

# Resilience in the Face of Sea Level Rise

An Architectural Response to Rising Sea Levels in Wellington, New Zealand

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Submitted in Partial Fulfilment for Master of Architecture (Professional) Degree  
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# Abstract

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Climate change is widely regarded as the leading global issue of the 21st century. There is now a general international agreement, supported by an overwhelming amount of scientific evidence, that the global climate is changing at an accelerated rate and that human-driven emissions of greenhouse gases into the atmosphere is the main factor driving this trend. Arguably the most devastating impact of climate change on the human civilisation will be a rapidly increasing rise in global sea levels, which are currently rising at an unprecedented rate, placing hundreds of millions of people at serious risk of inundation in coastal communities across the globe. In the case of New Zealand's capital city, Wellington, over ten percent of the city's residents are at risk of displacement by the end of this century. This thesis aims to find a solution to resident displacement in the coastal city, addressing the question,

*How can a resilient residential dwelling be designed for the coastal city, in response to the encroaching pressures of climate change driven sea level rise?*

This research question and its subsequent design aims have been achieved through a highly iterative design process resulting the development of a connected network of amphibious dwelling solutions which provide the residents of the selected focus community of Kilbirnie, a coastal suburb in Wellington city, with the capacity to accommodate, adapt and thrive in the face of sea inundation. Hereby ensuring the social sustainability of the coastal community, currently at serious risk of displacement as a direct result of climate change driven sea level rise.

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# 1. Introduction to Research

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## 1.1 DESIGN PROBLEM

For the first time in history more than half the world's population live in coastal cities located on the ocean periphery or in deltaic areas.<sup>1</sup> The meeting of the city and the littoral zone, the body of ocean extending from the high tide shoreline out 200m to sea,<sup>2</sup> has been identified as one of the most important environmental juxtapositions of this century.<sup>3</sup> In the case of New Zealand, our long-term association with lowland coastal regions dates back to early Maori settlements which were almost exclusively established in coastal areas because of access to kaimoana, seafood, and the ease of coastal travel on waka. European immigrants also found harbours ideal places to settle as they afforded sheltered ports for sea transportation networks. As a result, the vast majority of New Zealand's population lives in coastally located cities and towns.<sup>4</sup> It has been said that, the sea is a harsh mistress,<sup>5</sup> for where it once provided our ancestors with the ideal location for living, global warming is now causing sea levels to rise at an unprecedented rate, placing these same coastal cities at serious risk of inundation.

When assessing the implications of sea level rise on New Zealand's capital city, the Wellington City Council recently stated ***"that as a result of climate change, there is a risk that sea levels in Wellington could rise by as much as two metres by 2100."***<sup>6</sup> Such an event could see the destruction of over 18,000 homes, as well as cause crippling financial losses for the capital with the destruction of major regional infrastructure and community assets.

Unfortunately this is not an isolated event. Climate change is now widely regarded as the leading global issue of the 21st century. The perception that global warming is a myth is now long gone. The climate is changing at an accelerated rate and human driven emissions of greenhouse gases into the atmosphere is the main factor driving this trend. Alongside major regional temperature changes, the thawing of land ice and an increase in frequency and severity of extreme weather events, perhaps the most devastating impact of climate change on the human civilisation and their built environment will be a steadily increasing rise in global sea levels.<sup>7</sup>



In 2007 the Fourth Intergovernmental Panel on Climate Change (IPCC) identified in their report, 'Projections of Global Average Sea Level Change for the 21st Century', that sea levels could rise by as much as 600 millimetres by the end of this century. In the six years since this report, significant advances have been made in the understanding of how climate change is contributing to sea level rise, allowing for greater accuracy in future sea level rise predictions. The most recent international conference on sea level rise, the Association of Pacific Rim Universities's (APRU) 'International Workshop on Coastal Cities, Climate Change and Sea Level Rise' found that the global sea levels are now projected to rise upwards of 1.4 metres by 2100. This projection supports the earlier studies of Rahmstorf, 2007: Horton, et al., 2008 and Pfeffer, et al., 2008 each similarly finding that global sea level increases of 1.6 to 2.0m by 2100 cannot be ruled out.<sup>8</sup>

In 'The Impact of Sea Level Rise on Developing Countries' (2007) Dasgupta identifies that even a single 1m rise in global sea levels would cause the destruction of trillions of dollars worth of infrastructure and assets and result in the displacement of hundreds of millions of people across the globe.<sup>9</sup> It is therefore abundantly clear that strategies must be implemented now in order to reduce mass resident displacement and minimise the overall impact of climate change driven sea level rise on communities established in coastal areas.

## 1.2 THESIS QUESTION & AIMS

### Thesis Question:

How can a resilient residential dwelling be designed for the coastal city, in response to the encroaching pressures of climate change driven sea level rise?

### Aims:

- To provide a permanent and resilient residential accommodation solution to climate change driven sea level rise for the residents of Wellington City, with the knowledge that a resolved design could likely be adapted to suit the needs of other coastal communities at risk of inundation.
- To ensure social sustainability, through providing an existing community with the capacity to endure, or to continue to exist in the face of sea level rise. A solution must therefore be able to be implemented in preparation now, with the ability to adapt when inundated.
- The design solution to sea level rise must also be appealing to those at risk of inundation. The resilient accommodation solution must therefore be not only aesthetically desirable but also equivalent to that of a traditional Kilbirnie home in comfort, quality and price.
- To allow for a customizable dwelling solution in order to meet the needs of a diverse population and accommodate a wide variety of programs and uses.
- To guarantee the safety of all residents. This will be especially important once the dwelling is inundated, as Wellington is internationally renowned for its unpredictable littoral environment with high winds and choppy seas a common occurrence.
- To actively engage with the dynamic littoral environment within which the dwelling solution will occupy once inundated.

### 1.3 RESEARCH METHODOLOGY

A research through design strategy has been employed in the creation of this thesis.

From undertaking a comprehensive exploration of the design problem, including an extensive literature review and case study analysis, a specific set of design criteria, for the selected focus area of Wellington city, have been developed. An iterative design process was then employed in order to test ideas and produce a successful solution to both the research question and the established design criteria. Constant testing, simulations, analysis and critiques were undertaken to identify and reflect on the strengths and weaknesses of each design evolution. Once an appropriate solution was identified the design was then refined and resolved through an extended development period in order to produce a design which could potentially be employed to alleviate the encroaching pressures of climate change on the coastal city of Wellington. The scope of this design research is confined to the architectural design of a residential dwelling solution which can accommodate sea level rise.

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1 Brand, D. "Bluespace: A Typological Matrix for Port Cities." Urban Design International, 2007: pg 69

2 Oxford Dictionaries. Definition of Littoral Zone in English. 2013. [http://oxforddictionaries.com/definition/english/littoral\\_zone](http://oxforddictionaries.com/definition/english/littoral_zone). par 1

3 Olthuis, K. & D Keuning. Float: Building on Water to Combat Urban Congestion and Climate Change. Amsterdam: Frame, 2012. pg 40

4 Dawe, I. "Sea Level Rise – A New Zealand Context." Greater Wellington Regional Council, 2009: pg 1

5 Conrad, Joseph. "Heart of Darkness." London: Blackwood's Magazine, 1899. pg 27

6 Wellington City Council. "Assessing the implications of Sea Level Rise: Kilbirnie Town Centre." 2009: pg 2

7 UNFCCC. "Climate Change: Impacts, Vulnerabilities and Adaption in Developing Countries." United Nations Framework Convention on Climate Change (2007): 1-68. Retrieved March 2013 from <http://unfccc.int/resource/docs/publications/impacts.pdf>. pg 8

8 Evans, L. et al. "Perceptions of Sea Level Rise in Wellington City and Kapiti Coast Districts." Victoria University of Wellington (2012): pg 3

9 Dasgupta, S. et al. "The Impact of Sea-Level Rise on Developing Countries: A Comparative Analysis." World Bank Policy Research Working Paper no 4136, 2007. pg 44

## 1.4 THESIS STRUCTURE

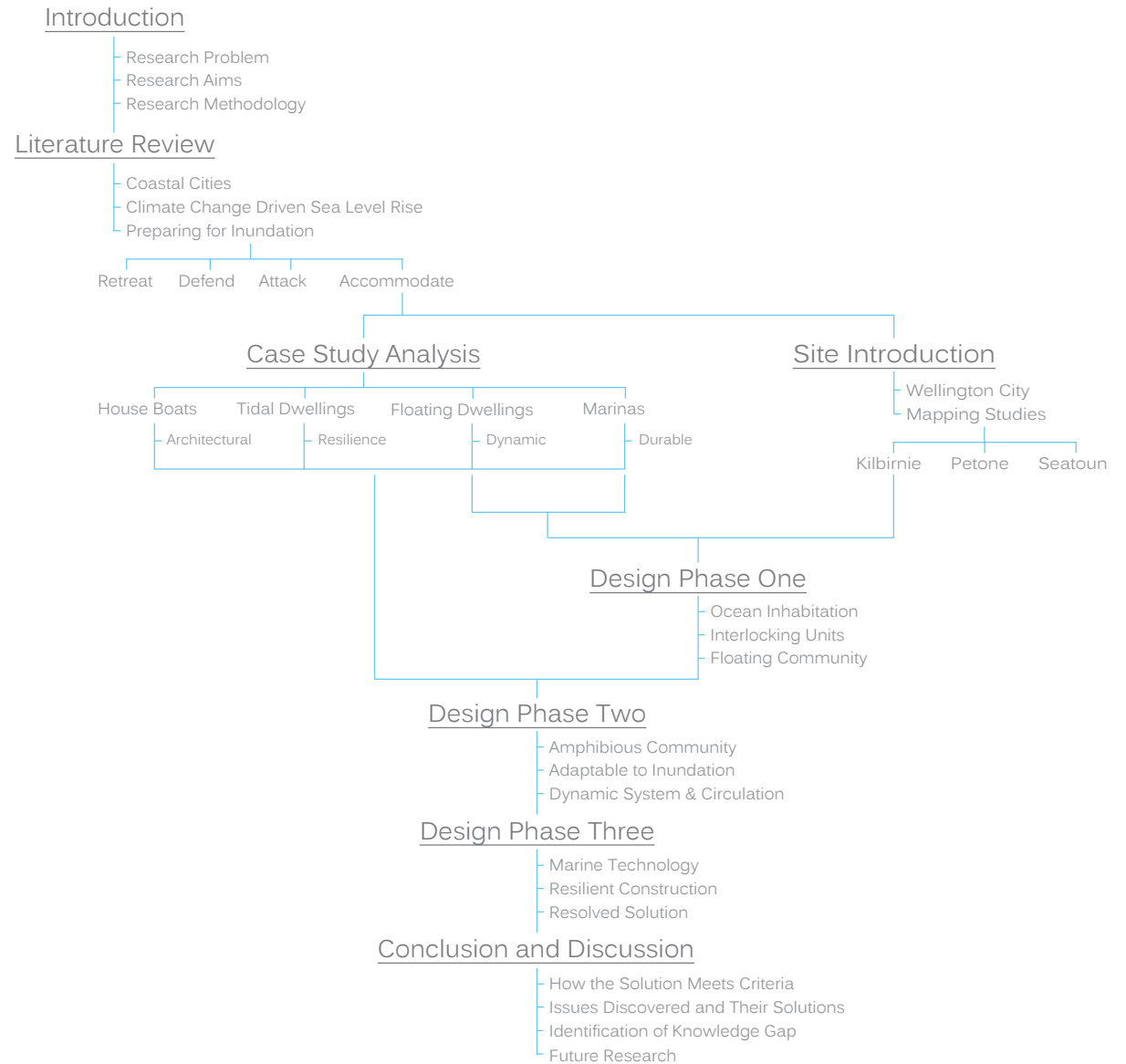


Figure 1: Thesis Structure Diagram





## 2. Literature Review

Building upon the design problem identified in the introduction, this literature review will introduce, analyse and critique possible sea level rise preparation options against the design criteria established by Nekooie of the University of Technology Malaysia. With the strategy of accommodation determined as potentially the most applicable for the preparation option, the literature review goes on to identify the practicalities of designing and constructing an amphibious community to mitigate the impact of sea level rise on the coastal city.



## 2.1 PREPARING FOR INUNDATION

There are a vast number of strategies that a coastal city may undertake in order to prepare itself for sea level rise. David Robinson of Building Futures groups these into three broad strategic options: Retreat - To move further inland so as to limit the potential effects of sea level rise; Defend - To construct a system of barriers in order to protect assets potentially at risk of inundation; and to Attack - To utilise the risk of inundation as a chance to form a new urban development.<sup>10</sup> Dr Mohammad Nekooie of the University of Technology Malaysia, a leading expert in the field of adaptive urbanism in response to climate change, suggests that the successfulness of each preparation option should be measured under the following criteria: affordability, time and construction difficulty, resilience, safety and adaptability to varying inundation levels as well as different communities needs, whilst maintaining a clear relationship between the city and the sea.<sup>11</sup> This criteria has greatly influenced the creation of my own design criteria for this design research project.

To retreat is to step back from the problem, to move critical infrastructure and housing to safer ground and allow for the previous city location to be inundated. In retreating, investment in current structures and infrastructure is lost as the area is reclaimed by the sea. New investment must also be made in relocating communities out of harm's way.<sup>12</sup> To date, due to the significant costs involved there are few current examples of retreat from rising sea levels, with the exception of the British township of East Anglia who were forced to move their entire city due to unprecedented coastal erosion, see Figure 2. This retreat option is not considered resilient, it is extremely expensive and difficult to undertake at an urban scale. It also breaks the well-established link between the land and sea.<sup>13</sup>

To defend is to ensure the sea water does not enter the current built environment through the use of permanent structural engineering works such as sea walls and breakwaters. Many of these hard engineered defences of the 20th century have been heavily criticised for reducing access to the water, damaging to coastal habitats as well as being an extremely costly endeavour to construct and maintain.<sup>14,15</sup> Current urban scale examples of a defend option include the Thames Estuary Barrier in London and the Maeslant Barrier in Holland, see Figure 3 and 4 respectively. As sea level rise will be incremental, this option becomes problematic in terms of implementation, given that these structures are also not easily adaptable to dramatic changes in water level.<sup>16</sup>

To attack is to view sea level rise as a positive occurrence, a chance to step seaward of the existing coastline and explore the development potential for extending coastal cities short on developable land out onto the water. An attack strategy could consist of land reclamation, floating structures or stilted structures which create a new urban scale building platform for urban expansion.<sup>17</sup> This strategy can be highly expensive due to, the size of construction, the lack of flexibility to address continuing sea level increases, and the option also leaves the greater portion of the current city exposed to inundation.<sup>18</sup> To date, most examples of an attack strategy for a solution to combat climate change are purely theoretical such as Floating New Orleans by TSI Engineering, see Figure 5.

