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Experimentation for Development for Ark'a Modulam Foundation as an Alternative to Create Amphibious Architecture in the Urban Floodplain in Kalimantan

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Abstract

Objective: This study describes the development study on amphibious foundation called Ark'a Modulam. To describe the development study of this Ark'a Modulam foundation. **Methods/Findings**: This study is arranged based on the first year of 3 years consecutively-planned research. The method used was engineering design to formulate the alternatives. The experimenta description and discussion supports the concept of amphibious architecture of living houses. **Application**: This study is hopefully able to benefit in developing flood resilient houses especially for urban floodplain settlement in Kalimantan.

Keywords: Amphibious, Architecture, Ark'a Modulam, Floodplain, Foundation

1. Introduction

Flood and water level rise that destructs urban downstream shows that it is supposed to create an innovation such as a water-based architecture. Principally, there are three types of water-based architectures namely stilts architecture, buoyant architecture, and amphibious architecture. In its development, the amphibious architecture is the latest innovation than the two others.

Flood that destructs floodplain is inevitable since the floodplain is the place where water flows when rainy season comes. However, it is possible to restrain or to minimize the impacts on the settlements that are located in that area. One of the solutions which is conducted across generation in Kalimantan is to make stilts houses. But today, because of global climate change, the floodplain settlements in Kalimantan are mostly submerged. Now the question raises up is whether the stilts houses are made higher? Then it needs higher piles, where the timber materials are now hard to obtain. Another alternative is to use concrete piles, but it still remains problem for a living house, since concrete piles are not effective, efficient, and of course costly for only a construction foundation of a house. A further alternative is to create a non stilts house yet is not submerged by water when flood come.

Today due to global warming and climate change, some houses built in urban wetlands in Kalimantan begins submerged by water when the flood level is high, although the house floor height is 2 meter from the ground. This condition needs a solution to create a cre-

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ative house that suitable with this condition where the form of later stilts houses is not submerged by flood when rainy season comes. By reviewing some floating architectures and stilts architecture, Ark'a Modulam[1] is offered to answer such challenges and as an alternative to solve and to develop living houses in wetlands. Since the Ark'a Modulam is a new innovation, this paper is aimed to introduce the amphibious architecture. Moreover, this is also to describe a development study of amphibious foundation called Ark'a Modulam in which the research is still in progress, and to discuss its relation as an alternative to implement the amphibious architecture.

2. Review of Related Literatures

2.1 Floodplain

Principally, nature has provided a space to expel water from the riverbed at a certain time. That space is called floodplain. As mentioned above that floodplain is basically a space that is adjacent to a riverbed where there will be high flooding in certain years due to overflowing from the riverbed. According to Cengiz (2013), 100 year flood cycle is used to identify the extent of flooding in the floodplain, or it could also use the 25 and 50 year cycle. Based on Suripin (2004), flooding is a condition where water is not accommodated in the drainage channel (*riverbed*) or obstructed the flow of water in the discharge channel, so that the water overflows in the surrounding area (*floodplain*), thus flood occur due to lack of channel storage capacity. Surpin (2004) added that flooding in the upstream part usually flows swiftly, has a large scouring force, short duration. While in the downstream area, the stream is not heavy (due to ramps), but the duration of the flood is long.

According to Suripin (2004), some characteristics of flood are: 1. The flood may attact immediately with a great intensity but may directly flow, 2. The flood attact slowly with a small rain intensity, 3. The flood attact seasonally (*seasonal flood*), 4. The flood attacts slowly but it may inundate for a long time at a depression area, and 5. The impact carried by the flood are inundation, erosion, and sedimentation. In general according to Kodoatie and Syarif (2006), the causes of flooding can be divided into two such as occuring naturally and occuring due to human activities.

Flood that occurs naturally are: 1. *Rainfall*. Rainfall may cause flood if the rain falls with a great intensity, with long duration, and with extensive areas, 2. *Physiography impact*. Physiography or geography of physical river such as shape, function, and slope of the river drainage area, river slope, hydrolic geometric, location of the river are the factors that cause flood, 3. *Erosion and sedimentation*. Erosion and sedimentation affect the reduction of river section capacity. Both are classic problems in Indonesia. The amount of sedimentation will reduce the channel capacity, resulting in puddles and flooding in the river, 4. *River Capacity* Reduction. Reduction of flood flow capacity in rivers can be caused by sedimentation resulting from erosion of slope of the river drainage area and excessive erosion of river embankments and sedimentation in rivers due to lack of cover vegetation and improper land use, and 5. *Impact of Tidal Water*. Tidal water retard water stream to the sea. When flood and tidal water come at the same time, the height of the puddle or flood becomes large because of backwater, 6). *Drainage Over Capacity*. Almost all the drainages in Indonesia are over capacity then they are to suffer flood annually when rainy season comes.

Flood that occurs for human's activities are: 1. *The decreasing function of watershed in the upstream area as a water catchment*. The capability of watersheds especially in the upstream to absorb rainwater is diminished by various reasons such as deforestation, improper agricultural activities, urban expansion, and other land use changes. This may exacerbate the flooding problem because it may increase the quantity and quality of flood, 2. *Slum*. Slum area existed across the river banks is a flow inhibitor. The cross-sectional area of the river flow will be reduced due to the use of the river for slum residents. The slum areas are as an important factor in urban flooding problems, 3. *Trash*. Poeple's habbits to throw the trash to the river may cause serious water level raise, 4. *Dam and structures.* Dams and structures such as bridge posts (poles) may increase flood level due to backwater effect, 5. *The Absence (damage) of Flood Controller*. The lack of mantaining the flood controller caused a serious damage on the controller or brokent that leads the controller does not work properly that in turn raise the water level, and 6. *Inappropriate Flood Control System Plan.* This control system may mitigate the impact of low to medium flood but it tends to enlarge the flood impact during a great floods.

2.2 Amphibious Architecture

The amphibious architecture[2-5] is an architecture designed to concern on flood in which the structures are planed to float when flooding, adjusting the water level, and may descend precisely back to its initial position. To float when flooding, it needs floating construction foundation. The floating material is *foam* or EPS, floating concrete construction, plastic drum or mineral water bottles. To descend normally, it needs base construction. To move up and down, it needs movement guided pole construction as shown in Figure 1.

