A Proposed Design of Floating House by Utilizing Buoyant Foundation: An Alternative Flood Resilient Housing in Masantol, Pampanga

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Abstract: - Due to its geographical location, Barangay Sta. Lucia Paguiaba in the Municipality of Masantol, Province of Pampanga (Philippines) experiences constant flooding throughout the year, severely damaging the infrastructure and creating problems for the locals. Using the Archimedes' Principle of Buoyancy, this research's primary goal is to address the town's flooding issues by proposing a floating house design as an alternative flood resilient housing. Three (3) sources of flooding in the said town make it vulnerable, especially during monsoon season. Due to this situation, a floating house with a dimension of 9mx9mx4m is designed with a mechanism which allows the house to float as the water level rises and sit on the ground in normal circumstances. Expanded polystyrene (EPS) is used in the foundation of the house as a floater, and it is attached to four vertical guidance posts and secured with pile guides to reduce its movement with the flood. Timber is used for the structural frames and other architectural components. The analysis of the floating house's structural members is done using the STAAD software. In the end, the floating house's estimated cost is also presented.

Key Words: — *Floating House, Resilient Housing, Buoyant Foundation.*

I. INTRODUCTION

The Philippines is one of the countries lying along the typhoon belt in the Pacific. It averages 20 typhoons per year, five of which have disastrous effects. It is extremely vulnerable to drought, landslides, flood/flash flood/flooding, tsunamis, sea level rise, storm surges, and other natural disasters because of its geographic location and physical environment (Asian Disaster Reduction Center, 2019). Flooding has a number of serious impacts, including loss of life, devastation of property, loss of crops and livestock, and impairment of health from illnesses caused by water. According to the Associated Programme on Flood Management (2013), communication lines and infrastructure, like power plants, highways, and bridges, are damaged and disrupted, which can result in certain economic operations ceasing, people being forced to leave their homes, and ordinary life being affected. Continuous stress can be brought on by losing property, being evicted from one's home, and having job and social plans interfered with.

In the modern era, researchers are exerting every effort to use technologies and innovation to overcome the impending natural disasters that our environment brings. People in our society concentrate on enhancing drainage systems, because they believe that an artificial channel built to reduce excessive water flow, especially during flooding, by transferring some of the water's flow to a lake or the sea is the only solution to a problem with infrequent water rise. However, the risk is not eliminated by flood control structures. If the design water levels are

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exceeded, flooding may still occur. These structures can enhance danger by creating a false sense of security and promoting settlements or economic activity in risky places if they are improperly designed, built, operated, or maintained (USAID, 2012). In addition, the usage of floating systems could also be an alternative to these flood control measures, aside from improving the drainage channels.

According to Ishaque et al., (2014), the floating home is a distinctive way of living on a buoyant platform without the worry of sinking and staying afloat with the highs and lows associated with the level of the water. It is a real home built to float. These kinds of homes were developed to eliminate the weakening and costly damage caused by floodwaters entering lowland areas around the world.

In geographic terms, a lowland is an area where the land is near or below sea level. According to the National Nutrition Council (2015), the most massive contiguous lowland in the Philippine Archipelago is Central Luzon, which makes up 7.1 percent of the nation's total land area with a total mass of 1.8 million square meters. The Pampanga River Basin is situated in Central Luzon's eastern region. According to the economic activity of the Philippines, it is regarded as one of the most significant river basins. According to Shrestha (2014), at least one flood event occurs in the aforementioned basin on a yearly average. Agriculture and homes in the affected area were damaged by extremely severe and catastrophic flooding in the river basin. That being said, one municipality in Pampanga, located at the delta part of the Pampanga River, has most of its barangays suffering from constant flooding even during the dry season when the tide level is high. As reported by Orejas (2022), residents experience up to two feet of flooding during high tide and rise to four feet during the rainy season that intrudes on properties and affects people's daily lives. In view of the foregoing, this research paper sought to develop a floating house design as an alternative solution to the consistent flooding in Barangay Santa Lucia Paguiaba, Masantol, Pampanga.