It appears that one of the most appropriate preparation options for the coastal city has been left out of the Building Futures literature. Increasing a society's ability to 'accommodate' sea level rise should not be overlooked. According to Robert Barker, founding partner of BACA Architects one of the leading firms on climate change and architecture, modern flood management, whether it be from sea level rise or flash flooding, is about living with rising water, not blocking it out.<sup>19</sup> An accommodation strategy allows for small scale resilient architectural interventions to be introduced into the coastal



city so that it can adapt to varying climate conditions, while maintaining the existing social fabric of the city and the strong relationship between the city and the sea.<sup>20</sup> An accommodation strategy could consist of floating or amphibious dwellings, kinetic architecture or soft infrastructure. There are a number of current examples of sea level rise accommodating architecture including, the amphibious house-boat communities throughout Europe, Cua Van Village in Vietnam and Koh Panyee Village in Thailand. An accommodation solution can be introduced into the coastal city incrementally at a more affordable rate when compared to kilometres of towering sea walls or a full or partial city relocation.<sup>21</sup> Considering Nekooie's criteria for designing for inundation, an accommodation strategy has the potential to be the most successful strategy for a great majority of coastal regions as it is highly affordable when compared to the other possible preparation options; it would allow for the important relationship between city and sea to be maintained and enhanced; and finally the option is adaptable and resilient to varying inundation levels. In the case of Wellington City, a recent council lead study identified that of the four broad solutions to inundation, Wellington residents were heavily in favour of introducing an accommodation strategy into the areas which are at risk of inundation across the city.<sup>22</sup>

## 2.2 ACCOMMODATION - LIVING WITH SEA LEVEL RISE

A great majority of the literature and research on living with water has been conducted at the Delft University of Technology in the Netherlands, the University of Technology Malaysia and by private firms BACA Architects and Waterstudios.NL. Together they have identified four sub-categories of ocean inhabiting dwellings; amphibious house boats; floating homes; tidal dwellings; and conventional marinas.<sup>23</sup> In order for coastal city residents to accept these ocean-going residences as viable homes for the future, Koen Olthuis founder of WaterStudios.NL, advises that water bound homes need to become equivalent to traditional homes in every respect: in comfort, in quality and in price. Only then will residents want to live permanently in low-lying coastal areas free from the fear of losing their homes, possessions and even lives to sea inundation.<sup>24</sup>

When sea level rise is accommodated and the resilient dwelling solution begins to float and move with the changing littoral environment, the permanent connection between dwelling and its site is removed. According to Deleuze and Guattari, an accommodative dwelling can therefore be considered a nomadic form of living, for it would dissolve the established conditions that we associate with the permanence of shelter and occupation. The renowned theorist's go on to identify that nomadic life however, does not mitigate our social norms; it is instead a life that offers great potential to create them.<sup>25</sup> Psychology researchers throughout history have compared living on the water with the aspiration of living in a symbiotic relationship with nature, much closer than would ever be possible on dry land. Many cultures and religions also identify water as both the creator and destroyer of life.<sup>26</sup> The classic example is the biblical story of Noah's ark.

Forming a water community creates a variety of different challenges compared with creating a community on dry land. The most obvious of which is that unlike land, the sea is in a constant state of change making circulation and stability significant challenges. Other issues include the occupation of the inter-tidal area, between high and low tides, rot and corrosion and buoyancy.<sup>27</sup> To be a desirable alternative these issues will need to be explored and resolved alongside the design criteria in the development of an amphibious housing solution to sea level rise in the coastal city.



Figure 2: Coastal Erosion in East Anglia, UK



Figure 3: Thames Estuary Barrier, London, UK



Figure 4: Maeslant Barrier, Hoel van Holland, Netherlands



Figure 5: Floation New Orleans, TSI Engineering

## 2.3 SUMMARY & REFLECTION

Global sea levels are rising at an unprecedented rate as a direct result of climate change. It is predicted that by the end of this century, wide spread inundation would see the displacement of hundreds of millions of people across the globe. In the case of Wellington City over 40,000, or 10 percent, of the city's residents would likely be displaced as their homes are at serious risk of inundation due to the low-lying nature of a significant portion of New Zealand's capital city. It is clear that a solution needs to be found to mitigate the impact of sea level rise on the coastal city and reduce mass residential displacement. From the literature it is apparent that a successful outcome must be adaptable to changing sea levels, stable, easily customizable, affordable, successfully make the connection between the user, the land and the sea and have sufficient architectural distinction so as to make them desirable for the target audience. It has been determined that from this criteria the most appropriate sea level mitigation strategy for the city of Wellington would be to accommodate, to increase society's ability to cope with the effects through the design of resilient and adaptable architectural solutions.

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- 10 Robinson, D. et al. "Facing Up to Rising Sea Levels: Retreat? Defend? Attack? : The Future of our Coastal and Estuarine Cities." Building Futures, Institution of Civil Engineers (2009): pg 2
  - 11 Nekooie, M. et al. "Evaluating the Performance of Amphibious Urbanization as a Climate Change Adaptation Strategy by Pest Analysis." University Teknologi Malaysia, 2011: pg 6
  - 12 Robinson, D. et al. "Facing Up to Rising Sea Levels: Retreat? Defend? Attack? : The Future of our Coastal and Estuarine Cities." Building Futures, Institution of Civil Engineers (2009): pg 3
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  - 17 Woodruff, D. & Falk, J. "International Workshop on Coastal Cities, Climate Change and Sea Level Rise." University of California San Diego. San Diego: Association of Pacific Rim Universities, 2012. Retrieved March 2013 from <http://apru.org/news/item/359-the-apru-international-workshop-on-coastal-cities-and-sea-level-rise>. pg 6
  - 18 Robinson, D. et al. "Facing Up to Rising Sea Levels: Retreat? Defend? Attack? : The Future of our Coastal and Estuarine Cities." Building Futures, Institution of Civil Engineers (2009): pg 9
  - 19 Baker, R. "Modern Flood Management is About Living with Rising Water , Not Blocking it Out." The Architects Journal (2008): pg19
  - 20 Robinson, D. et al. "Facing Up to Rising Sea Levels: Retreat? Defend? Attack? : The Future of our Coastal and Estuarine Cities." Building Futures, Institution of Civil Engineers (2009): pg 12
  - 21 Baker, R. "Modern Flood Management is About Living with Rising Water , Not Blocking it Out." The Architects Journal (2008): pg 19.
  - 22 Evans, L. et al. "Perceptions of Sea Level Rise in Wellington City and Kapiti Coast Districts." Victoria University of Wellington(2012): pg 15
  - 23 Nekooie, M. et al. "Evaluating the Performance of Amphibious Urbanization as a Climate Change Adaptation Strategy by Pest Analysis." University Teknologi Malaysia, 2011: pg 6
  - 24 Olthuis, K. & D Keuning. Float: Building on Water to Combat Urban Congestion and Climate Change. Amsterdam: Frame, 2012. pg 40
  - 25 Deleuze, G., & Guattari, F. Nomadology: the war machine. New York: Semiotext, 1986. pg 2
  - 26 Pasternack, R. "Aquitecture: Water-based Architecture in the Netherlands." Delft University of Technology (2009): Masters Architecture Thesis. pg 5
  - 27 Desfor, G., Laidley, J., Stevens, Q., & Schubert, D. Transforming Urban Waterfronts: Fixity and Flow. New York: Routledge, 2011. pg 16





### 3. Case Study Analysis

Throughout history human civilisations have looked to the water as a source of sustenance, travel and in a number of cases as a location for dwelling. The method of dwelling on or near the water differs across the globe with the most common forms of water dwelling consisting of house boats, tidal dwellings, boats and marinas. When designing a resilient and accommodative dwelling strategy for sea level rise in the coastal city these existing methods of water dwelling make valuable design case studies as architects and builders seek to successfully build on water. Each case study has been analysed against the six key design attributes identified in the literature review:

- Adaptability: potential to be fit for land and sea, meet changing environment
- Stability: be safe and stable to ensure resident comfort and well being
- Customizability: ability to be changed to meet needs of diverse users
- Affordability: potential for a resident to purchase a floating dwelling
- Littoral relationship: connection between user and sea
- Architectural Distinction: the appeal of a solution to an at risk community.

The analysis will identify the strengths and weaknesses of each case study which in turn can be used to inform the design process of this thesis.



### 3.1 EUROPEAN HOUSE BOATS :

#### Steigereiland IJburg \_ Amsterdam, Netherlands

Commonly regarded as the most appropriate solution to accommodating sea level rise in the coastal city, house boats and amphibious houses line the shores of many major European and North American cities including London, Amsterdam, Hamburg, Vancouver and Seattle.<sup>28,29</sup> The house boats are typically custom designed to a high standard and employ advanced technical solutions for buoyancy and water-tightness concerns. Although this form of housing is highly desirable in the regions noted above, custom design and construction has meant that the floating homes are usually unaffordable for most people and accommodate only the elite.<sup>30</sup>

Developed in 2003, Steigereiland IJburg in the Netherlands possesses the largest community of these floating and amphibious homes with over seventy five residences.<sup>31</sup> Similar to a marina berth, each of these dwellings are rigidly connected to a network of floating walkways surrounded by a number of breakwaters, see Figures 8 - 10. The house boats can then rise and fall with the changing tides without excessive rocking due to the tamed littoral environment.

To restrict excessive private ownership of Amsterdam's waterways, the local government has placed strict maximum measurements on these floating homes; 7 x 10m floor plan with a 1.5m draught beneath the waterline.<sup>32</sup> These footprint size restrictions have meant that most floating homes have been constructed three stories high so as to ensure a similar floor area to those of traditional Dutch homes. Unfortunately in doing so the centre of mass in many of these designs is much higher than that required to ensure balance and stability. As a result, when a boat passes by or when multiple occupants stand in one corner of the dwelling it's not uncommon for the floating home to lean over uncomfortably, see Figure 10.<sup>33</sup>

What can be gleaned from this precedent is that living on the water can be desirable, to the point where there are restrictions imposed, but it is important to ensure that the height of a dwelling when floating is proportional to its width in order to maintain stability and user comfort not only in calm waters but also in choppy seas. Prefabricating these dwellings would also increase the affordability and appeal of this form of solution to the typical resident at risk of inundation.

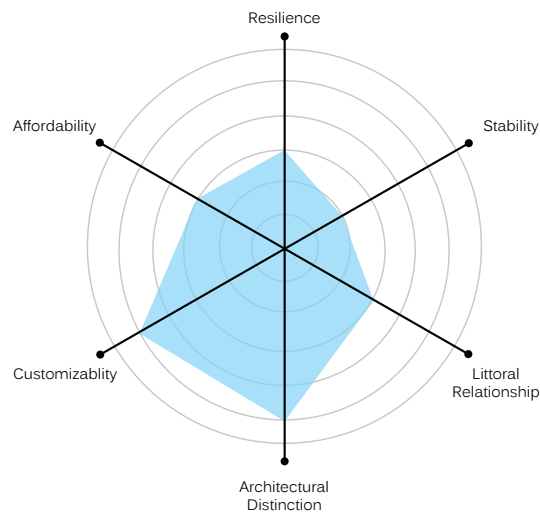


Figure 6 : IJburg's Achievement of Key Criteria





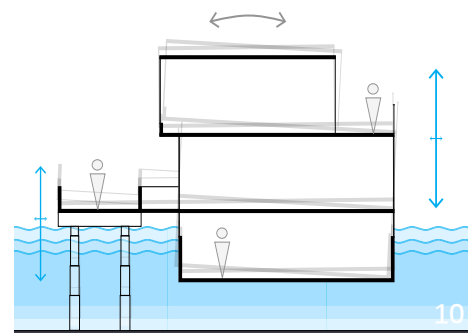
7



8



9



10

Figures 7, 8, 9, 10:  
Ijburg House Boats, Aesthetic Derived from Land Based Architecture  
Linear Arrangement of Ijburg Floating Community  
Circulation Away from Waters Edge  
House Boat Diagram

### 3.2 FLOATING DWELLINGS :

#### Cua Van Village \_ Halong Bay, Vietnam

Located in Halong Bay in Vietnam, the World Heritage site of Cua Van Village is one of the world's most iconic floating communities.<sup>34</sup> Cua Van consists of almost 200 independent floating homes and boats with over 800 residents, see Figure 12 and the Chapter 3 cover image.<sup>35</sup> The village was formed sixty years ago when rising sea levels and the steepness of terrain forced residents to leave their land based homes and develop a floating community.<sup>36</sup>

Located dozens of kilometres from the mainland city of Bai Chay, the residents of Cua Van Village have no land ownership and their main livelihood is fishing, aquaculture and more recently tourism.<sup>37</sup> Circulation through the community occurs primarily by boat or raft. Unlike house boat communities and most marinas, the floating village is without fresh water, power or infrastructure. This becomes especially problematic when waste is dumped into the same body of water that the community relies on to gather their food and water supply.<sup>38</sup>

The key strength of the Cua Van Village as a case study for this thesis is its dynamic relationship between the resident and the ocean in which they occupy. As the floating homes are not connected and have only one anchor point beneath the ocean's surface, changes in the littoral environment, such as waves, wind and currents can greatly inform the spatial relationships between the floating dwellings throughout the village, see Figure 15.<sup>39</sup>

Similar to coastal communities across the globe, the life of the Cua Van fishing village is under serious threat as a result of climate change. Although the community was originally sheltered by the surrounding islands, climate change is causing increasingly violent storms to hit the village, killing fish, damaging homes and equipment and in rare cases sinking a number of the communities floating homes.<sup>40</sup> Unfortunately due to the design and poor construction of a number of the homes, the floating dwellings of Cua Van village are not resilient to the changing environment, placing growing numbers of residents and their families at risk.

Cua Van clearly indicates that a community can actually exist without conventional infrastructure and without a strict connection to the land. The village's heritage listing and the significant numbers of tourists annually also illustrates a vast interest in the possibility of living in a symbiotic relationship to the ocean. This case study primarily reiterates the importance of ensuring adaptability to changing conditions when designing an ocean dwelling community.

