

**GROWING** the  
ARCHITECTURE  
of Barbados

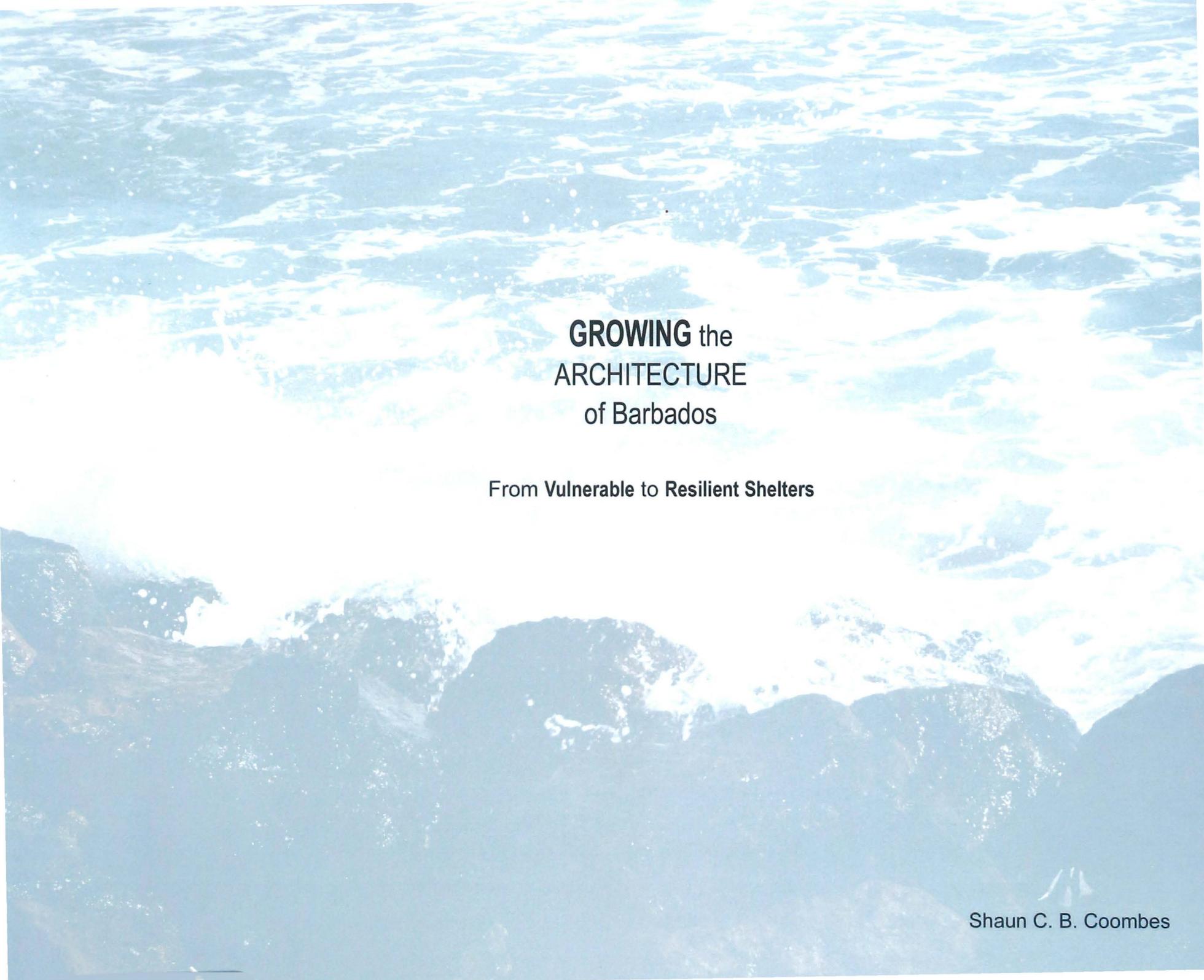
From **Vulnerable to Resilient Shelters**

by  
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A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs  
in partial fulfillment of the requirements for the degree of

Master in Architecture (M.Arch)

Carleton University  
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Shaun C. B. Coombes

An aerial photograph of the ocean with white-capped waves crashing over dark, jagged rocks. The water is a deep blue, and the foam is bright white. The perspective is from directly above, looking down at the sea.

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## Acknowledgments

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## **Abstract**

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This thesis looks at the vulnerable housing stock on the island of Barbados. The island is vulnerable to a number of natural disasters namely hurricanes, earthquakes, floods and, tsunamis. The types of vulnerable housing stock on the island are, in some cases, built of inferior materials or with substandard building techniques. This thesis will look at such vulnerable housing and some of its contributing factors. We will analyze some of the most recent housing solutions being produced by the National Housing Corporation (NHC), a government run organization, to see in what ways they are successfully or unsuccessfully addressing the problem of vulnerability. This analysis will provide valuable insight and information on what may be the more successful methods employed in the event of natural disasters. Should a radical pre-emptive approach be used to improve the housing stock in order to mitigate the effects of natural disasters? Or are there other options we should consider? This thesis will aim to explore potential housing designs from pre-emptive to resilient.

## Glossary - Abbreviations

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ASH	Aided Self-Help
BDB	Barbados Development Bank
BMFC	Barbados Mortgage Finance Company
BNB	Barbados National Bank
CARICOM	Caribbean Community
CDB	Caribbean Development Bank
CDC	Common Wealth Development Corporation
DEM	Department of Emergency Management
HCF	Housing Credit Fund
HPU	Housing Planning Unit
ICB	Insurance Corporation of Barbados
IDC	Industrial Development Corporation
IMF	International Monetary Fund
MHLURD	Ministry of Housing and Lands, Urban and Rural Development
NHA	National Housing Authority
NHC	National Housing Corporation
NIF	National Insurance Fund
RDC	Rural Development Commission
UNIDO	United Nations Industrial Development Organization
UDC	Urban Development Commission
USAID	United States Agency for International Development

**Glossary - Location of Barbados**

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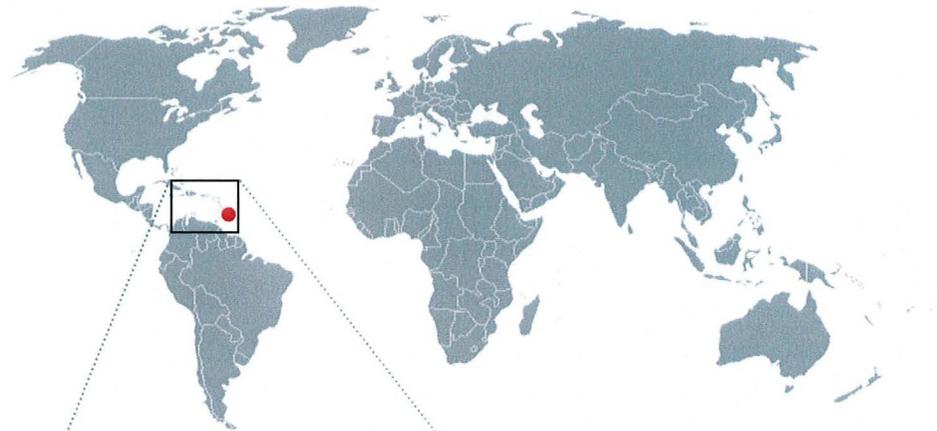


Fig.1.0. Location of the West Indies



Fig.1.1. Location of Barbados in the West Indies



Fig.1.2. Island of Barbados



## Introduction

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<sup>1</sup> Hurricane Ivan Grenada 2004 <<http://www.nhc.noaa.gov/outreach/history/#ivan>>

<sup>2</sup> 4.6 Earthquake 2007 <<http://www.caribbean360.com/index.php/news/12678.html#axzz26SYwUGbZ>>

<sup>3</sup> Haiti Earthquake 2010 <<http://earthquake.usgs.gov/earthquakes/pager/events/us/2010rja6/index.html>>

Having lived much of my life in Barbados I have observed the slower paced lifestyle that living on a small island can offer compared to larger, developed countries. This does have its benefits, but can also make one less proactive when it comes to preparing for the potential threats that natural disasters - such as hurricanes, earthquakes, floods, and tsunamis - may bring. Barbados has not been hit by any major disaster in more than 50 years. This has created a somewhat selective amnesia over the period of time that has elapsed since then. There have been some “close calls”, most notable would be Hurricane Ivan in 2004 that at the last minute dipped south of the island and hit Grenada head on.<sup>1</sup> 90% of the infrastructure and homes on that island were destroyed, and for a time this sent the island into almost total chaos. There was some damage to homes in Barbados, but the level of destruction was minimal in comparison. Another wakeup call was in 2007 when an earthquake measuring 4.6 on the Richter scale caused damage to some homes and businesses, and eventually shut the island down, sending everyone into the streets of the capital city of Bridgetown. The island has almost no history of earthquakes because it is a coral stone island and therefore not volcanic.<sup>2</sup> More recently in 2010, with the earthquake in Haiti and similar events worldwide, the local Barbados government disaster emergency agencies and planners now have started a dialogue.<sup>3</sup> This nevertheless was a small wake up call to what could happen in the future. It is because of this that planning strategies need to be put into place now in order to safeguard the island's future.

Developed and Developing nations have made attempts to address the threat of natural disasters in their own ways. Some approaches have been more successful than others. The levels of success for many of these approaches are usually determined



Fig. 1.3. Bottom Bay Beach, Barbados

## Introduction

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by the successful execution of a number of factors, such as political, social, and economic. As a result, each nation has its own level of success and failure in approaching and addressing these areas. Unfortunately, when the governments of these nations fail to execute the tasks needed to facilitate action in these types of areas, it is usually the people who fall into the lowest economic bracket that suffer the most when natural disasters strike.

This thesis will look at the housing stock of Barbados and their vulnerability to a number of natural disasters - particularly hurricanes, earthquakes, floods, and tsunamis. First we will look at situating Barbados in its geographical context. Then we will look at the low to middle income typical housing types, with a focus on one of the more traditional Barbadian architectural types known as the Bajan Chattel house. After this we will look at some of the main areas that contribute to the vulnerability of the housing stock on the island. Finally, my proposed design will illustrate via a pre-emptive approach the need to explore new technologies that can create a more resilient housing solution for Barbados. This design will look at some selected case studies and will show aspects that contribute to the building's resilience, its reinterpretation and adaptation of local housing types, as well as building materials and systems to create a new housing solution. My proposal is important because it could provide additional contributions to society as a whole. With this said, should we explore a more drastic pre-emptive approach, to improving the housing stock of Barbados in order to mitigate the effects of natural disasters? Or should we consider other options?

Situating Barbados

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Fig.1.4. Home destroyed in 1955 by Hurricane Janet

<sup>4</sup> Facts about Barbados: <<https://www.cia.gov/library/publications/the-world-factbook/geos/bb.html#>>

<sup>5</sup> UWI seismic <<http://www.uwiseismic.com/General.aspx?id=46>>

<sup>6</sup> UWI seismic <<http://uwiseismic.com/General.aspx?id=1#>>

<sup>7</sup> UWI seismic <<http://uwiseismic.com/General.aspx?id=1#>>

**Tsunamis:** Tsunamis are giant waves caused by earthquakes or volcanic eruptions under the sea. source: <<http://oceanservice.noaa.gov/facts/tsunami.html>>

**Storm Surge:** A storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide. source: <[http://www.nws.noaa.gov/om/hurricane/resources/surge\\_intro.pdf](http://www.nws.noaa.gov/om/hurricane/resources/surge_intro.pdf)>

The island of Barbados is the eastern most island in the West Indies, north of Venezuela. The total land area of Barbados is 430 sq km, with 97 km of coastline, the highest point is Mount Hillaby at 336m, its natural resources are petroleum, fish and natural gas. The total population is 288,725 (July 2013 est.) and the capital city is Bridgetown with a population of 112,000 (2009 est).<sup>4</sup> The majority of the local population of Barbados live along its south-east, east and west coast.

As an island nation, Barbados is vulnerable to a number of natural disasters, including hurricanes, earthquakes, floods, tsunamis as well as landslides and cave-ins.

Barbados is one of the few non volcanic islands in the Caribbean, instead it is made up primarily of coral. This, however, does not reduce the fact that it is still vulnerable to earthquakes and tsunamis caused by nearby active volcanoes within the Caribbean island chain. At present there are 19 active volcanoes that are likely to erupt within the eastern Caribbean.<sup>5</sup> The closest volcanoes are Kick ‘em Jenny (off the coast of Grenada), The Soufriere volcano (at the northern region of St. Vincent) and the Soufriere volcanic centre (at the southern region of St. Lucia).<sup>6</sup> With the potential threat of an active volcano there are also other risks which can threaten Barbados, such as earth tremors, tidal waves, and tsunamis. During an earth tremor for example, the earth violently moves in multiple directions, which can affect the integrity of a structure. These tremors can also cause tidal waves or tsunamis, which can cause high levels of damage to coastal regions and in some cases even move quite far inland, thereby extending the damage to non-coastal regions.<sup>7</sup>

### Disaster Timeline

- 1751 tsunami caused by earthquake
- 1780 Great Hurricane 4000 souls lost
- 1831 hurricane 2000 souls lost
- 1902 Tsunami in Bridgetown caused by volcanic eruption of Soufriere in St. Lucia
- 1910 land slippage north of island
- 1939 tsunami caused by Kick ‘em Jenny
- 1953 earthquake 175km north-west of St. Lucia
- 1955 hurricane Janet 38 souls lost 688 made homeless
- 1970 flood caused by tropical cyclone having large effect with millions of dollars in damage
- 1984 flooding in the north, St. Peter north of island families homeless
- 1985 flooding in St. Philip southern part of the island
- 2004 Hurricane Ivan 85% of all houses destroyed in Grenada minimal damage in Barbados
- 2007 cave-in at Arch Cot family of 4 lost
- 2007 Earthquake minimal damage, island shutdown
- 2010 Hurricane Tomas millions of dollars in damage

<sup>8</sup> Hurricane Sandy <[http://www.nhc.noaa.gov/graphics\\_at3.shtml?5-day-nl](http://www.nhc.noaa.gov/graphics_at3.shtml?5-day-nl)>

<sup>9</sup> Hurricane Janet Monthly Weather Review, pp. 321 <[http://www.aoml.noaa.gov/hrd/hurdat/mwr\\_pdf/1955.pdf](http://www.aoml.noaa.gov/hrd/hurdat/mwr_pdf/1955.pdf)>

<sup>10</sup> Spoke Daily Chronicle Sept 24th 1955 pp.1 : <<http://news.google.com/newspapers?id=D-ZX-AAAAIBAJ&sjid=sfYDAAA-IBAJ&pg=2467,770720&dq=christ+church+on+barbados&hl=en>>

<sup>11</sup> Source DEMA article <<http://www.cero.gov.bb/pages/Resources.html>>

**Hurricane:** A hurricane is an intense, rotating oceanic weather system that possesses maximum sustained winds exceeding 119km/ hr (74mph). It forms and intensifies over tropical oceanic regions.<sup>9</sup>

Hurricanes are another of the major natural disasters that have affected Barbados in the past, and continue to do so Today. An example of this is Super Storm Sandy, which affected the northern Caribbean and east coast of the United States in 2012 causing billions of dollars in damage and many lost lives.<sup>8</sup> For Barbados, one of the more devastating hurricanes to affect the island was back in 1955 by hurricane Janet. Hurricane Janet passed the south of the island with winds in excess of 120 mph (193 kph).<sup>9</sup> With property damage of over 5 million US dollars over 50% of all houses on the west coast of the island destroyed, a death toll of 38 people, this was the worst hurricane to affect the island in over 75 years.<sup>10</sup> This event was a major wake-up call for Barbados. Since then we have had some close brushes with other hurricanes, most recently Tropical Storm Tomas in 2010, but none so bad as in previous years. This storm caused millions of dollars in damage, with over 2,123 homes affected.<sup>11</sup> This storm made many people revisit the memories and stories of 1955 Hurricane Janet, and as a result many people made changes to fortify their homes against potential future hurricanes. Nonetheless, even to this day may people living on the island still reside in vulnerable homes. To illustrate the damage possible and the reason why local builders should employ better building practices we will look at the house “ Santa Nita”, located in Christ Church the southern parish that had sustained much of the damage afflicted by Hurricane Janet.



