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The Design, Construction and Evaluation of a Pilot Project of a Bahay Kubo Inspired Floating Home

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Abstract In the overpopulated deltas of the Philippines people live in are-as that see floods regularly. The floods are being caused by a com-bination of tides, heavy rainfall and land subsidence. The demand for safe and affordable housing is immense, yet available dry land is scarce. By implementing floating homes in vacant former rice fields, demanded new building space is becoming available. To come to a sustainable design that fits in the Pampanga Delta, traditional building designs as the Bahay Kubo have been analysed. Many aspects of this design correspond with modern sustainable development goals. By means of parametric building simulations, key aspects of the Bahay Kubo have been used to provide the home with good performances in indoor climate and structural behavior. Now the first pilot building has been built, the home is being tested for validating the parametric models and to evaluate the building design. The first round of test results has led to proper insights in indoor climate, user friendliness, and affordability. Initial design improvements have been made and will be used in upcoming developments such as the construction of a floating neighborhood and the construction of floating classrooms.

Keywords Floating architecture · Flood events · Vernacular · Pilot building · Affordability

1 The Pampanga Delta

The situation in coastal areas of the Pampanga Delta in the northern part of the Manila Bay Area in the Philippines resembles many urbanized areas of Southeast Asia. Analysing the housing situation, and generating and evaluating implementable designs of housing types can thus be translated to other regions that are dealing with similar problems [1].

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The housing situation in the provinces Pampanga and Bulacan is highly affected by floods which are mainly the result of incoming seawater by tidal movement and by overflow of rivers after heavy rainfall. A worsening trend in these floods is detected. Worsening trends are caused by a combination of channel filling by sediments from floods and lahars, deforestation, rapid urbanisation, channel encroachment and sea level rise. Moreover, nowadays the main impact on these worsening trends is ground subsidence [2, 3]. Groundwater overuse causes land around northern Manila Bay to subside with a subsidence rate of around 5 cm per year. This land sinks relatively fast since extraction rates are higher than recharge rates. Rapid urbanisation has a big impact since it causes an increasing demand for groundwater. Land subsidence occurs all over large urbanized parts in Southeast Asia (Fig. 1) [4].

Where growing rice on rice fields was once one of the biggest sources of income, it is nowadays no longer possible due to salinization and high water levels. For this reason, over the last decades many rice fields have been transformed into fish ponds. Due to the increase in flood events, fish ponds overflow regularly. As a consequence, many of the fish ponds have been abandoned, and thereby large flooded areas currently don't have any spatial function anymore [1] (Fig. 2).

1.1 Housing Situation in the Pampanga Delta

Another phenomenon that affects the housing situation in Bulacan and Pampanga is rapid urbanization. In the following 30 years, more than 60% of the world's population is expected be found in cities and urban areas. This fast and often unplanned development results in serious problems due to scarcity of land, congestion and poverty. The current deficits in housing are in the low cost sectors and the housing

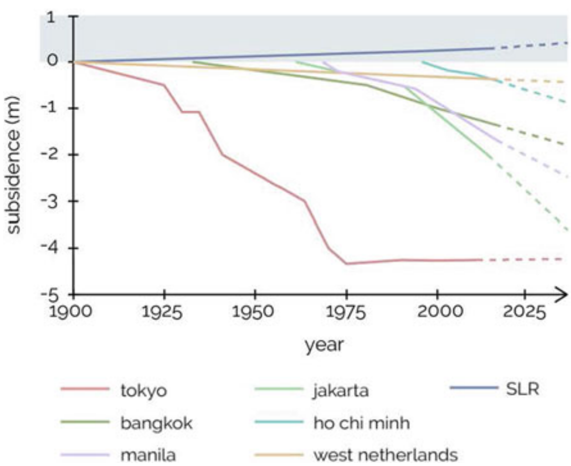

Fig. 1 Ground subsidence in Southeast Asian cities [4] (adjusted by author)

Fig. 2 Flooded streets and ground subsidence in the Pampanga delta

backlog has been estimated to will have reached over 10 million units in the Philippines in 2030 [5]. This rapid urbanization not only occurs in Metro Manilla. Also smaller settlements in the Manila Bay Area, like the previous described coastal areas, face this problem.