2.3 History

The history of amphibious architecture starts at a camp in Louisiana precisely on a floodplain of the Raccourci river (Figure 2a). Amphibious architecture is in the form of temporary housing for river fishing activities, and was built around the mid-1970s. The floating material used in this amphibious house is EPS *(expanded polystyrene).*

In order to deal with sea level rise, Netherlands in 2006 built an amphibious housing in Maasbommel with an innovative architectural form (Figure 2b). In addition, the floating material used is also classified as innovative, namely concrete material. Floating material made of con-

Source: http://buoyantfoundation.org/

Figure 1. Amphibious house and lower and higher stilts houses in overcoming great flood.

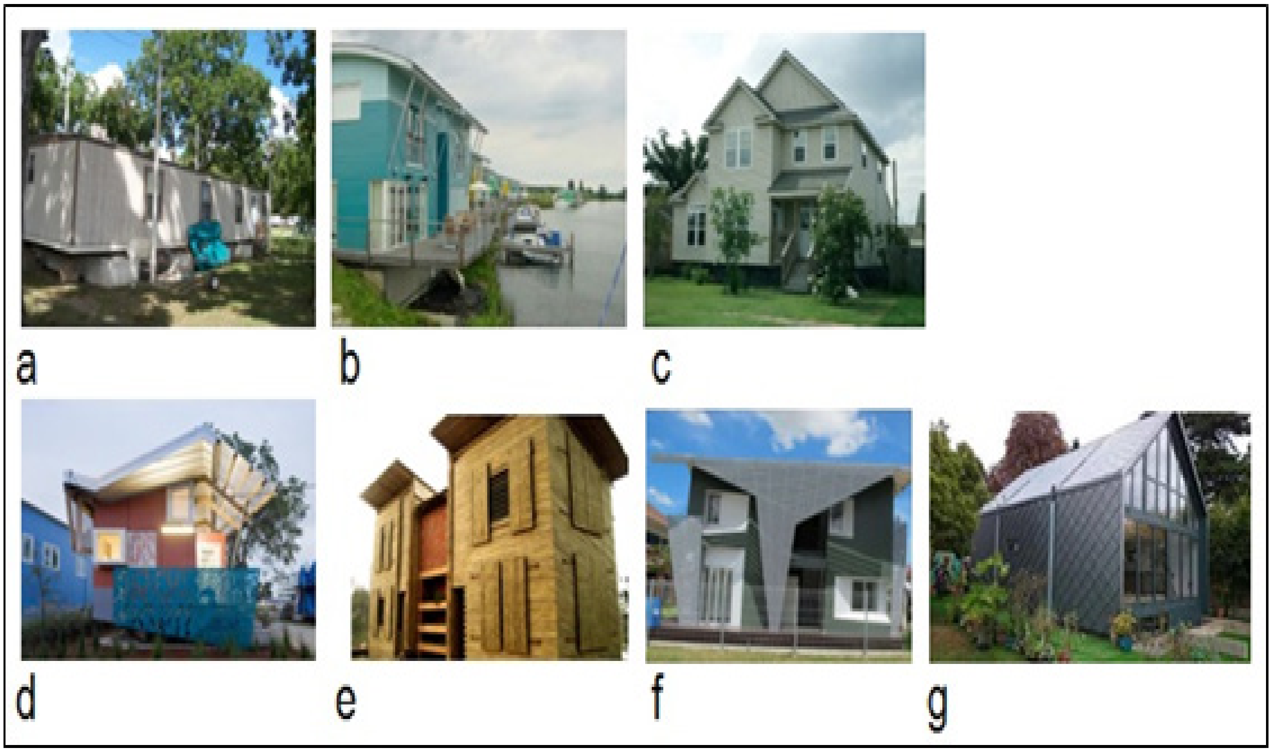

Figure 2. Amphibious architecture design.

crete also functions as a foundation that can float and descend.

The amphibious houses called Noah's Ark Project (Figure 2c) was built in 2007 in New Orleans. In 2009, in New Orleands was also built amphibious houses called *Float House* (Figure 2d). In the development, the amphibious house was built in Bangladesh (Figure 2e). The amphibious house that was S2 thesis project called *Lift House* because it works as a lift. In 2014, the amphibious house was built in Bangkok (Figure 2f) dan in 2015 was built in England (Figure 2g). The amphibious houses were made to cope flood and tidal water rise.

In Indonesia long before 1970 exactly in 1920, it was an amphibious like house that existed in a river precisely in the middle of the Batanghari (Jambi) river corridor, in the middle of the Barito (Kalteng) river corridor, and in the middle of the Kapuas (Kalbar) river corridor. The amphibious like houses gather in river sediment that tends to be flat. The river sediment is an inside of bend in a meander so that it does not flow fast when the river water is high.

2.4 The Innovation Development of Amphibious Houses in Indonesia

In Indonesia context, the amphibious houses have not been such developing rather than other countries. It still remains concepts, ideas, and research products that have not been applied yet. In term of research product, Puslitbangkim (center for settlement and housing development and Research) has made a flood resilient house model scale 1:1 made of bamboos (Figure 3a). Moreover, Architecture department of UNPAR Bandung has also made a picture of amphibious house model (Figure 3b) called *Rafta* (Rumah Apung Fabrikasi pada Tepi Air).