II. Methodology

The following pages of the study described the methodology used by the researchers. The researchers opted to use a mixed method design of research. According to George (2021), mixed methods research combines quantitative and qualitative research. As this type of research integrates the benefits of both methods, researchers can gain a more comprehensive picture than a standalone quantitative or qualitative study. The researchers chose this approach to propose a solution in Masantol, Pampanga, that can adopt a design for a flood-resilient house through Buoyant Foundation.

To be specific, the researchers used the Explanatory Design type of mixed methods design, which according to Rice and Galbraith (2008), is a mixed method design that has two phases, starting with the quantitative phase and then followed by the qualitative phase of the study. As this design begins in its quantitative phase, greater emphasis is on the quantitative methods than the qualitative methods by the researchers.

The researchers gathered flood data from the Municipal Disaster Risk Reduction and Management Office (MDRRMO) of Masantol, Pampanga. The data collected are the flood and high tide data recorded in the years 2021 and 2022, specifically the recorded maximum height of flood experienced by the town during monsoon season and high tides. Furthermore, secondary data was also collected from different news articles to support the flood data that the municipality provided.

There are no hard and fast rules on how many people you need to include in your research, but depending on your research kind and research question, some researchers believe that between 10 and 50 participants is sufficient (Creswell & Creswell, 2018). In line with this, the researchers interviewed with the Municipal Engineer of Masantol and some of the residents in Barangay Santa Lucia Paguiaba to collect further information regarding the flood situation in the municipality.

The software used for analyzing the data is Microsoft Excel. This is to determine the maximum height of flood that has occurred in the said municipality. Moreover, Structural Analysis Design (STAAD) Pro software was used for analyzing and designing the structure of the floating house. Nonetheless, the researchers computed the loads, both live and dead, to determine the buoyant force and ascertain the effectivity of the floater and the capacity to get the factor safety.

III. Results and Discussions

3.1 Flood and High Tide Data

The collected flood data for the years 2021 and 2022 in Barangay Santa Lucia Paguiaba, Masantol, Pampanga are as follows:

Table.1. Flood and High Tide Data

Year	Maximum Flood Level	Maximum High Tide Level
2021	2.5 ft	4.9 ft
2022	3.0 ft	5.2 ft

In 2021, the recorded maximum flood level at Santa Lucia Paguiaba, Masantol, Pampanga is 2.5 ft. In comparison, the maximum high tide level from the same year is 4.9 ft. In 2022, the maximum flood level from the said barangay was recorded to be at 3.0 ft. In contrast, the maximum high tide level is 5.2 ft.

3.1.1 Statements of the Residents

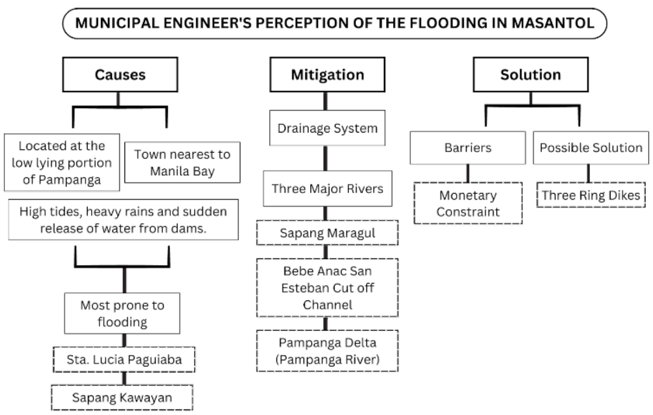

Fig.1. Municipal Engineer Summary of Interview

a. Causes

Masantol's residents face flooding every day. Thus, it appears that it has become a common occurrence there. The municipal engineer stated the primary cause of the problem is its geographic location, *"Masantol is located in Pampanga's low-lying region. Aside from Macabebe and Hagonoy, Bulacan, in the southern part, this town is the lowest and nearest to Manila Bay. Masantol is at the very end of the Pampanga River. Since the Pampanga River receives all the water from the northern portion, such as Nueva Ecijia, it floods practically all of our barangay when water exceeds over our dikes, especially during the rainy season"*. Aside from that, he also enumerated other sources of flood, "We have three sources of flooding in Masantol: high tide, heavy rains, and then sudden release of water in dams." The municipal engineer also recalled an instance where the Angat Dam would release water unexpectedly. *"Calumpit is flooded to a height of around (3) meters, or roughly equivalent to almost one storey of a building, wait for an hour, and the flood has already reached the left bank of Masantol."*.