Figure 3 shows the municipality of Hagonoy in the province of Bulacan. Settlements are developed along the riverside. The river was of high importance for daily life of people, since it was used for transportation, fishing industry and sewage system. People settled in family owned compounds along those rivers. Over multiple generations this family-owned land has been divided over multiple family members, who built their houses on these plots. Due to this rapid urbanization, these areas are now fully occupied with buildings. Expansions to areas further away from the city are not possible (anymore), since these areas are permanently exposed to flooding [1].

A negative side effect is that squatters settle themselves in self-built structures above the river. These informal settlements obstruct the waterways, which results in an increase of the flood risk. Furthermore these provisionally built structures are often highly vulnerable for typhoons. Due to an increase in intensity of typhoons in the near future these structures will become even more insecure to inhabit [6].

Fig. 3 Hagonoy (Bulacan). Settlements along the riverside

This combination of scarcity of buildable land, a relatively large housing backlog, an increase in flood events and an increase in typhoon intensities, creates an enormous demand for safe, sustainable and affordable housing.

2 Analyses of Vernacular Architecture

An answer to developing these safe, sustainable and affordable houses that are suitable for the Pampanga Delta area can be found by analysing vernacular building types. Vernacular buildings are ancient buildings which are not designed or built by formally-schooled architects and engineers. They rely on designs, skills, craftsmanship and traditions of local builders [1].

2.1 The Bahay Kubo

The Bahay Kubo (which literally means cube house) is a Philippine building type of which its architectural principles were created in the pre-colonial era. This ancient building type provides a practical template for designing sustainable, climate-conscious, energy-efficient houses and buildings. As most vernacular architecture in the Southeast Asian regions, the Bahay Kubo is built from low-cost, readily and locally available materials—in this case, mostly bamboo and nipa leaves. The Bahay Kubo is specifically designed for a tropical climate and this is reflected in multiple design principles like a tall pitched roof, large roof overhangs, wooden stilts and large openings in the facades [1].

Nowadays the Bahay Kubo has disappeared from the streets and a more foreign Western-style architecture model has been adopted. These homes mainly consist of a combination of concrete and corrugated steel plates. In contrast to the Bahay Kubo, these contemporary buildings need air conditioning to create a comfortable indoor climate, which entails relatively high costs for homeowners. Because of these relatively high energy costs and growing environmental awareness, many of today's designers and engineers re-examine the design principles of the Bahay Kubo and its approach to the contemporary design challenges in a simple way.

2.2 Parametric Analyses

Main vernacular design-strategies of the Bahay Kubo are a hipped roof, large roof overhangs, (wooden) stilts, and large openings in the facades [7]. The common goals of these design strategies are to create a comfortable indoor environmental quality by enhancing natural ventilation and by protecting the building from direct sunlight. By means of parametric analyses of these four design principles, four main 'lessons learnt from the Bahay Kubo' have been created.

First, it is essential to create sufficient openings in the facades to increase indoor thermal comfort by an increase of air velocity. By creating large openings in the façade from the ground floor up to 0.85 times the façade-height, a significant increase in thermal comfort level can be gained [7].

Secondly, by creating large overhangs an increase in comfort level can be gained. Large overhangs or eaves influence thermal comfort by creating an increase in air velocity and a decrease in radiant temperature. Eave lengths of 0.6 times the floor height under an angle of 15° are giving a proper protection against direct sunlight and thus a significant increase in thermal comfort level [7].

Thirdly, placing the building on stilts influences the thermal comfort level in a positive way. By increasing in stilt height, the wind speed for natural ventilation increases with an exponential decay. An optimum of the height of the stilts mainly depends on costs and local flood levels [7].

Finally, a hipped shaped roof influences the comfort level positively. By increasing the angle of the roof, an increase in comfort level can be gained, since it allows heat to dissipate and it lowers the area subjected to solar radiation. As well by adding openings in the roof, buoyancy driven ventilation can be enhanced. Furthermore, a hipped roof improves the water drainage. An angle close to 30° is advised to decrease wind pressures during strong winds [7] (Fig. 4).

3 The Design and Construction of the Pilot Building

These lessons from analyzing the Baha Kubo need to be translated to current situations in order to come to a buildable design. In this paragraph these translations and the design of the pilot building are described.