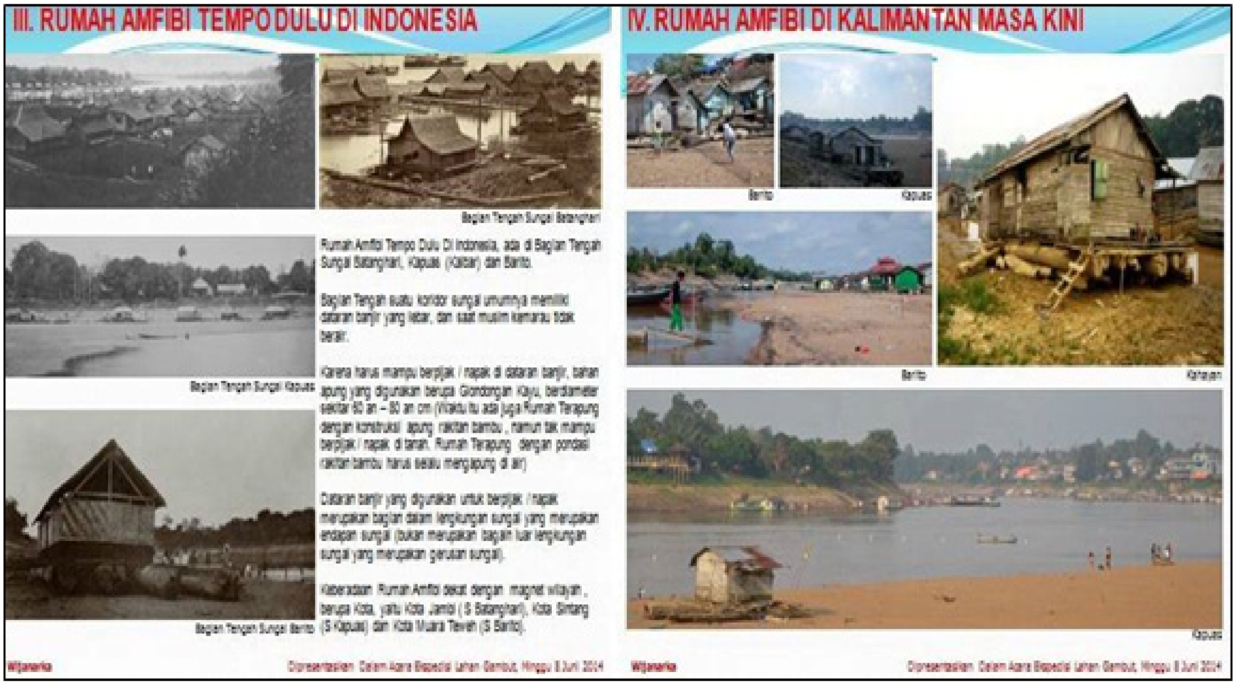

Figure 3. The amphibious like houses in Indonesia in past time and in recent time.

2.5 Amphibious Foundation Techniques

According to the history of amphibious architecture and its innovation in Indonesia, the foundation techniques are the most central points in order to make it floats when flooding (as water fills the dock) and it may descend when not flooding (as water recedes). Three techniques are common to create an amphibious architecture: 1. *Sticking technique*, 2. *Basement technique*, and 3. *Mixed techniques of sticking and piling.*

2.6 Fondasi Ark'a Modulam

Ark'a Modulam is a construction module and main poles of amphibious houses that function as a foothold that descend to the base construction when the wetland

Table 1. Capacity calculation comparison and cost estimation

Foundation type	The capability when floating (floating construction)	The capability when not floating (piers/ base construction)	Estimated cost by second class wood
Tipe A (4 drum)	701,60 kg	16.000 kg	Rp. 4.953.900,-
Tipe R (8 drum)	1.428,78 kg	25.600 kg	Rp. 6.546.375,-
Tipe K (16 drum)	2.880,32 kg	51.200 kg	Rp. 10.685.600,-

Source: Wijanarka, 2017

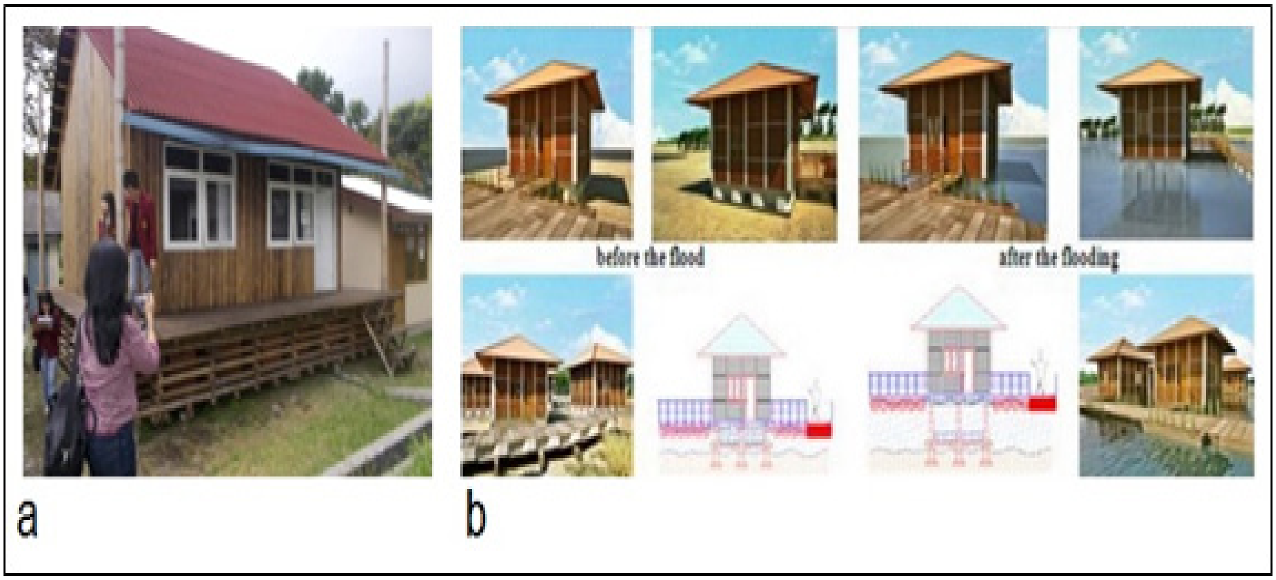

Figure 4. Amphibious house innovation in Indonesia.

is dried and floats when the wetland is watery. The Ark'a Modulam consists of three main construction parts: 1. movement guided pole construction, 2. Base construction, and 3. Floating construction. The Ark'a Modulam consists of three types (Figure 4a), such as A (for 4 drums), R (for 8 drums), and K (for 16 drums). The cost estimation for assembling and floating capacity of the models are listed on Table 1.

