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Amphibious housing for vulnerable communities in Jamaica

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Abstract

Significant flood events are increasing at an exponential rate all over the world as a result of climate change. Jamaica has the second highest economic risk exposure to two or more hazards, predominantly storms and floods, according to the 2008 update of the Natural Disaster Hotspot study by the World Bank.

Affordable amphibious housing is a proactive solution that enables people to remain in their communities of origin and provides a safe and healthy living environment during flood events. Amphibious housing technology already exists in Europe and North America and has been successfully deployed for more than three decades. These houses, however, can cost upwards of $400,000, making them an unrealistic option for hundreds of millions of the world´s vulnerable low-income populations. Our challenge is to retrofit existing homes with amphibious foundations for less than USD $5,000.

Our goal is to finalize designs for amphibious retrofits to existing homes that would be followed by a construction program that would incorporate teaching the construction techniques. This will benefit the communities through gaining flood-resilient housing while simultaneously building the capacity of local communities in Jamaica and demonstrating the legitimacy of amphibious architecture as a sustainable housing typology. Results from our research will directly lead to developments in amphibious housing technology as an innovative flood mitigation solution specifically designed to serve the world's most vulnerable populations.

Keywords: Keywords: buoyant foundation, amphibious housing, flood mitigation, vulnerable populations, low-income housing, capacity building

1. Introduction

Flooding is estimated to represent 40% of all natural hazardous events in the world and is one of the most tangible results of anthropogenic climate change. While the frequency and intensity of flood events are increasing, only 1% of development aid goes toward disaster risk reduction (UNISDR 2012, Disaster Risk Reduction). Flooding and natural hazardous events also have a disproportionate impact on the world's most socio-economically vulnerable populations.

Tropical storms, hurricanes and floods are the hazards that have had the greatest impact in Jamaica, which has the second highest economic risk exposure to two or more hazards according to the 2008 update of the Natural Disaster Hotspot study by the World Bank. 96.3% of the national population, 94.9% of the national territory and 96.3% of the GDP are vulnerable to these hazard events. This vulnerability is exacerbated by other factors such as a heavily debt-burdened economy and weak building code enforcement. Flooding is a serious and ongoing issue in Jamaica that will only continue to worsen as climate change causes more severe weather events and rising sea levels encroach on communities in low-lying floodplains. More than 120 Jamaican rivers flow from the mountains to the coast, resulting in numerous low-lying and flood-prone areas. Between 2002 and 2010, floods damaged 2,553

homes and affected 41,656 people. Storms reported in 2004, 2007 and 2008 killed 27 and negatively affected over 388,000 people. (Prevention Web, 2010)

Fig. 1-Communities in Jamaica vulnerable to flooding
(Image source: Water Resources Authority-Government of Jamaica)

There is a need for a comprehensive re-examination of how we construct in flood-prone areas that requires a paradigm shift in our assumptions and strategies. For certain limited applications, amphibious construction can provide a solution to the problem. Relocation strategies continue to fail. The use of statically elevated homes, built on elevated platforms or stilts, is an ineffective solution that separates dwellings from the ground level and disrupts the spatial continuity of a community. As global warming stimulates sea level rise and more extreme weather events, flood depths are predicted to increase as well. A flood mitigation strategy that relies on permanent static elevation will become inadequate when severe floods reach heights beyond the levels that were anticipated at the time of construction.

2. Background

Affordable amphibious housing is a proactive solution that enables people to remain in their communities of origin and provides a safe and healthy living environment during flood events. An amphibious house is one that sits on the ground the majority of the time, but which is capable of rising up to float on the floodwater, and then returning to its exact original location as the flood recedes. Modern amphibious housing technology already exists in North America, Europe and Asia, and has been successfully deployed in Louisiana for more than three decades and in vernacular applications for centuries. Newly constructed amphibious houses, however, usually cost upwards of $400,000, making them an unrealistic option for hundreds of millions of the world´s vulnerable low-income populations. Our challenge in Jamaica is to design amphibious retrofits to existing housing at a price lower than USD $5,000. Meeting this challenge will produce a successful prototype that can be employed worldwide in a variety of cultures and environmental contexts.