Fig. 1.5. House upturned, Hurricane Janet 1955

In figure 1.6 the house Santa Nita, which was built of locally quarried soft stone, shows severe damage to the roof and the front façade where the majority of the external wall was removed during hurricane Janet in 1955. The extents of the damage also show the remnants of the front porch handrail and roof, which were torn away from the main structure. This would have been due to the lack of adequate steel reinforcement within the external wall structure. With large eave overhangs and the lack of steel straps used in connecting the roof to the poorly reinforced exterior wall made them more susceptible to failing. These failures in the roof, wall connections, and reinforcement during extended high winds, not to mention the impact of blown debris, would most certainly have caused this damage. In figure 1.7 over 50 years later we can see the changes that were made soon after hurricane Janet, which entailed the removal of the roof eave and its replacement with a parapet wall. This drastically reduced the chances of roof failures, and has become a typical detail used in Barbados for this reason. The other changes we see are the concrete roof and column supports over the porch, with a low concrete wall enclosure surrounding it. It is examples like these that illustrate the changes we see as a direct response to the damages caused by hurricane Janet. With the addition of steel and concrete the home has been shored up and its vulnerability has been reduced.

Barbados is no stranger to the ravages of these dangers. Therefore, it is imperative that Barbadians take heed of the warning signs (however minimal they may seem) in order to prepare for what may come. Knowing what we know now, these preparations may just be what saves more lives and reduces the level of damage creating a more resilient society as a result.



Fig.1.6. "Santa Nita" damaged during Hurricane Janet 1955



Fig.1.7. "Santa Nita" with parapet roof, and concrete front porch 2012

Housing

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Fig.2.0. Bajan Chattel Houses

Typical Low to middle income housing types



Fig.2.1. Typical wooden home



Fig.2.2. Typical concrete block wall home



Fig.2.3. Typical wood and concrete block wall home

<sup>12</sup> Minimum and maximum temperatures in Barbados<<http://www.barbados.climatemps.com/>>

There are a range of building types used in Barbados from wood, stone, to concrete block wall and a combination of wood and concrete block wall. These building types have been adapted for the local tropical climate in Barbados, which ranges in temperature from a minimum average temperature of 21 degrees Celsius (69.8 degrees Fahrenheit) and a maximum average temperature of 30 degrees Celsius (86 degrees Fahrenheit), with an overall average temperature of 26 degrees Celsius (79 degrees Fahrenheit).<sup>12</sup> The rainy season is between the months of June and October where during these periods that the island is most vulnerable to Hurricanes. In this chapter we will briefly look at the typical low to middle income housing types and then focus on the traditional Bajan Chattel house. This will allow us to see the relevance in its adaptability and its locally-informed architecture which in turn will help to inform my proposal.

<sup>13</sup> Barbados Advocate Newspaper, 10th February 2011 " Things that Matter: National icon - The Barbados Chattel House", by: Sir Henry S. Fraser.

<sup>14</sup> Ibid

**Bajan:** The colloquial name or shortened form of Barbadian.

**Chattel House:** Traditional Barbadian style home.

### The *Bajan* Chattel House

The Barbados Chattel House has been a part of Barbadian culture for many years, and because of this it is a symbol of Barbadian architectural heritage and pride. The term "Chattel" is an old English word for movable possessions. The word is a derivative of the old French "chattel" and Latin "capital", meaning property as opposed to land.<sup>13</sup>

The History of the Chattel house can be traced back as far as the early 19th century in Barbados. Some of the early descriptions of the Barbados Chattel house can be found in the Barbados Globe and Colonial Advocate, 25th February 1839. They are described by author John Briggs:

The rural labourers' best erected cottages have their walls framed of joist, then boarded and shingled; the partitions framed of planks then boarded; roofs framed of planks then boarded and shingled, the flooring of joists and boards...<sup>14</sup>

These houses were originally built by the sugar plantation workers on nearby land that was leased to them by the plantation owners. In the event that the worker had to move from one plantation to seek work at another, the house could be dismantled wall by wall, packed onto a carriage or flatbed truck, and transported to its new location and rebuilt there. The materials of the Chattel house were mostly of cheap and readily available materials that could be found on or near the plantation. This would include scrap wood planks for flooring and walls, old shingles, shakes,



Fig.2.4. Traditional Bajan Chattel house

<sup>15</sup> Barbados Advocate Newspaper, 10th February 2011 " Things that Matter: National icon- The Barbados Chattel House", by: Sir Henry S. Fraser.

palm fronds, or re-appropriated galvanized corrugated sheeting for roofing. The foundations were usually of wooden posts, rubble, or soft stone that designed to also elevate the house above the ground in order to reduce the risk of flooding.<sup>15</sup>

In this way the houses were built with the local environment and climate in mind. They were cool during the day due to their high gabled roofs and high level windows within the gable. The steep gable also provide good levels of shedding rain and has a higher resistance than flatter roofs with larger eave overhangs when it comes to certain high wind speeds during tropical storms. One of the strategies afforded by the wooden post foundation was that this type of structure allowed for quick and easy removal of wood ants, termites, and other types of vermin that threatened the structural integrity of the house. The use of Green Heart or Purple Heart woods, which usually came from South America, would be used for the post foundations whenever available because of their natural resistance to these vermin.

The Chattel houses that exist today in Barbados are credited for their style, delicate detailing, relatively good level of resilience, adaptability, and mobility. These housing types are beautiful examples of Barbadian architecture as they reflect the times in which they were created. They are also economical and have innate features which make a very practical application for those who have used them over the years. For example these housing types can be built in stages and sit on a temporary foundation. My proposal reinterprets this modularity with the use of a hexagonal footprint but sits firmly on a foundation. Also they are predominantly made of wood, but as time goes on the owner can make additions to these



Fig.2.5. Chattel House during the 1940s

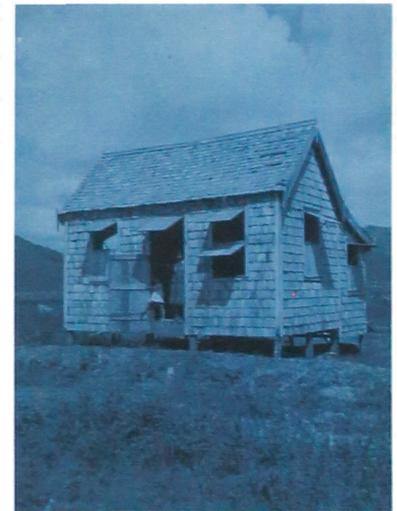


Fig.2.6. Chattel House during the 1940s

## Housing: Typical and Traditional Housing Types

## Chapter 2

structures with concrete block. Similarly my proposal can be used as an addition or an alternative to an existing chattel house. Finally the Chattel houses are built in various arrangements and this concept too has been preserved in my proposal. It is this important feature that has made these housing types very attractive, due to their ability to be built in stages from a one room unit to multiple rooms, as the owner can afford. This is still widely seen in practice to this day and has been one of the main reasons why this feature has been preserved and reinterpreted in my proposal which will be discussed later.

### The Anatomy of The Bajan Chattel House

The Bajan Chattel house depicted to the right has high jalousie windows which work well for sun shading and controlling light and ventilation. The high gabled roof helps keep the house cool during the day as well assist in keeping the roof down onto the structure during high winds. Very little roof over-hang helps reduce the risk of uplift during tropical rain storms.<sup>16</sup> The addition of the front verandah, the ornamentation, and symmetrical design, are all features influenced by the Georgian architectural style.<sup>17</sup>

<sup>16</sup> wind uplift on roofs <<http://www.davidoprevatt.com/wp-content/uploads/2010/02/dixon-prevatt-struct-cong-wind-uplift-testing-01-25-2010.pdf>>

<sup>17</sup> Potter et al, pp. 50

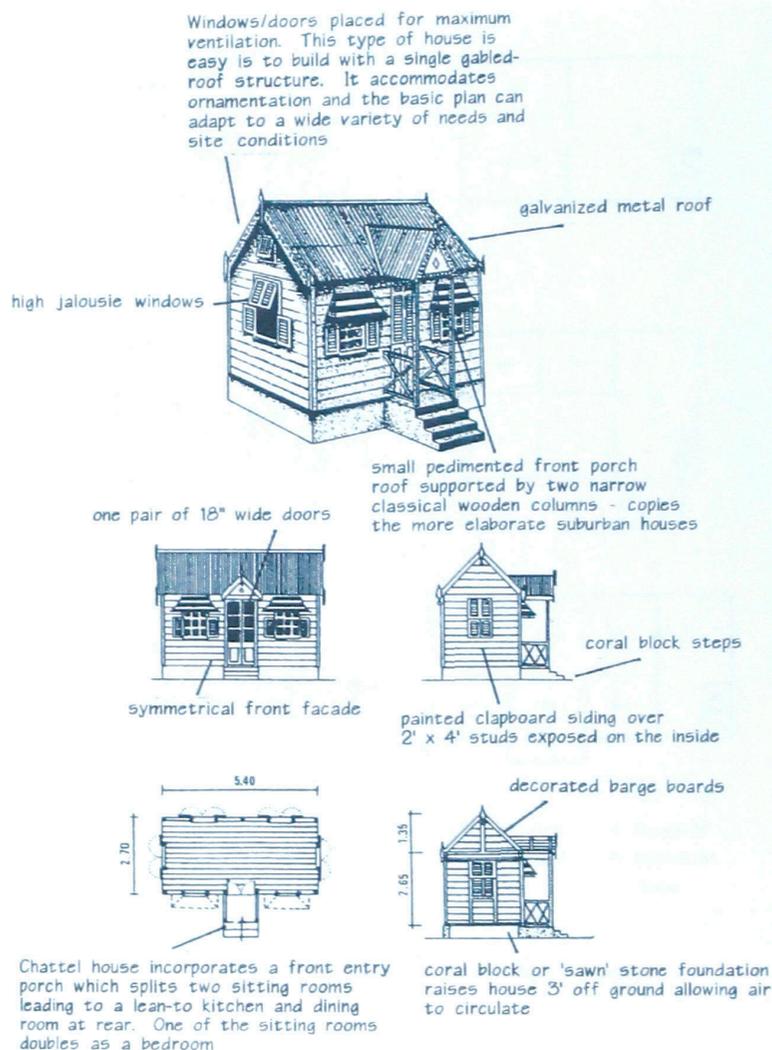


Fig.2.7. The Anatomy of the Bajan Chattel House

The traditional chattel house in its most typical form can be shown with 3 distinct stages of upgrading and development.

Stage 'A' is the most basic single gabled timber chattel, which is divided internally into two rooms, a back yard and an outhouse at the rear.

Stage 'B' is the "bipartite timber chattel" which has a second bay with a lean-to roof that can also be upgraded to a second gable. The second bay is also divided into two rooms for a total of four rooms.

Stage 'C' is a "tripartite timber chattel" with a third bay bringing the total of rooms to six with the middle bedroom projecting in order to give better ventilation as well as space for a central corridor. In the future these rear bays will be converted with concrete blocks, which will be discussed later in my project proposal. The front, in some cases, may take on a pedimented porch with further detailing. This style of incremental construction is strongly rooted in the Barbadian tradition and has influenced much of the low to middle income housing on the island.<sup>18</sup>

<sup>18</sup> Potter et al, pp. 60

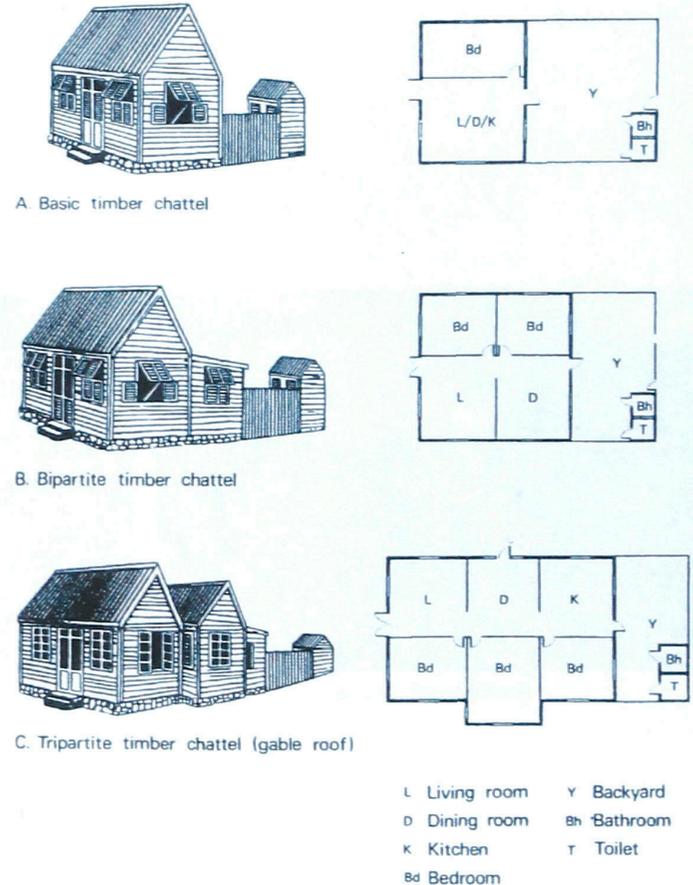


Fig.2.8. The 3 basic stages of the Bajan Chattel House

Typical Chattel House



Fig.2.9. Left facade



Fig.2.10. Front facade



Fig.2.11. Right facade



Fig.2.12. Typical Streetscape of Chattel Houses



Fig.2.13. Chattel House in transition-left



Fig.2.14. Chattel House in transition- right

#### Transition from Wood Chattel house to Concrete Block Wall house

The typical Chattel House, as previously described, expands, over time, from front to back by the addition of modular bays which are attached to one another. The expansion phase is usually to the satisfaction of the occupant. The expansion process will start in wood from front to back and then in many cases will transition from wood to concrete block from back to front in incremental stages. Some expansions or transitions also start from both ends, and the process works towards the middle. In this case the wall transition is placed outside of the wood structure and encapsulates the wood structure footprint, which is later removed as each bay or section is completed.

Vulnerable Housing

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Fig.3.0. Judy's Front Door

<sup>19</sup> The Barbados Statistical Service's, population and housing census 2010.

### Vulnerable Housing in Barbados

As previously mentioned, Barbados has not gone completely unaffected by natural disasters. There have been a number of them over the years and they have caused damage to the housing stock on the island. Due to this there has been an attempt, by local agencies, such as the National Housing Corporation (NHC) and the Department of Emergency Management (DEMA), to reduce this vulnerability. Nonetheless, these agencies have been unable to make an impact as far reaching as they would like. As a result of this, there are still a number of houses that are of low standard construction, which contributes to the potential vulnerability of the island's housing stock. At present 17,101 houses out of a total of 92,197 houses in Barbados are made from wood alone, while 2,543 houses are made of stone. These are the two most vulnerable housing types due to the materials used in their construction. This results in a total of 19,644, or 21%, of the number of potential higher level vulnerable homes in Barbados.<sup>19</sup> However, this number is suspected to be even higher since this figure does not take into consideration the total number of homes which have been constructed with substandard building methods. To date, no survey has recorded this information. With the ravages of time and the lack of adequate maintenance many of these structures are now at higher risk of being damaged and therefore may pose a threat to life in the event of a natural disaster.

It is important, therefore, to look at examples of what makes some of these housing types vulnerable. Following this we will acknowledge some of the work being

done by the previously mentioned agencies, and others, who are working to reduce the level of vulnerability of the islands housing stock through improving the standards of building throughout the island. This will bring an awareness of what is being done and where possible changes could be implemented in my proposal.

Examples of local vulnerable housing



Fig.3.1. Images of houses in vulnerable state



Fig.3.2. Images of houses in vulnerable state



Fig3.3. Images of houses in vulnerable state

These are typical examples of occupied chattel houses which have not been adequately maintained and thus representative of some of the higher level vulnerable homes in Barbados. These houses have failing foundation walls, compromised structural integrity due to lack of maintenance, and as a result pose a risk to those who occupy these homes. This is usually the result of inadequate inability to afford any housing or structural maintenance. Consequently, the rate of deterioration drastically escalates due to their increased susceptibility to the elements.

<sup>20</sup> Jonathan Platt, Technical Officer at the Barbados National Standards Institute (BNSI), meeting, January 2013.

Meeting with Technical Officer at the Barbados National Standards Institute (BNSI).