All of the barangays in the town get flooded, especially those along the river banks that are not protected with their dikes. The situation of the barangay that is most susceptible to flooding in Masantol's southern portion was described by the municipal engineer, "Barangay Sapang Kawayan, which is close to the sea and actually faces Manila Bay, is the most vulnerable to floods and is also highly dangerous, especially when there is a tsunami or a storm surge." Another barangay in the northern portion of Masantol, which he noted as being prone to flooding, "In Barangay Santa Lucia Paguiaba, their roads begin to flood at noon. Flood rises to a height of 3 to 4 feet during high tide and decreases during low tide. Unless there is a sudden release of water at the Angat Dam, which has happened before and reached the height of the flood up to one storey. When it floods, the water is not usually rough because of the mangroves preventing the waves.".

b. Mitigation

Despite having a drainage system and other flood prevention measures, flooding still occurs every day, *"When it comes to drainage systems, we have three (3) major rivers: the Sapang Maragul, the Bebe Anac San Esteban Cut-off Channel, and the Pampanga Delta - which is the Pampanga River. All of these rivers are connected to Manila Bay."* Having these rivers as the drain is still not enough. As the municipal engineer stated, *"Every flood from upstream travels through this town because it is at the end and closest to Manila Bay. The flood produced upstream will be caught by Masantol. This town isn't even a meter above sea level by now."* However, the municipal engineer stated that the municipality has plans to prevent floods, *"We currently have plans to upgrade roads and maintain the check gauges because that is all we are able to do with the municipality's 20% Development Fund."*.

c. Solution

In addition to the current plans of the municipality, the municipal engineer stated that they are in full support of research studies such as the one conducted by JICA (Korean funded) to construct ring dikes, *"It is to be built where the residences are concentrated to protect merely the residences and not the livelihood of the people (fishponds). The proposal is three (3) ring dikes for Masantol and one (1) ring dike with pumping station in Macabebe. The municipalities are requesting to have just one ring dike that covers the whole Masantol and Macabebe instead. There will only be small areas that cannot be covered if ever. But they claimed that our request would cost significantly more money."*

The municipal engineer also pointed out that, *"The hindrance when it comes to solving the problem is monetary constraint. Masantol will continue to experience flooding, but if a ring dike is built, we will be safe. Masantol is protected, but what about the areas beyond the dike? Now, water will reach* *those locations. This project will cost hundreds of millions and maybe as much as 500 million. The government will pay for the affected lots and residences, so if the ring dike we're building is particularly long, a significant sum of money will be required."* In addition, they welcome individuals to exchange knowledge about flood mitigation, in particular the ring dike, including the amount to be allocated and how to go about doing it. Then, just in case, they invited the DPWH to help ensure that the Korean Company's study would be supported later.

A Non-Government Organization gave the town two floating evacuation centers. The floating mechanism is made of plastic drums and the top is made of lightweight materials. However, the municipal engineer pointed out that, *"The others don't want to stay there because they say the rope might be cut while they are sleeping and they might end up in Manila Bay."*.

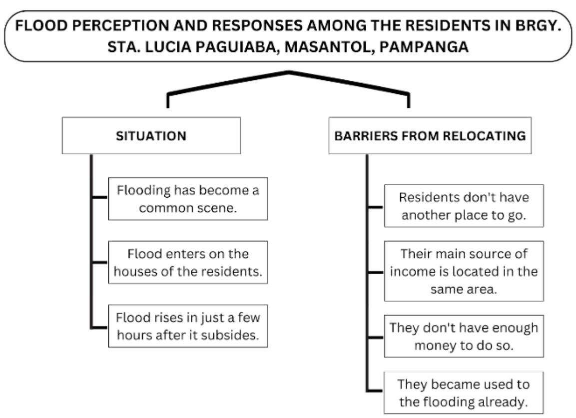

Fig.2. Residents Summary of Interview

The researchers interviewed ten (10) Barangay Santa Lucia Paguiaba, Masantol, Pampanga residents. Most of the participants have been residing there since birth and are thus able to share their experiences with the problem in their area.