We have partnered with CARIBSAVE, an NGO with an extensive range of sustainable development projects across the Caribbean, to identify at-risk communities and engage with them in an effort to understand the nature of their challenges, their capacities and their natural and built environment. This includes, but is not limited to, gaining familiarity with Jamaica's housing types, materials and modes of construction, neighbourhood patterns, life styles and cultural preferences.

Amphibious foundations are a cost-effective, resident-friendly alternative to permanent static elevation for housing in areas where rising flood waters are not accompanied by high flow speeds. There is growing awareness that homeowners in established neighbourhoods are resistant to permanent static elevation, a strategy that disrupts a neighbourhood’s appearance and causes daily inconvenience, with no assurance of providing sufficient protection in an extreme flood event. Amphibious foundation systems retain a home's close proximity to the earth and relationship to the ground level by supporting the house at a slightly raised elevation under normal circumstances. When flooding occurs, the house floats to as high a level as is necessary to remain safely above water, then settles

back into its original position as the water recedes. Successful amphibious foundation systems are functioning in Maasbommel, Netherlands, and at Old River Landing, Louisiana, where they provide flood protection that is both more reliable and more convenient than can be obtained from permanent static elevation.

Fig. 2-House in Old River Landing, Pointe Coupee, Louisiana, USA with amphibious foundation (photo credit: Elizabeth English)

The initial field research phase has identified communities that could benefit from amphibious housing initiatives, informing the design strategies of the second phase of the project. The focus of this phase of the project develops all of the design and technical aspects including community liaison, urban planning, architecture and engineering. Our work builds upon initial designs that have been developed over the past several years by the Buoyant Foundation Project team, and refines these designs to respond to local conditions in collaboration with a local civil engineering consultant. The design is predicated on integrating amphibious strategies already in use in Louisiana, informed by local and vernacular building typologies. This design research was applied to prototypes of a retrofit to an existing house. Initial designs investigate several buoyancy strategies already proven in amphibious housing and propose the most appropriate option or set of options as well as exploring the options and challenges inherent in retrofitting existing housing. The selected system(s) is reviewed by a hydrologist/fluid dynamicist for stability under varying flood and flow conditions. Selection must also be made from a range of options for a vertical guidance system that will restrain any horizontal movement of the home when it is floating. This includes the determination of optimal guidance post configurations; in terms of spacing, height and number. The research and design of these identified components will be developed by our research team at the University of Waterloo in collaboration with the analysis provided by the local Jamaican engineering consultants.

3. Housing Typologies in Jamaica

In contemporary construction, the most common housing type in Jamaica is a single-storey structure constructed in one of two ways: 1. concrete masonry units (CMU's) on a poured-in-place concrete slab-on-grade or 2. 'pier-and-beam' construction—a wood joist and beam platform raised on foundation piers of either CMU's or timber. There

are common variations of these basic configurations, such as a wood-framed structure on a poured-in-place concrete slab-on-grade.

Fig. 3. concrete masonry unit structure on concrete slab (photo credit: Scott Turner)

Fig. 4. wood frame structure on pier-and-beam platform (photo credit: Scott Turner)

These structural configurations can range from modest shacks to large, luxurious dwellings, but the basic strategy is similar across all scales. While concrete construction is the more prevalent of the two, it is more vulnerable to flooding due to the proximity of its floor plate to the ground level. The raised floor platform of wood-frame construction gives it a margin of adaptability to low flood levels and the ability to dry out after flooding events due to the air flow beneath the house that the raised platform affords.

In terms of suitability to amphibious construction, structures built on a concrete slab-on-grade are functionally incompatible while structures with raised floor platforms constructed of wood are ideally suited to amphibious applications. The structural logistics of a raised floor platform allows for a flotation substructure to occupy the space between the bottom of the floor structure and the ground. The relative light weight of a wood frame construction requires considerably less buoyancy to achieve flotation versus concrete masonry unit wall structures.