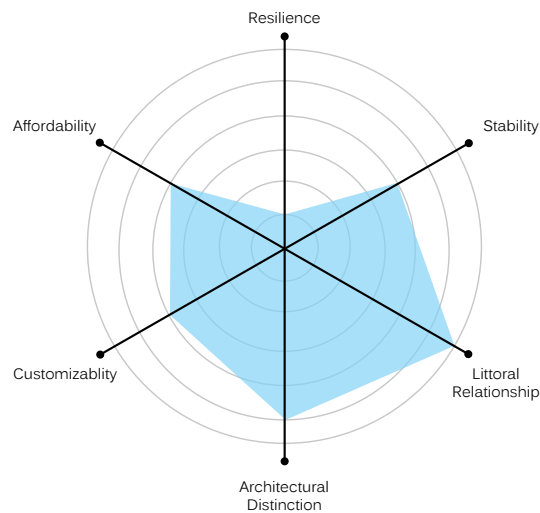
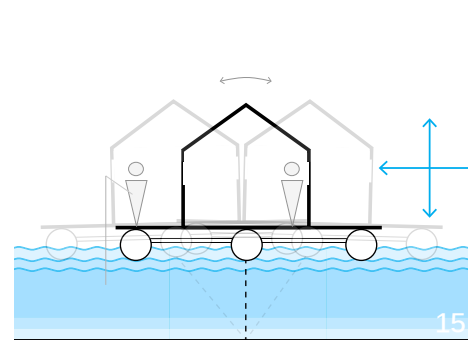


Figure 11 : Cua Van's Achievement of Key Criteria





Figures 12, 13, 14, 15:  
Cua Van Village in Halong Bay  
Many Dwellings are Poorly Constructed from Cheap  
Materials  
The Village is a Major Tourist Attraction in Vietnam  
Floating Dwelling Diagram

### 3.3 TIDAL DWELLINGS :

#### Koh Panyee Village \_ Phung Nga Bay, Phuket, Thailand

The settlement of Koh Panyee was established by nomadic Malay fishermen and their families at the end of the 18th century. During this time, land ownership in Thailand was strictly limited to only those of Thai decent. The immigrants were able to circumvent this law by constructing a delta community consisting of stilt houses, floating platforms and floating dwellings on the bay in the shelter of Panyee island.<sup>41</sup> The settlement has now grown to over 1500 residents with almost 200 residential dwellings as well as a mosque, primary school, restaurant, market, recycling station and a floating football field.<sup>42</sup>

It is the adaptability of this community to suit the changing littoral environment which determines its relevance as a case study for this design research. Koh Panyee is subject to a two metre tidal range with very strong incoming and outgoing currents due to its location at the intersection of two major rivers to the North and Phung Nga Bay to the South, see Figure 18. Half the community is constructed on stilts three metres above ground level. The remainder of the community floats and moves with the currents at high tide before dropping to rest in the mud at low tide, see Figures 19 and 20.<sup>43</sup>

Unfortunately in recent decades the village has been unable to sustain itself on fishing alone. The communities need to house its growing population, as well as the fact that power is four times the price of the mainland due to the complexities of retrofitting reliable services across the bay, has caused Koh Panyee to turn to tourism in order to survive, during the dry season a constant stream of tourists now jet boat to the village from nearby Phuket.<sup>44</sup>

In July of this year, I was fortunate enough to travel to Koh Panyee with my partner and observe the dynamic tidal community firsthand. In doing so I learned that it is possible to live in an amphibious community capable of occupying both land and sea in a single given day. This factor is especially important given that sea level rise is a gradual occurrence, therefore a resilient community can be constructed on land now, with the knowledge that it will be able to successfully occupy the same location when it is inundated.

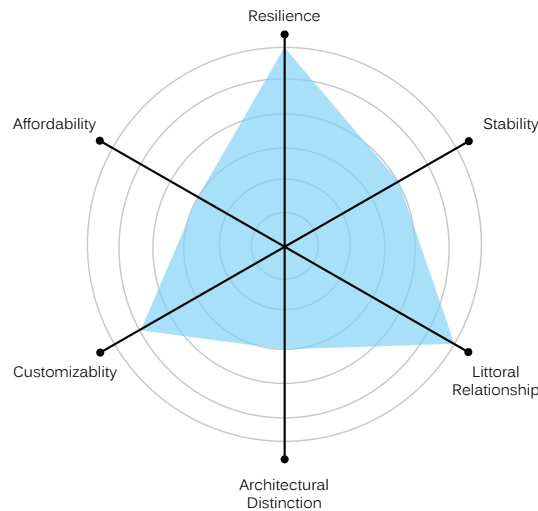
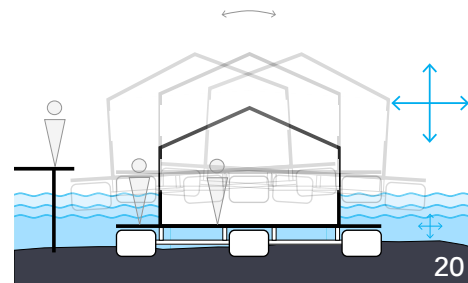


Figure 16 : Koh Panyee's Achievement of Key Criteria





Figures 17, 18, 19, 20:  
Koh Panyee Village Consists of Both Fixed and Amphibious Platforms and Buildings  
The Village in the Shelter of Panyee Island  
During Low Tide Access Through the Community is Restricted in a Number of Areas  
Tidal Dwelling Diagram

### 3.4 MARINAS & MOORINGS :

#### Evans Bay Marina \_ Kilbirnie, Wellington, New Zealand

Marinas are a popular occurrence in waterfronts throughout most major coastal cities. They provide an on water location for the storage of keel boats, fishing boats and large multihulls. Similar to the purchasing of property, marina berths and moorings are able to be purchased for the exclusive use of an individual or a collective group.<sup>45</sup> It is common in most marinas for a number of berth owners to permanently live onboard their vessels.

Evans Bay Marina is the only facility in the lower North Island of New Zealand with both sheltered berths and private swing moorings, therefore allowing the marina to cater for a diverse number of users.<sup>46</sup> Storing a boat in a sheltered berth provides the occupant with easy pedestrian circulation to shore through a system of jetties and gangways. Similar to most marinas, Evans Bay Marina has a number of more expensive berths with metered power and water services for those who are living permanently in the marina. In contrast swing moorings are very affordable to purchase but they are only accessible by dingy, have no services and are completely exposed to the dynamic littoral environment, compare Figures 23 and 24.<sup>47</sup>

Specifically designed to withstand the harsh marine environment, yachts and boats are available in a wide range of shapes and sizes to suit the needs of every nomadically inclined individual. A significant portion of these boats have been designed purely for speed rather than comfort, causing their internal spaces to often be cramped and dark.<sup>48</sup> Large seawalls have been constructed to shelter most marinas in order to reduce discomfort and sea sickness caused from the rocking motion of boats as a result of sea movement, see Figure 25. Unfortunately this often causes the water to become stagnant allowing trash and waste to gather.

Although specifically designed for the ocean, boats generally make for uncomfortable permanent residences. Despite this there are a number of aspects of yacht and marina design, such as form, materials and other marine technology that could easily be adapted into a successful permanent dwelling solution. Services, pedestrian access and generous internal spaces would need to be provided for all residences in order to improve the attractiveness of an ocean dwelling to the typical Wellington resident.

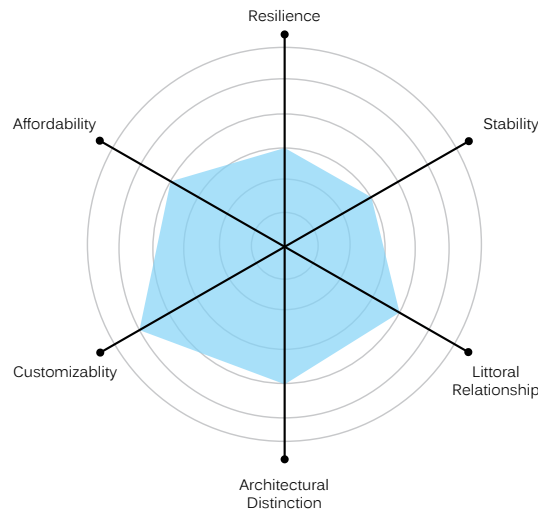


Figure 21 : EB Marina's Achievement of Key Criteria





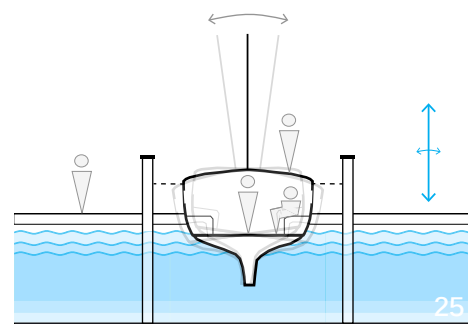
22



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Figures 22, 23, 24, 25:  
 Evans Bay Marina, North of Kilbirnie  
 Vacant Marina Berth in Evans Bay Marina  
 Yachts Swinging on Moorings in Storm  
 Marina Dwelling Diagram

### 3.5 SUMMARY & REFLECTION

After reviewing an extensive range of sea level rise accommodating architecture against the established design criteria, see radial diagrams, it was discovered that the most successful case study for implementation in the coastal city is the tidal or amphibious community of Koh Panyee Village. This community is capable of successfully occupying land and then adapting to float with the changing ocean environment once inundated. Although this case study is deemed the most collectively successful project against the design criteria, each of the other case studies excel in their own right and these strengths should also be incorporated into the design of a resilient dwelling strategy for Wellington City and the weaknesses avoided.

In conducting the case study analysis an important discovery was made. To date, all domestic sea level rise accommodation has been constructed in sheltered ocean environments. Alarming 75% of the coastal cities at risk of sea level rise are fully exposed to the unpredictable ocean, including the majority of the Wellington waterfront, the defined study area of this thesis.<sup>49</sup> Unsheltered, sea-ready architecture appears to have been largely ignored in both the literature and in practice, with the exception of major industrial and marine projects such as oil rigs and floating platforms. There is a significant gap in the literature which would benefit from redress in order to allow for these exposed regions to begin their preparations for sea inundation.

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- 28 Baker, R. "Modern Flood Management is About Living with Rising Water , Not Blocking it Out." *The Architects Journal* (2008): 10,19.
- 29 Rotmans, J. "The Floating City into an Ocean of Opportunities." *Urgenda* (2008): 1-16.
- 30 Sussman, P. "Bouyant Market: Are Floating Homes the Future of Housing." 2007. CNN.com/technology. <<http://edition.cnn.com/2007/TECH/science/08/20/floating.houses/>>. par 3
- 31 Rohmer, M. *Floating Homes IJburg*. 2011. Retrieved from [http://www.rohmer.nl/floating\\_homes\\_IJburg](http://www.rohmer.nl/floating_homes_IJburg). par 1
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- 33 Pasternack, R. "Aquitecture: Water-based Architecture in the Netherlands." *Delft University of Technology* (2009): 1-42. Masters Architecture Thesis.
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- 35 Travel to Halong. *Villages : Cua Van Village*. 2011. Retrieved from <http://www.traveltohalong.com/villages>. par 2
- 36 Nguyen, L. "An Overview of Ha Long Bay's Fishing Villages." *World Monuments Fund* (2012): 3. Retrieved from [www.wmf.org/journal/overview-ha-long-bay%E2%80%99s-fishing-villages](http://www.wmf.org/journal/overview-ha-long-bay%E2%80%99s-fishing-villages). par 3
- 37 Bowman, P. "Ocean As Place For Urban Life: Building on Water to Combat Urban Congestion & Climate Change." *Victoria University of Wellington* (2011): Architecture Masters Thesis. pg 30
- 38 Nguyen, L. "An Overview of Ha Long Bay's Fishing Villages." *World Monuments Fund* (2012): 3. Retrieved from [www.wmf.org/journal/overview-ha-long-bay%E2%80%99s-fishing-villages](http://www.wmf.org/journal/overview-ha-long-bay%E2%80%99s-fishing-villages). par 5
- 39 Bowman, P. "Ocean As Place For Urban Life: Building on Water to Combat Urban Congestion & Climate Change." *Victoria University of Wellington* (2011): Architecture Masters Thesis. pg 30
- 40 Whikeed, S. *Koh Panyee*. 2012. Retrieved from <http://phuket.thailandabout.com/islands-around-Phuket/koh-panyee.html>. par 1
- 41 Calder, S. *Thailand: Ko Panyee's Room with a Sea View*. 2001. Retrieved from <http://www.independent.co.uk/travel/asia/thailand-ko-panyis-rooms-with-a-sea-view-664189.html>. par 4
- 42 Whikeed, S. *Koh Panyee*. 2012. Retrieved from <http://phuket.thailandabout.com/islands-around-Phuket/koh-panyee.html>. par 2
- 43 Wilkinson, S. *Koh Panyee: Everything You Need to Know About Koh Panyee*. 2007. <<http://www.phuket.com/magazine/pan-yee-island.htm>>. par 1
- 44 Calder, S. *Thailand: Ko Panyee's Room with a Sea View*. 2001. Retrieved from <http://www.independent.co.uk/travel/asia/thailand-ko-panyis-rooms-with-a-sea-view-664189.html>. par 1
- 45 Jeffery, K. "International Sailor's Multihull Guide 3.ed." *Chicago: Avalon House Publishing*, 2002. pg 32
- 46 Wellington City Council. *Evans Bay Marina*. 2008. <<http://wellington.govt.nz/recreation/marinas-and-boatramps/evans-bay-marina>>. par 3
- 47 Greater Wellington Regional Council. "Swing Moorings & Marina Bearths." 2009. <<http://www.gw.govt.nz/Swing-moorings-&-Marina-bearths/>>. par 1-3
- 48 Olthuis, K. & D Keuning. *Float: Building on Water to Combat Urban Congestion and Climate Change*. Amsterdam: Frame, 2012. pg 4
- 49 Hanson, S, R Nicholls, and N Ranger. "A Global Ranking of Port Cities with High Exposure to Climate Extremes." *Climate Change* (2011): 90-11.







## 4. Site Introduction

This chapter introduces the city of Wellington, the focus area for this design research. A comprehensive mapping study of the three areas most at risk of inundation then follows, before the site of Kilbirnie is selected as the core focus for the remainder of this research. The destruction of a two metre rise in sea level is then clearly illustrated through an progressive series of simulations at a community and street level.