a. Situation

The participants claimed that almost every day there is flooding in Barangay Santa Lucia Paguiaba. The barangay is next to a river; therefore, they frequently suffer high tide. When there are strong rains, the flood gets worse. The participants said that the water rises to their knees or even higher in this case. Moreover, since they cannot get back to their regular activities, others struggle at these times. Some participants also mentioned that they were asked to evacuate because water had entered their homes, but they did not want to leave their homes and possessions.

b. Barriers from Relocating

Despite the continuing struggles in Barangay Santa Lucia Paguiaba, according to the participants, they are unable to leave their homes because they have no other options, some do not have anywhere else to go, and others lack enough money to rent a place. One participant claimed that since the residents were not leaving their homes, it was to her advantage to sell since she owned a store.

c. Locals' Views of the Floating House

The participants were asked how many people lived in their homes. A participant mentioned that she stays home by herself. While some participants only have three (3) people living in their homes, another participant said they have five (5) people living in their houses.

The researchers asked them whether they would prefer to live in a floating house if it were made available to them as an alternative flood-resilient home. Nine out of ten participants said they would consider moving into a floating house as long as it is safe and livable. Furthermore, they do not particularly care how the floating house looks as long as it is cozy and secure. Some participants agreed that the floating house should, at the very least, include a bedroom, living room, bathroom, and kitchen.

3.2 Materials: Architectural and Structural

The following list (see Table 3 and Table 4) consists of the primary materials in the construction of a floating house unit with consideration to be the lightest as possible without sacrificing the necessity and compromising the structural integrity of the unit:

Table.2. Architectural Materials

ARCHITECTURAL	
MATERIAL	**DESCRIPTION**
Roof	Galvanized Corrugated Sheet
Wall	Gypsum Board
Ceiling	Gypsum Board
Windows	Regular Glass
Floor	Hardwood Board
	Marine Plywood

Table.3. Structural Materials

STRUCTURAL	
MATERIAL	**DESCRIPTION**
Timber Frame	Columns 100x150 mm
	Joist 50x100 mm
	Studs 50x75 mm
	Truss Edges 100x200 mm
	Studs 50x75 mm
Floater	EPS Foam
Pile Guide w/ Roller	Galvanized w/ Rubber Rollers
Vertical Guidance Post	Galvanized Steel Pipe
Isolated Footing	Reinforced Concrete

3.3 Considerable Incoming Loads in the House

The following unit weights shown below are based on NSCP 2015 Table 204-2 and Table 205-1.

Table.4. Considerable Incoming Loads

MATERIALS	DESCRIPTION	UNIT WT
ARCHITECTURAL		
Exterior Walls	50 x 100 @ 400mm, 15mm gypsum, insulated, 10mm siding	0.53 KPa
Interior Walls	Wood or steel studs, 13mm gypsum board each side	0.38 KPa
Ceiling	Suspended metal lath and gypsum plaster	0.48 KPa
Roof	Galvanized Corrugated Sheet	0.72 KPa
Floor	Hardwood Board	0.22 KPa
	¾" Marine Plywood	0.22 KPa
STRUCTURAL		
Structural Framing, Truss and Joist (GLT-30F-E2-SP/SP)	Glue Laminated Timber	3.71 kN/m
Floater	EPS Foam	0.128 kN/m^3

USE OR OCCUPANCY		
CATEGORY	**DESCRIPTION**	**UNIFORM LOAD**
Residential	Basic Floor Area	1.9 KPa
Total Dead Load (from STAAD)		**187 kN**
Total Live Load		**122 kN**
TOTAL FACTORED LOAD		**309 kN**

3.4 Capacity of the Floater

The weight of the floater is equal to 13 kilograms with a thickness of 1 meter considering a cubic meter of the floater for analysis. The calculated results for the capacity of floater are the following: the unit weight of EPS is 0.128 kN/m^3, the weight of the structure has a total of 309 kN, the weight of the object (styrofoam) is 8.192 kN. The submerged height is 0.49 meter, and the accumulated weight with 0.9 meter assumed safe submerged height of the floater for the maximum capacity is equal to 556.864 kN.