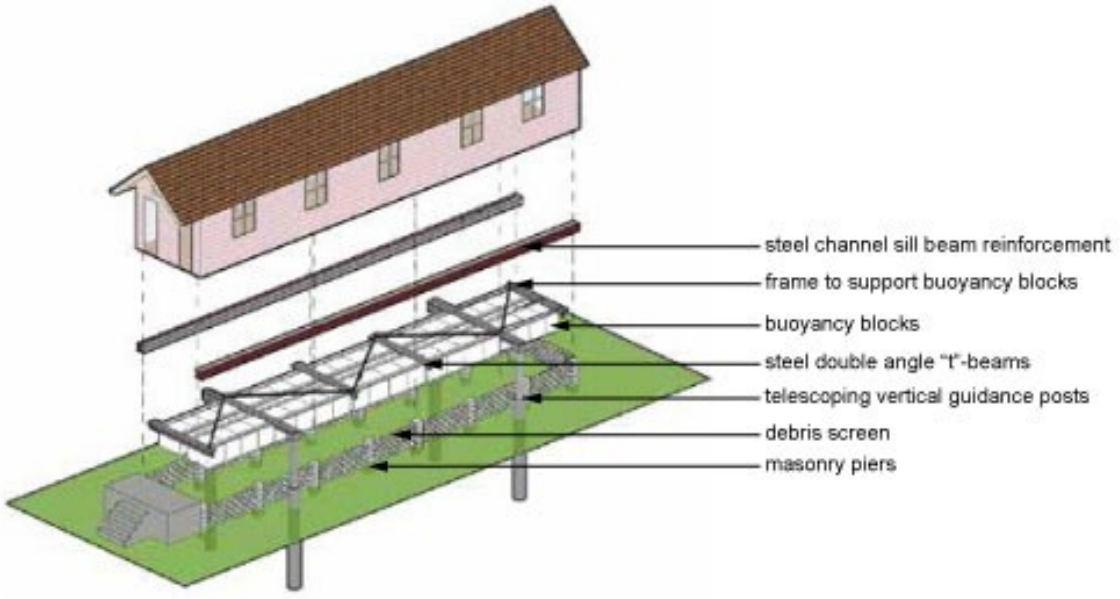

Fig. 5-Buoyant foundation schematic diagram (photo credit: Buoyant Foundation Project)

4. Community Profiles of Flood-Vulnerable Areas in Jamaica

We visited these communities in April 2015. The following accounts are a summary of the concerns the people in these communities shared with us in the conversations we had during our visit.

4.1 Bliss Pastures

Bliss Pastures is a small, flood-prone community near Wakefield, Jamaica. The ongoing inhabitation of the area, despite the flooding it faces, has been attributed largely to the residents' financial inability to leave, although others are drawn to the area because of its peaceful lifestyle and low crime rate. The region tends to follow a cycle of flood and drought; after a long drought, rain is often constant for a period of about 1-2 months. This can cause a nearby pond to overflow, and previously dry soil to become greatly over-saturated and incapable of absorbing more water, flooding the region. While the floodwater passes through various communities in Wakefield, Bliss Pastures gets the worst of it. The water collects in Bliss Pastures after passing through other areas due to its lower topography. While the flooding is usually relatively minor, Bliss Pastures has experienced severe flooding as well. There have been two major floods in the last 25 years, both of which occurred in September, which is high season for rain in Jamaica. During these floods, water levels have nearly reached the top of the houses, causing great damage to homes, ruining crops, killing animals, and destroying the livelihood of the residents. When the area floods like this, residents are forced to evacuate and stay elsewhere, usually with relatives, until the water recedes and the land dries out, which can take more than a month. After such an evacuation, it is not uncommon for those who can afford to leave to decide the floods are too great a risk, and they do not return.

The government offered aid after the first large flood in the form of monetary compensation, food, and new land the residents could choose to inhabit. However, many of these residents could not afford to build new homes or move their existing homes to the new land, and chose to stay in Bliss Pastures in the absence of any other realistic options. The land that was offered has since been occupied, and the government has not offered any more assistance to those who stayed behind in Bliss Pastures.

The most recent of these harsh floods was in 2009, but the people in the community expect the next flood to be similarly severe, as they are in the midst of a particularly long drought. Community members fear the negative impact flooding will have on their lives, and seem very interested in the prospect of amphibious retrofits for their houses. The concept was not met without concern however, as many residents are worried about government involvement. Government corruption in Jamaica is common, and residents fear that government concerns may take over the project, and limit it by applying their own agendas. Other challenges the project may face in Bliss Pastures include concerns that the landowners (as many residents either rent, or squat on land that isn't theirs) will object to having new construction or changes made to structures on their property. Another issue is the public health and safety concerns due to the overflow of pit latrines, which are common, during severe flooding.