In a short interview with Mr. Jonathan Platt the technical officer at the Barbados National Standards Institute (BNSI) where the main topic of discussion was on the Barbados National Building Code (BNBC). The BNSI promotes standardization and publishes all of the local standards of Barbados. The BNSI is also the publisher of the BNBC. Therefore it was important to ask Mr. Platt about the status of the most recent edition of the BNBC. When asked which code edition was the most current. Mr. Platt had explained that the most recent to date is the 1993 edition. When asked if all persons responsible for building in Barbados were required by law to use the BNBC. He replied that the code was not legislated by law and is only used voluntarily by professionals and artisans involved in the building process. He had expressed his concerns about this and would like to see it legislated by law. When asked on his views, on the reason why a more recent code has not been published as yet. He replied that there is a draft code which has been in the works for a number of years and is still under review by the local authorities and professional institutions. Mr. Platt did however express his views that a new updated version is also important as the current building code is outdated and does not cover some of the new technologies and building systems for current construction requirements.<sup>20</sup>

<sup>21</sup> Barbados National Building Code, Preface pp. 3

<sup>22</sup> Ibid

<sup>23</sup> Ibid

The standard building practice on the island is to obtain the relevant permits from the necessary institutions which allow the building of any structure to be carried forth. One of these major governing institutions is the Barbados Town and Country Development Planning Office, which oversees and regulates all construction and development on the island. Some of the regulatory documents used in observing the guidelines are the Planning Act of Barbados and the Barbados National Building Code (BNBC). The Barbados National Building Code is modelled after the Caribbean Uniform Building Code (CUBiC), which was published in 1985. The CUBiC building code was created by the Caribbean Community (Caricom) Secretariat through a jointly funded project by the Caribbean Development Bank and the United States Agency for International Development.<sup>21</sup> The BNBC refines and simplifies the many technical provisions with regards to the various building classifications, and recognises the many administrative arrangements in use in Barbados.<sup>22</sup> It also lays out the technical requirements and standards for design and construction with regards to concerns of structural sufficiency and durability, fire safety, health and amenity, all of which are essential minimum provisions related to public interest.<sup>23</sup> At present it is important to note that the BNBC is not legislated by law as previously explained by Mr. Platt and therefore is used voluntarily by owners and professionals alike. This creates challenges in the quality of structures, the correct use of building practices, and building technologies, as well as the enforcement of building codes. These are just some of the issues that arise with a building code which is not legislated by law and enforced.

The use of the building code by all responsible from the planning and designing stage to construction should follow the most current industry standards as

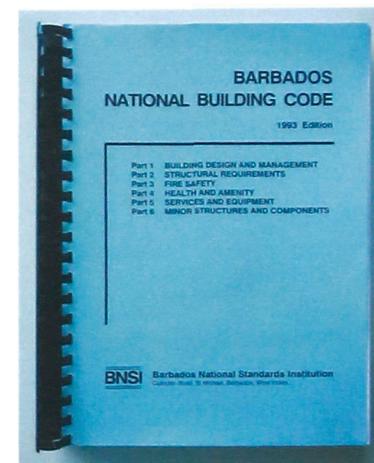


Fig.3.4. Barbados National Building Code 1993 edition

<sup>24</sup> Bia news article. May 20th 2011. <<http://www.bia.bb/home.html>>

<sup>25</sup> Information from the Barbados Institute of Architects (BIA)

previously outlined to ensure that the finished product performs as intended. As such, it is important, that the building code stay current with the new building systems and technologies that are being used. Keeping the building code current and enforcing its use will help to reduce the vulnerability of housing on the island. My proposal will look at combining traditional building technologies through new technological advances which will help to ensure a strong and resilient product.

There have been discussions among professional circles who acknowledge that the most recent code, the 1993 edition of the BNBC, is outdated. Some of the professional organizations taking the lead in this are the Barbados Institute of Architects (BIA) and the Barbados Association of Professional Engineers (BAPE).<sup>24</sup> These professionals have expressed that the BNBC does not cover the needs of construction when it comes to new construction materials, technologies, building systems, and the changing needs of society which requires new regulations in order to help safeguard the public.

The news in recent years, talks of a new edition of the BNBC that is being worked on by the above professional organizations together with the Government to have this new BNBC completed and submitted for approval. At present this document is in draft form, but once it is completed it will have up-to-date requirements that will match the new technologies, building systems, and public safety needs for construction today.<sup>25</sup> The intension is also to have this new code legislated by law. In doing so, this will make it illegal for anyone to construct any building that does not meet local requirements, therefore helping to reduce the vulnerability of the local housing stock. This will also help to create guidelines that will maintain the

standards of building new structures that employ new technologies that the older building code did not provide for. This is why it is important that both safety regulations and trained persons work together with these new technologies in order to continue the pursuit of less vulnerable construction.

#### Discussions on Vulnerability and Building Regulations

The following is an interview with a local Civil Engineer who has been involved with the assessment of damage after natural disasters in the Caribbean, in general and in Barbados in specific. He has made many contributions and has been an advocate of reducing the vulnerability of the housing stock of Barbados. I asked his opinion on the level of vulnerability of the housing in Barbados, and what he thought were important factors with regards to the BNBC, including what changes would he make in order to improve the BNBC. This was important as it provided valuable insight from a professional in the field who has firsthand knowledge of the issues Barbados and neighbouring islands have faced and the ways in which they have responded to these issues.

Mr. Grenville Phillips II is a Civil Engineer in Barbados and is well known to voice his opinions on the substandard housing on the island. Mr. Phillips has also expressed his concerns about the vulnerability of the island to the many disasters that could affect the local housing stock. When asked about what makes the housing in Barbados of such low standards, he replied that the low standards were specific to the structure not the functionality. He expressed that this was due to the absence of shear walls to resist lateral forces from hurricanes and earthquakes,

For further information Mr. Phillips also directed me to the Walbrent College website which he founded. He founded this college because he saw the increasing need to educate people on the correct building standards that should be used in Barbados.

bending steel reinforcement to the extent that they fail, the inadequate filling of block-wall cores and the inadequate frequency of roof fixings were among the main contributors to the low standard construction. In other words, due to poor building practices, and lack of necessary structural components these structures are more susceptible to the effects of natural disasters. This observation by Mr. Phillips is important in that it highlights a danger that could have severe consequences for the future if not rectified.

When asked what changes should be made to reduce this vulnerability, he replied that there were only two areas that have been proven to work:

1. Enforce the Barbados National Building Code
2. Educate those directly involved in the building process most notably the supervisors and artisans (i.e. the site foremen and the tradespersons).

These two key initiatives were proven successful by two real life scenarios explained by Mr. Phillips.

The first initiative of effective enforcement of national building standards was shown to be successful after Hurricane Luis in 1996, which had impacted the island of Saint Martin (shared by France and the Netherlands). The Dutch Saint Maarten had low enforced building standards, where as the French St. Martin had the most effective building standards in the Caribbean at the time. This difference in building standards was visible after Hurricane Luis passed through. The damage sustained to the Dutch side of the island suffered excessive damage despite experiencing lower wind speeds, while the French side, which was impacted by

<sup>26</sup> Walbrent College, <<http://walbrent.com/2012/01/21/proven-solutions-to-sub-standard-building-construction/>>

<sup>27</sup> Ibid

higher wind speeds, sustained less damage by comparison. This revealed that, the actions of the French side to enforce the building standards, as opposed to the lack of such enforcement on the Dutch side, directly correlated to the level of damage sustained by each side.<sup>26</sup>

The second initiative as outlined by Mr. Phillips was offering a half day training workshop to the entire nation's building supervisors and artisans. In 2004, immediately after the passing of Hurricane Ivan which had devastated the island, the president visited almost all of the parishes in Grenada except for the island of Carriacou (which is a dependency of Grenada). With each visit to these parishes training was provided to all of the building supervisors and artisans in providing higher standards of repairs and strengthening. After the passing of Hurricane Emily over Grenada in 2005 most of the damage sustained was in Carriacou - the only territory of Grenada the president was unable to visit and train. Low quality standards used to repair the damage done in 2004 by Hurricane Ivan made the houses ill prepared to withstand the damaged created by Hurricane Emily in 2005.<sup>27</sup>

These two initiatives, expressed by Mr. Phillips, demonstrate how important it is that such activities be carried out. Their success shows that it is highly advantageous to enforce higher building standards in Barbados. It is therefore imperative that a training regime be mandatory in Barbados, as this will have a direct effect on the quality and security of the housing stock of Barbados. After discussing the Barbados National Building Code with Mr. Phillips, I next ask him what additions

<sup>28</sup> Roof Truss Anchor, <[http://www.brcwestindies.com/technical\\_manual.html](http://www.brcwestindies.com/technical_manual.html)>

<sup>29</sup> Grenville Philips emailed response February 2013

he would make to the new one. In response, he suggested replacing the roof connection detail (Fig 2.405B) with ones that uses truss anchors (see BRC web site),<sup>28</sup> and including a section on precast concrete.<sup>29</sup> These additions are both indicative of responding to new and improved building technologies. In the first case, one is improving the integrity of the roof structure through better structural connections utilizing the hurricane strap. In the second case, the other is including precast concrete. Precast concrete is also the addition of a newer building technology that has seen an increased use in the past ten years. This is especially so in the construction of the new housing units being provided by the National Housing Corporation which we will discuss further.

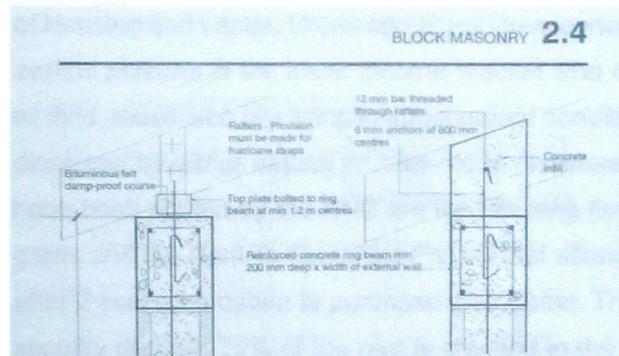


Fig.3.5. BNBC Fig 2.405B



Fig.3.6. Truss Anchor from BRC

<sup>30</sup> National Housing Corporation < <http://www.nhc.gov.bb/>>

<sup>31</sup> HELP Programme NHC < <http://www.nhc.gov.bb/>>

**List of Assisting Agencies and Organizations in Barbados**

- Barbados Association of Professional Engineers (BAPE)
- Barbados Institute of Architects (BIA)
- Caribbean Development Bank (CDB)
- Caribbean Disaster Emergency Management Agency (CDEMA)
- Coastal Zone Management Unit (CZMU)
- Department of Emergency Management (DEM)
- Ministry of Housing, Lands and Environment (MHLE)
- Ministry of Social Care, Constituency Empowerment, Urban and Rural Development or Country Assessment of Living Conditions (CALC)
- Nation Commission for Sustainable Development (NCSD)
- National Housing Corporation (NHC)
- Town and Country Development Planning (TCDP)

The list on the left shows some of the organizations who are involved in the re-housing program taking place around the island. The main organization we will focus on will be the National Housing Corporation (NHC) who is tasked with this issue of re-housing. The discussion of the NHC will give us a further understanding of the procedures in acquiring a home from the NHC, some of the issues that they face, how they are being dealt with and where my proposal will help in alleviating some of these issues.

The National Housing Corporation takes on the role from its predecessor organizations, which provided housing for the needy from 1936 to 1973. The NHC was formed in 1973 and has continued to provide housing for the needy as it evolved over the years. The NHC is a Government run institution by the Ministry of Housing and Lands, Urban and Rural Development (MHLURD). Today the NHC assists persons in the lower income bracket who either do not own a home and/or land, those who are living in substandard conditions and those who have been displaced by either natural or man-made disasters.<sup>30</sup> Some of the programs that have been started by the NHC are the Housing Every Last Person (H.E.L.P) program, and the Rent To Own Pilot Project that allows those who have been renting after 7 years the option to purchase their home. This is done where the 2 months security deposit, 70% of the rent is credited to the purchase and 30% of the rent goes towards the NHC to cover maintenance, insurance and other charges.<sup>31</sup> If the tenant is unable to complete the sale then further time is allotted in order to accommodate the tenant.



Fig.3.7.NHC Logo

<sup>32</sup> Minimum wage in Barbados <[http://www.gisbarbados.gov.bb/index.php?categoryid=15&p2\\_articleid=7805](http://www.gisbarbados.gov.bb/index.php?categoryid=15&p2_articleid=7805)>

<sup>33</sup> National Housing Corporation <<http://www.nhc.gov.bb/>>

**Currency Exchange Rate:** \$2.00 BBD = \$1.00 USD approximately

In an average case for a potential tenant to obtain a home and land in the Rent-To-Own programme the tenant must be employed and earning no more than \$3000.00 BBD per month which is at the higher range of the low income bracket in Barbados. The minimum wage in Barbados is \$1000.00 BBD per month.<sup>32</sup> In some cases loans may be given by local banks to assist the tenant through the NHC. An application is submitted by the potential tenant for eligibility to the NHC office. Once the tenant satisfies the requirements they are put on to a wait-list in order to be housed. The NHC also works in cooperation with the local private sector where the NHC employs both small and large construction firms to construct the housing units.<sup>33</sup> In recent times the NHC has been obtaining funding from international financial institutions such as the Caribbean Development Bank (CDB) and other similar agencies in order to finance some of their building schemes. The NHC housing programs consist of starter homes, 1, 2 and 3 bedroom houses and

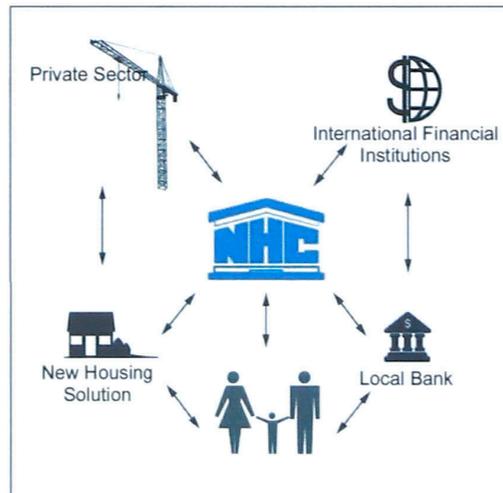


Fig.3.8. The NHC housing system cycle

<sup>34</sup> National Housing Corporation < <http://www.nhc.gov.bb/>>

<sup>35</sup> Lanette Napoleon-Young meeting at NHC January 2013.

infrastructure to the sites. The cost of the starter homes through the NHC are in the range of \$85,000.00 to \$190,000.00 BBD with some over \$200,000.00 BBD and these unit sizes range from 536 ft<sup>2</sup> to 836 ft<sup>2</sup>. Most recently the NHC has started to provide high-rise housing as well within the core and the periphery of Bridgetown. One of the issues raised by the NHC was the difficulty in obtaining land for housing where obtaining accurate land ownership information posed a challenge. An example of this is in cases where disputes among family members over who rightly owned the land being willed to them hinders the building process.<sup>34</sup> This and other similar instances are some of the causes that slow down the purchasing of land for new housing projects. At present there is a backlog of approximately 15,000 persons who are waiting to be housed. Even though within the last 5 years the NHC has produced over 1,500 new housing units and two high-rise towers, there has still been a large backlog providing for those in need of adequate housing.<sup>35</sup> My proposal will work with the NHC and address the issues they have been having by providing an alternative housing solution. The proposed housing solution can be produced using a high percentage of locally renewable building material that will meet or exceed the rate of construction time with improved adaptability, comfort and protection.

**Starter homes provided by the NHC**



Fig.3.9. Two Bedroom starter home



Fig.3.10. One Bedroom starter home

The NHC has been trying to facilitate the provision of land and housing units even though they admit there have been challenges in providing land in some areas of the island. It is understood, however, that the NHC has obtained lands in the northern and southern parts of the island. This land acquisition will assist them in meeting some of their re-housing goals. It is also very important that, as they continue to produce these housing units they also continue to oversee and regulate the building practices of the construction of these units in order to ensure that they meet required building regulations. At present many of these housing units are produced with new building systems, such as precast concrete and as mentioned earlier the most recent building code has not caught up with such building practices. This is also why it is so very important that building supervisors and building artisans alike be properly trained in building construction so that they are able to correctly use these new building materials and systems. With my proposal the use of a method for re-evaluating the finished product after one year of occupying the house is also key to refining the housing solution, especially those that are being produced on a mass scale. This will be discussed further as to the positive aspects that can be obtained from this.

<sup>36</sup> Lanette Napoleon-Young meeting at NHC January 2013.

### Experimental Post Occupancy Evaluation (POE) Housing Survey

**Post Occupancy Evaluation (POE)** -involves a systematic evaluation of buildings being occupied usually from those who use and occupy them. It evaluates how well the buildings satisfy the user's needs and identifies ways in which to improve the building design, performance and suitability.