Hence, the submerged height that is 0.49 meter is less than the total height of the styrofoam that is 1 meter. The floater with a thickness of 1 meter can accommodate up to 556.864 kN which makes it greater than the total weight of the structure with the value of 309 kN. Therefore, it is safe.

3.5 Foundation for Vertical Guidance Post

3.5.1 Isolated Footing Design

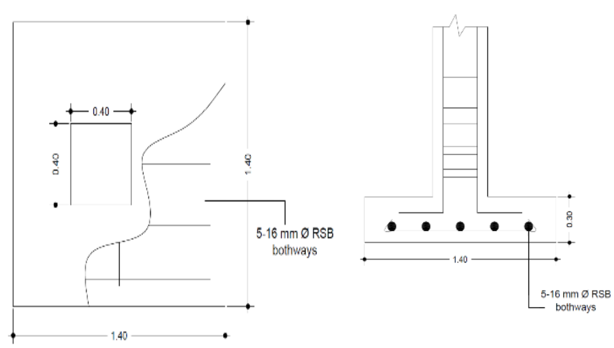

Fig.3. Structural Detailing of the Footing

As shown in Figure 3, the researchers used 1.4 meters by 1.4 meters footing with a total depth of 0.3 meters safe against overturning moment and is adequate against wide beam shear and punching shear, with 5 pcs 16mm-diameter bars both ways.

3.5.2 Reinforced Concrete Column

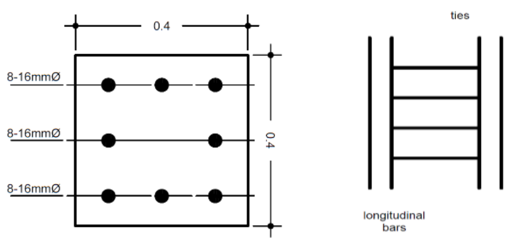

Fig.4. Structural Detailing of the Column Pedestal

As shown in Figure 4, the researchers used 400mm x 400mm column pedestal with 8pcs -16mm⌀ reinforcement and uses 250mm spacing in ties.

3.5.3 Base Plate and Anchor Bolts Design

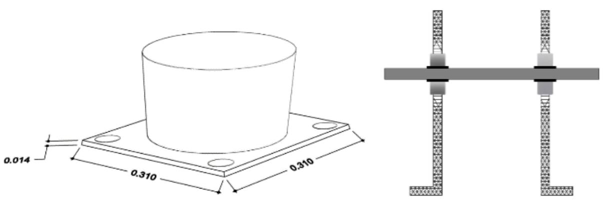

Fig.5. Base Plate and Anchor Bolts Design

The design of the base plate used (see Figure 5) was 310mm by 310mm, has a thickness of 14mm, and is fastened to the concrete pedestal with anchor bolts that are 4-16mm in diameter.

3.6 Projected Cost

The researchers considered the suitable materials primarily used by the residents of Masantol, Pampanga who are open to utilizing an alternative way of housing. Additionally, the architectural and structural analysis data will be exerted to determine the amount of floating house materials required. Furthermore, this computation process was based on a book entitled “Simplified Estimate by Max Fajardo”. The prices of the materials are pulled out from the Philippine Construction and Materials Prices and the local hardware stores. To put the price clearly, a floating house that measures 9 meters wide and 4 meters high will cost roughly 595,750.284 pesos in materials and 234,243.809 pesos in labor costs, for a total estimated cost of 829,994.093 pesos.

A report carried out by Generalao (2017), the National Economic Development Authority defined economic housing as a type of housing that falls under the affordability level that includes low-income earners. Economic housing is the new way to promote economical and resilient development to cities, suburbs, and towns. It is designed to provide comfort while considering the environment and cost. Moreover, it promotes a stabilized, vibrant, and resilient society that is more equipped to adapt throughout time from a social, economic, and environmental perspective. In this case, All Properties (2022) points out that economic housing classified as affordable falls between P450,000 and P1.7 million price range where lower income groups are captured. These homes are often the box kind, with one bathroom, one toilet, and the potential owner is free to upgrade the furnishings (HUDCC, n.d.). These would show that the estimated total projected costs of the researchers amounting to P829,994.093 fall under economic housing.