3.1 Pilot Building Design

First, building on stilts has been a proper solution for enhancing natural ventilation and for protection against floods. However, due to increasing land subsidence, and thus increased and more severe flood events, stilts become less advantageous. Furthermore, available land in the coastal areas of Bulacan and Pampanga to build the demanded new homes is nowadays scarce. A solution for this lack of available space may come from the previously described vacant former fish ponds and rice fields. By implementing floating structures or floating homes in these areas, there will be new space available. Another side effect is that people do not have to move to places far away from family or work, since these vacant fish ponds and former rice fields are located close to currently built settlements. Furthermore, these

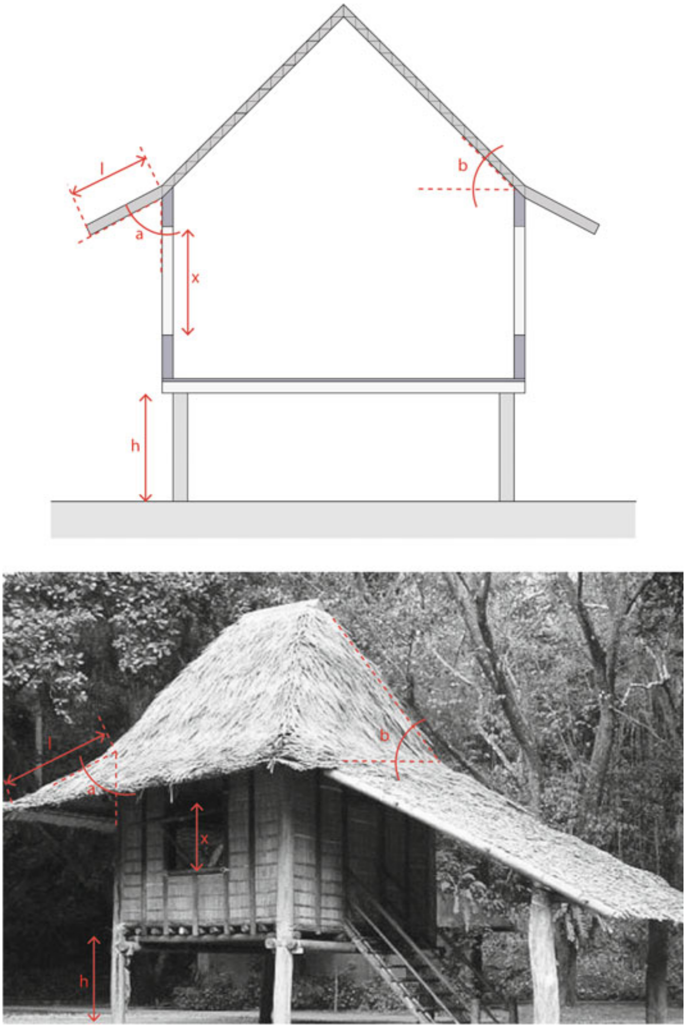

Fig. 4 Vernacular design principles of the Bahay Kubo

floating houses can provide a dry and safe place for living without being vulnerable for daily floods [1].

By constructing locally prefabricated modules of locally available renewable materials and recyclable materials a floating foundation can be built. By prefabrication, the production can take place in controlled and dry climate conditions, without the impact of floods. This has a positive influence on the quality of the building and can reduce building costs [8]. A number of parameters are important for the design of the floating foundation. Due to the lack of heavy machinery and a construction site that is relatively hard to access, it is important that the floating foundation consists of light weight building modules that can be carried and transported by hand. By simply connecting these modules on the water, a stiff and stable floating platform can be created. The intended material must be locally available and, of course, as sustainable and affordable as possible. By making use local, renewable and recyclable products, both the CO_2 emission and the costs can be kept as low as possible. The floating foundation consists of nine timber modules filled with recycled plastic barrels. By predicting the depth, and tilting behaviour, it is possible to create a structure in a way that the timber elements in every load case remain above the water level. Upon this floating foundation, prefabricated panels can be installed and can be connected to each other. Like the lessons learnt from the Bahay Kubo these panels can be opened to create a naturally ventilated indoor climate [1] (Fig. 5).

On top of the wall panels, a prefabricated hipped roof can be placed. The shape of the roof can be copied directly from the Bahay Kubo. However, large eaves will form a weak part of the structure during strong winds. Typhoon resiliency becomes more important, since intensities of typhoons are increasing. Openings in the roof enhance natural ventilation and natural light. In case of typhoons they can be closed. Eaves that protect the building from direct sunlight and from monsoon rains can be folded inwards. Since the building is totally made of locally produced and locally available prefabricated building parts, it can easily be repaired with new elements in case of damages by typhoons.