3. Experiment Method

3.1 Method of Trial Model Formulation

To conclude a phisical test model draft, three phases were conducted. The first phase was to select Ark'a Modulam foundation type as a prototype. The aspects that underpinned were the capability to withstand float-

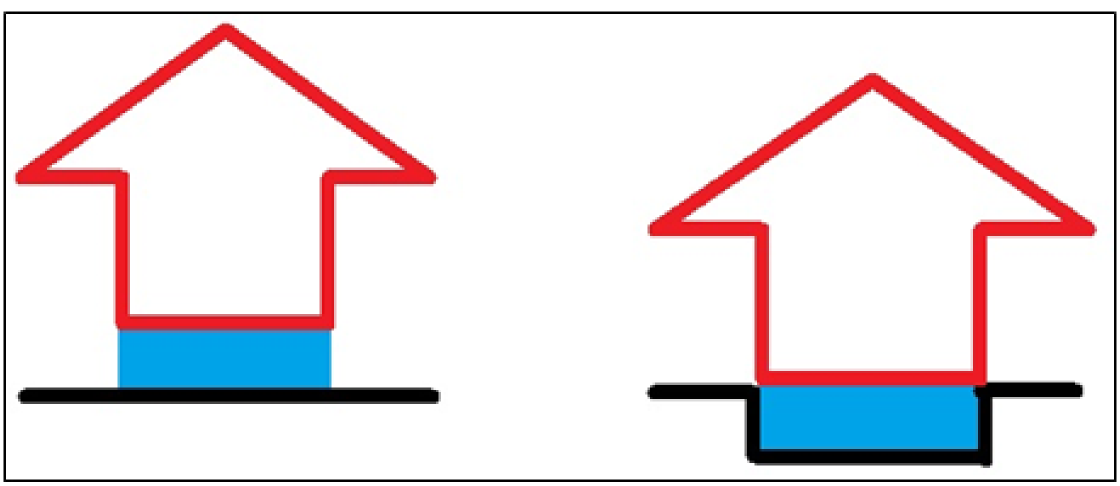

Figure 5. Scheme of three amphibious foundation techniques.

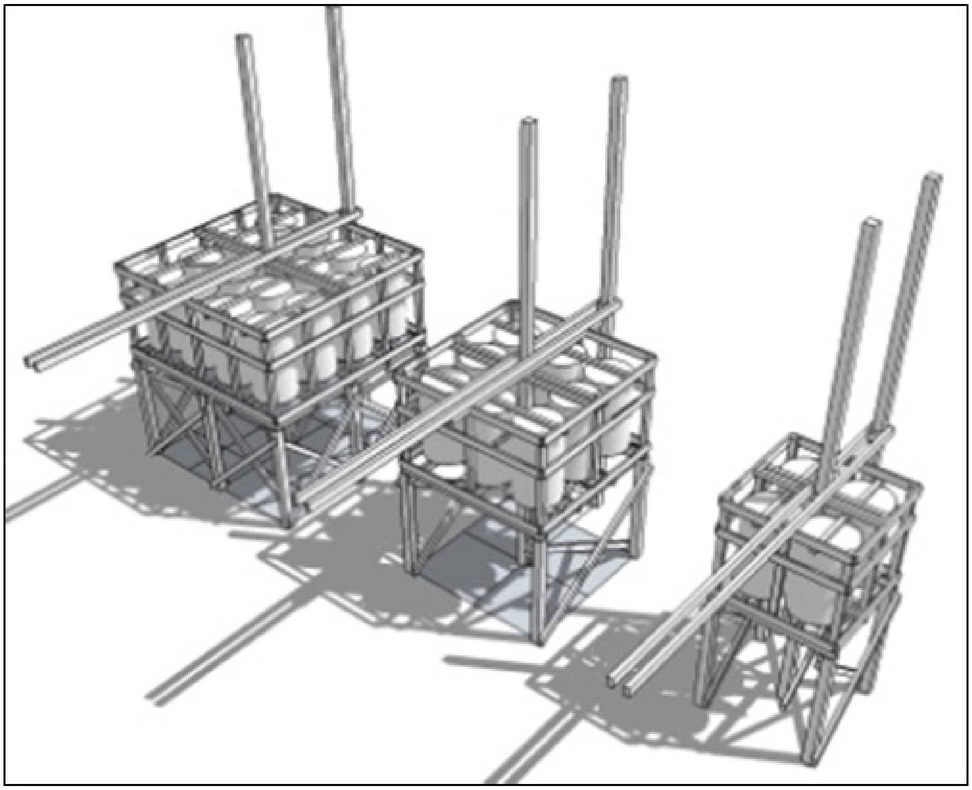

Figure 6. Three types of Ark'a modulam foundation dan development type A.

ing construction load when floating (when flooding), the capability to withstand base construction load when not floating (when not floating), ease of manufacturing, easy of developing, efficient in the use of materials and efficient in funding. In stage 1, type A was chosen as the prototype to be developed in stage 2.

Phase 2 is the development of a type A foundation construction pattern. In this stage, type A foundations are developed into 2 construction patterns named patterns A.1 and A.2. Both are then developed again, each into a more efficient construction pattern. Pattern A.1 is developed into A.1.1 and pattern A.2.1.

Phase 3 is the selection of the draft model which reviews the pattern A.1.1 and A.2.1. The aspects that are used as the basis of the selection are the ease of manufacturing, the effectiveness of channeling the loading force, efficient use of materials, efficient funding, ease of installation of floating and aesthetic materials. The study and formulation of the draft model is based on an evaluation of four development models (Figure 5-7). The study results show that the A - 2.1 development model was chosen as the model to be tested in the field. The A - 2.1 development model is an effective, efficient and feasible model in the field.

For the implementation of physical test at the research site, three alternative patterns of connection between the floating constructions and the constructionpedestal with the vertical driving poles construction. The three alternatives are: 1. Alt.1 construction pattern A - 2.1, 2. Alt.2 construction pattern A - 2.1, and 3. Alt.3 construction patterns a - 2.1. In the physical test at the research site, two foundations are needed for which the main pillar is connected. If the three alternative patterns as shown in Figure 3 is paired with the same foundation pattern with 3 meters' main pole distance, the results are as shown in Figure 8.