#### 4.1 WELLINGTON CITY

Located at the south-western tip of the North Island of New Zealand with a latitude of 41° 17' South, Wellington is the southernmost capital city in the world.<sup>50</sup> The city is the political capital of New Zealand and is internationally recognised for its creative arts and culture, as well as its frequent susceptibility to gale force winds and steep terrain.<sup>51</sup> With a restricted amount of buildable land available between the Wellington Harbour and the surrounding mountain ranges and over 400,000 residents, Wellington is one of the most densely populated cities in New Zealand. The city is comprised of a core central business district with a number of smaller suburban townships scattered throughout the banked hillsides or low lying coastal areas to the North, South and East.<sup>52</sup> The region is prone to high seismic activity, with a major fault line running directly through the centre of the city. As a result, residents typically experience several earthquakes every year.<sup>53</sup> Despite this, the Mercer Quality of Living Survey ranked Wellington the 12th best city in the world in which to live in 2010.

Due to the low lying nature of a significant portion of Wellington city, a third of Wellingtonian's live less than five metres above current sea level, and a highly alarming 40,000 residents are potentially at serious risk of inundation within the next century according to the Wellington City Council as they live less than two metres above current sea level.<sup>54</sup> The communities most at risk of inundation as a result of climate change driven sea level rise in the capital city are the suburbs of Petone, Kilbirnie and Seatoun, see Fig 26 - 28.<sup>55</sup>

#### 4.2 MAPPING STUDIES

A comprehensive mapping study was undertaken in order to assess the distinctiveness of these three suburbs and determine if a dwelling solution would need to be customised to mitigate the impact of sea level rise on each site, or if a single universal solution could be designed to cater for all three sites, see all maps in Appendix A.

Although the extent of potential inundation varies due to differing topography, the mapping analysis illustrates that a number of common factors are shared across these three sites. All three areas are predominantly domestic settlements; have core vehicular arteries along the shoreline; have very exposed littoral environments with a similar ocean depth; and have very poor geology comprised mainly of marine sediment which will likely result in large scale liquefaction once inundated. It has therefore been determined that although each site has its unique characteristics, a single design strategy to sea level rise in Wellington Harbour could be employed across all three sites. The suburb of Kilbirnie has been selected as the core focus site for the remainder of this design research, over the expansive community of Petone and the small suburb of Seatoun, with the understanding that the resolved solution for the community of Kilbirnie could likely be adapted to suit the needs of other communities at risk of inundation.





Figure 26 : Petone



Figure 27 : Kilbirnie



Figure 28 : Seatoun

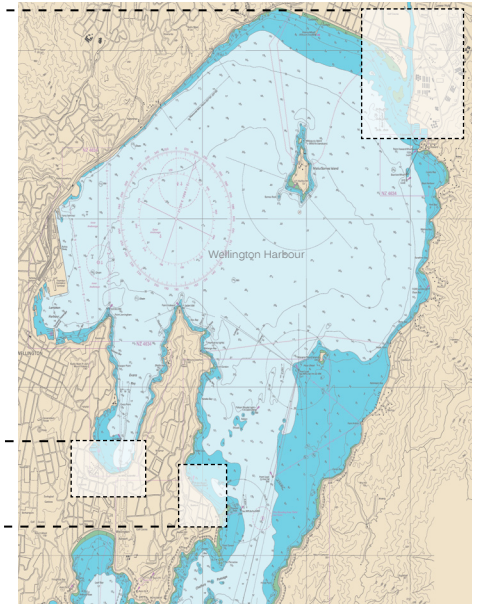


Figure 29 : References of Sites Within Wellington Harbour

### 4.3 INTRODUCTION TO KILBIRNIE

The Wellington suburb of Kilbirnie lies three kilometres south-east of the city centre on the isthmus between Evans Bay to the North and the Cook Strait to the South. Gale force winds often funnel between the two large mountain ranges that flank the suburb resulting in the frequent grounding of planes at Wellington International Airport and large breaking swells within Evans Bay, see Figure 30. The low lying land mass on which the suburb of Kilbirnie now sits was initially formed in 1855 when a 8.2 magnitude earthquake struck the Wellington region causing a flat strip of land to be raised from the harbour to connect the Miramar Peninsula, previously Miramar Island, with the rest of Wellington City, see Figure 31. As a result, most of the Kilbirnie community is constructed on porous land less than two metres above current sea level.<sup>56</sup>

Kilbirnie is a largely domestic suburb with a population of 6,400 residents.<sup>57</sup> In comparison to the remainder of Wellington, Kilbirnie is a diverse and multi-cultural community with a much lower socioeconomic status than the regional and national norm, see Figure 33.<sup>58</sup> Although the average house price in Kilbirnie is far cheaper than the regional average at \$350,000, most residents in the community live in rented single story timber villas constructed prior to the Second World War, see Figure 34.<sup>59</sup> An extensive collection of Kilbirnie community statistics compared with the regional and national averages can be found in Appendix B.

The Kilbirnie community possesses a number of significant anchoring features including the character shopping area of Bay Road, a regional community recreation centre and sports field, a number of primary and secondary schools as well as a number of facilities which cater for the wider region including, Wellington International Airport, the ASB Sports Centre, the Wellington Regional Aquatic Centre and the Metlink Bus Depot, see Figure 36.<sup>60</sup> The community also has a very rich maritime history in the neighbouring Evans Bay, see Figures 38-42.

An urban analysis of Kilbirnie reveals the suburb can be divided into three clear sections; the historic linear grid established by the New Zealand Company in the 1840's, the grid informed by the sites surrounding topography and the land reclaimed, in 1900 and 1940, to the north of Kilbirnie as the community steadily grew, see Figure 35. Unfortunately this reclamation effectively destroyed the connection between Kilbirnie's city centre and the sea. It is interesting to note that the pre-1900 Kilbirnie shoreline is very similar to that which would be observed in the event of a two metre sea level rise in Wellington Harbour by 2100. Such an event would see the inundation of over 450 homes, 3 schools, 6 community buildings and over 60 retail and commercial buildings, destroying residents livelihoods throughout Kilbirnie, see Figures 43-50. In order to ensure social sustainability, the Wellington City Council recommends in 'Assessing the Implications of Sea Level Rise: Kilbirnie Town Centre' (2009) that priority be placed on ensuring the protection of important community buildings and infrastructure over individual residences which could be removed incrementally as sea levels rise, see Figure 37. After these old homes have been removed the resilient dwelling strategy designed through this research could then be introduced to provide for permanent dwelling in a community with a currently uncertain future.





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Figure 30, 31, 32, 33, 34:  
 Evans Bay in a Strong Northerly  
 Wellington Shoreline Pre 1855 Earthquake  
 Kilbirnie Panorama from Maupuia Park  
 Kilbirnie Festival, Bay Road  
 Typical Kilbirnie Dwellings



Kilbirnie Urban Analysis

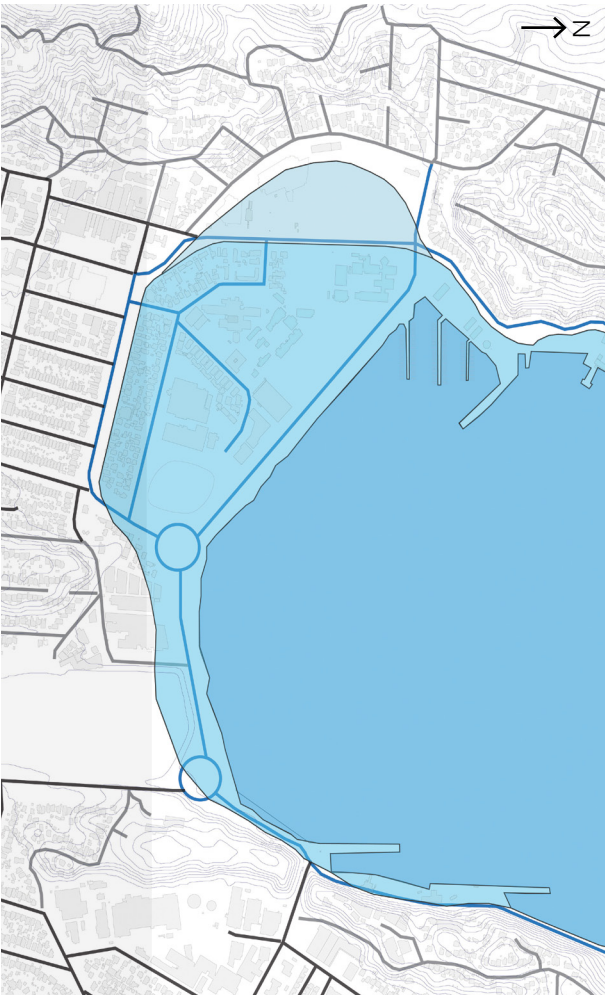


Figure 35: Kilbirnie Urban Grid & Land Reclamation

- Key:
- |                        |                             |
|------------------------|-----------------------------|
| 1900 Reclamation       | Historic Linear Grid        |
| 1940 Reclamation       | Grid Informed By Shoreline  |
| 2013 Current Shoreline | Grid Informed By Topography |

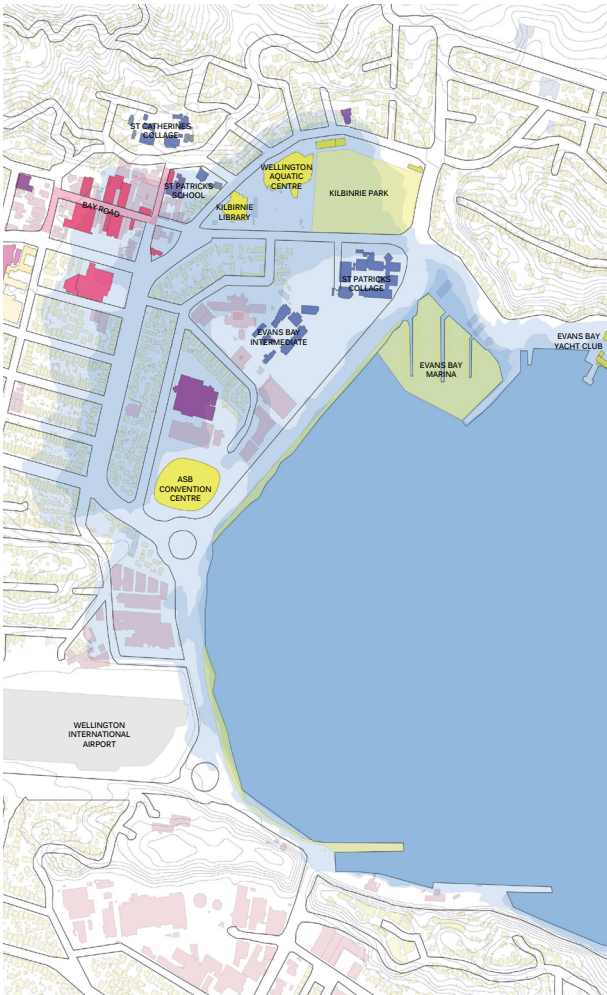


Figure 36: Kilbirnie Community Anchor Points

- Key:
- |                          |             |
|--------------------------|-------------|
| Recreational / Community | Airport     |
| Retail / Commercial      | Residential |
| Cultural / Religious     | Commercial  |
| Institutional            | Sea Level   |

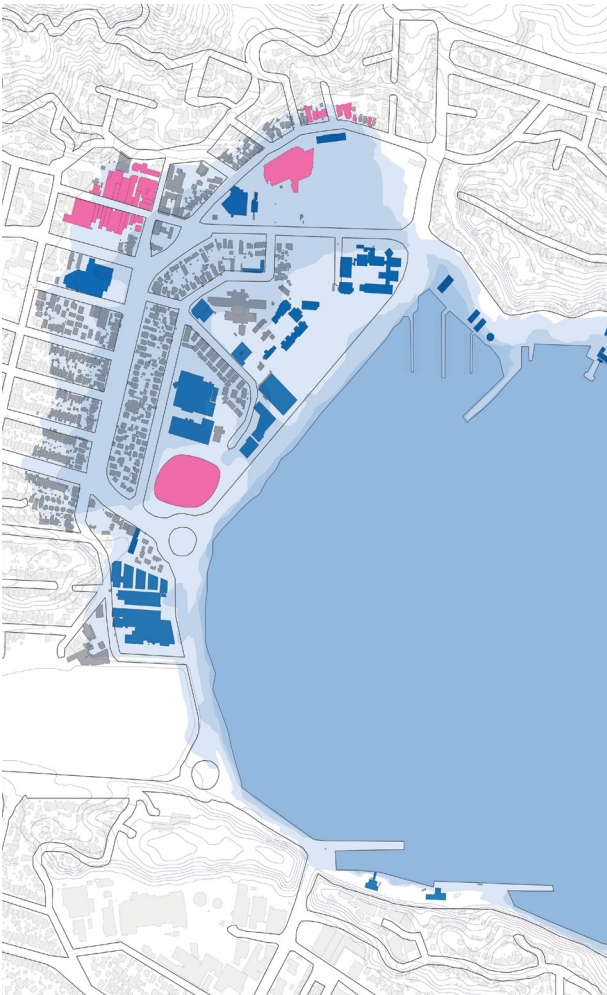


Figure 37: Proposed Plan for Inundated Buildings

- Key:
- |                                     |
|-------------------------------------|
| Buildings Which Must Be Protected   |
| Buildings Which Should Be Protected |
| Buildings To Be Removed             |
| Sea Level                           |



## Evans Bay Marine History



Figure 38, 39, 40, 41, 42:  
 Evans Bay Slip, 1922 - 1972  
 Miramar and Burnham wharves, 1920 - 1929  
 Evans Bay Yacht Club, 1921 -  
 Shelly Bay Naval Base, 1939 - 1945  
 Len Southwards 100mph Redhead Jet Boat, 1953