4.2 Congo Town & Logwood Valley

Congo Town & Logwood Valley are small communities near Bliss Pastures. The residents in these areas have faced similar flood conditions to that of Bliss Pastures, with 2 major floods in the last 10 years (one in 2008-2009, and one in 2012), both of which occurred as a result of heavy rainfall (continuous for about a week). When it floods, people cannot leave their houses, and it kills the animals and plants they rely on for sustenance. These conditions have led several community members to leave permanently, with others saying they only stay because they have nowhere else to go, as they have not been provided land to move to. They have not received any government compensation, but were told of a plan to dig a canal that would divert excess water to the river. As there have not been any recent floods, residents think it is possible that this plan has gone through, but they are not entirely sure.

4.3 Port Maria

Port Maria, Jamaica lies on the north coast of Jamaica, about 55 km north of Kingston. It is the capital of Saint Mary Parish and has a population of approximately 7,500 people. This community faces regular flooding, both minor and severe, from the Otram River that flows through it and empties its water into the Caribbean Sea. The river's water is usually muddy and not particularly clean; residents avoid using it when possible. The entire

community floods with water from this river virtually every time there is heavy rainfall, although it sometimes floods without any rainfall at all. The flooding impacts all of Port Maria, but is particularly problematic for homes situated along the banks of the river.

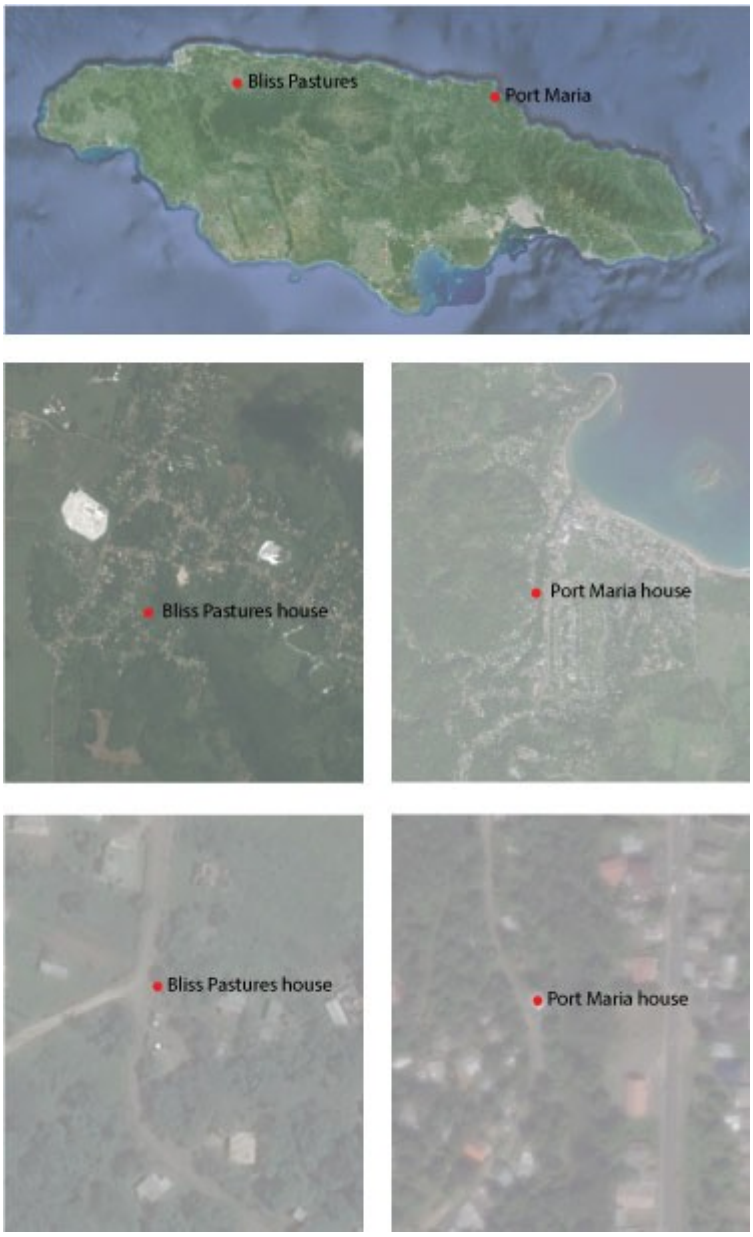

Fig. 6. Maps of study communities and project houses in Jamaica (maps by: Scott Turner)