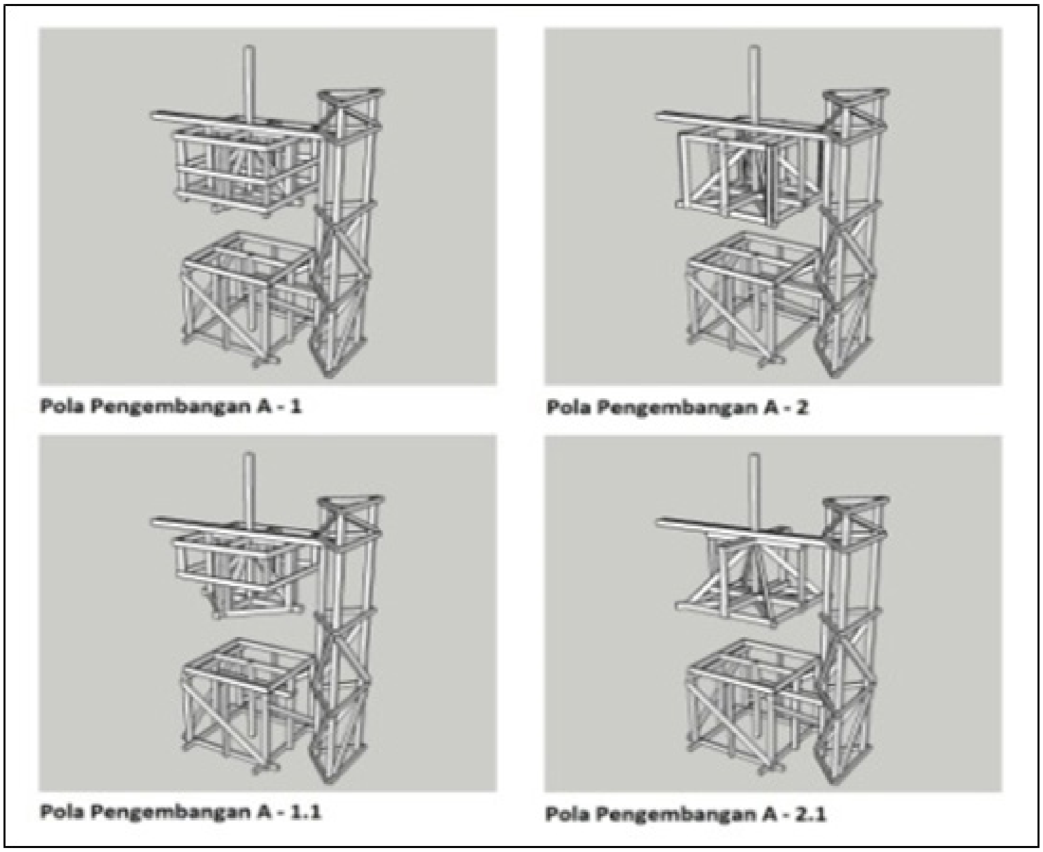

Figure 7. Four models of development.

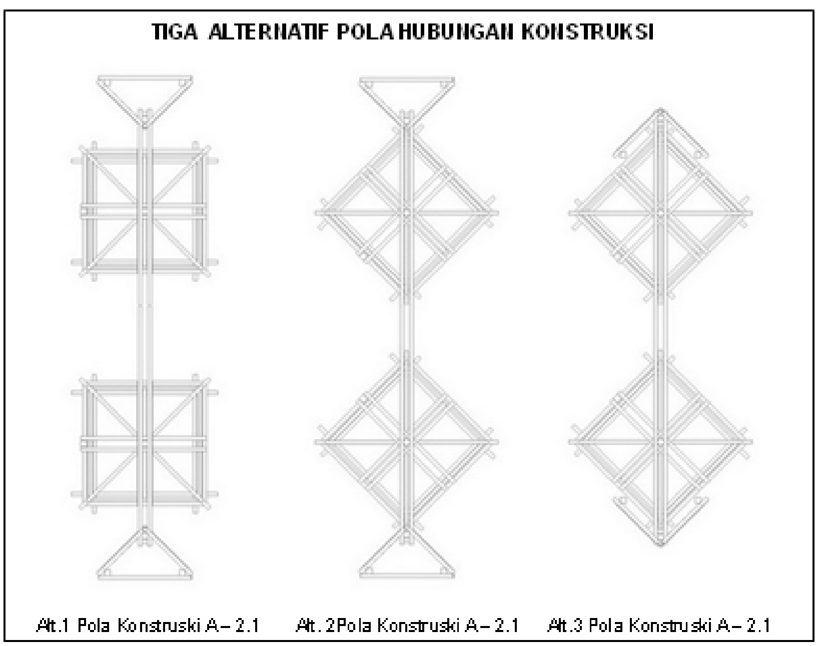

Figure 8. Three alternatives of connective construction development pattern.

Of the three pairs of connection, the pedestal distance of Alt.2 - pattern A - 2.1 and Alt. 3- pattern A – 2is shorter than Alt.1- pattern A - 2.1. With a short distance, the pedestal construction of Alt.2 and Alt.3 is as a foundation than Alt.1. When viewed from the connection of the pedestal construction with the vertical driving pole construction, Alt.3 is tighter than Alt.1 and Alt.2. When viewed from the connection of floating construction with the vertical driving pole construction, Alt.3 is also tighter than Alt.1 and Alt.2. If the floating construction moves upwards, the vertical driving pole construction especially the two supporting pillars, will stabilize the position of the floating construction. Thus, Alt.3 is considered applicable as a trial model draft.

3.2 Floating Test Design and Material

Type Alt.3 pattern A-2.1 consists of three models of construction such as the construction of pedestal, the floating constructions and the vertical driving pole construction (Figure 9). The main buoyant poles construction are connected with a beam to the vertical driving pole construction. This is intended to keep the floating construction moves vertically and it functions as a tape that keep stable the construction and moves horizontally.

The base construction size

Length and width	=	165 cm
Height	=	70 cm

The floating construction size

Length and width	=	165 cm
The frame height	=	109,5 cm

The base construction and the floating construction are formed according to the size of 200 litre plastic drum.