Source: <[http://www.postoccupancyevaluation.com/case\\_studies/default.shtml](http://www.postoccupancyevaluation.com/case_studies/default.shtml)>

In an interview with the manager at the NHC Mrs. Lanette Napoleon-Young, when asked if the NHC carries out any POEs after one year of completion of their housing projects she had responded that at this time the NHC does not carry out any formal POEs. When asked if the NHC plans to carry out POEs in the future she responded that the NHC does intend to carry out POEs in the future.<sup>36</sup> After being made aware of this I undertook an experimental POE on a number of housing units across the island. The POE form that was designed was called a Residential Performance Evaluation (RPE) and consisted of 23 questions. Those being surveyed were given anonymity and were made aware that this was for research purposes and was not an official survey which was optional. The survey could be completed in approximately 5 to 10 minutes. The first section of the form contained contact information and basic descriptions of the type of home and number of occupants in the home. The second section rated the home on its perceived performance and overall satisfaction. The rating scale used was as follows: [Poor=1 Fair=2 Good=3 Very good=4 Excellent=5]. The areas rated were the exterior grounds of the lot, the facades of the building, all of the internal spaces of the building where sound quality was also rated, windows and doors, security, lighting, electrical, plumbing, internal finishes and adequate hurricane, rain, flood and earthquake protection. The last section allowed for further comments if necessary. The question usually asked here were if any further future expansions or alterations to the building were intended.

<sup>37</sup> Experimental Post Occupancy Evaluation conducted in January 2013

After compiling all of the data from the survey from over 25 participants it was found that there were some areas that may need to be explored further in order to fine tune the survey. The survey was done externally from the NHC and therefore a closer collaboration with the NHC would also help to fine tune this survey. It was thought however to make an attempt as a trial that will help to provide relevant feedback which could be provided to the NHC as possible starting points. In doing so this survey would then be further developed and refined for the specific environmental and climatic context of Barbados. Some of the more common responses which resulted from this survey were as follows:

The general responses to the exterior facades were rated good with the bedrooms on average rated between fair to good. There were some comments on some previous plumbing issues where toilets and faucets had malfunctioned. Some other comments were some windows towards the windward side showed heavier wear and tended to leak during a rain storm. An area also discussed was related to the jointing between precast wall units that showed some surface cracks which were more of an aesthetic issue. The overall concern for security and confidence in the structure to withstand a moderate natural disaster was rated good.<sup>37</sup> These were some of the overall areas that were more popular which with a more refined survey with a larger survey base would help to give an even clearer picture as to the areas of concern. This exercise however was a good test where as mentioned earlier shows good potential and could be used in the future to help inform the NHC and those designing and building the starter homes which areas could be further refined. It is important that a POE be carried out especially on housing units which are being mass produced as this too can help to refine the housing units for the future.

**Starter Home:** A starter home is a housing unit that is of relatively small floor area that comes with the basic necessities for housing. It is intended to be lower costing, easier to obtain for first time home owners who fit certain requirements as first time low income earners and is designed with the intention that the occupants may make further upgrades and expansions on their own to the unit in the future with the necessary permits.

The following four housing projects are located around the island and will be explored by highlighting some of the new starter homes and low to middle income housing units. These examples employ new building systems, with some traditionally influenced and more contemporary housing designs. They will be critically analyzed for their favourable or less favourable characteristics, and will be assessed for their contribution to the improvement of the vulnerable housing stock of the island. In doing so this will aid us in charting the possible future direction of housing solutions for Barbados, and in turn this will help to inform this thesis on the development of a future design proposal for new housing solutions.

### Location Map

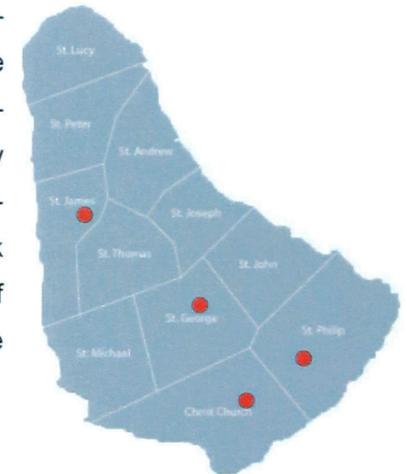


Fig.3.11. Locations of housing projects across Barbados

**Information**

Housing type: Apple Blossom  
 Floor plan options: 1  
 Cost approx.: \$332,000.00 BBD  
 (approx. \$167,000.00 USD)  
 Floor area: 1008 ft<sup>2</sup> (93.64 m<sup>2</sup>)  
 Material: Precast- Hollowcore pre-  
 stressed concrete, timber frame roof



Fig.3.12. Floor plan



Fig.3.13. Three Bedroom starter home

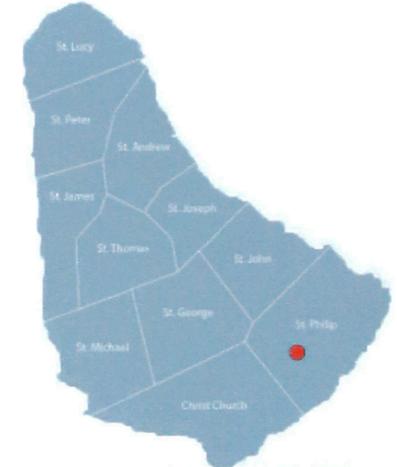


Fig.3.14. Location of Emerald Park, St. Philip

source: <http://www.caribbeanhomesltd.com/index.php?RootSection=3&Section=12&ParentSection=3&Seq=7>

floor plan source: [http://www.caribbeanhomesltd.com/SiteAssets/APPLE\\_BLOSSOM\\_LEFT\\_BROCHURE\\_FLOOR\\_1.jpg](http://www.caribbeanhomesltd.com/SiteAssets/APPLE_BLOSSOM_LEFT_BROCHURE_FLOOR_1.jpg)

This housing unit is constructed of modular pre-cast concrete walls and hollow core pre-stressed concrete floor slabs with timber framed roof. In this case it is lifted two storeys above the ground with the lower level left open. This system is very useful in this type of starter home because it gives the resident the option to convert the lower level into a garage or apartment at a later date. The successful qualities in this design are: its ability to reduce the chances of flooding of the upper level considerably, future expansion, good ventilation for the upper level, and the use of the high columns or piloti allow the building to sit more evenly on an uneven site. In this example the site does not have a drastic gradient, and the need to elevate the house is with the intension to develop the lower section in the future. The windows may still be vulnerable to storm force winds without added protection.

**Information**

Housing type: Contessa  
 Floor plan options: 1  
 Cost approx.: \$193,800.00 BBD  
 (approx. \$96,900.00 USD)  
 Floor area: 556 ft<sup>2</sup> (50.0 m<sup>2</sup>)  
 Material: Precast- Hollowcore pre-  
 stressed concrete, timber roofing

source: <<http://www.caribbeanhomesltd.com/index.php?RootSection=3&Section=12&ParentSection=3&Seq=7>>

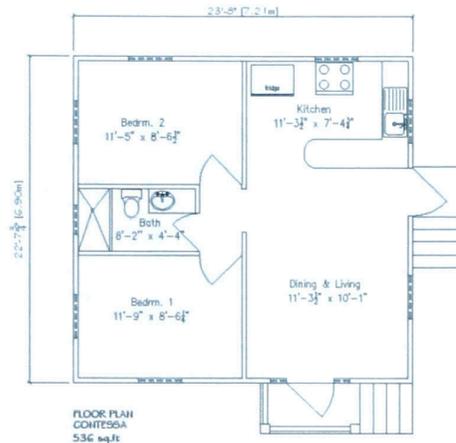


Fig.3.15. Floor plan



Fig.3.16. Two Bedroom starter home

This housing unit is constructed in a similar fashion to example 1. The building is supported by four concrete columns connected to a concrete ring beam elevated above the ground.

The use of precast concrete in the building's construction increases its performance compared to traditional building materials of wood and moderately so for concrete block if subjected to fire and hurricane force winds. It has a seismic loading performance that is satisfactory if the adequate connections and adherence to the use of seismic code requirements (again the current building code may need this area updated). The elevated floor in the event of a flood will help to reduce the chance of internal flooding. With adequate hurricane straps as these units were required to have and a reduced eave over hang which can be seen in the image there is less vulnerability to uplift due to storm force winds. Small roof over front entry may be vulnerable to uplift in storm force winds. Further window protection may be needed in order to reduce the risk of flying debris during storm force winds.



Fig.3.17. Location of Drax Hall Green, St. George

3 housing options



Fig.3.18. Housing options for Sugar Cane house type

Information

Housing type: Sugar Cane  
 Floor plan options: 3  
 Cost: \$289,300.00 BBD  
 (approx. \$144,650.00 USD)  
 Floor area: 804 ft<sup>2</sup> (74.69 m<sup>2</sup>)  
 Material: Precast- Hollowcore pre-stressed concrete, timber roofing

source The villages at Coverley <<http://villagesatcoverley.net/residences/the-homes>>

The construction methods of this building are similar to examples 1 and 2, with some obvious design changes. The housing unit sits lower to the ground where the building envelope sits flush to the ground level which may make this home more vulnerable to flooding however, the sloped gradient away from the building may help with drainage. The roof is of timber construction with little to no eave overhang which may help reduce the risk of uplift during storm force winds. The windows are of good quality but there may be a lack of storm proofing where there is exposed glass. One design limitation is the lack of option for expansion as this is against the regulations of the community plan stipulated by its covenant. This, however, is the only housing type that may be classified differently than a starter home.



Fig.3.19. Location of The Villages at Coverley, Christ Church



Fig.3.20. Sugar Cane house type



Fig.3.21. New expandable starter home

**Information**

Housing type: 1 Bedroom

Floor plan options: 1

Cost: \$165,000.00 BBD  
(approx. \$82,500.00 USD)Floor area: 476 ft<sup>2</sup> (44.0 m<sup>2</sup>)

Material: Precast- Hollowcore prestressed concrete, or cast in-situ concrete, concrete block and wood panel and timber roofing

source: NHC <<http://www.nhc.gov.bb/>>

This housing unit is built of concrete blocks and wood panels with cast in-situ or precast concrete floors. This small unit sits on a steel reinforced, solid filled, concrete block foundation wall. The two side exterior walls are also made of alternating, solid filled, concrete block and the front and back facades are made of wood siding panels inserted within a concrete structural frame. The roof is a gabled roof with projected eaves and wood trust frame support. The orientation of this particular unit on an inclined slope, which allows for good drainage minimizing the chance of flooding. The roof eaves do extend past the structure, which may be susceptible to uplift in high winds. In addition, the front and rear wood panels may be vulnerable to flying debris during high winds as well. However, the front and rear panels do offer the flexibility of future expansion. This is one of the most recent adaptations made by the NHC that offer expansion to the front and rear.



Fig.3.22. Location of Lancaster Phase 2, St. James

## Local Illustrated Examples

## Chapter 3

These local examples are some of the more recent housing solutions that have been used by the NHC to improve the living quality and lower the susceptibility to natural disasters. Some of the more successful features we observed were the elevated structure allowing the expansion to take place on the lower level, the use of precast structures, elevated foundations to reduce the chance of flooding, minimal eave overhangs to reduce the chance of uplift and expandable facades front and back. Some of these examples will be used to help inform this thesis. In the next chapter we will look at my proposal and how it will help alleviate the re-housing issues and the vulnerable housing stock through a pre-emptive approach.

**Growing Architecture: Project Proposal**

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Fig.4.0. South Coast Barbados

Proposal

**Pre-emptive:** doing something or taking action to stop an unwanted act or perceived threat from happening.

The proposal is to reinterpret local traditional building methods together with the implementation of a technology which has been used for coral reef restoration and apply it to growing coral housing units to aid in the re-housing effort that the NHC is doing. The technology that will be used in this process is known as Biorock™. We will explore what Biorock™ is, some of its recent applications, and how and where this technology will be used in the proposal. The proposed designs will illustrate this new use of the Biorock technology to provide housing for those who are in need. Two sites will be used, one will be the site of a local fishing complex for growing and harvesting these housing units and the second site will be used as a case study to show the application of this housing unit within the local context. This will allow us to explore the process of how this coral housing unit works and what it can offer as a pre-emptive approach to improving the local housing stock.

<sup>38</sup> Global Coral Reef Alliance <<http://www.globalcoral.org/Biorock%20Mineral%20Accretion%20Technology.htm>>

<sup>39</sup> Seacrete Green-trust.org <<http://www.green-trust.org/seacrete.htm>>

<sup>40</sup> Biography WolfHilbertz.com <<http://www.wolfhilbertz.com/>>

<sup>41</sup> Ibid

<sup>42</sup> Ibid

<sup>43</sup> Ibid

<sup>44</sup> Ibid

<sup>45</sup> Ibid

<sup>46</sup> Ibid

Electro- Accretion, also known as Mineral Accretion Technology or the Biorock process, is a patented marine technology used to create what is called Seacrete.<sup>38</sup> The term “Seacrete” is the name given to the result of the Biorock process. This process of growing seacrete of Biorock is a relatively new technology intended to be an alternative construction material with similar mechanical strength to concrete.<sup>39</sup> This technology was invented by Wolf Hilbertz and Dr. Tom Goreau during the early 1970s.<sup>40</sup> Hilbertz was a German-born futurist architect, inventor, marine scientist, and Professor. He has taught at a number of universities including the University of Texas, Southern University, and McGill University.<sup>41</sup> It was at the University of Texas that Hilbertz first set up and eventually founded the Responsive Environments Laboratory in order to explore the automated creation of the built environment.<sup>42</sup> Several years later his focus shifted to the construction of underwater structures using a method similar to that of living corals.<sup>43</sup> It was the many experiments done in this area of research that created the material used known today as seacrete or Biorock™.<sup>44</sup> With this he went on to found and cofound a number of organizations and laboratories including The Symbiotic Process Laboratory, Marine Resources Co., Biorock Inc., and the Global Coral Reef Alliance just to name a few.<sup>45</sup> He has lectured and conducted hands-on workshops around the world on his work. He is also the author of several US and international patents, and in 1998 he and his colleague Dr. Thomas Goreau were awarded the Theodore M. Sperry Award for Pioneers and Innovators, which is the highest award of the Society for Ecological Restoration.<sup>46</sup>



Fig.4.1. Biorock reef restoration



Fig.4.2. Biorock reef restoration

<sup>47</sup> Wolf Hilbertz, *Electro-Accretion: Grow Shelters from Sea Minerals*, 1987 <[http://www.google.ca/url?sa=t&rct=j&q=electro-accretion%20gorw%20shelters%20from%20sea%20minerals&source=web&cd=3&cad=rja&ved=0C-DwQFjAC&url=http%3A%2F%2Fwww.wolfhilbertz.com%2Fdownloads%2F1987%2Fhilbertz\\_el\\_accretion\\_1987.pdf&ei=t7Fl-Uc6COuSJ2AWqmYDwBw&usg=AFQjCNH2eOmYaSM2maY1JgBrIn7gOI9Q-CA&bvm=bv.43828540,d.b2l](http://www.google.ca/url?sa=t&rct=j&q=electro-accretion%20gorw%20shelters%20from%20sea%20minerals&source=web&cd=3&cad=rja&ved=0C-DwQFjAC&url=http%3A%2F%2Fwww.wolfhilbertz.com%2Fdownloads%2F1987%2Fhilbertz_el_accretion_1987.pdf&ei=t7Fl-Uc6COuSJ2AWqmYDwBw&usg=AFQjCNH2eOmYaSM2maY1JgBrIn7gOI9Q-CA&bvm=bv.43828540,d.b2l)>

<sup>48</sup> Global Coral Reef Alliance <[http://www.globalcoral.org/frequently\\_asked\\_questions.htm#Where are Biorock reefs in operation](http://www.globalcoral.org/frequently_asked_questions.htm#Where%20are%20Biorock%20reefs%20in%20operation)>

<sup>49</sup> Ibid

Hilbertz had proposed using his Biorock technology to grow homes, ships, pipelines, piers, reefs, structural members for large buildings, and artificial islands for half a million people.<sup>47</sup> Over the years Hilbertz had focused his attention on learning more from this relatively new technology through his reef restoration programs. At present the Global Coral Reef Alliance started by Hilbertz and Goreau is a non-profit, Non Governmental Organizations (NGO) which uses the Biorock technology for growing, protecting and managing vulnerable coral reefs against marine diseases, physical destruction, and other issues caused by global climate change through reef restoration.<sup>48</sup> In this was Biorock's influence can be seen as touching both natural and structural scenarios.