#### 4.4 KILBIRNIE SEA LEVEL RISE - URBAN SCALE

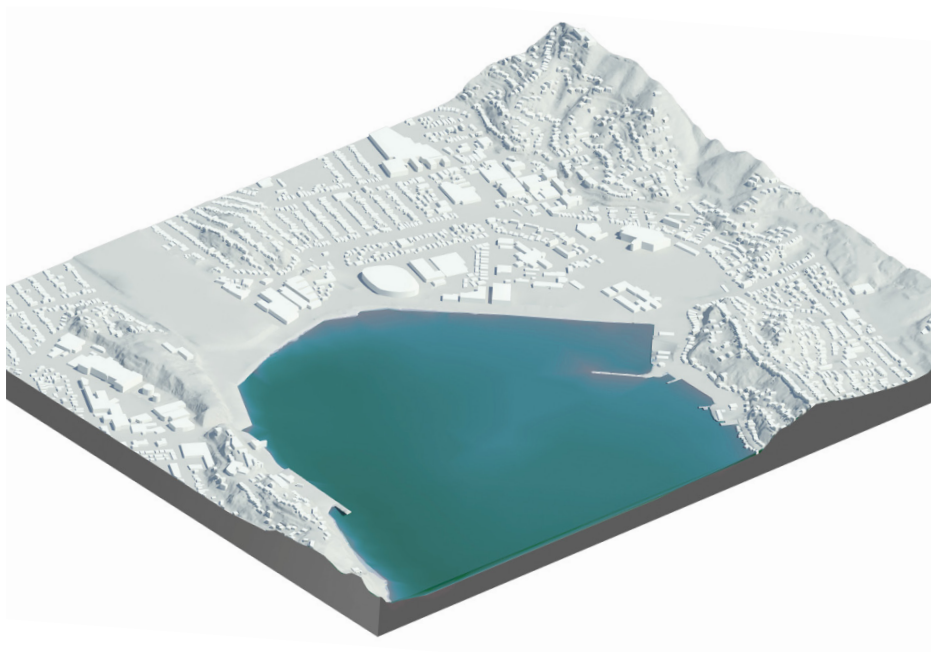


Figure 43: Kilbirnie : 2013 - 0m Sea Level Rise

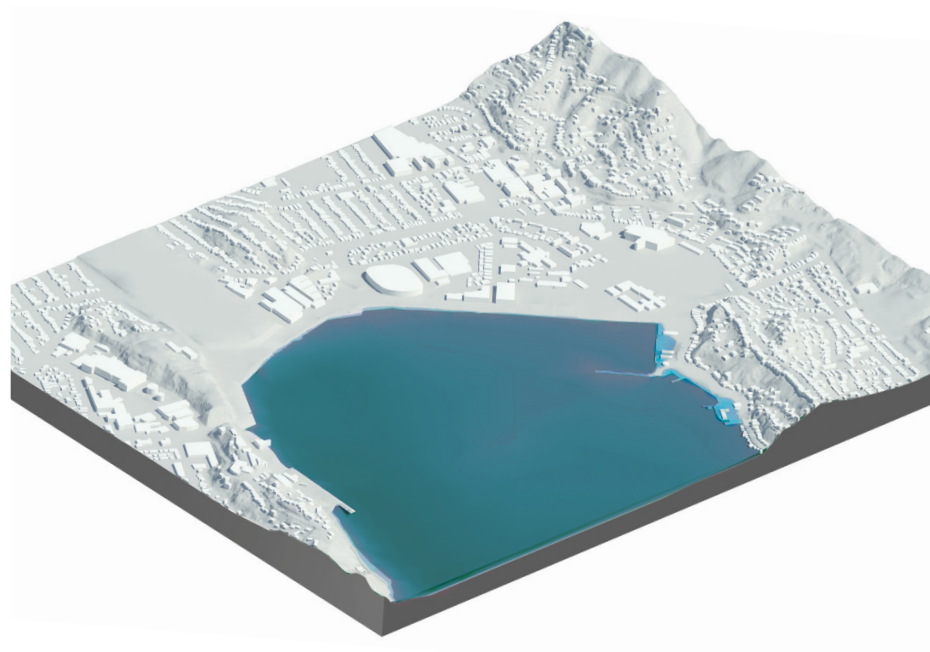


Figure 44: Kilbirnie : 2050 - 0.7m Sea Level Rise  
Evans Bay Marina and Evans Bay Yacht Club are Inundated



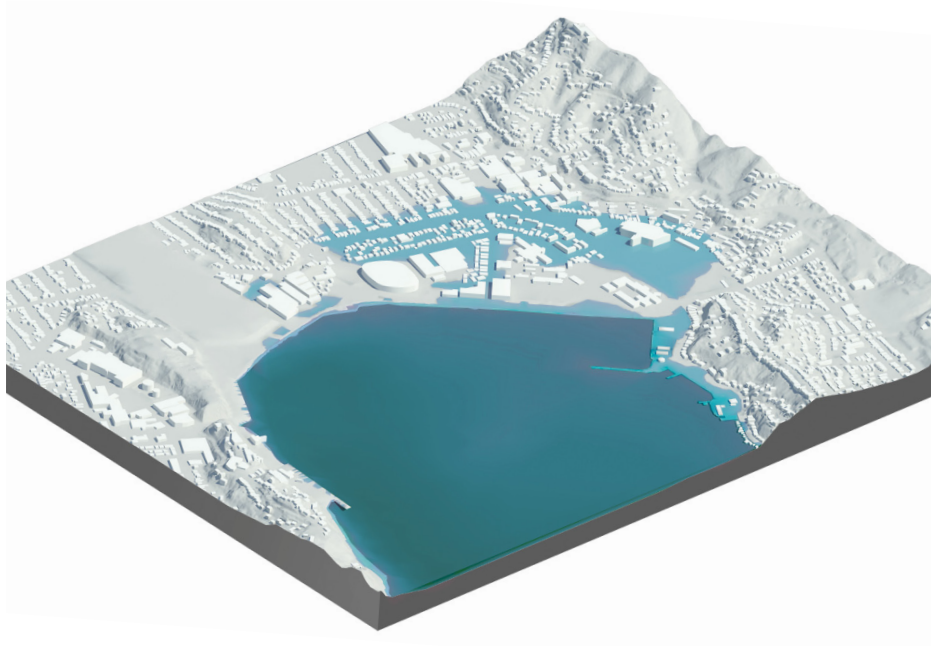


Figure 45: Kilbirnie : 2075 - 1.2m Sea Level Rise

Sea levels rise above State Highway One flows down Tacy ST and inundates a significant portion of North Kilbirnie

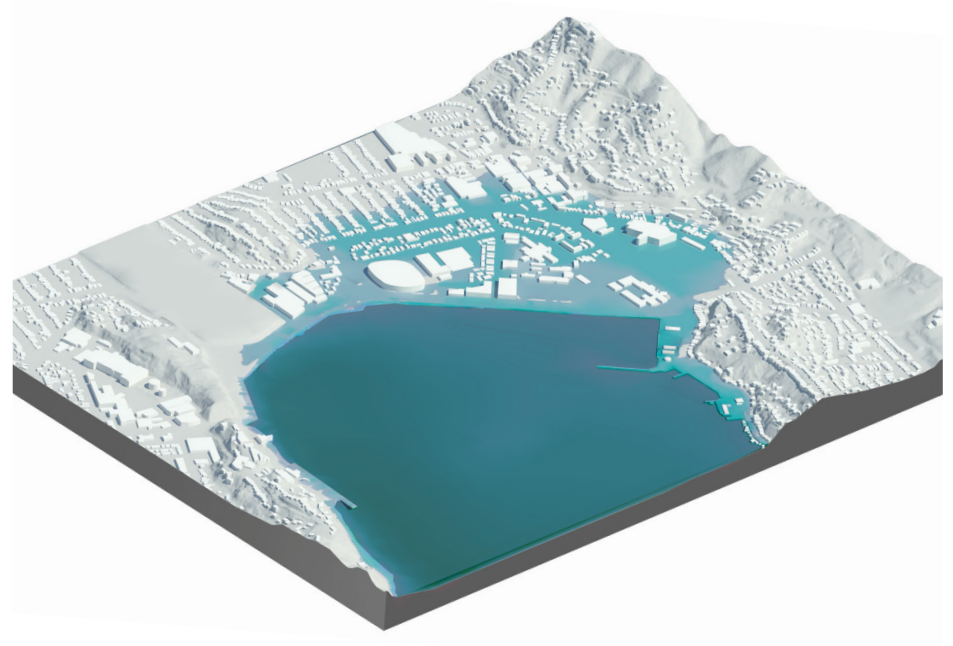


Figure 46: Kilbirnie : 2100 - 2m Sea Level Rise

The greater portion of Kilbirnie is inundated

## 4.5 KILBIRNIE SEA LEVEL RISE - STREET SCALE



Figure 47: Kilbirnie : 2013 - 0m Sea Level Rise

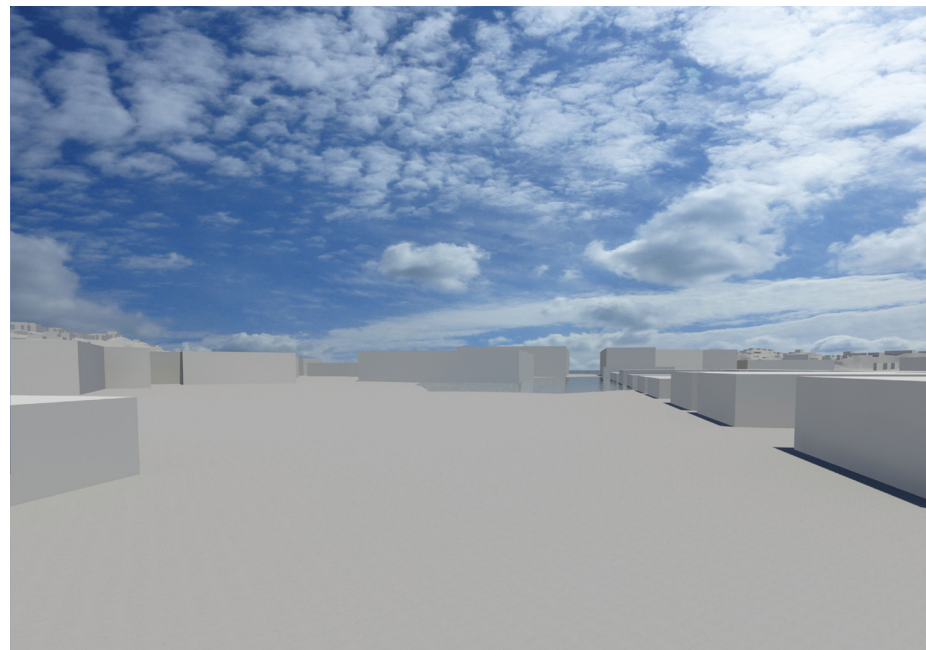


Figure 48: Kilbirnie : 2050 - 0.7m Sea Level Rise  
Small amounts of sea water pool near Evans Bay, buildings  
at risk of inundation begin to be removed

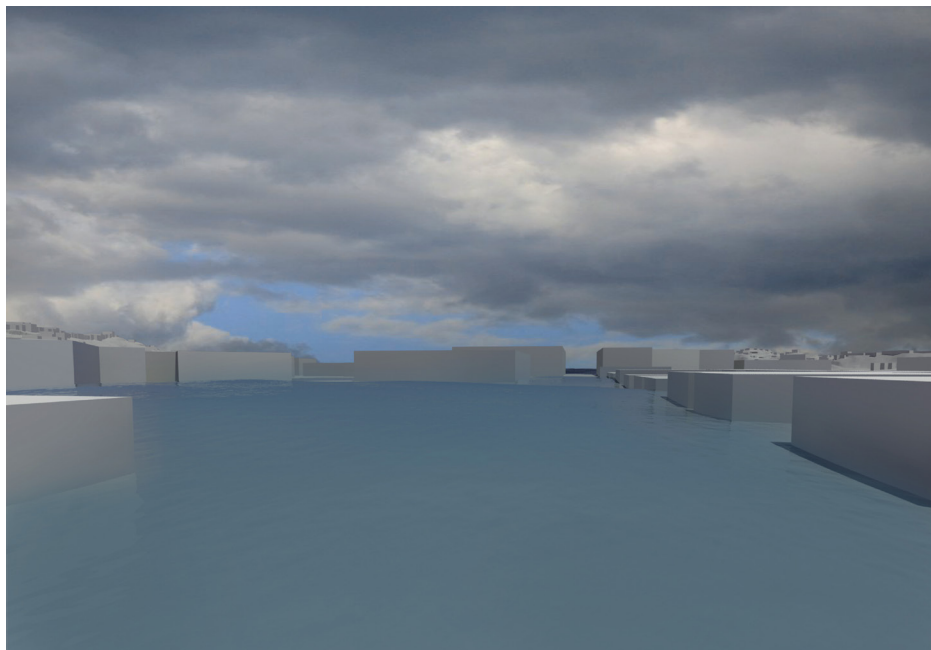


Figure 49: Kilbirnie : 2075 - 1.2m Sea Level Rise

The street is completely inundated with as much as 800mm of water in some areas

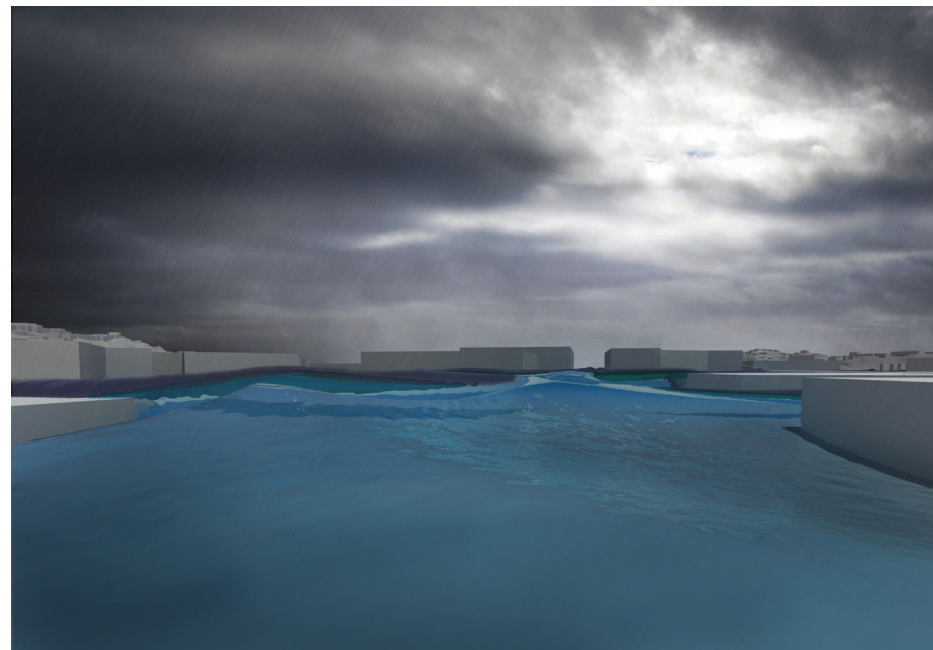


Figure 50: Kilbirnie : 2100 - 2m Sea Level Rise

The street is inundated in 1.6m of sea water, large swells begin to form when water is disturbed between surviving buildings

In order to fully understand the magnitude of destruction which would be caused by a two metre rise in sea levels in Wellington Harbour by 2100, a progressive series of simulations of the suburb of Kilbirnie illustrating the dramatic rise in sea level every quarter of a century from 2050 to 2100 from both an urban and street level have been produced, see Figures 43- 50. In order to create these images a digital model of Kilbirnie has been generated in Autodesk Revit from 0.1m contours of the suburb provided by the Wellington City Council. This model has then been taken into Autodesk 3ds Max where the renowned ocean simulation plug-in Houdini Ocean 2013 has been used to illustrate not only the level of inundation but also clearly communicate the swells and disturbance patterns which would likely occur as the ocean inundates the low lying community.