The vertical driving poles size

Height	=	400 cm
Distance among poles	=	40 cm

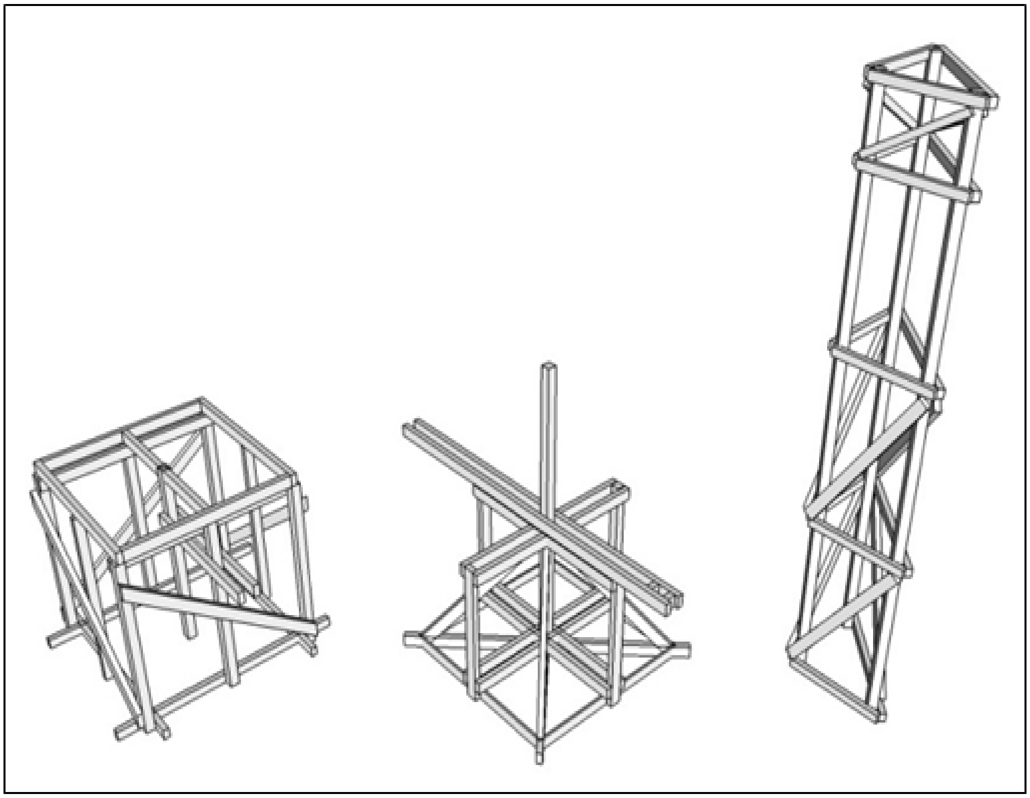

Figure 9. Design type Alt.3 pattern A-2.1.

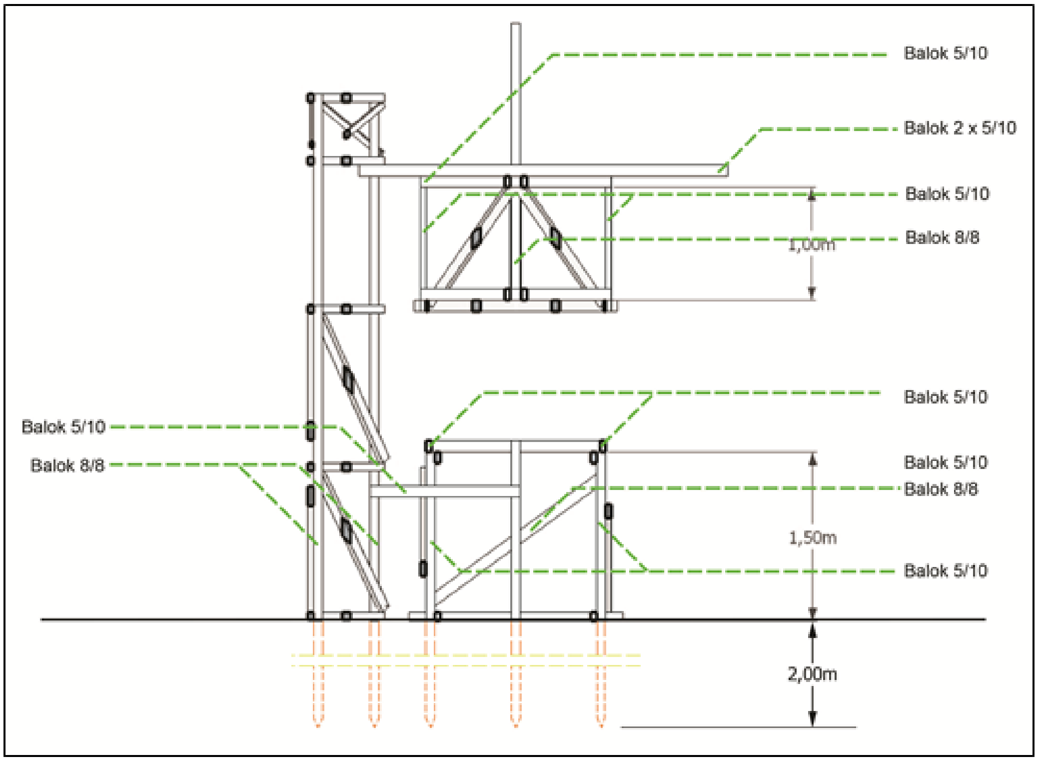

Figure 10. Piece of type Alt.3 pattern A-2.1.

In practice, the base construction poles and vertical driving poles construction were planned to plug in the ground. It is around 1 meter or more under the ground (Figure 10). The material used for the plugged in poles construction is wood. The wood size is 8/8 for the base construction, and 5/10 for the beam, and 5/5 for the joists. For floating construction, the size is 8/8 for main poles, 5/10 for the beam, adn 5/5 for a frame beam, and 5/7 for the backing buoyant materials. Fot the vertical driving poles construction, the wood size is 8/8 for the main poles, 5/7 for the supported poles, and 5/7 for the joists. The wood used are Meranti and Kruing. The connection construction among the wood used bolt and nails to attach to the joists. The floating material used is plastic drum 200 litre.

In this study, type A was developed into two construction patterns A.1 and A.2. (Figure 5). Two development patterns then developed again into a more efficient construction pattern. Pattern A.1 was developed into A.1.1 and pattern A.2 was developed into A.2.1. (Figure 4b). The results of the study show that pattern A - 2.1 is an effective and efficient model, so that pattern A - 2.1 is used for flotation trial. Furthermore, pattern A - 2.1 was developed in a layout so that it produced type Alt.3 pattern A-2.1.

Type Alt.3 pattern A-2.1 consists of three construction models namely the the base construction, the floating constructions, and the vertical driving poles construction (Figure 7). The main floating pole construction is connected with a beam to the vertical driving poles construction. This is why the floating construction moves vertically and is as a tape so that the floating construction keeps stable and does not move horizontally. Base construction size has 165 cm length and width and 70 cm height. The floating construction size has 165 cm length and width and 109.5 cm frame height. The vertical driving pole construction size has 400 cm height and 40 cm distance between poles. In practice, the foundation poles and the vertical driving pole construction are plugged into the ground with at least 1 meter or more grounded.

4. Results and Discussion

4.1 Results

In the first year of experimentation, the material used for the construction was wood. For the base construction, the wood size is 8/8 for poles, 5/10 for beams and 5/5 for joists. For floating construction, the wood flow is 8/8 for the main pole, 5/10 for the frame beam and 5/7 for the buoyant material. For vertical driving pole construction, the wood size is 8/8 for main pole, 5/7 for supporting poles and 3/5 for joists. The wood used is Meranti and Kruing wood. The construction of the connection between wood using bolt and nails to attach to the wood. In this experiment, the buoyant material used was a 200 liter capacity plastic drum. The number of plastic drum is 4 that arranged vertically. The drum diameter is 58.5 cm and the drum height is 92.5 cm. Since in this trial does not have any loading above the floating construction, the ground construction poles and the vertical driving poles are plugged into the ground for 50 cm.