3.7 Overall Shape

The design of the floating house has a square shape. It is an amphibious house that is attached to a fixed pile system. It is a single-storey house that is made from lightweight materials; the walls are made from wood board braced by wood studs, slab deck is made from wood joist frame and thicker wood boards, the portion of roof is finished by galvanized corrugated sheet, and the frame is made from timber. The house has a foot print and living space of 64 sq. meters. The shape of the floating house provides high stability and safety from danger due to wave forces.

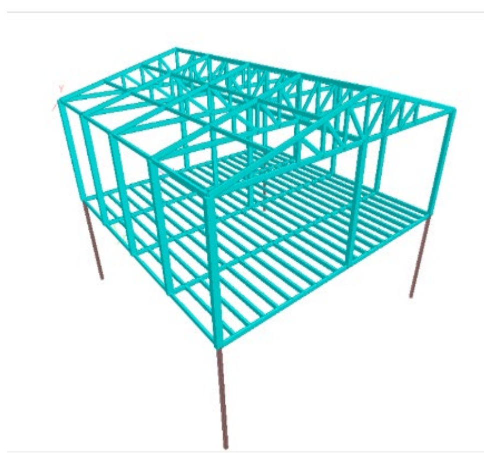

Fig.6. Structural Frame (STAAD)

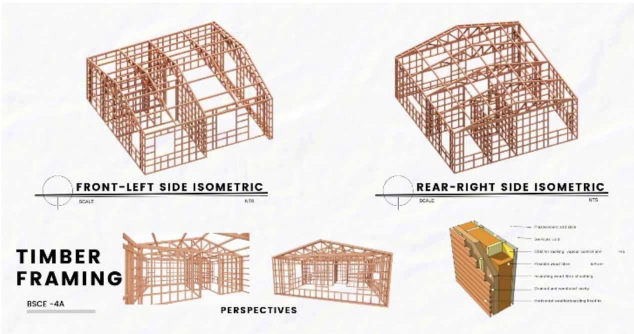

Fig.7. Timber Frame

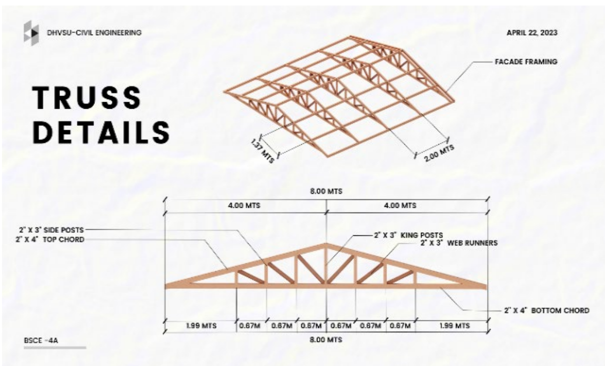

Fig.8. Truss Details

Fig.9. Normal Elevation

Fig.10. 1-Meter Flood Elevation

Fig.11. 2-Meters Flood Elevation

Fig.12. 2.75-Meters Flood Elevation

Fig.13. Front Elevation

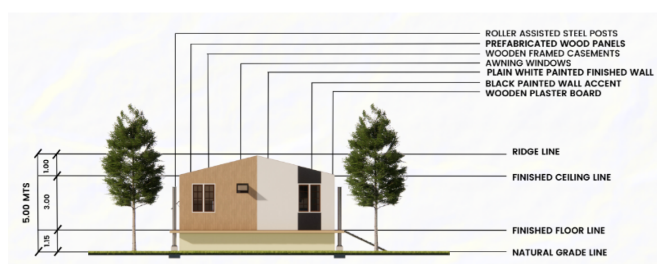

Fig.14. Rear Elevation

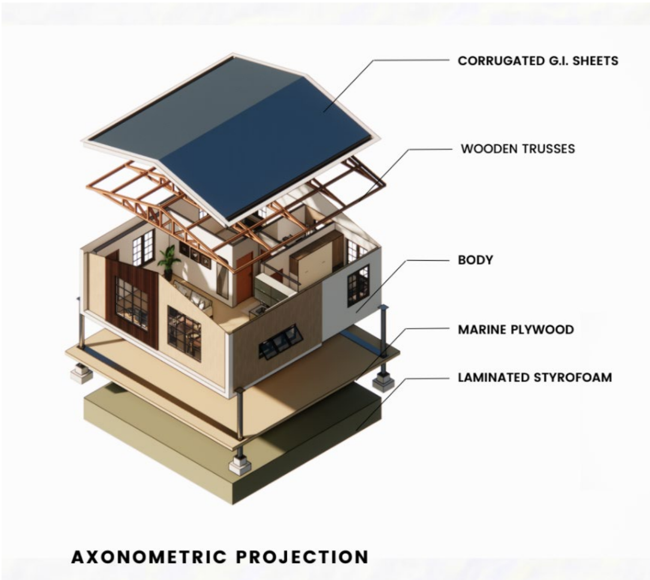

Fig.15. Axonometric Projection

Fig.16. Steel Post Details

Fig.17. Floor Plan

IV. Conclusion and Recommendation

4.1 Conclusion

Being situated along the Pacific typhoon belt, the Philippines is already expected to experience numerous typhoons every year, making the country susceptible to natural disasters such as floods, storm surges, and sea level rise, which can become major problems that the people need to face multiple times in a year. To cope with the existing conditions, engineering and architecture disciplines must step up and embrace modern techniques and use innovative ideas as a solution. In view of this, floating structures will play a significant role as an aid to low-lying areas affected by serious flooding happening almost all year-round.

Barangay Santa Lucia Paguiaba in the municipality of Masantol, Pampanga will be the site where this project will occur as the municipality experiences flooding frequently due to moderate to heavy rains and high tides. This study will be useful to the residents once it is further studied and has been completed.

The researchers have viewed the natural features of Santa Lucia Paguiaba, its condition, and the housing issue its residents have been facing every year. An interview with a few residents of the barrio was also conducted to help the researchers develop their own floating house design. The designed amphibious house was primarily made of wood and used EPS foam as its floating foundation, which is notable considering that the floating mechanism for the majority of existing floating houses uses plastic barrels or drums. Additionally, this design is attached to four vertical guidance posts and secured with pile guides, unlike some existing floating houses that are supported by chains. For its design, architectural and structural drawings are provided with mathematical computations for support. Additionally, a simple video of the floating mechanism of the structure was created for visualization.