The Biorock process as described by Hilbertz,

uses low voltage direct current electricity to grow solid limestone rock structures in the sea and accelerate the growth of corals providing homes for reef fish and protecting the shoreline. The electrical current causes minerals that are naturally dissolved in seawater to precipitate and adhere to a metal structure. The result is a composite of limestone and brucite with mechanical strength similar to concrete. Derived from seawater, this material is similar to the composition of natural coral reefs and tropical sand beaches. This patented process increases the growth rate of corals well above normal, giving them extra energy that allows them to survive in conditions that would otherwise kill them. At the same time these structures attract huge numbers of fish, and also provide breakwaters that protect the shore and get stronger with age. Biorock reefs, with their lush coral swarming with fish, have become major ecotourism attraction.<sup>49</sup>



Fig. 4.3. Biorock electro-accretion process



Fig. 4.4. Biorock™ sample

<sup>50</sup> Bio of Ortega <<http://cac.mcgill.ca/home/archive.php?ID=35&letter=o>>

<sup>51</sup> Bio of Ortega, <http://cac.mcgill.ca/home/archive.php?ID=35&letter=o>

<sup>52</sup> Basic Technology: Mineral Accretion for Shelter. Seawater as a source for Building. Pp. 62. <<http://www.globalcoral.org>>

<sup>53</sup> Ibid

<sup>54</sup> Alvaro Ortega, <<http://www.globalcoral.org>> low cost technology>

<sup>55</sup> Basic Technology: Mineral Accretion for Shelter. Seawater as a source for Building. Pp. 62. <<http://www.globalcoral.org>>

The Biorock process has also been seen by others to have possibilities as a building material, Alvaro Ortega is one of those who believes strongly in its potential.

Basic Technology: Mineral Accretion for Shelter. Seawater as a source for Building:

Alvaro Ortega was a Columbian Architect (born in 1920 and died in 1991), who studied architecture at McGill University and then later at Harvard University in the 1940s.<sup>50</sup> Ortega was heavily invested in modernism greatly influenced by Marcel Breuer and Walter Gropius. He developed an architecture that attempted to merge the art of design with the art of engineering.<sup>51</sup> He was a world renowned expert on low-cost building materials and technology mainly for housing. He was also an advisor to the United Nations in this area for those in less developed countries.<sup>52</sup> He expressed that it was important that architects who are interested in improving housing for the world's growing population combine their research and skills with the scientific community in order to use natural resources for housing.<sup>53</sup> This was because he had observed that there were two resources not yet fully utilised for the production of building materials: those from volcanoes and those from oceans. In an article in MIMAR 31 it was proposed that sulphur resulting from volcanic activity and mineral accretion of seawater be used as a building material. He firmly believed Mineral accretion (Biorock technology) was a resource for low-cost materials and an exciting possibility for providing better human shelter.<sup>54</sup> He thought there should be more attention given to the usefulness of this technology to help reduce building costs and help promote the use of natural resources.<sup>55</sup> The

experimentations by Wolf Hilbertz with his Biorock technology were highly promoted by Ortega, who commented on the use of this technology for creating water tanks for aquaculture, the formation of artificial reefs, and the use of implementing this technology to roof structures in order to bring construction costs down.

These are just some of the examples for which Ortega saw the use of Mineral Accretion through the Biorock technology. The progress made with biorock™ in reef restoration and shoreline defence shows the great potential it may have as a building material. It is important that it become a part of the building process as it is an abundant renewable resource which society can benefit from in many ways. As technology has advanced considerably since the early days of using this technology it is time that it be used to enhance the built environment in other ways especially as an option for building shelters in Barbados. My proposal expands on the use of this technology and utilizes its great potential as a building material to help produce locally inspired housing solutions which offer many benefits to the island.

How the Biorock Process will be implemented in Barbados:

The coral housing units are first constructed out of a recycled steel mesh. They are constructed by trained builders that have completed a series of workshops which will help to educate and guide the process from preparation of the structural mesh frames to the submersion of these frames in an artificially created reef that will aid in growing these units. This will then be followed by a selective harvesting, or removal, of these newly grown coral housing units within a 3 to 6 month period. Harvested frames will be replaced by new frames ready for submersion. The housing units will be prepared near to the landing site (i.e. fishing complex at Oistins Bay) and will then be taken to the building site for installation and completion. From there the frames will be ready to hand over to the new occupants.

Pilot Project:

The pilot project for this proposal will be situated off the south coast of the island at Oistins Bay in Christ Church. Oistins Bay is a town at the heart of one of the larger fishing communities on the island. This region has also experienced storm surges in recent times and the inclusion of this system in this area will aid in mitigating the effects of future storm surges. The local fishing community will also be included in the training and maintenance of these reefs and the submerged frames. The introduction of eco tourism to this area will help increase visitor numbers to the island and improve business within the area. This will help to bring a further awareness to the local community of this new building system, and as a result both the

community and the project will benefit. This will be due to more job creation, potential increase in fish populations, a better protected shoreline, and the production of a new source of locally produced and grown housing units.

**The Artificial Reef:**

The artificial reef provides protection for these frames as well as the electrical charge that stimulates the growth of the coral over these frames. When the housing units are removed the void space before it is refilled with another unit, it could be occupied for a specific length of time to teach diving classes or for research if necessary. The artificial reefs also create a habitat for the local fish population, provide protection from shoreline erosion and damage to nearby homes, which may be threatened by storm-surge.

**Workshops:**

Having workshops in the fishing village that will teach good building practices and training in using the new technology will help strengthen the connections between the community and the local authorities. Having more organizations or persons involved will result in further-reaching positive effects.

**Funding:**

Most of the funding will come from the local government through the NHC. Other contributions will be obtained from the local tourism industry by providing diving tours and training schools as well as some potential international and local investors.

The Coral Housing Units and their benefits:

The production of these housing units will help to reduce the number of those who are waitlisted for housing through the NHC. These housing units being produced of strong and durable material with high standards for the local and international building standards will benefit from a more resilient housing system. This in turn will contribute to lowering the risk of vulnerability of housing on the island. The benefits of producing these types of housing units will contribute to an improved up-to-date building code, an island wide training program providing good building techniques and standards, as well as training in the production and construction of these housing units. This results in a form of specialization.

Other Benefits:

The surrounding bay over the artificial reef would become a marine sanctuary which will help to increase the local fish population. A similar scenario to this was done in Jamaica in Bluefields Bay which shares some of the issues Barbados has also been affected within such as the introduction of the Lion fish which has been affecting the local fish population. Please see Appendix 1 and 2 for further reading on the Bluefields Bay project. With regards to eco tourism these artificial reefs and submerged growing coral housing units will be an attraction to visitors to the island and a similar example can be seen in Grenada where a local diver and sculptor Jason de Caries Taylor started the world's first underwater Aquatic Gallery that exhibits his underwater sculptures made from concrete and are used as artificial reefs. Please see Appendix 3 and 4 for further information on this example.

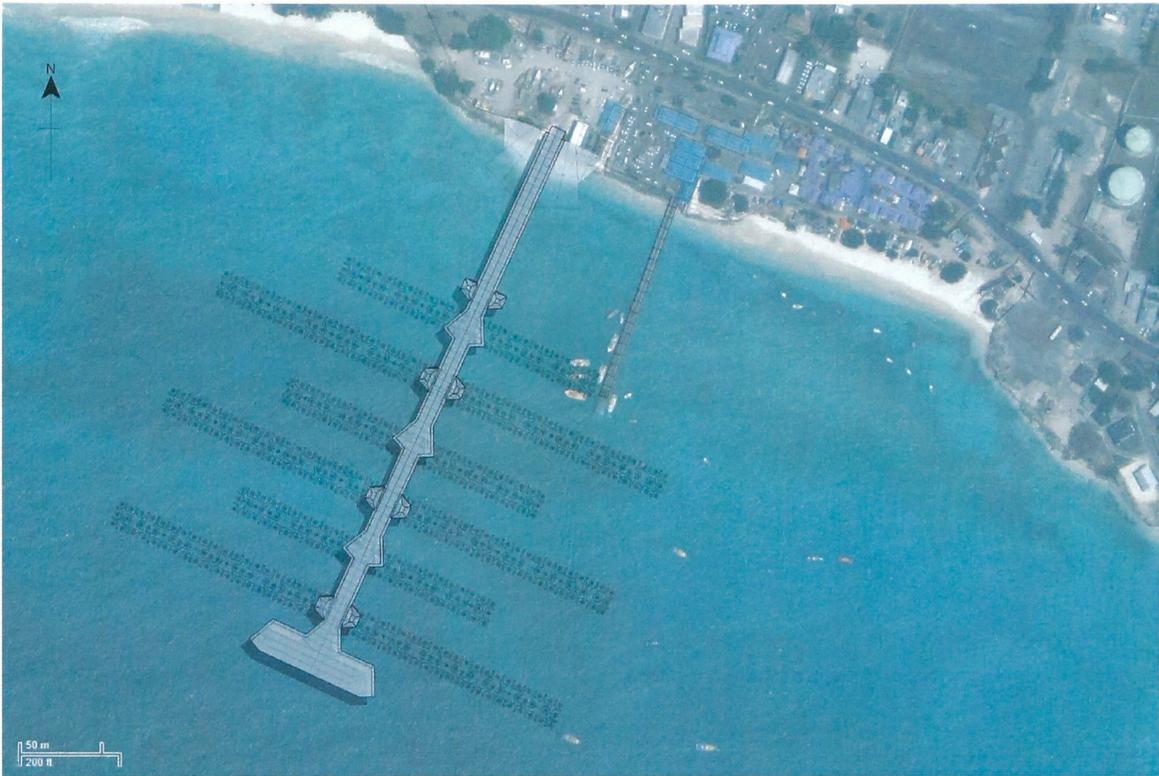


Fig.4.5. Site plan proposed jetty



Fig.4.9. Location of Oistins Bay Jetty, Christ Church



Fig.4.6. East view existing jetty



Fig.4.7. Existing jetty north view



Fig.4.8. West boat launch

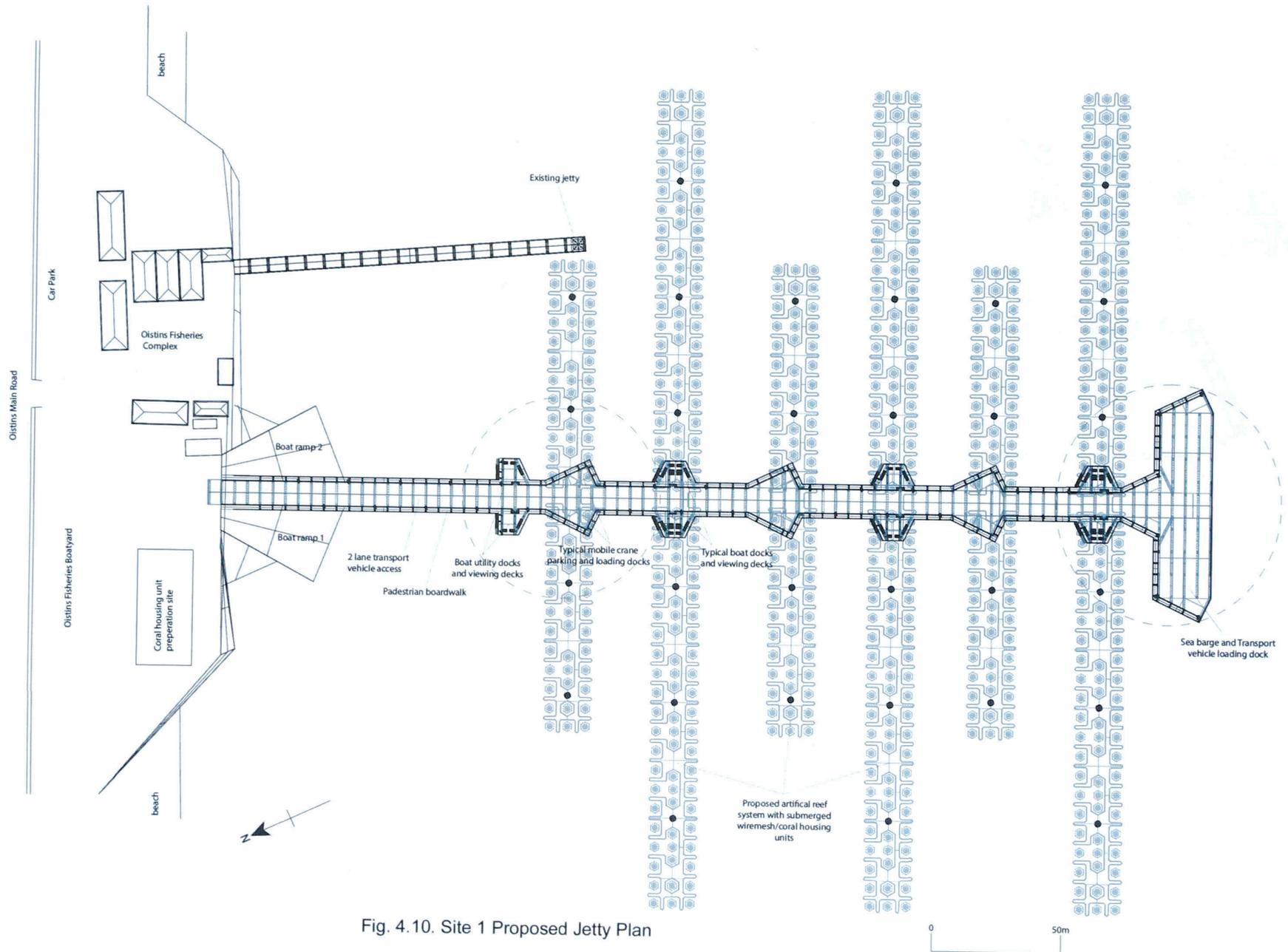


Fig. 4.10. Site 1 Proposed Jetty Plan

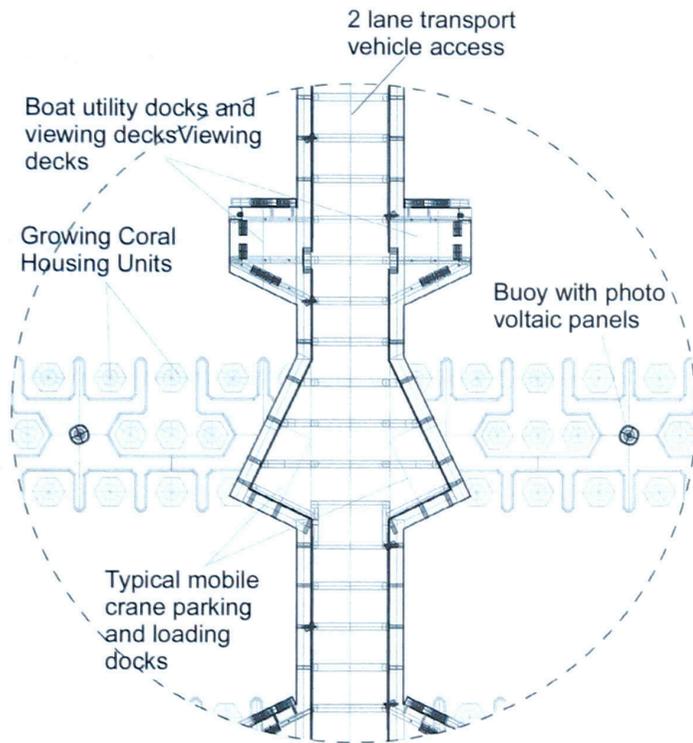


Fig.4.11. Enlarged Plan of Jetty 1st viewing deck

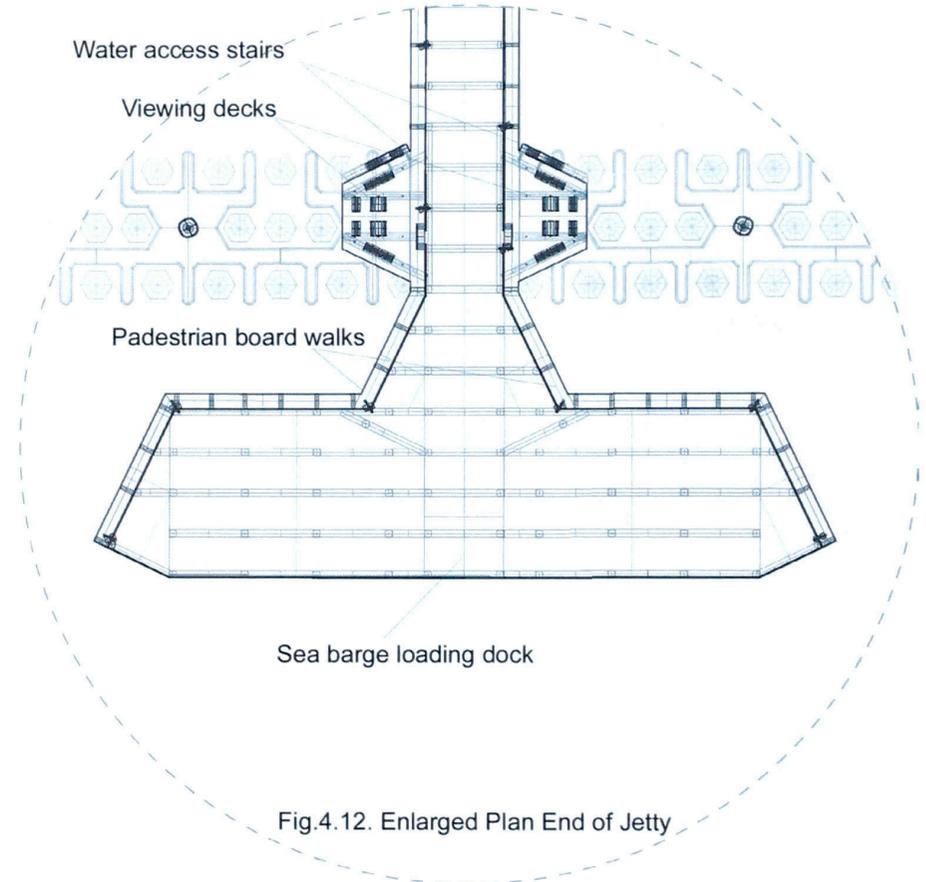


Fig.4.12. Enlarged Plan End of Jetty

0

50m

The artificial reef and how it works

The artificial reef consists of two modules the internal and the end. These modules are made of gation baskets of wire mesh filled with boulders and secured to the sea bed through piles as anchors. Floating buoys are anchored to the mesh of the gation baskets where a small D/C current is supplied to the mesh in order to start the Biorock process. The mesh becomes completely covered in layers of accretion creating a shell over this artificial reef. The pre-formed mesh of the coral housing units are lowered into their respective niches where they are secured by anchor chains to the reef and the units are attached to the D/C supply where the Biorock process begins to grow. When the accretion is complete within 3 to 6 months these fully grown coral housing units are harvested and are replaced by new units where the process is repeated.