The floating test is carried out in a village at the floodplain in Palangka Raya exactly at Jl. Anoi Complex Mendawai. From the observation of the site, the height of the flood at this location can reach 2 meters. Therefore, the surrounding residential houses use masted construction with 2.5 m - 3 m height. From the results of the experiment, it was found that the weight of floating construction without four drums was 157 kg. When the water level reaches 98 cm, where the height of the foundation construction was 70 cm submerged, the floating construction with 5/10 wood base beams have not been floated up. It began to float up when the water level reaches 115 cm.

When the floating construction detached of a construction pedestal, a plastic drum 12 cm submerged. With the connection of a bound beam to keep stable the main floating poles with the vertical driving poles construction, when the water recedes, the floating construction descend to the normal or original position (to the pedestal) as shown in Figure 11-12.

Figure 11. Experiment construction and its manufacture.

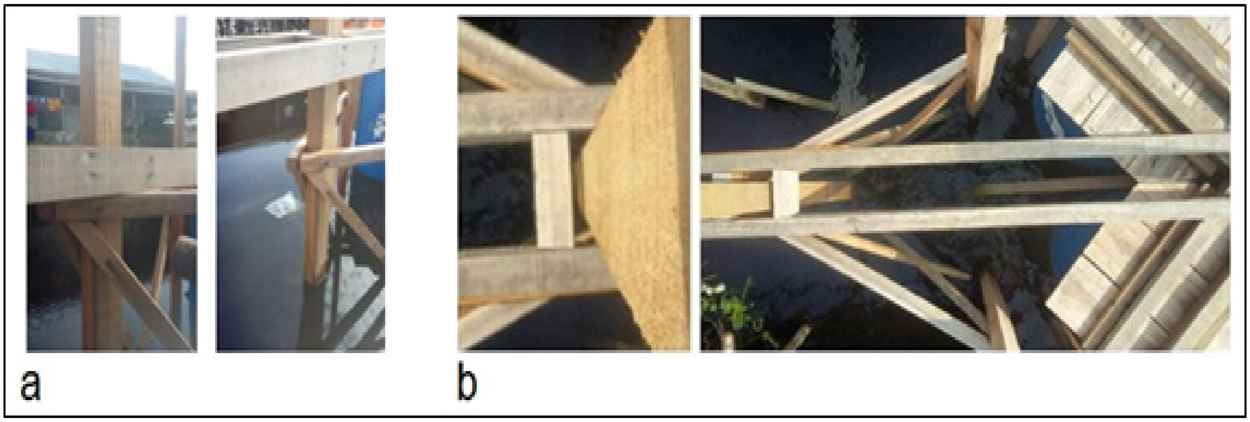

Figure 2. a) the floating construction when not floating (left) and the floating construction when floating at 141 cm water height (right). b). The connection of a bound beam to tighten the main poles of floating construction and the vertical driving poles construction.

4.2 Discussion as an Alternative to Create Amphibious Architecture

Floodplain is a flat land on the left and right side of a riverbed created by sedimentation, which is a river ecosystem that will be flooded when river water overflows and functions as a center for biological life of wetlands, and is now widely used by human activities as agricultural and urban land .

In relation to urban activities in Kalimantan, the floodplains in urban areas have now developed into settlements. Because it is a wetland that will always be

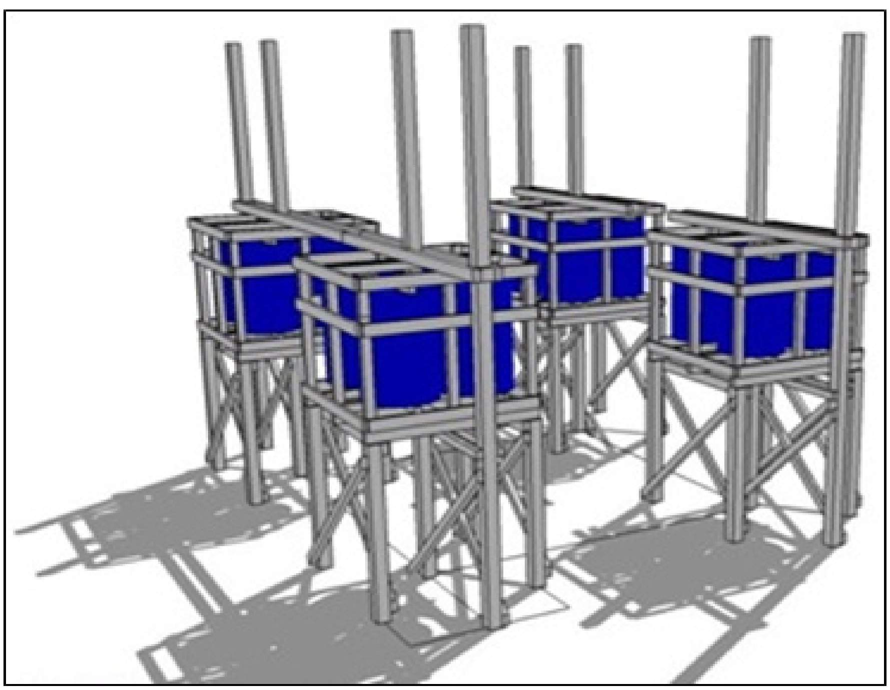

Figure 13. The ilustration of laying position of Ark'a Modulam foundation with 3x3 meters grid.

flooded in the rainy season, the houses built on the floodplain are stilts houses whose poles are 1 to 2 meters high. In Kalimantan especially in the middle and upstream, the width of the floodplain is very wide. Palangka Raya is an urban area in the central part of Kalimantan that has a very wide floodplain where now some parts of it have developed into settlements. Generally in Kalimantan the houses are in the form of stilts wooden houses where the pillars also function as a foundation. At the floodplain which is the location of the pilot project, the average height of the pole is 2.5 meters. The distance between the foundation poles is in average of 1 meter forming a grid pattern. The height of the pole is based on the maximum flood water that has ever happened before.