## 4.6 SUMMARY & REFLECTION

According to Wellington City Council, one tenth of Wellingtonian's live less than two metres above current sea level due to the low lying nature of a significant portion of the capital city and are therefore at risk of inundation within the next century. Following the identification of those communities most at risk of inundation in the greater Wellington region as Petone, Kilbirnie and Seatoun, a comprehensive urban analysis established that although the extent of potential inundation differed across the sites, the three sites were similar enough in the core areas to warrant a similar solution. A single resilient dwelling solution could be designed for the chosen focus site of Kilbirnie with the understanding that the design could easily be adapted to suit the needs of other sites throughout Wellington City and more than likely other coastal cities which share a similar climate, culture and littoral environment. The simulation images and the physical scale model, see Figure 51, illustrate the destruction that a two metre sea level rise could have on the coastal city of Kilbirnie and reiterates the importance of finding a successful accommodation strategy.

Figure 51:

1 : 2000 Scale Model of Kilbirnie with a Sea Level Rise of 2 Metres

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- 50 Guinness World Records. Guinness World Records 2014. London: Guinness World Records Ltd, 2013. pg 277
- 51 Watford, Garston. "Wind Around Tall Buildings." BRE Digest Jan. 1994: 1-12. Print. pg 1
- 52 Dawe, I. "Sea Level Rise – A New Zealand Context." Greater Wellington Regional Council, 2009: pg 1
- 53 Greater Wellington Regional Council. Earthquakes. 2013. Retrieved from <http://www.gw.govt.nz/earthquakes>. par 1
- 54 Statistics New Zealand. Are New Zealanders Living Closer to the Coast? 2006. Retrieved from [http://www.stats.govt.nz/browse\\_for\\_stats/population/migration/internal-migration/are-nzs-living-closer-to-coast.aspx](http://www.stats.govt.nz/browse_for_stats/population/migration/internal-migration/are-nzs-living-closer-to-coast.aspx). par 21
- 55 Evans, L. et al. "Perceptions of Sea Level Rise in Wellington City and Kapiti Coast Districts." Victoria University of Wellington (2012)
- 56 New Zealand History online. 1855 Massive Earthquake hits Wellington Region. 2013. Retrieved from <http://www.nzhistory.net.nz/massive-earthquake-hits-wellington>. par 1
- 57 Statistics New Zealand. Kilbirnie, Wellington. 2006. Retrieved from <http://profile.idnz.co.nz/Default.aspx?id=366&pg=8114&gid=240>. pg 1-22
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- 59 Statistics New Zealand. Kilbirnie, Wellington. 2006. Retrieved from <http://profile.idnz.co.nz/Default.aspx?id=366&pg=8114&gid=240>. pg 1-22
- 60 Wellington City Council. "Assessing the implications of Sea Level Rise: Kilbirnie Town Centre." (September 2009): 1-14.









## 5. Design Process

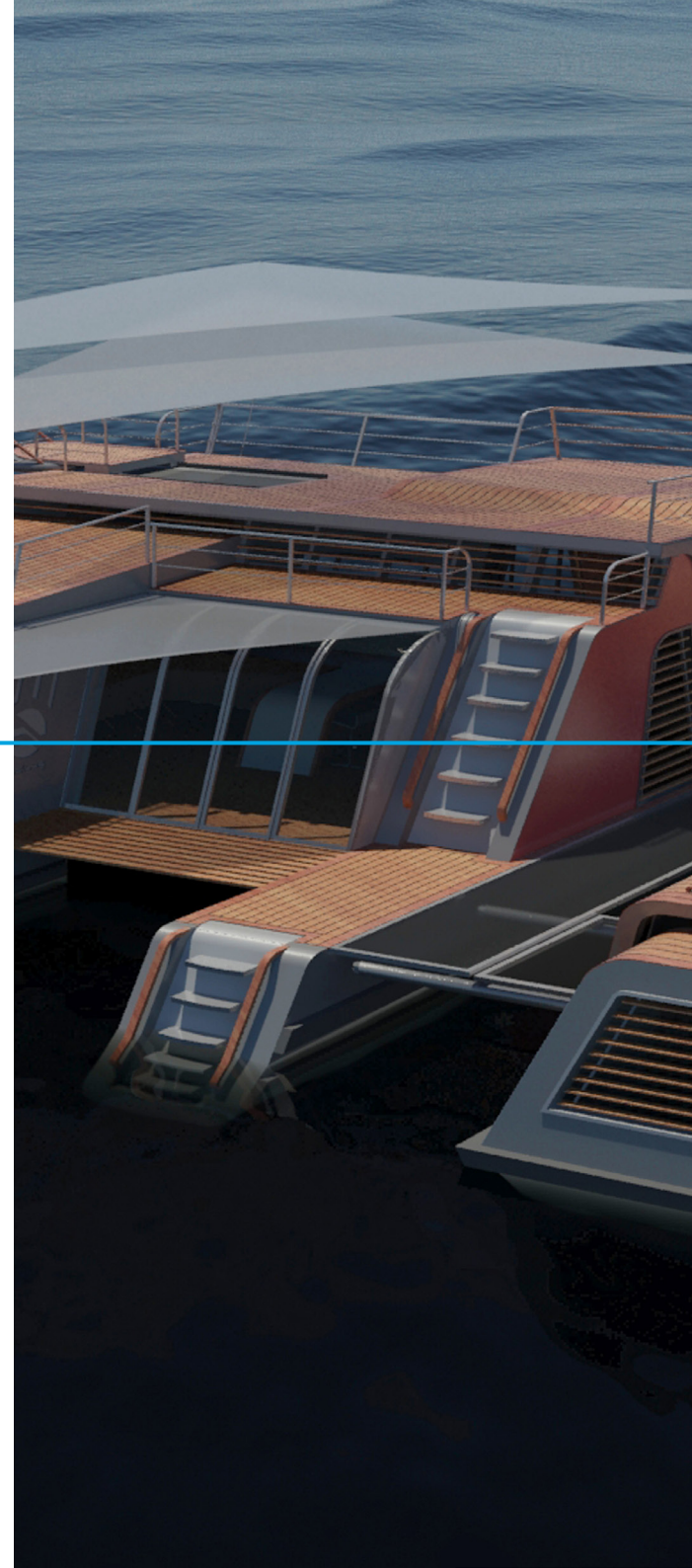
Due to the iterative nature of this research through design investigation, the design component of this thesis has been divided into three individual sub-chapters with each segment providing a modified approach to the design problem and research question *'How can a resilient residential dwelling be designed for the coastal city littoral zone, in response to the encroaching pressures of climate change driven sea level rise?'*

Each design iteration has been analysed against the research aims by means of a number of comparative analysis, tests and simulations in order to identify and reflect upon their strengths and weaknesses. The resulting design solution at each stage was then formally critiqued by a number of highly educated academic reviewers as well as practitioners from architecture, engineering and boat building backgrounds. Their feedback along with my own design reflection was then carried into the following phase of design development.

The first design exploration builds upon the lessons learnt from the case studies and strives for ocean inhabitation in the face of sea level rise.

The second design exploration improves upon the issues identified in the first approach and focuses on a dwelling solution which ensures resilience and adaption.

The third and final design exploration builds upon the success of the previous approaches and implements marine technology into a revised form and design aesthetic. It provides a successful resilient dwelling solution capable of implementation within the decade to minimise resident displacement in the suburb of Kilbirnie as a result of sea level rise.



## 5.1 Design Phase One

The design intent of this first phase of design development aims to ensure that the community of Kilbirnie is able to accommodate inundation through the implementation a network of interconnected ocean inhabiting dwellings. The final concept at the end of this design phase is neither a house, nor a boat, but a hybrid of the two in the form of a floating dwelling specifically designed for permanent inhabitation of the untamed ocean. Building from the view of the Dutch Housing Minister Sybilla Dekker, who recently stated, “You cannot fight water. You have to learn to live with it”,<sup>61</sup> it is intended that a number of Kilbirnie residents, deemed at risk of inundation, could begin to live in these floating ocean dwellings within the decade in order to allow the community to adapt to the practicalities of living with and on the water prior to the inevitable inundation of the low lying Wellington suburb.

Through inhabiting the ocean, a water community could be progressively established to the North of Kilbirnie in Evans Bay over the coming decades and when sea levels do eventually rise to inundate the former community of Kilbirnie, the floating community would simply rise with the changing environment and would therefore be less affected by rising sea levels, as shown below in Figure 52.

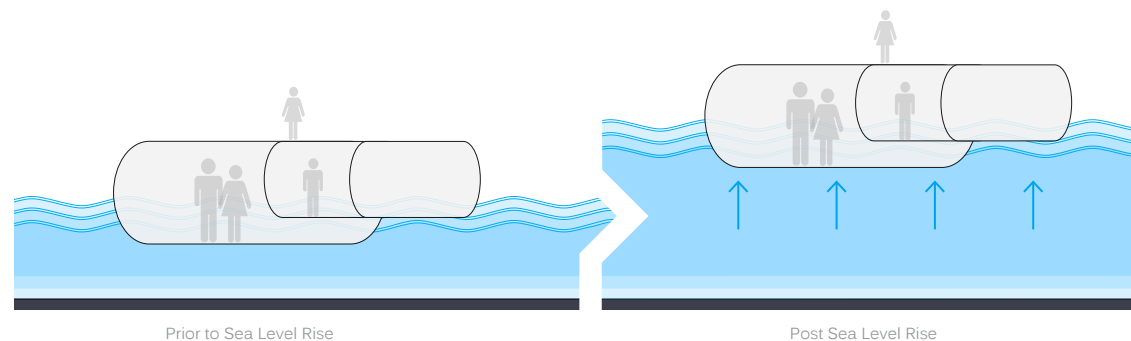
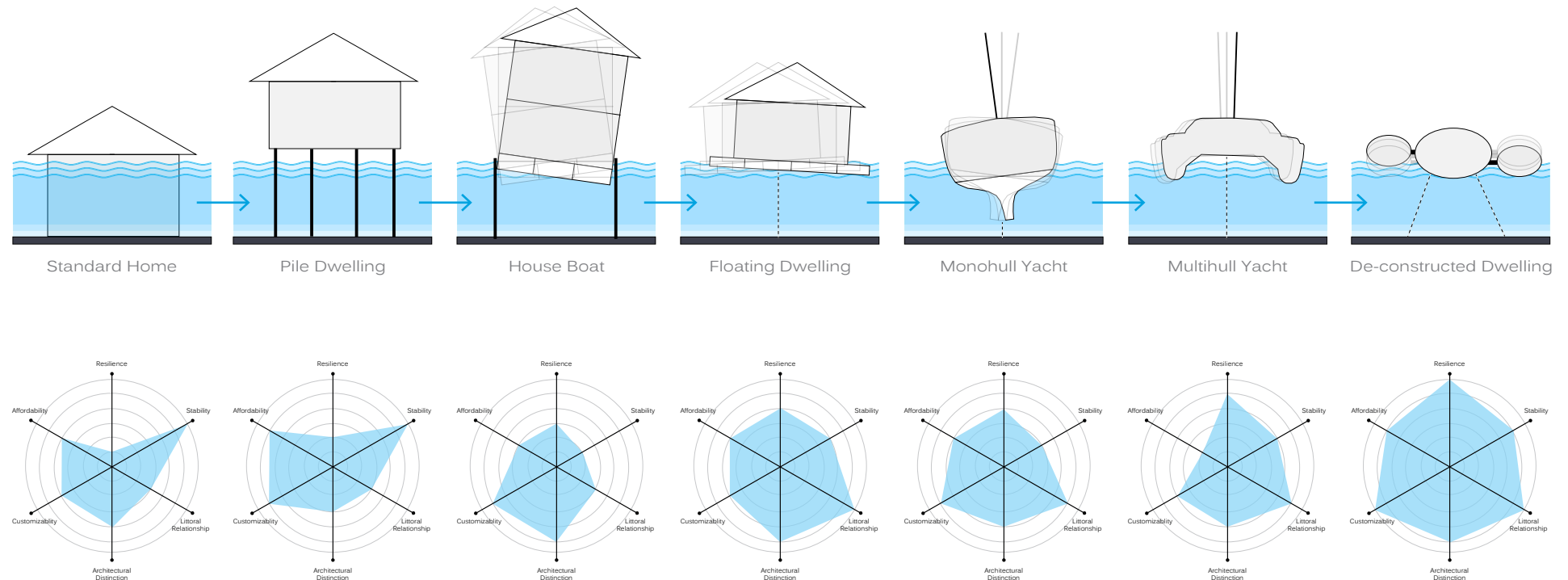


Figure 52: Ocean Inhabitation Diagram



### 5.1.1 COMPARING OCEAN INHABITATION SOLUTIONS



Through employing the same design criteria and radial diagrams previously used in analysing the former design case studies, the possible solutions to permanent ocean habitation can easily be compared against one another, see Figures 54 - 60. From observing these diagrams it can be determined that both a house and a boat are unsuitable for permanent occupation when inundated and that instead the most appropriate method of providing resilient dwelling for the Kilbirnie community in the face of sea inundation is potentially a deconstructed dwelling system. A deconstructed dwelling, created from separating the programme of a multihull into individual prefabricated components for simple user customisation, would be able to easily adapt and remain stable despite the constantly changing environment through progressive articulation.