Flooding generally occurs from June-September, and sometimes in November-December. During these regular floods, water usually goes to just below knee height, however, these floods have been getting progressively worse, with water getting higher with every flood. Flooding causes pit latrines to flood, not only causing a strong odour, but creating serious health hazards such as ring worm, and something locals call “grunge itch”. While flooding usually takes about a day to recede, it takes months for everything to dry, with fungus appearing as a result. Floods also bring more insects, such as mosquitoes, to the community. The most recent flood occurred in February, 2015.

About every two years, there are very high floods, with between 3-4 major floods in the last 6 years, the worst of which occurred in October 2012 (which seems to have been peak season for major floods). Flood water during these major floods often reaches as high as waist level, damaging homes and possessions, and greatly disrupting the people's lives. The government has stopped selling land in the area, and is aware of the risk people face living in the area. Despite this, the government does little to help beyond minor financial assistance, as they see the residents as people who are aware of the risk they are taking and choose to ignore it, rather than that they are a marginalized population who cannot afford to live anywhere else.

4.4 General Notes and Observations

It is likely that most of the people in these regions have some high school education, but little more. As such, they do not have many options or prospects in terms of living situation and employment, and thus they welcome any assistance. Almost all of the residents are disenchanted with the political process, and are wary of working with government agencies that they perceive as corrupt. They do not expect that much can be accomplished if the government is involved.

Additionally, it seems that generally during floods, men stay behind to ensure as many things remain intact as possible, while women and children evacuate and move in with relatives. Residents seem to dislike having to stay with relatives during these periods, as they would prefer to be self-sufficient, and find the process a bit humiliating.

5. Amphibious Design Retrofit

The two houses we have selected for an amphibious foundation retrofit are located in the communities of Bliss Pastures and Port Maria. They typify the common 'pier-and-beam' method of construction—a wood joist and beam platform on foundation piers of either CMU's or timber. The elevation above grade that this assembly affords is a key pre-condition for the application of a buoyant foundation. Slab-on-grade construction does not allow the possibility of the structure to rise with the flood waters.

The buoyant foundation allows a house to rest on their existing foundation piers in dry conditions and rise with the flood waters. The assembly that enables this adaptability consists of buoyancy elements below the existing floor structure, a structural substrate that connects the buoyancy elements to the floor structure and a vertical guidance system that restricts the lateral movement of the house as it rises with the water level and allows it to return to its initial position on the foundation piers.

The primary considerations informing the design of the buoyant foundation retrofits to these houses are cost-effective material strategies and the need to reinforce the existing structures, which have, to varying degrees, structural vulnerabilities when exposed to the lateral forces of floodwater and the elevation of the structure by the buoyant foundation.

The strategy we employed to achieve both cost-effectiveness and the reinforcement of the houses' floor structure was to secure the buoyancy elements to the existing structure with marine plywood strapping oriented perpendicular to the floor joists and to secure each of the existing joists to the existing sill beams with galvanized steel hurricane ties.

We employed two different material configurations in the designs for the Port Maria house and the Bliss Pasture house. While both projects required a high degree of cost-sensitivity, we investigated materials and techniques that could achieve an effective, safe and structurally sound solution at the lowest cost possible in our designs for the Bliss Pastures house. Our design strategy for the Port Maria house employed more conventional materials and elements while still achieving a cost-effective solution.

The key innovation in our design is the utilization of recycled 5-gallon jugs in the buoyancy assembly. They are inexpensive, readily available and provide a 'do-it-yourself' buoyancy option that enables people to retrofit their houses with inexpensive and effective flood mitigation assemblies. The jugs are aggregated within galvanized steel 'chicken wire' cages in modules 3 wide and 4 deep affixed to the marine plywood strapping installed below and perpendicular to the floor joists. In the Bliss Pastures house, 370 jugs are assembled, giving 15,407 lbs of buoyancy—130% of what is required to enable the elevation of the house in a flood event.