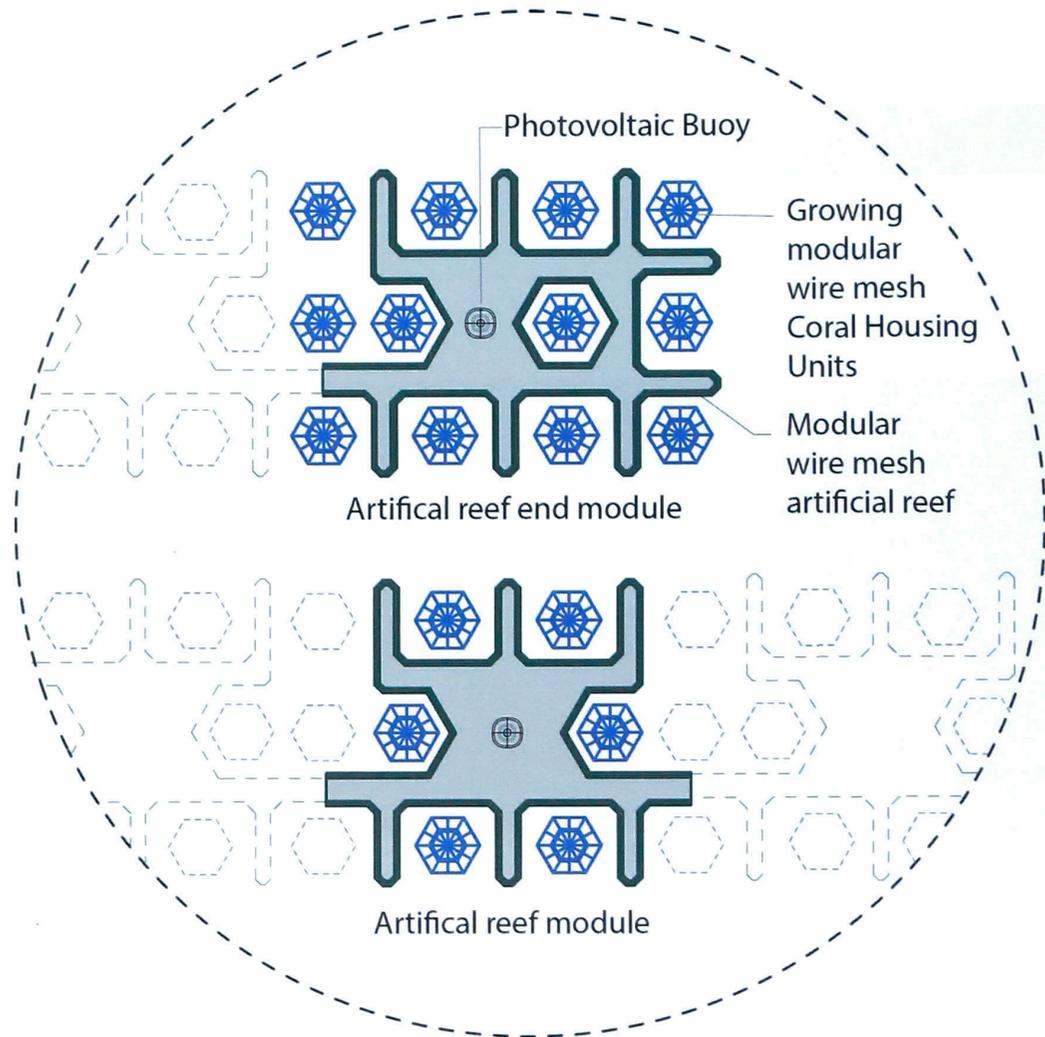


Fig.4.13. Typical internal and end of artificial reef modules



Fig.4.14. Jetty Section

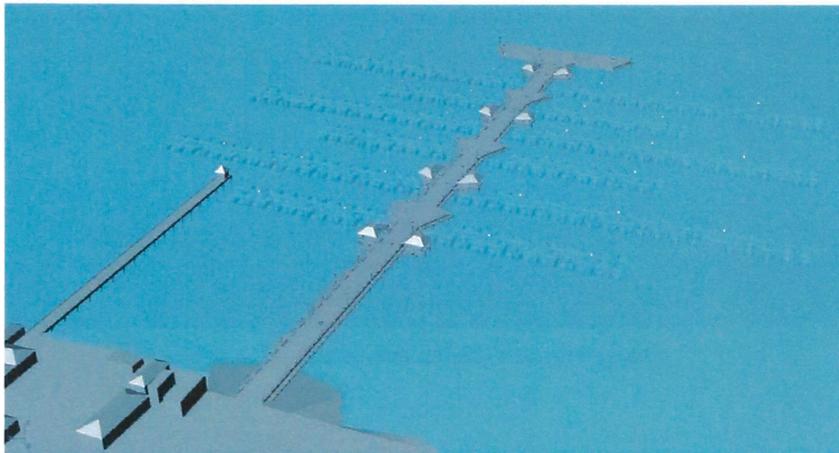


Fig.4.15. Aerial view of jetty

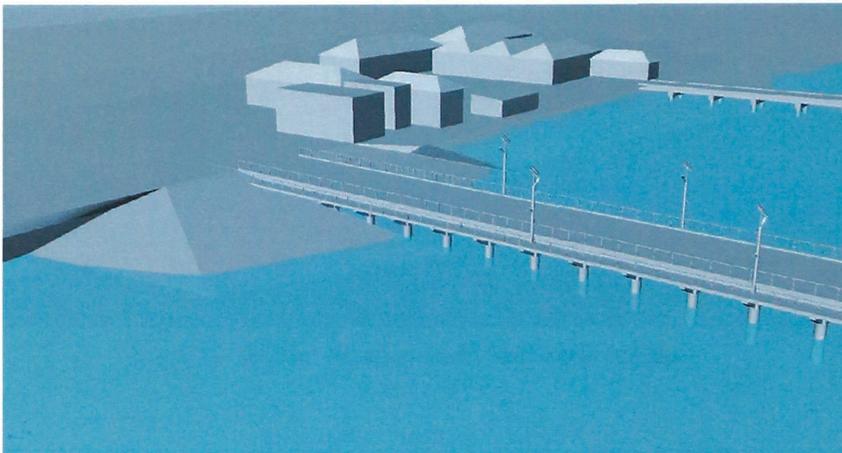


Fig.4.16. Boat Ramps

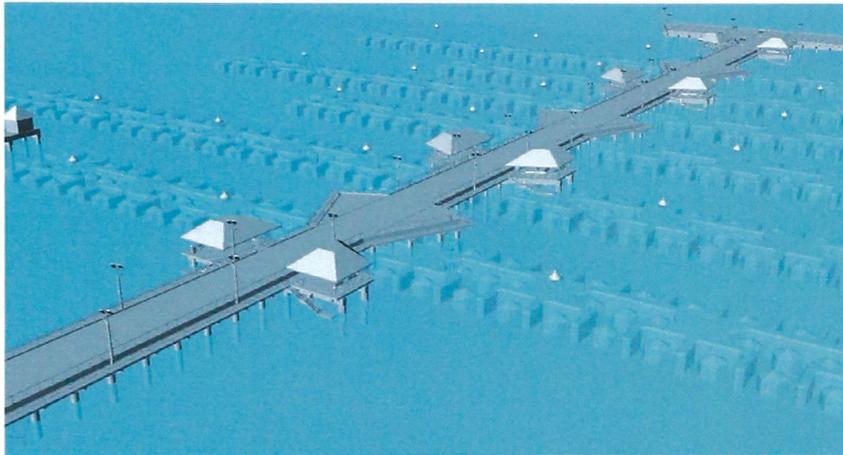


Fig.4.17. Aerial view of jetty and reef system



Fig.4.18. Service, viewing decks and water access

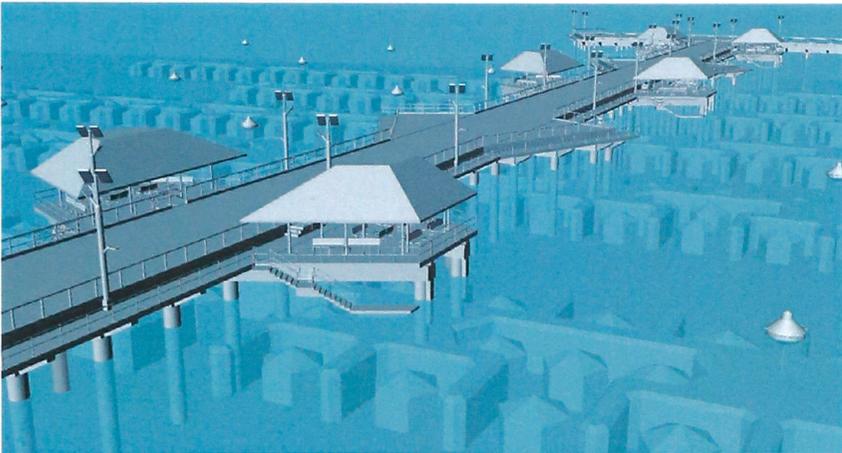


Fig.4.19. 2nd viewing decks over coral reef with growing housing units

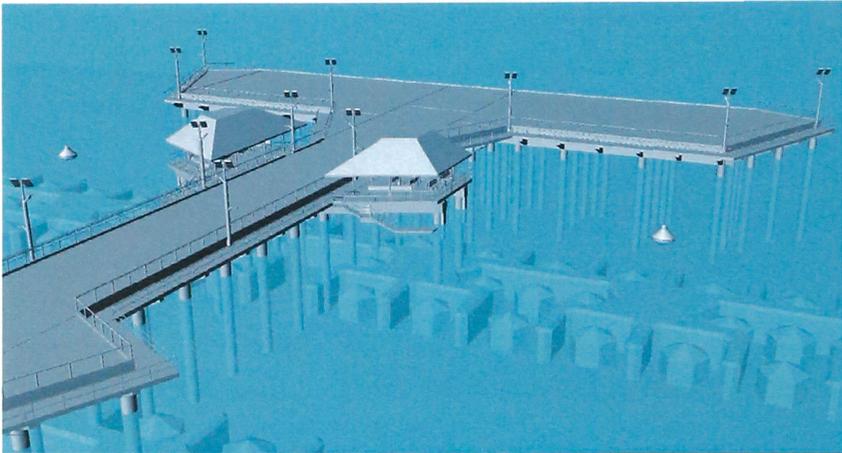


Fig.4.20. Mobile crane deck with 4th viewing deck and loading dock

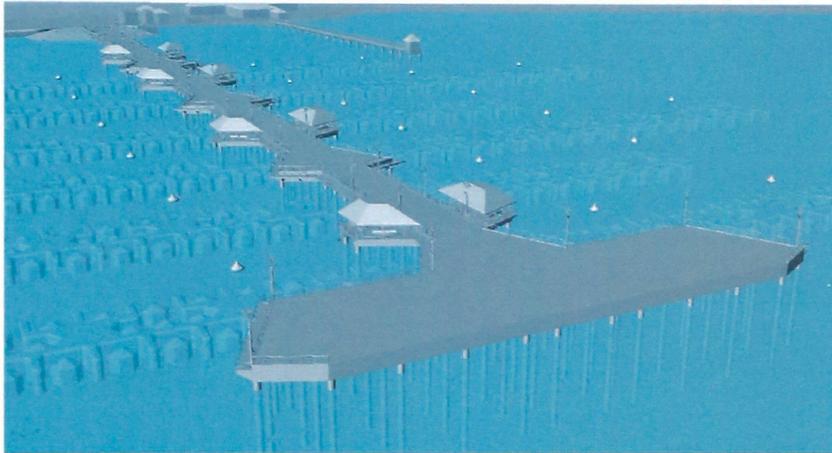


Fig.4.21. Loading dock and jetty looking north east

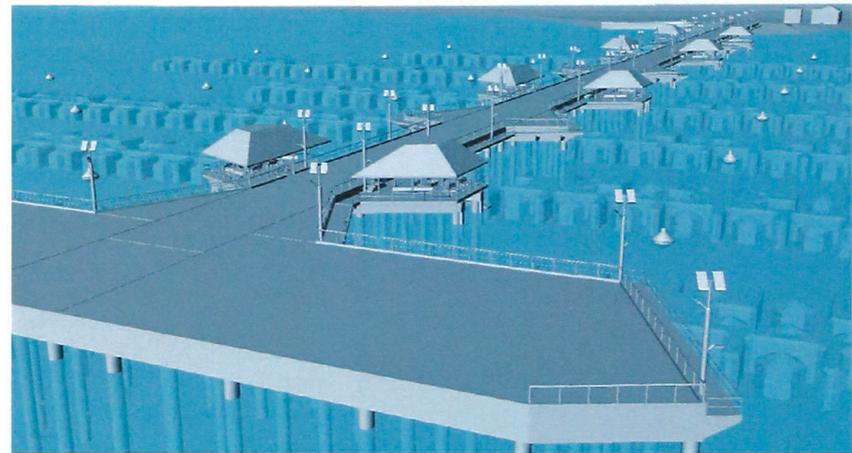


Fig.4.22. Close up of loading dock looking north to shore



Fig.4.23.Under water view of coral reef system with submerged growing coral housing units

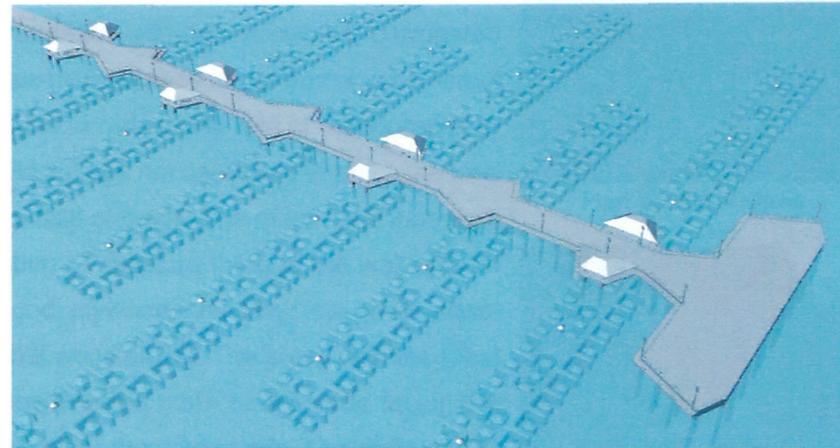


Fig.4.24.Aerial view of artificial reefs and all eight viewing decks

Judy's house was once a typical, well kept Chattel house in its time. It is located at Mahogany Lane, in Bridgetown, Barbados. This home has been a part of the local streetscape for more than five decades. In its prime it was one of the very proud features of the typical Barbadian streetscape, now it has seen better days.