4.2 Recommendations

Several recommendations were made from the findings of the study. They are directed especially to the students, society, and future researchers. Moreover, additional research can be conducted to help improve the proposed alternative flood-resilient floating house design.

Students should be meticulous in the importance of principles and computations in Civil Engineering. They should invest in this skill, exert adequate time to practice them, and apply it to real-life situations. These can help them progress and add value to society in the future.

Society needs to be briefed on how a floating house could improve their way of life, especially for those who live in flood-prone areas. Their understanding of how a floating house is constructed could be used to provide future researchers to acquire more data. At the same time, they could influence investors and Non-Government Organizations (NGOs) to fund the utilization of floating houses.

Future researchers interested in pursuing this study should consider expanding the scope and use a bigger population so that many individuals may benefit from it. It is advised that future researchers in the fields of sanitary and electrical engineering should create plans for plumbing and electrical systems. For electricity, the use of solar power is recommended. And in terms of sanitary sewers or other plumbing works, telescopic pipes and water hoses could be installed. Furthermore, future researchers should conduct additional studies on the steel design of the vertical guidance post. The inclusion of a stopper and its calculation at the underpart of the pipes are advised. It will be beneficial in the absence of the flood, where the computed loads will be transferred to the vertical guidance post to prevent the compaction of the laminated styrofoam. It is suggested to think about looking if there are any possible alternative materials in order to replace the steel pipes, base plates, and anchor bolts in the vertical guidance posts of the floating house or making research to provide a solution for corrosion on the materials used since using steel in areas with high levels of salinity is not a good choice. To ensure the project's longevity, the researchers suggested conducting further studies on all the materials. Lastly, it is suggested that further studies should be carried out on means of construction to make the design readily available to society.

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