Figures 53, 54 - 60:  
Current Ocean Inhabitation Solutions  
Comparing Solutions Against Design Criteria

## 5.1.2 FORM DEVELOPMENT

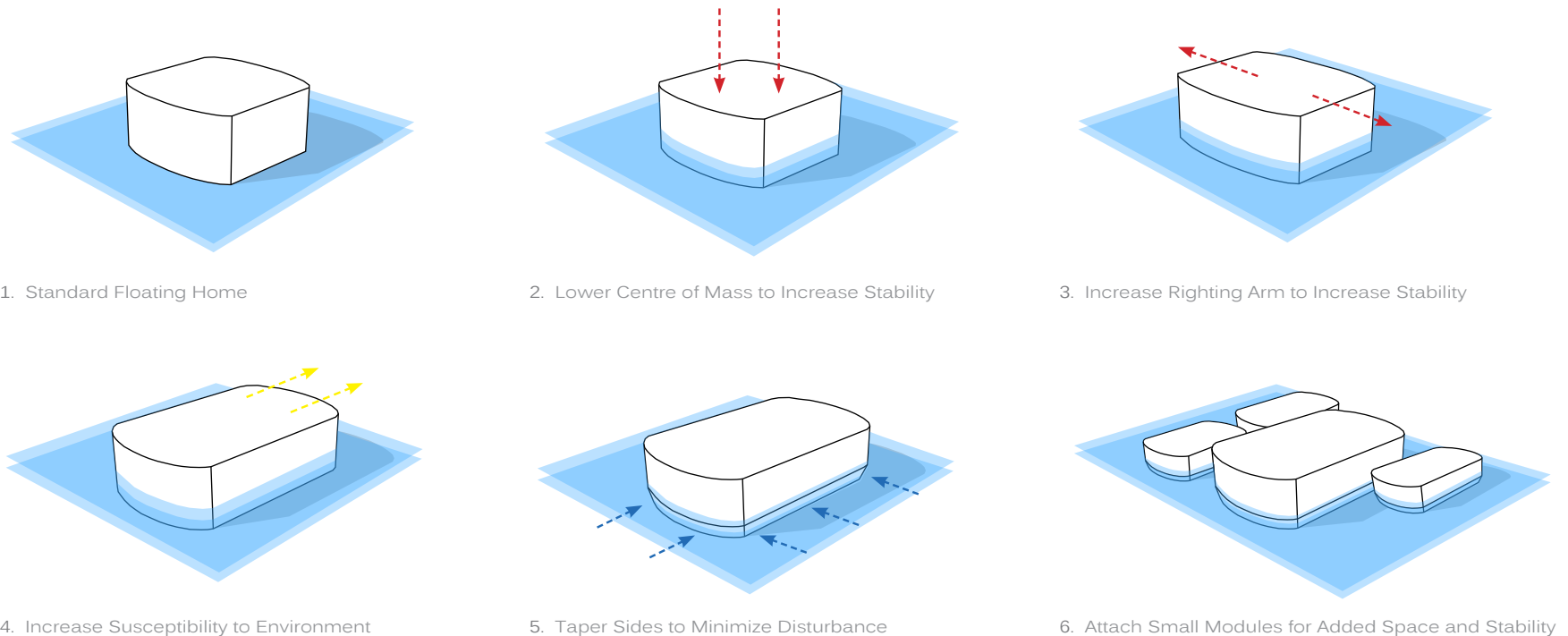


Figure 61: Development of Dwelling Form

### Key:

- Stability Based Change
- Wind Based Change
- Sea Based Change

In order for coastal city residents to accept floating residences as viable homes for the future, even in the event of unprecedented sea level rise, Koen Olthuis founder of WaterStudios.NL, advises that floating homes need to become equivalent to traditional homes: in comfort, in quality and in price.<sup>62</sup> Focus was therefore placed on ensuring balance and stability in an unstable environment in order to guarantee resident safety and comfort, while also ensuring that the dwellings form would be economical to construct even when employing high quality materials. The form design of the deconstructed dwelling was developed in six basic steps, see Figure 61. Starting with a simple floating cube, the design was lowered into the water and widened to increase stability for the residents within. The design was then stretched and tapered to allow the dwelling to move and rotate, or wind vane, with the changing littoral environment. This minimizes the likelihood of crosswinds and side-chop effecting floating dwelling. The final step was to attach the private modules which are able to articulate with the changing conditions, to further increase stability and resident comfort.

### 5.1.3 PROCESS OF INHABITATION

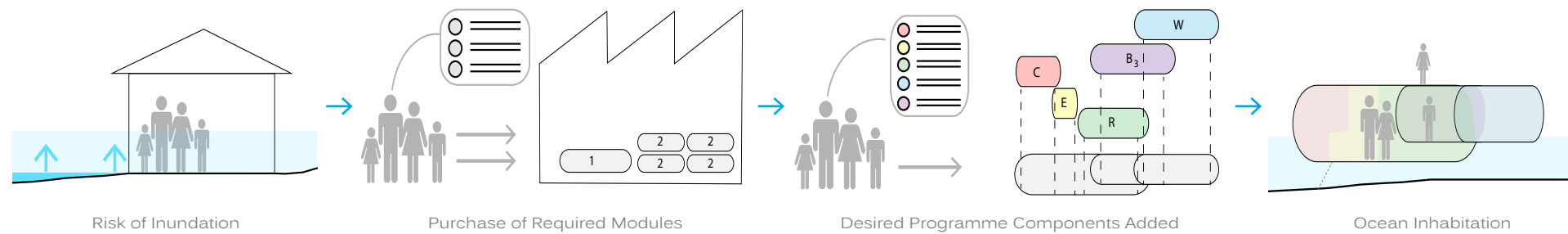


Figure 62: Process from Risk of Inundation to Ocean Inhabitation

### 5.1.4 INTERCHANGEABLE DWELLING CONFIGURATIONS

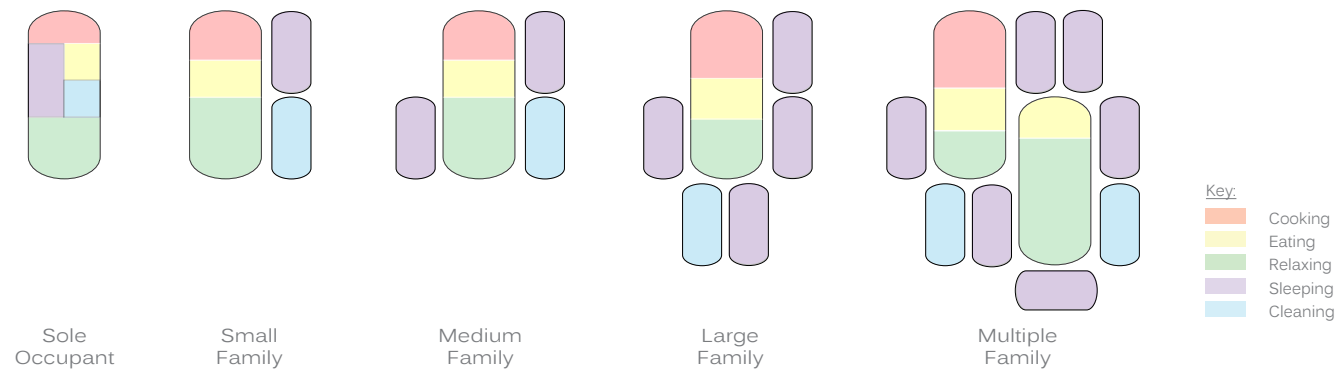
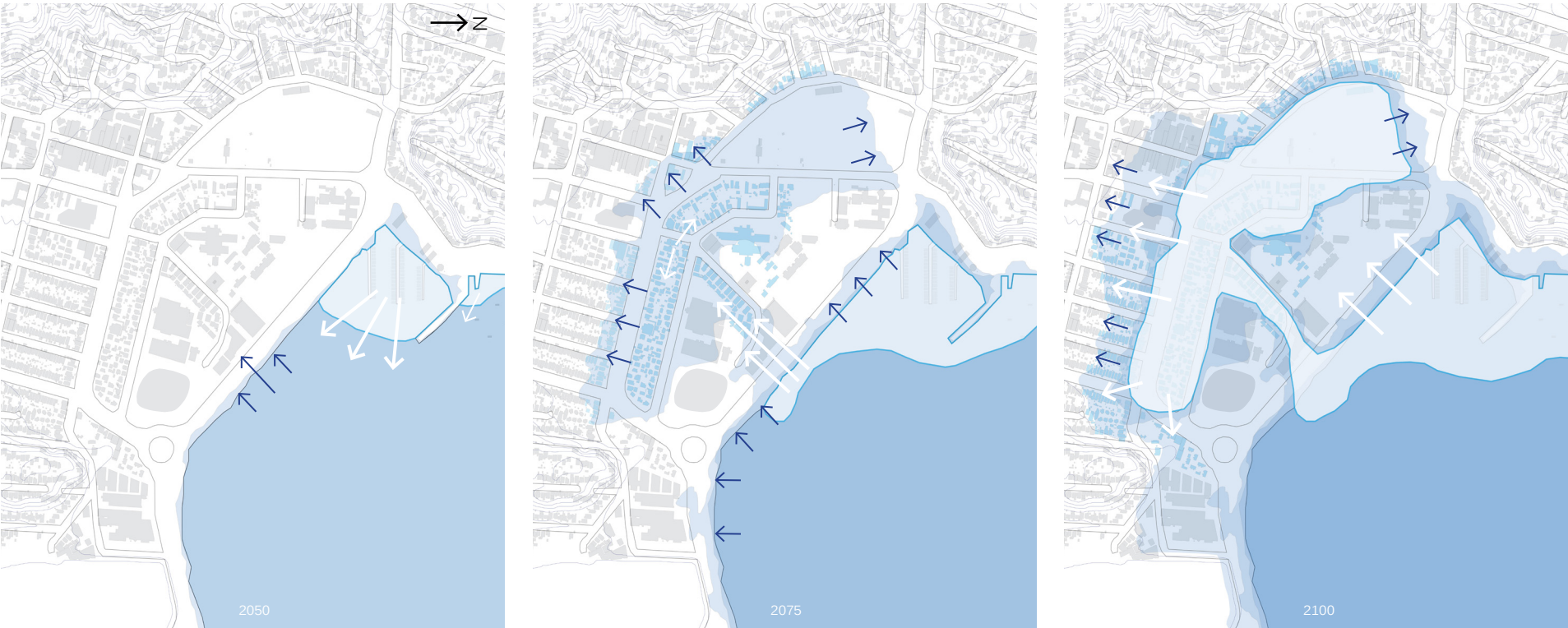


Figure 63: Multiple Possible Dwelling Configurations

The community of Kilbirnie is very diverse; it is therefore highly important that a residential solution is easily adaptable and customised to meet the needs of a variety of different users. When a household are deemed to be, or feel they are at risk of inundation they will be able to rent or purchase a deconstructed floating dwelling. The household could potentially choose a selected number of prefabricated modules and have them fitted with a type and arrangement of programme to form their own user specific floating dwelling, see Figure 62. The above diagram illustrates a variety of different dwelling arrangements that could be employed to meet the needs of a variety of different resident groups.

5.1.5 INCREMENTAL DEVELOPMENT OF THE DWELLING COMMUNITY



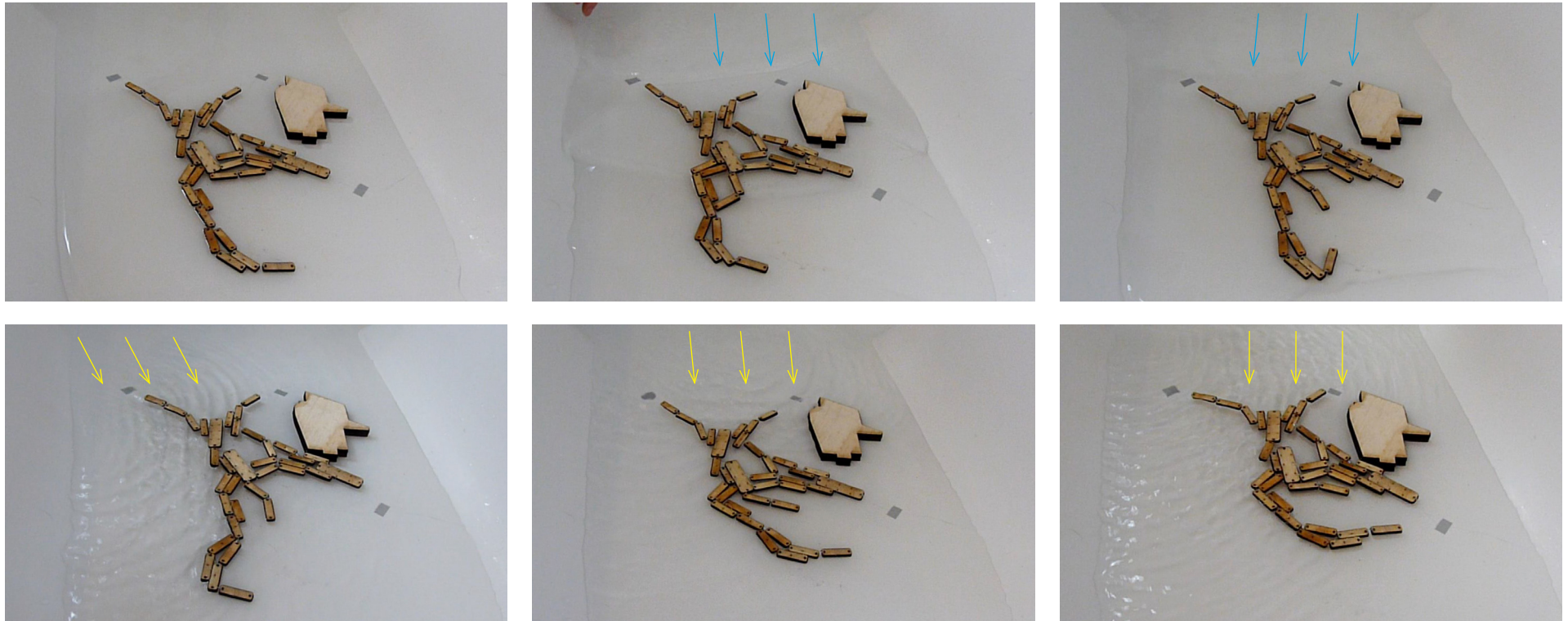
Figures 64 - 66: Incremental Development of the Ocean Inhabiting Community

Key:

Sea Inundation	Remaining Buildings	Future Inundation
New Community	Removed Buildings	Future Growth of Community

An ocean dwelling community would be initially introduced into the semi-sheltered area of Evans Bay Marina, due to the ease of access and serviceability.<sup>63</sup> As the popularity for the solution grows, this community can expand out into the bay. When Kilbirnie is first inundated in 2075 the level of inundation will not be deep enough to allow the floating dwellings to move further inland. It is not until 2100, when most of the suburb is inundated in a metre of water, that the new floating community can successfully re-connect with the existing city, see Figures 64 - 66.