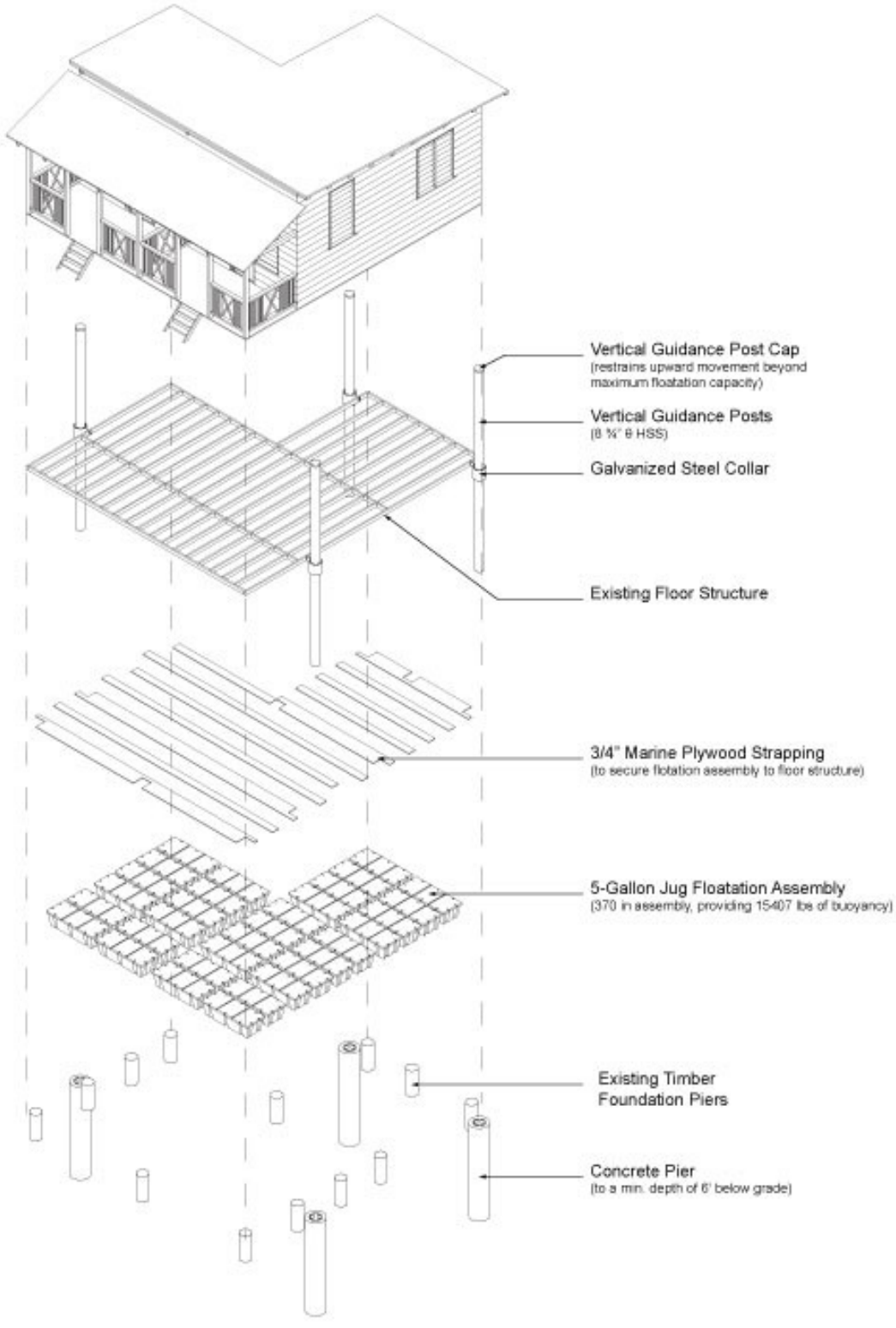

Fig. 7. Buoyant foundation retrofit schematic-Port Maria house (drawing by: Scott Turner)