In current development, along with the effects of global warming the stilts houses with 2 - 2.5 meters height in the floodplain settlements, most of the residential floors are submerged in floodwater. To mitigate and anticipate that event in the following years, a number of houses have raised their houses higher by dismantling part or all of the house, then adding foundation poles with wood, and rebuilding or replacing their houses. From the elevated house, several houses have experienced two elevations. The addition of wood for the pole is now constrained by the difficulty of obtaining wood and also the high price of wood.

Type Alt. 3 pattern A - 2.1 is the development of the Ark'a Modulam foundation prototype. The Ark'a Modulam (*Ark'a Amphibious Module*) is a construction module and main poles that if the block are not filled with water, the foundation of the house will descend on the ground or foundation construction, and if the blockare filled with water, the foundation of the house will float. With Ark'a Modulam, it is expected that the floor of the house will overcome the maximum floodwater. Ark'a Modulam is expected to be an alternative foundation for an amphibious house which is a water-based house that combines two other types of water-based houses, namely stilts houses and floating houses. To create the amphibious house with Ark'a Modulam, the foundation is arranged in a grid with a module of 3x3 meters, so that

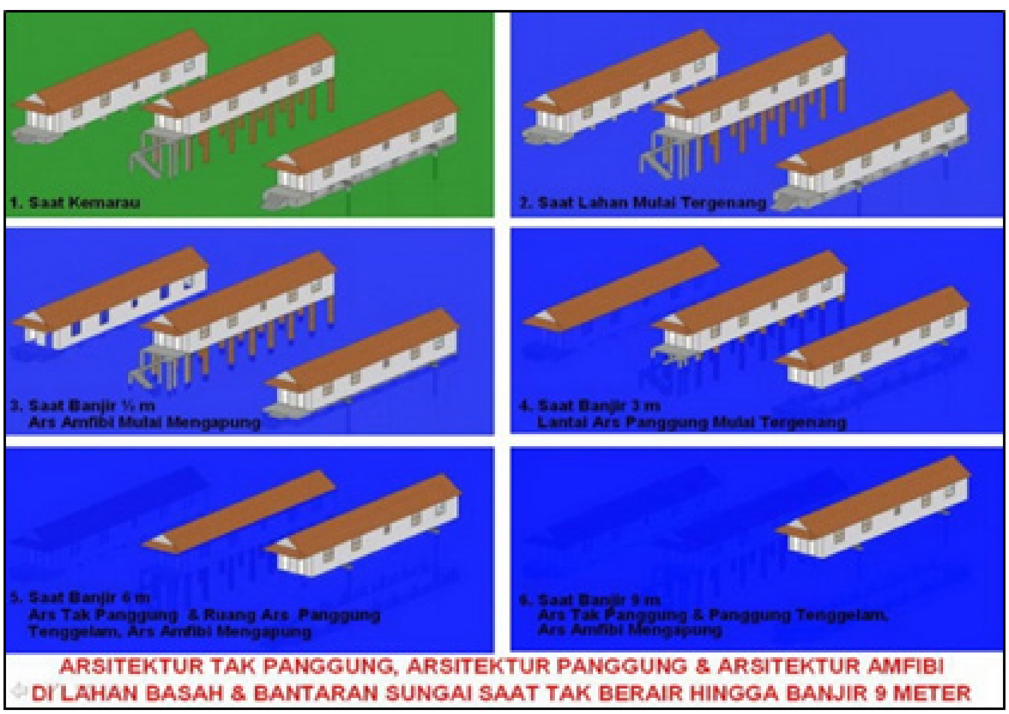

Figure 14. The comparison of stepped house, stilts house, and amphibious house when flood reaches 9 meters.

the distance between the main poles of the foundation is 3 meters (Figure 13).

When compared to the stilts house which are basically water-based houses, the amphibious house will follow upward by floating rather than the stilts house (Figure 14). If the water gets higher, the amphibious house tends to remain free of flooding, while the stilts house is likely to be flooded, because the height is fixed and static. Since the house has a vertical stationary nature unlike amphibious houses, it needs to set higher poles to adapt to the height of the floodwater which is getting higher by first dismantling part or all of the house as happened in Palangka Raya today. While amphibious houses does not need to adapt to the height of floodwater which is getting higher but only increase the height of the vertical driving poles construction. Thus, to adapt to the height of floodwater which is increasingly high, residents of amphibious houses can still stay at home without disruption when the vertical driving pole construction is added.

According to the observations of floating houses in Palangka Raya and some literatures in relation to buoyancy when floating, it is known that on average the floating construction that is submerged is around 40-70% of the height of the floating structure or floating material. Figure 6 has loading weight on the floating construction (with 4 plastic drums @ 200 liters). In order the floating construction that submerged is not more that 70%, the weight of the building (plus the weight of the floating foundation frame) for one foundation should not be more than 568 kg. For the amphibious house where the house will be filled with household furniture that also causes weight, therefore the weight of home furniture also needs to be a component in determining amphibious home planning. Space planning along with their furniture that produces a balance of mass, of course will also determine the success of creating flood resilient settlements with the foundation of the modular ark type Alt. 3 pattern A - 2.1.

5. Conclusion

The results of the floatation experiment of Ark'a Modulam type Alt. 3 pattern A - 2.1 with 200 liter plastic drum floating material is still the starting point of experiments. Based on the results of the experiment type Alt. 3 pattern A - 2.1, shows that the construction of the foundation may be used as an alternative to create amphibious houses. However, comparing the load of the construction and the buoyancy needs to be carefully calculated so that when flood attacts, the house can float. In addition, the calculations of the constructive power of the vertical driving poles and the foundation construction also need to be carried out carefully, so that when floating the vertical driving pole is able to hold the house horizontally, and when not floating the construction is able to withstand the house mass. Thus, the foundation type Alt.3 pattern A - 2.1 which is the development of the Ark'a Modulam foundation is considered applicable to use to create amphibious architecture in urban floodplains in Kalimantan, especially to create a simple residence in amphibious architecture concept.

Amphibious Architecture is a water-based architecture alternative that designed to adapt to flooding and sea level rise. While Ark'a Modulam is an alternative foundation to create amphibious architecture. Since it is an alternative, there might also be other alternatives to create amphibious architecture. It is hopefully that this paper will be useful to create other amphibious foundations so that innovations in amphibian architectural design will emerge that can adapt to flood and sea level rise that are now attacking urban downstream areas.

6. Acknowledgement

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