The home consists of two wooden attached units of approximately 10 feet by 16 feet each, on a temporary rubble stone foundation with two connected, corrugated steel gabled roofs. However, over the years maintenance to the home has been of low quality and as a result has not been able to reduce the rate of deterioration to the structure. Judy has tried what she could but has not been able to make the kind of repairs she would have liked to due to a lack of funds. The quick fixes that were made with the attempt to stop the infiltration of moisture through the wall system were done by installing scrap sheets of wood, plywood, and other low-grade materials installed over the deteriorating external wood siding. The areas with the most repairs are those on the windward side towards the north east façade facing the street. It is also the same side that is exposed to the driving rain. The state of disrepair and lack of adequate maintenance has been a noted feature in some local news media and watchdog bloggers within recent years as the state of this home now represents a number of houses within the urban core that are very vulnerable and thus pose risk to property and human life in the event of a disaster. At the end of 2012 and beginning of 2013, government officials surveyed the home and made plans to demolish it because of its risk. It would be replaced with a more modern and secure structure.

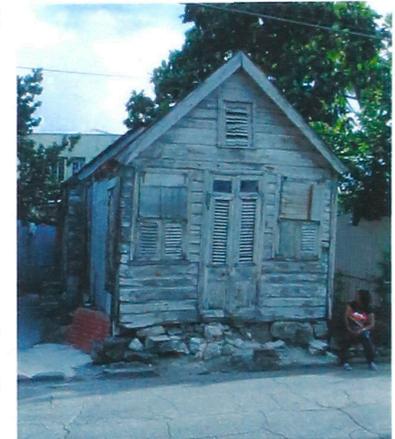


Fig 4.25. Judy's House

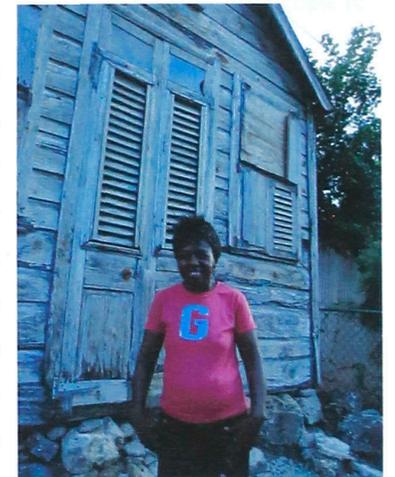


Fig.4.26. Judy



Fig.4.27. Inside Judy's House

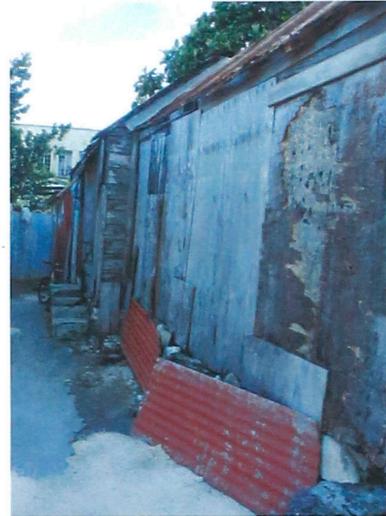


Fig.4.28. Quick fixes



Fig.4.29. Quick fixes



Fig.4.30. Judy's house on Mahogany Lane

<sup>56</sup> Urban Development Commission  
UDC <<http://www.udc.gov.bb/>>



Fig.4.31 Front east corner of Judy's House



Fig.4.32 Front west corner of Judy's House

This recent news does have a promising outlook for Judy, who may sooner than later, get the new home she wanted. These efforts have been spearheaded by the Urban Development Commission (UDC) a Government run organization that deals with the infrastructure and housing within the urban core.<sup>56</sup>

It is one of the ongoing struggles that the local Government is trying to combat and has been faced with many challenges due to the large number of people on wait-lists for new housing. This is why it is vital that we make the necessary attempts to try and help alleviate the high demand for housing put on the NHC. This is where my proposal will intervene in order to help remedy this issue.

The example of Judy's house shows the lack of maintenance and substandard building methods which are not up to today's international building standards. These are the major contributing factors which have led to this building becoming a hazard to the people and its environment.

The design proposal looks at providing a new housing solution for Judy where the existing structure is replaced with the new coral housing unit consisting of three housing pods shown in the design proposal. Some of the characteristics of the traditional Chattel house will be reinterpreted and used within this project. Some of these characteristics would include the angled side windows which offer better ventilation and views to the outside. The house is elevated above the ground to prevent flooding and offer better security. The roof and high level windows allow the hot air to rise keeping the interior cool. The design of the exterior walls which have small cavities also have an insulating benefit which helps to regulate the building's temperature at a comfortable level. The exterior folding shutters provide a sunshade but can be closed to give added protection to the window opening. These are just some of the areas that show improvements to the previous house.



Fig.4.33. Site Map Judy's House

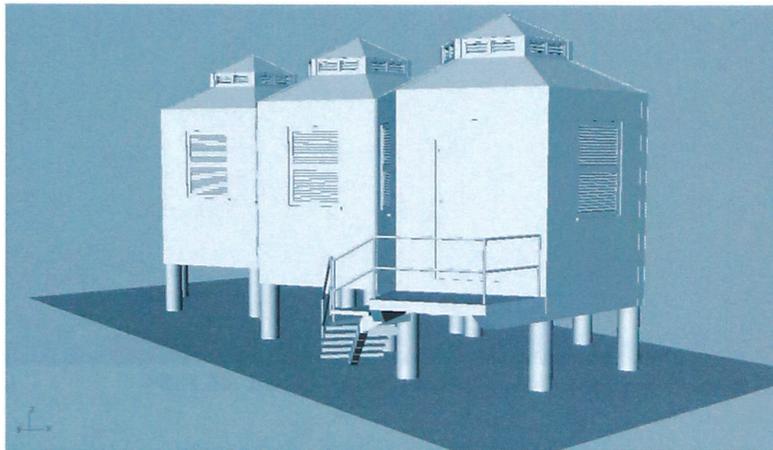


Fig.4.34. Perspective of Judy's proposed house.

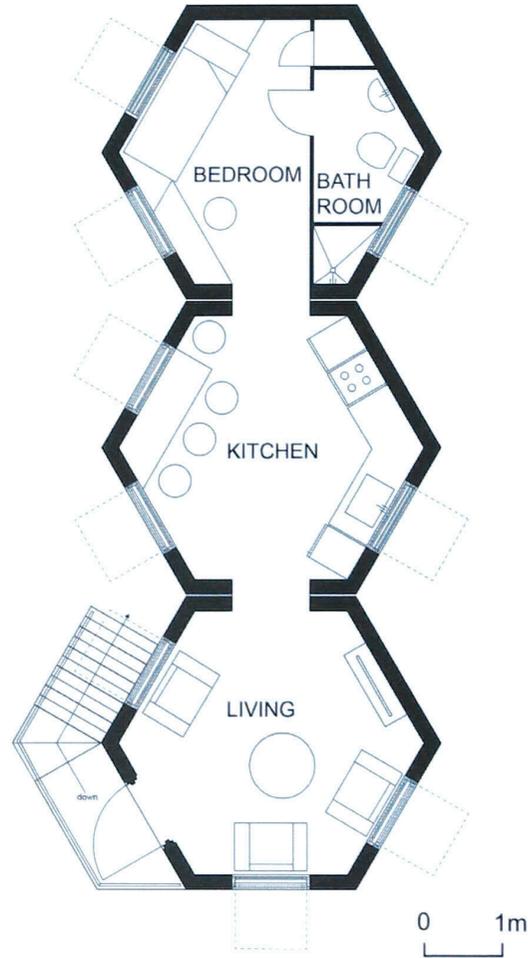


Fig.4.35. Ground floor plan

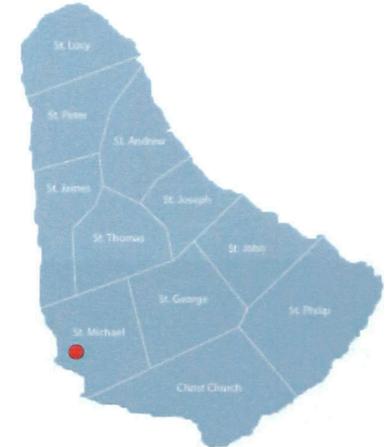


Fig.4.36. Location of Judy's house Mahogany Lane, Bridgetown



Fig.4.37. Judy's existing house

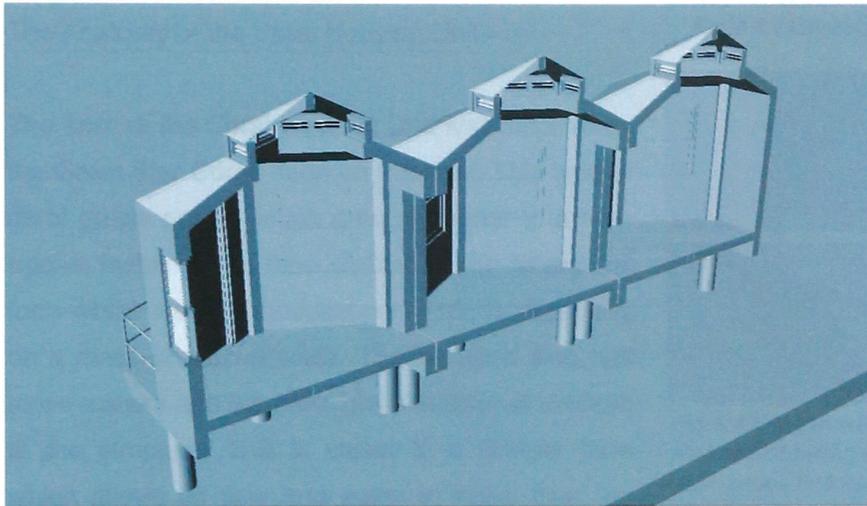


Fig.4.38. Sectional perspective of Judy's propose house



Fig.4.39. Perspective of structural skeleton



Fig.4.40. Hexagonal housing unit expansion stages

The Anatomy of the Coral Housing Unit

The form of the Coral Housing Unit was inspired by the Great Star Coral, seen on the right. This type of coral grows polyps which group together in a hexagonal fashion. This form distilled to the hexagonal form works well for modular connections especially on a mass produced scale. The hexagon also has more corners and therefore gives additional strength to the structure. This is closer to a circular form which allows air flow and water to move over the shape better with less restriction. This will allow the structure in the event of a natural disaster such as a hurricane, to withstand high wind speeds due to the shape. The expanding of this form from one unit up to seven units also gives it a high level of expansion and adaptability.



Fig.4.41. Great Star Coral

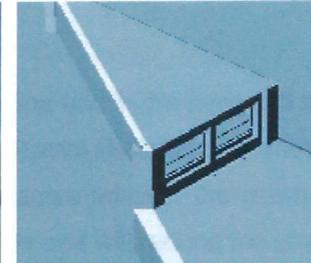


Fig.4.42. High level vent

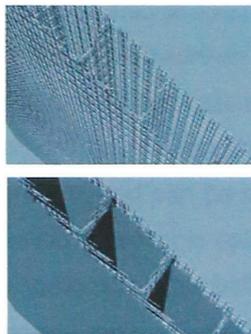


Fig.4.43. Mesh wall sections showing internal cavities before and after coral accretion



Fig.4.44. Typical coral housing unit module section

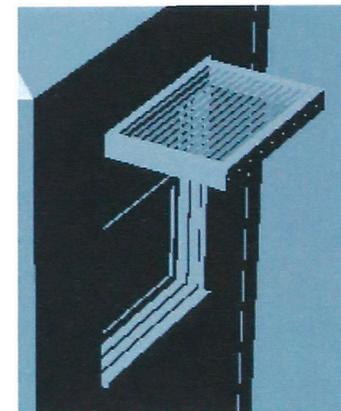


Fig.4.45. Double hung sash window inside and vertical folding sliding louvered shutter outside

The Anatomy of the Coral Housing Unit

The mesh that is pre-formed to the shape of the housing unit in the form of 3 inner mesh layers and 3 outer mesh layers makes up the internal skeleton or framework for the coral to grow. Once the coral has grown or accreted over the mesh this would be known as the skin. It is strong in compression and will reduce the chance of penetration of rain and objects impacting on the skin. The internal mesh also absorbs this impact. The mesh is also shaped to form the main structure which is part of the larger skeleton that can be seen on the previous page. This will also allow the units to be stacked vertically to create a second level. The floor is constructed in the same fashion and can be grown separately in the shape of a “T” slab. This method gives added strength and can be produced independently if needed. The main structure is supported by seismic columns. This is where the main connection points at the top of the column are bolted to the main structure using seismic connections. The windows which allow the building to breath, have an internal double hung sash window for air and sound control. The external window is a vertical folding, sliding louvered, shutter. This window can act as a sunshade and also be closed to reduce light and improve security and protection in a storm. Between what is called the sub roof or the lower roof and the crown roof, there are 2 small high level vents on each side of the roof which help to exhaust hot air and keep the air moving with the intent to cool the building. The external wall also has cavities which allow for the access of plumbing and electrical conduit. These are just some of the characteristics of the anatomy of the Coral Housing Unit.

## Conclusion

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The exploration of housing in Barbados and the vulnerability that still exists is alarming and made even more so in light of the natural disasters that continue to affect the world today. With the many issues of an inferior housing stock, the back log of persons in need of good housing, the lack of an up-to-date building code which is enforced by law are some of the main issues that continue to be a concern as was outlined in this thesis. Through observing the tried and tested housing design of the Bajan Chattel House which has locally informed, well adapted characteristics for the Barbadian climate. It was important to retain the essence of these design fundamentals and reinterpret them for the new housing solution of the future. This would be done through the use of the Biorock technology which has shown high potential as a building material. Therefore, the vulnerability of Barbados and its housing stock must be addressed. My proposal has demonstrated this in a number of ways. It looks at using a local material resource such as coral combined with the Biorock technology to provide housing. A new jetty is proposed which will be built in stages in order to do the first tests towards a new viable building program. The jetty proposed will provide access for transport vehicles and mobile cranes to implant these manufactured wire mesh units into the artificial reef to be harvested at a specific time. With trained workers producing these units the island will benefit tremendously. Some of the areas to benefit will be the increased job opportunities, rapid encouragement to publish a current building code which will be enforced by law, the implementation of POEs which will help to refine these housing units for the future, a boost for the economy in attracting visitors interested in eco-tourism, the creation of a marine sanctuary which will directly benefit the local fishing community, the provision of artificial reef systems which will help to

## Conclusion

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reduce the effects of storm surge and most importantly an improved housing solution that will reduce the vulnerability of the Barbadian housing stock. These all combined make the use of the Biorock technology a positive step forward. It is understood that further physical tests would have to be done on a small incremental scale within the Oistins Bay. These tests will help to fine tune and direct the building methods of this new experimental building procedure, which will need to have trials done in order to chart the best way forward. Together with the local fishing community the NHC and its partners, this could become a reality. Therefore it is important to make this pre-emptive approach where efforts could be made towards reducing the large number of those in need of good housing.