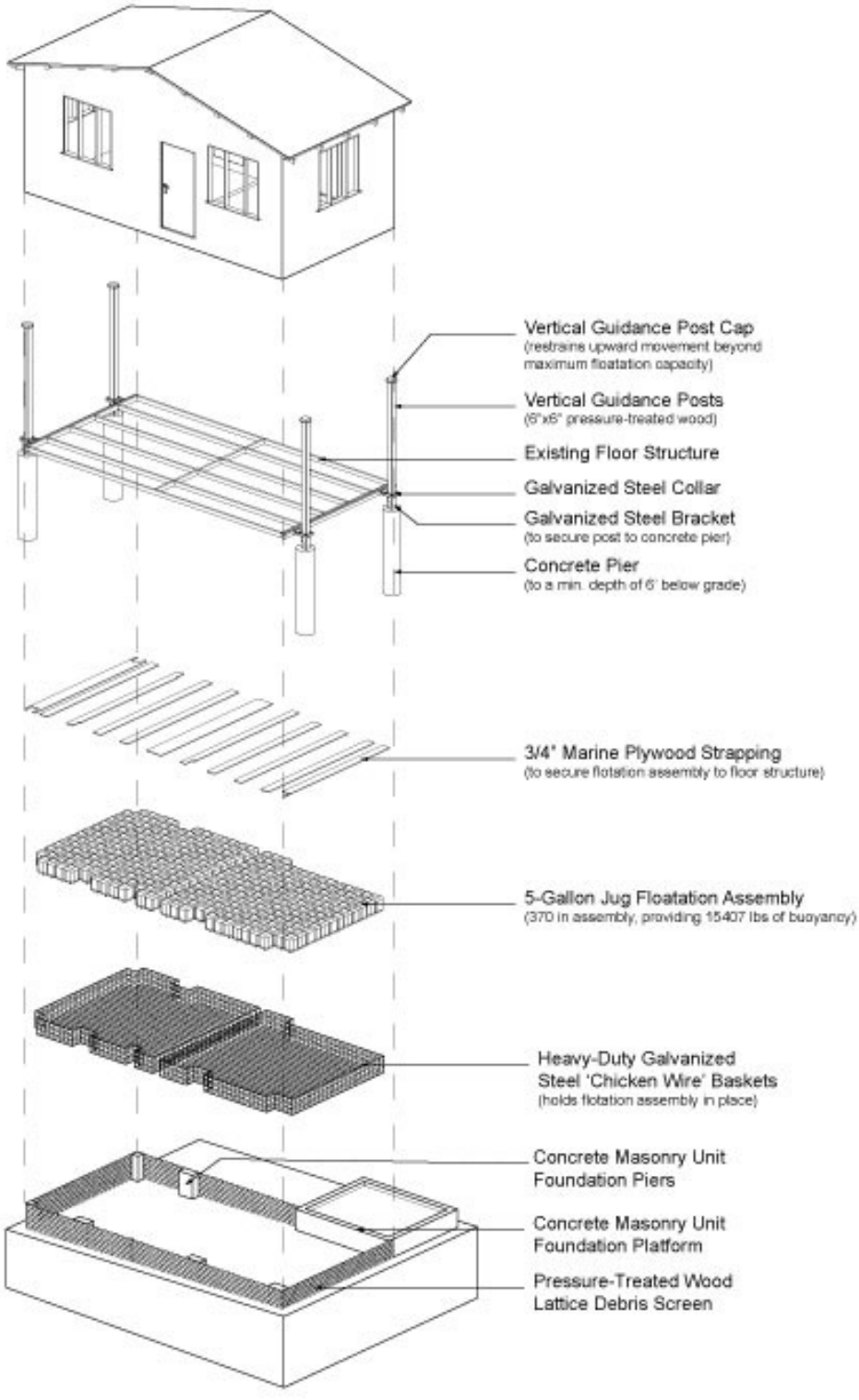

Fig. 8. Buoyant foundation retrofit schematic-Bliss Pastures house (drawing by: Scott Turner)

6. Conclusion

The amphibious foundation retrofits we have designed for the selected houses in the communities of Bliss Pastures and Port Maria, Jamaica exemplify the possibility of enabling vulnerable communities to be flood-resilient at a modest cost. Furthermore, it is a technique that can have low-cost and do-it-yourself applications that can be taught fairly easily, enabling communities to transfer this knowledge and build capacities for resilience and self-sufficiency.

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