imelda. (2007). *Sustainable Construction*. Jakarta: PT Gramedia Pustaka Utama.

Architectural Institute of Japan (AIJ). (2005). *Architecture for Sustainable Future*. Tokyo: Institute for Building Environment and Energy Conservation (IBEC).

Barendregt, Bart. (2004). "Architecture on the Move: Processes of Migration and Mobility in the South Sumatran Highlands" in *Indonesian Houses*, edited by Reimar Schefold, et al. Singapore: Singapore University Press.

Rambay, Arbain. (2009). *Belajar dari Rumah Kampung Naga (Learning from Kampung Naga House)*. Retrieved from http://arkeologi.web.id/articles/etnoarkeologi/173-belajar-dari-rumah-kampung-naga

Guerreiro, Antonio J. (2004). "The Bornean Longhouse in Historical Perspective, 1985-1990: Social Processes and Adaptation to Changes" in *Indonesian Houses*, edited by Reimar Schefold, et al. Singapore: Singapore University Press.

Hermanto, B. & Malangjudo, S. (1987). *Hierarchy of the Public Space in Kampung Naga*. Yogyakarta: Gadjah Mada University.

Indartoro, I. (1987). *Kampung Naga: A Study of the Relationship between Beliefs, Tradition and the Pattern of a Traditional Village*. Yogyakarta: Gadjah Mada University.

Irawan, Steven J. (2009). *Hunian yang Berkelanjutan dengan Sistem Modular di Surabaya Barat* (*Sustainable Housing with Modular System in West Surabaya)*. Final Project Report. Surabaya: Petra Christian University.

Lawson, Bill. (1996). *Building Materials, Energy and the Environment*. Red Hill: Royal Australian Institute of Architect.

Millet, Didier. (2002). *Indonesian Heritage: Arsitektur*. Jakarta: Grolier International Inc.

Simons, J.A. et al. (1987). *Psychology: The Search for Understanding*. New York: West Publishing Company.

The Institute of Structural Engineers. (1999). *Building for a Sustainable Future: Construction without Depletion*. London.