<sup>57</sup> Bluefields Bay <<http://philippajacks.co.uk/2011/01/the-fish-can-done-a-marine-sanctuary-project-in-jamaicas-blue-field-bay/>>

In Jamaica the local fishermen who depended on the local waters heavily on their means for survival were depleting the local fish stock due to the destructive fishing methods and compounded by the growing unemployment many locals saw this as their only option. By the mid 2000's Jamaica became the most over-fished country in the Caribbean. Evidence of this was seen in the local fishing community of Blue-fields Bay on the south-western coast. The drop in the supply of the local fish population also meant the local fishermen had to spend longer hours and travel further away from their village in order to meet their daily quota. The local agencies came together with the local fishing community to try and remedy this increasing problem. It was decided in 2009 by the Jamaican Government to create nine marine sanctuaries around the island. One area in particular was that of Bluefields bay. By obtaining this designation fishermen were then restricted from fishing within the designated bay in order for fish stocks to increase. This was encouraged by the local Government who employed the fishermen to upkeep and maintain the marine sanctuary.<sup>57</sup> Funds were also procured through tourists and local visitors to the area as well as the local hotel sector. These funds also went towards fueling, maintaining the boats and equipment as well as equipment for protecting and maintaining the local reef areas and boundaries. Within a few years the fish population began to rise to a healthy number which fishermen were then allowed to fish within the protected zone through the use of a more regulated and controlled manner. This helped to maintain the local fish population and increase its fish population to a healthy supply. More recently in 2011 further reef restoration and expansion was continued with the assistance of the Jamaican Government and the Canadian International Development Agency. The work was carried out by specialists from EcoReef Inc and the local fishing community. This consisted



Fig.A1.0. Bluefields Bay Jamaica

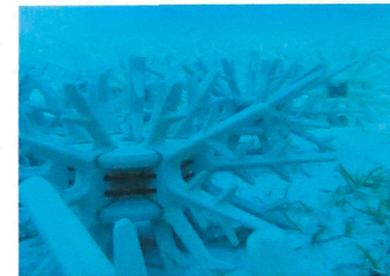


Fig.A1.1. Ceramic Artificial reef in Bluefields Bay Jamaica

<sup>58</sup> Eco Reefs: INSIDE IICA JAMAICA Newsletter July - October 2011, PG 2. <http://www.iica.int/Eng/regiones/caribe/jamaica/IICA%20Office%20Documents/Newsletters%20-%20Inside%20IICA%20Jamaica/IICA%20Jamaica%20Newsletter%20Q3%202011.pdf>

<sup>59</sup> Bluefields Bay <<http://philippajacks.co.uk/2011/01/the-fish-can-done-a-marine-sanctuary-project-in-jamaicas-bluefield-bay/>>

of installing over 350 ceramic artificial reef units which were transplanted within small pieces of live coral within the Bluefields Bay. This has been showing continued progress and is helping to sustain the local coral reef and fish colonies.<sup>58</sup> In 1992 the Lionfish was accidentally introduced into the Caribbean, which has been wiping out many of the Caribbean reef fish. The local fishermen in Bluefields bay have been catching these fish in order to protect the local reef fish and in they have been trained to prepare these fish for cooking which are then sold to the local hotel sector. This is also another source of income for the fishermen. Plans are also in the works for an underwater reggae theme park which will feature sculptures of local reggae artists made by local artists which will also help to support the local community. This venture has been proven to be successful in similar underwater parks like those in Grenada and Cancun.<sup>59</sup> At the Oistins Bay in Barbados, my proposal will seek to employ some of these similar strategies previously mentioned. These namely, creating an artificial reef and marine sanctuary, getting the local fisher folk involved in the day to day operations and maintenance of the reefs and obtaining additional funds from visitors to the marine sanctuary. The Bluefields Bay project is a good precedent which will also inform the thesis proposal as previously discussed.



Fig.A1.2. Lion fish



Fig.A.1.3. Bluefields Bay fishing-boats

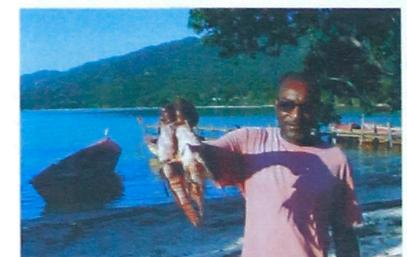


Fig.A1.4. Bluefields Bay fisherman with lion fish catch

<sup>60</sup> Biography of Jason deCaires Taylor  
 <<http://www.underwatersculpture.com/pages/artist/bio.htm>>

<sup>61</sup> Ibid

<sup>62</sup> Ibid

<sup>63</sup> Ibid

Jason deCaires Taylor is an artist and sculptor who grew up in Europe and in Asia, where he spent much of his formative years exploring the coral reefs of Malaysia. Taylor graduated from the London Institute of Arts in 1998 with a BA Honours in Sculpture and went on to become a fully qualified diving instructor and underwater naturalist with now over 17 years diving experience.<sup>60</sup> With his combined talent as a sculptor, his knowledge of underwater life and skill as a diver in 2006 he founded and created the first underwater sculpture park in the world. It is located in Grenada in the West Indies and is now listed as one of the Top 25 Wonders of the World by National Geographic.<sup>61</sup> Taylor's most recent work is MUSA (Museo Subacuatico de Arte), an underwater sculpture museum off the coast of Cancun, Mexico and is described by Forbes as one of the world's most unique travel destinations. Taylor's work is unique in its own right and as he says his works have a, "practical, functional aspect, offering positive interactions between people and fragile underwater habitats while at the same relieving pressure on natural resources."<sup>62</sup> Taylor's work is constructed to be assimilated by the ocean and made from inert objects to become living and breathing coral reefs. Taylor's work has been seen as, "portraying human intervention as both positive and life-encouraging."<sup>63</sup> With his approach Taylor has expressed that on 10-15% of the ocean bed has table enough substratum to allow reefs to form naturally. Understanding this in order to increase the number of reefs in the areas that need assistance, artificial reefs are created from materials that are durable, secure and environmentally sensitive. The coral growth on these artificial objects happens naturally at the rate of growth of the type of coral that attaches to these objects. Over time this creates an artificial reef which becomes teaming with coral and helps to support an entire marine

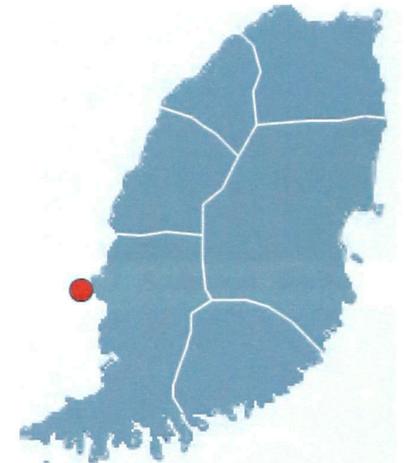


Fig.A.1.5. Millionaire Bay, Grenada

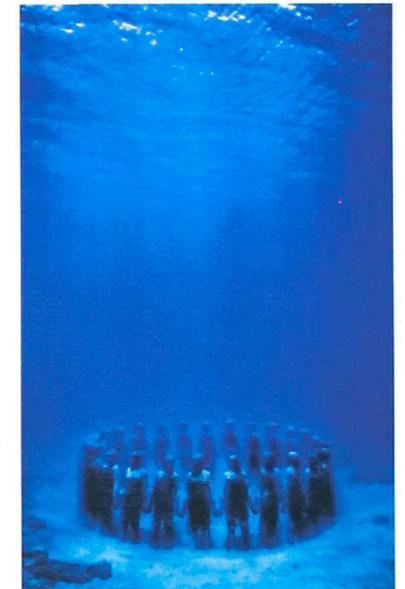


Fig.A.1.6. Sculptures, Grenada

<sup>64</sup> Artificial Reefs by Taylor <<http://www.underwatersculpture.com/pages/environment/artificial-reefs.htm>>

<sup>65</sup> Artificial Reefs by Taylor <<http://www.underwatersculpture.com/pages/environment/artificial-reefs.htm>>

ecosystem as Taylor has expressed.<sup>64</sup> Visitors to his underwater galleries have expressed such elation when experiencing these works which are in some ways paradoxical artistic expressions. His works have been examples of successful marine conservation which also bring awareness to the cycle of life and the fragile balance of the world's reef ecosystems. Taylor also explains that,

“One of the greatest benefits of artificial reefs is that they have lifted the pressure of natural reefs which, over the past few decades, have been over-fished and over-visited. By diverting attention to artificial reefs, natural reefs have now been given a greater chance to repair and regenerate.”<sup>65</sup>

These are some of the areas which will be adapted and implemented. The examples that are illustrated here are the use of an artificial reef which promotes the growth of coral, reducing stress on other natural coral reefs, the encouragement of eco tourism, increasing the natural bio diversity of the marine life are some of the main features which this project has helped influence the thesis.



Fig.A1.7. Sculptures, Grenada



Fig.A1.8. Sculpture, Grenada

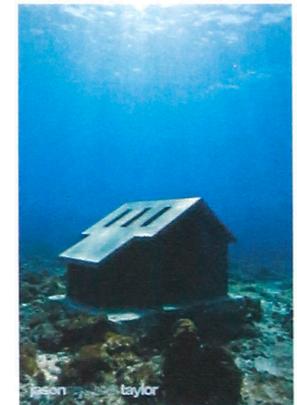


Fig.A1.9. Miniature house for fish by Jason De Caires, Grenada

<sup>66</sup> All questions from Global Coral Alliance <[http://www.globalcoral.org/frequently\\_asked\\_questions.htm#Why do corals grow faster on a Biorock structure](http://www.globalcoral.org/frequently_asked_questions.htm#Why%20do%20corals%20grow%20faster%20on%20a%20Biorock%20structure)>

The following are some questions and answers related to the Biorock Technology where the responses were provided by those at the Global Coral reef Alliance.<sup>66</sup>

*Why are coral reefs dying?*

“Reefs die for many reasons: rising water temperatures, sewage, eutrophication, disease and negligence. A reef ecosystem that took hundreds of years to grow can be destroyed in a single afternoon by dredging, dynamite or cyanide fishing.”

*What are the consequences of reef morbidity?*

“When coral reefs die, fish populations disappear beaches and shorelines are damaged. Unprotected by breakwaters, fragile land areas become vulnerable to erosion, saltwater intrusion and destruction from waves. For an already damaged reef, regeneration is very slow taking several decades, even under ideal conditions.”

*Why are mineral accretion bio rock reefs needed?*

“Global warming has caused significant reef mortality around the world. The prognosis is that oceans will continue to warm until world leaders recognize the long-term consequences of turning a blind eye to the problem.”

A few governments have tried to address the problems by building sea walls out of concrete, steel, coral rubble or sand bags. But these materials soon rust, corrode, collapse and need to be rebuilt. In contrast only breakwaters and reefs made of mineral accretion can provide permanent, cost-effective protection capable of keeping pace with rising global sea levels.”

*How much faster does coral grow with mineral accretion?*

“Mineral accretion growth rates are typically from one to several centimeters of new rock per year, depending on the surface area of the structure. The rate at which the coral grows depends on the amount of current, the size of the structure and the species of coral. Typically, growth rates are about 3 to 5 times faster than normal.”

*Why do corals grow faster on a Biorock structure?*

“Corals grow at accelerated rates with mineral accretion because the electricity flowing through the structure creates chemical conditions (high pH) at the surface of the growing limestone crystals and at the surface of the coral’s limestone skeleton, greatly speeding up their growth.”

“Corals normally have to spend a large part of their energy to create these conditions in order to grow their skeleton, but mineral accretion provides the right conditions for free, leaving the coral with much energy for tissue growth, reproduction and resisting environmental stresses.”

*How is a Biorock reef built?*

“To build a Biorock reef, an electrically conductive frame, usually made from readily available construction grade rebar or wire mesh, is welded together, submerged and anchored to the sea bottom. Sizes and configurations are infinite and are varied to fit the setting. A low voltage direct current is then applied. (Power sources can include chargers, windmills, solar panels or tidal current generators.) this initiates an electrolytic reaction causing mineral crystals naturally found in seawater, mainly calcium carbonate and magnesium hydroxide, to grow on the structure.”

*What materials are used in a biorock reef?*

“The structure is built from ordinary construction materials typically available almost anywhere in the world. This can include steel rods, pipe or rebar. Other materials necessary for the project include electrical cables and epoxy or silicone sealants to protect the electric connections. While the main structure serves as the cathode, another electrode, the anode, is a special titanium mesh that does not corrode.”

*How are Biorock reefs powered?*

“To power the mineral accretion process, a low DC voltage is necessary. The source of this current generally depends upon the environment near the reef. If a ready supply of electricity is available, cables can be attached to the structure. In more remote areas, solar collectors are usually the energy source. These panels will generally be set up on shore to feed current to the Biorock reef via submerged cables. Power can also be supplied by other non-polluting sources such as wind-mills or tidal current generators.”

“In practice, a low voltage direct current is fed to the reef via cables. The structure acts as a cathode. A special inert material is used as the anode to complete the electrical circuit. The low power is completely safe for swimmers and marine life.”

*How do you anchor a Biorock reef?*

“In most coral reef environments, structures sit on limestone bedrock where they eventually cement themselves solidly to the hard bottom. Usually structures are held in place against wave forces by their own weight or by filling them with rocks. In hurricane regions, where there is a tradeoff between how long it takes to get the structure solidly cemented to the bottom and when the first hurricane hits, we drill holes for vertical rebar supports a couple of feet is usually adequate. In sand, we anchor reefs using rebar pounded into the substrate.”

*How are the corals attached?*

“Coral fragments are wedged into crevices and holes within the structure or attached using plastic cable ties or steel binding wire.”

*What happens after the coral fragments are attached?*

“Within Days to weeks, as the mineral accretion grows around the attached coral fragments, corals begin to grow at accelerated rates. Their rapid growth is directly attributable to the electrical current in the underlying steel framework.”

*Will natural corals settle and grow on Biorock structures?*

“Coral larvae, which are millimeter-sized freely-swimming baby corals, will only settle and grow on clean limestone rock. This is why conventional artificial reefs made of tires or concrete rarely exhibit hard coral growth.”

“But, when these coral larvae find a limestone surface, they attach themselves and start to grow skeletons. Mineral accretion is exactly what they are searching for. As a result, there are very high rates of natural coral settlement on Biorock structures.

*Are fish and other marine creatures attracted to Biorock reefs?*

“Like an oasis in the desert, all forms of coral life are quickly attracted to Biorock reefs. Many forms of reef life have been observed to be attracted to the structures and none repelled.”

*Have mineral accretion results been documented?*

“During 1998, when more than 95% of the corals in the natural reefs in the Indian Ocean died, only 20-40% of the corals on the five mineral accretion structures at

Ihurur in the Maldives died. This was a difference of less than 5% survival on the natural reef versus 60-80% survival on mineral accretion reefs was a dramatic demonstration of just how well this process works in a stressed environment.”

*Where are Biorock reefs in operation?*

Bali Indonesia, Jamaica, Ihuru and Vabbinfaru Maldives, Yucatan Mexico, San Blas Islands Panama, Papua New Guinea, Saya de Malha, Seychelles and Phuket Thailand.

*How far off shore can one place a Biorock reef?*

“Normally we use shore based DC power sources (chargers, solar panels, wind-mills etc.) Because of voltage drops in the cable to the structure we prefer to work within 100 yards of the power source. But there is no problem going further if one is willing to boost the voltage at the source to compensate for voltage drops. We have a coral reef structure in the Maldives that is more than 400 Meters from shore.”

*How deep beneath the surface of the water can one place a Biorock reef structure?*

“There is no limit to the depth. Normally we build structures in shallow water (5 to 25 feet bottom depth) because corals grow best in brightly lit shallow water, but we also try to have them deep enough that boats can't run into them.”

*Why aren't there more Biorock reefs?*

“There are many requests..., but unfortunately there is little funding available from governments, international philanthropic agencies or private foundations.”

Source: <<https://www.cia.gov/library/publications/the-world-factbook/geos/bb.html>>

- Location: eastern most Caribbean Island 13 10N, 59 32 W
- Total Land Area: 430 sq KM
- Length and Width: 34km L, 23km W
- Coastline: 94 km
- Climate: rainy season (June to October) 50 to 66 inches per year of rainfall
- Terrain: relatively flat; rises gently to central highland region
- Highest Elevation: 336m
- Land Use: arable land 37.21%, permanent crops 2.33%, Other 60.46% (2005)
- Industries: tourism, sugar, light manufacturing, component assembly for export.
- Natural Resources: petroleum, fish, natural gas
- Agriculture Products: sugarcane, vegetables, cotton
- Natural Hazards: infrequent hurricanes, periodic landslides, periodic flooding , infrequent earthquakes and, tsunami
- Population : 284,000 (2009)
- Population Density: 631 people per sq km ranked 14th in the world
- Majority of population live along south east, east and west coast of island.
- Total No. of Dwelling Units: 92,197 (2010 housing census)
- Wall material of housing stock: 18.54.% (17,101) wood, 2.75% (2,543) stone, 50.18% (46,273) concrete block, 6.40% (5,903) wood & concrete, 16.57% (15,280) Wood & concrete block, 4.78% (4,410) concrete, 0.75% (687) not stated (2010 housing census)
- Member of the Caribbean Community (CARICOM) and Organisation of Eastern Caribbean States (OECS)



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