A first pilot home of this design has been built in Macabebe (Pampanga) on a vacant former rice field (Figs. 6 and 7).

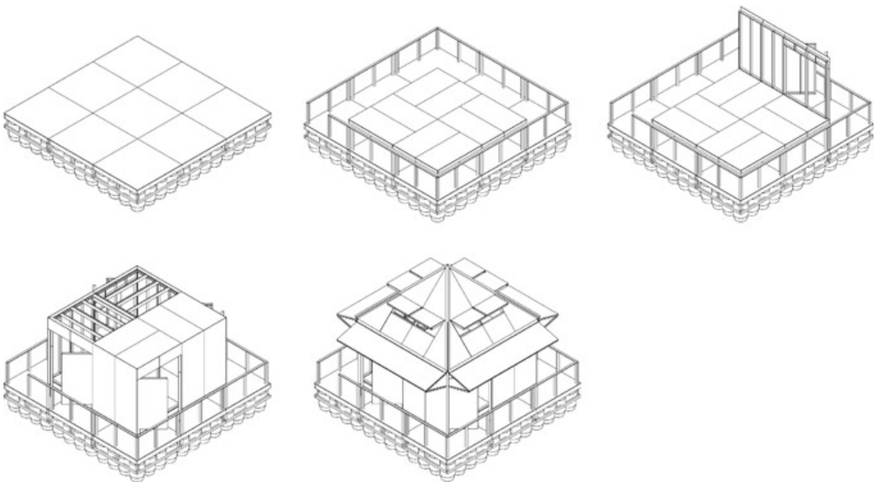

Fig. 5 Design of the locally prefabricated floating pilot home

Fig. 6 Floating foundation modules

Fig. 7 The pilot home on a former rice field in Macabebe (Pampanga)

4 Evaluation of the Pilot Building

Within this pilot project, the floating home is evaluated in multiple ways. The technical performance is evaluated by monitoring the indoor environmental quality. The user experience has been evaluated by multiple families who have lived in the pilot house.

In this paper, key lessons that follow from the evaluation of the pilot building are elaborated and potential design improvements are generated.

4.1 Evaluation of Indoor Environmental Quality

The main parameters that determine the indoor environmental quality are thermal quality (comfort), air quality, sound quality, lighting quality, ergonomics and cleanliness. As the house is located in a tropical climate and the main goal is to provide a comfortable indoor quality without using artificial air-conditioning, thermal comfort is given priority in this study.

To evaluate the thermal comfort level, it has been measured how the indoor temperature relates to a certain thermal comfort range. For this comfort range, the ASHRAE adaptive comfort model for the Manila region is used. The temperature is considered as acceptable when it is between a lower comfort limit of 22.3 °C and an upper comfort limit of 30.5 °C. By also taking natural ventilation into account, comfort limits increase with a number that depends on the wind speed [9].

To monitor the thermal comfort level, the following parameters are measured:

- Dry-bulb temperature measured with HOBO U12-012 data logger and IoT Monitoring Devices
- Operative temperature measured with HOBO U12-012 data logger and IoT Monitoring Devices
- Surface temperature measured with Thermochron I-button
- Relative humidity measured with HOBO U12-012 data logger and IoT Monitoring Devices Air velocity measured with Extech SDL350 hotwire anemometer.

The measured results show that the comfort performance of the building is satisfactory for most of the time, except for the attic floor. During the hottest days the attic floor exceeds the upper comfort level with relatively high numbers. From the in situ measurements it can also be seen that the air velocity is relatively low in the attic compared to the other spaces in the house. Figure 8 shows the dry bulb temperature in multiple zones in the home. As well the upper comfort limit for each zone is shown [9].

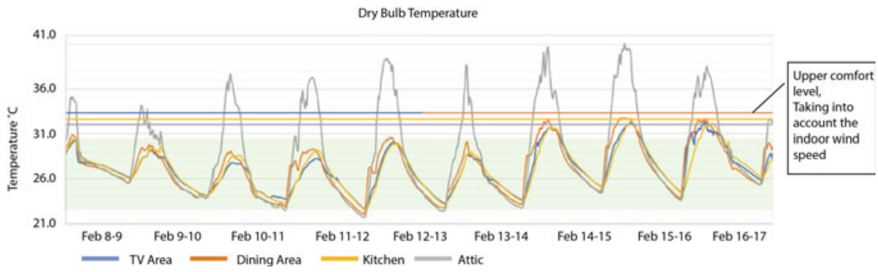

Fig. 8 Dry bulb temperature in each zone of the pilot home [9]

4.2 User Experience

Besides the indoor environmental quality, the user experience is an important aspect for evaluating the floating pilot home. A first test round in which a family of 4 people has inhabited the floating home for a time period of 5 months has been completed. Through semi structured interviews, with open ended questions main topics of the benefits and main topics of improvements of this floating home have emerged.

The first residents of the floating home stated that they prefer living in this home over living in their current house. The main reason for this statement is that unlike their own home situation, this home stays dry during flood events. The interviews also substantiate the comfortable indoor temperature, since the residents describe the indoor climate as cool and comfortable with a pleasant airflow through the building. Other benefits of the floating pilot home are mainly in terms of ambiance, view and material use.

In addition to these advantages, there are also a number of points for improvements. The first residents have been interviewed about how they experienced possible motions of the floating home. Residents indicate that motions can be felt with two different causes. The first of these is wind induced movements. Strong tropical storms cause roll, pitch and sway motions. Sway motions have been limited by increasing the stiffness of the bamboo mooring system, by adding bamboo diagonals.

Secondly, movements of people on the floating foundation cause roll and pitch motions. The resident indicates that both people induced and wind induced movements were noticeable, but that they never made the resident feel unsafe. For further research, it is advised to monitor the motions of the floating home.

Other points for improvements are the design of the sleeping zone in the attic and in the design of the openings.

4.3 Lessons Learnt for Further Developments

From the results of monitoring the thermal comfort of the pilot house it can be stated that the comfort performance of the attic space needs to be improved. To achieve this, a number of design improvements have been proposed. Climate models show that with these measures a desired temperature can be achieved in every room in the home.

Solar heat gain can be reduced by lowering the attic to the height of the ground floor door frame and hence the attic is protected by the foldable eaves.

The air velocity in the attic can be increased by adding extra openings at the bottom level of the attic zone.

Heat dissipation can be improved by providing openings at the top of the roof.

Air velocity can be better controlled by providing operable louvers incorporating principles of so-called Dutch door and collapsible doors [9].

For future projects, it is advisable to build configurations of multiple interlinked floating homes. The floating platform hereby widens, which increases the stability of the floating object. The house will be less sensitive to wind and movements of people. Since the foundation consists of a modular system, it is relatively simple to expand the floating foundation without changing the design.

It is advised to include these lessons in the development of upcoming floating projects such as envisioned floating neighborhoods and floating schools (Figs. 9, 10 and 11).

Fig. 9 Proposed design improvements [9]

Fig. 10 Floating classroom design

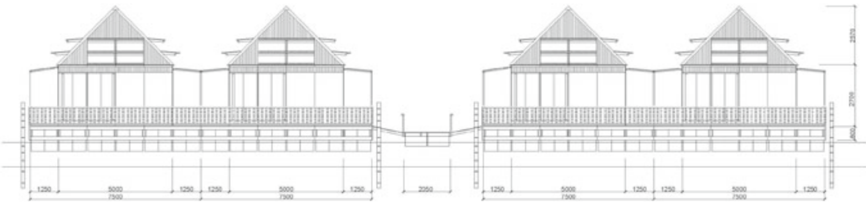

Fig. 11 Configuration of connected floating homes

5 Conclusions

Analysing vernacular design principles offers a rich repertoire of architectural and engineering knowledge in the field of design, innovations, and low-tech techniques. It can be an useful tool to use these old-age low-tech techniques for contemporary design challenges. By translating these vernacular principles to design, energy efficient buildings can be created, that are perfectly suited for their location. By testing this design with a pilot project, these vernacular design strategies are evaluated. In the pilot home a comfortable indoor climate has been created, however there is room for improvement in the attic floor. For following projects it is advisable to place more openings in the facades and to create openings in a way that heat can dissipate from the rooftop.

Connecting several floating homes together makes the floating platform more stable and less susceptible to wind and movements of people.

By incorporating the lessons from the pilot project in upcoming floating developments, a better contribution can be made to improving living conditions for residents of flood prone areas such as the Pampanga delta.

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