### 5.1.6 FLOATING COMMUNITY SIMULATIONS

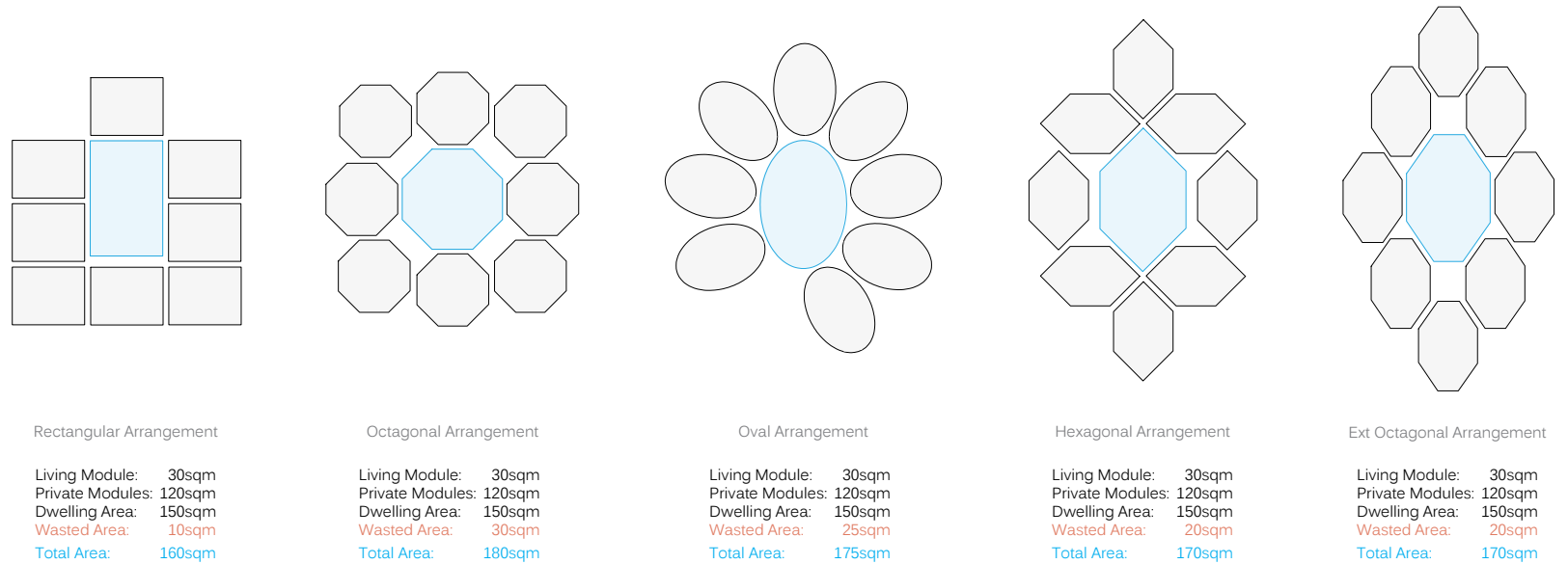


Figures 67 - 72: Three Anchor Point Floating Community with Inundated Buildings

A series of simulations were undertaken in order to explore the influence of the dynamic littoral environment on the floating community and to determine the most appropriate number of units per anchor point as well as identifying the most successful connection strategy. Each system was tested from a variety of different directions and in differing weather conditions relative to a moderate storm. After a number of experiments, it was established that the floating dwellings should be rafted together where possible, rather than attached end-to-end, and that there should be at least one anchor per ten floating modules. Figures 67 - 72 represent a series of changing spatial relationships that could occur in the floating community over a twelve hour period in Evans Bay if such a system of connections and anchors were to be employed. When comparing these stills to those of the earlier experiments, see Appendix C, it is clear that the anchored community appears to move more gradually with the same environmental conditions and could therefore be considered more comfortable for the potential occupants, especially those prone to sea sickness.

Key:  
→ Wave Direction  
→ Wind Direction

### 5.1.7 ARRANGEMENT ANALYSIS OF GEOMETRIC PRIMITIVES

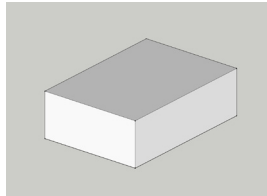


Figures 73: Arrangement Analysis of Geometric Primitives

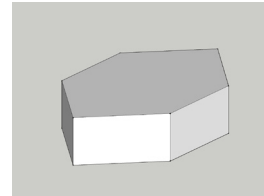
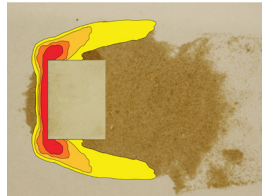
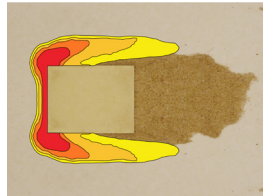
Due to the expansive nature of the floating dwelling, as a result of the requirement to remain only single storied to maintain stability, it is essential that the ocean inhabiting community is efficient in its use of space so as to mitigate unnecessary urban sprawl. Five primitive geometries have been arranged with a single 30sqm living module and eight private modules that are half the size of the living module. When reviewing the figures it is clear that the octagonal arrangement is the least efficient given the quantity of void space between the modules and that the rectangular arrangement is the most efficient and could therefore allow for more households to be housed in a smaller total area.



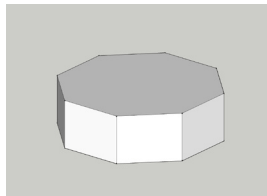
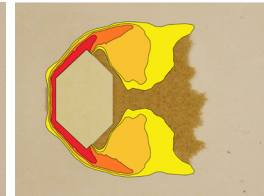
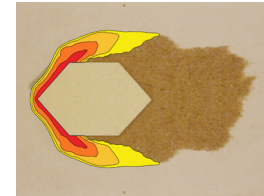
## 5.1.8 AERODYNAMIC TESTING OF GEOMETRIC PRIMITIVES



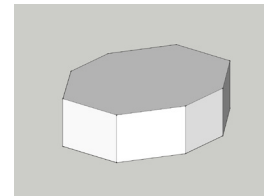
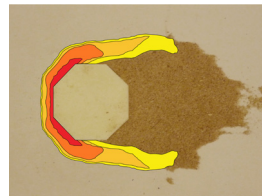
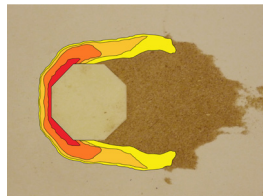
Figures 74- 76: Rectangular Form



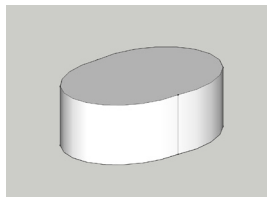
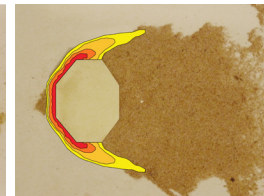
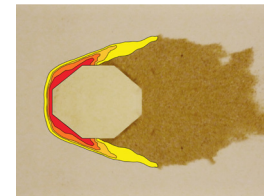
Figures 83 - 85: Hexagonal Form



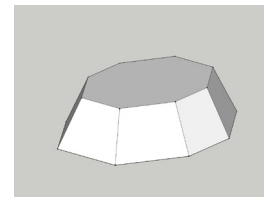
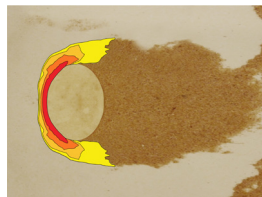
Figures 77 - 79: Octagonal Form



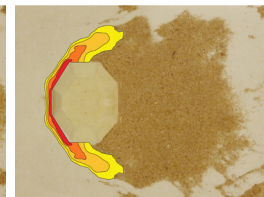
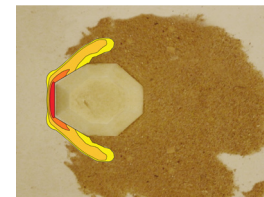
Figures 86 - 88: Extended Octagonal Form



Figures 80 - 82: Oval Form



Figures 89 - 91: Tapered Octagonal Form



### Key:

<span style="color: red;">■</span> Very High Wind Disturbance	<span style="color: orange;">■</span> Medium Wind Disturbance
<span style="color: orange;">■</span> High Wind Disturbance	<span style="color: yellow;">■</span> Low Wind Disturbance

Wind disturbance around fixed and floating units can greatly impact the ferocity of the ocean environment.<sup>64</sup> In order to alleviate this avoidable disturbance a series of wind tunnel tests were undertaken on a variety of different geometries so as to find the most aerodynamic form. From analysing the longitudinal and latitudinal results of five primitive geometries it can be concluded that the extended octagonal form is the most aerodynamic, due to its comparably small disturbance pattern. It was then identified that this disturbance could be further minimised by tapering the edges of this form. After comparing the efficiency of arrangement and the aerodynamic properties of the primitive geometries it was determined that a design loosely based upon an extended octagon would be the most successful when designing an efficient and comfortable floating dwelling.

### 5.1.9 DEVELOPING AN AESTHETIC

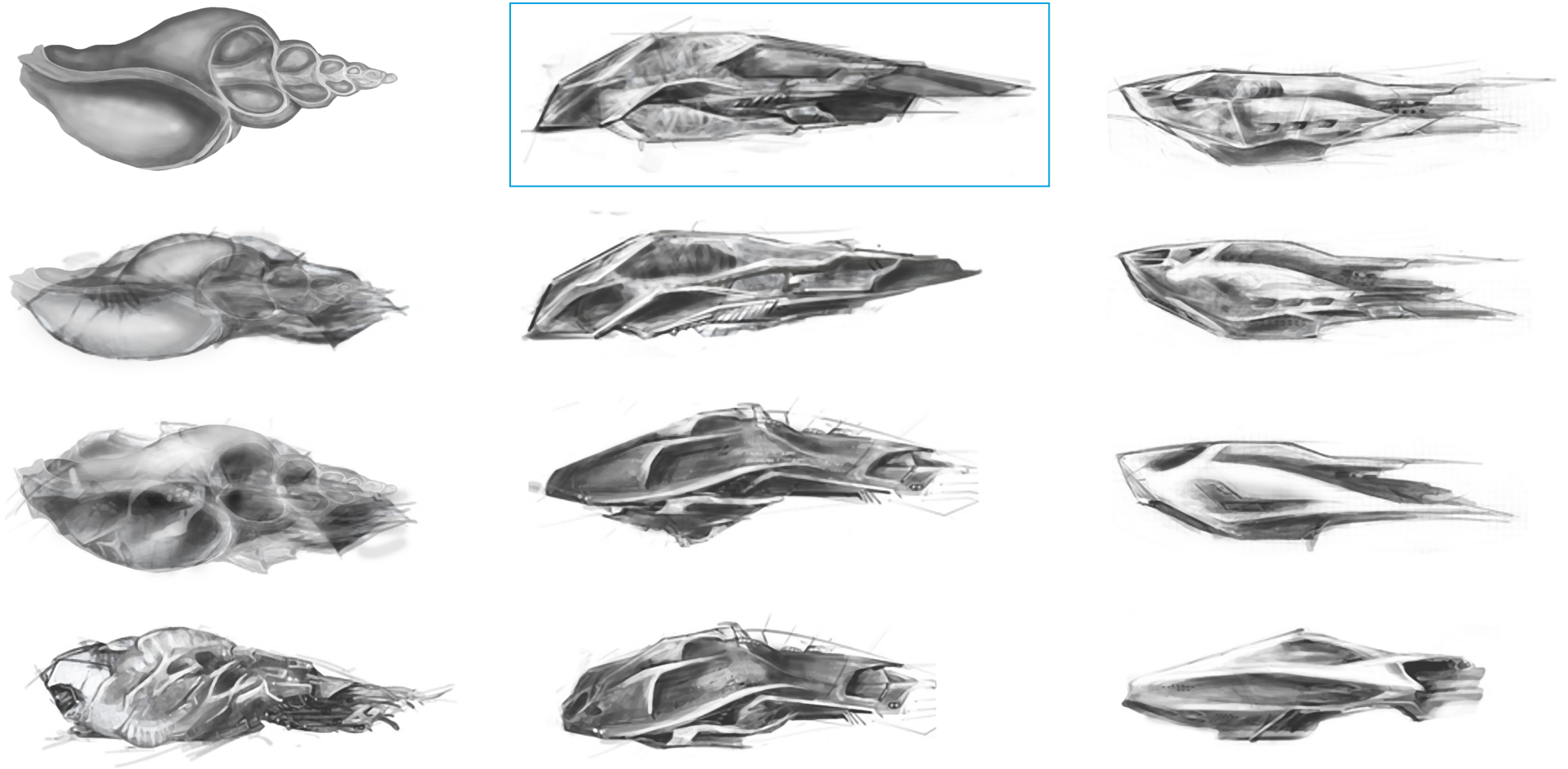


Figure 92: Abstracting Bivalve Shell to Find Design Aesthetic



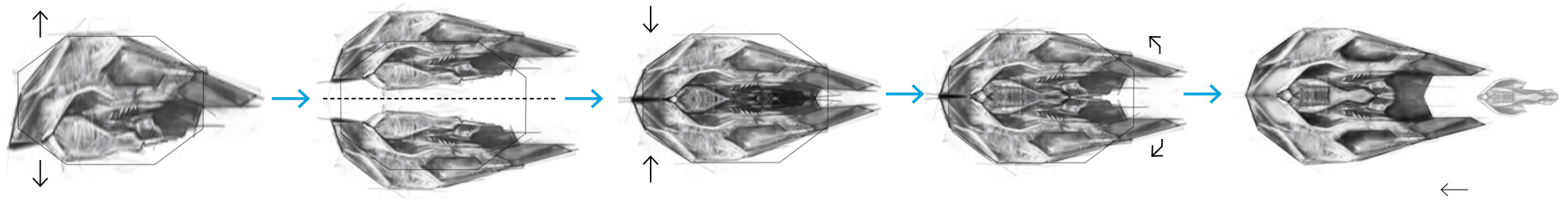
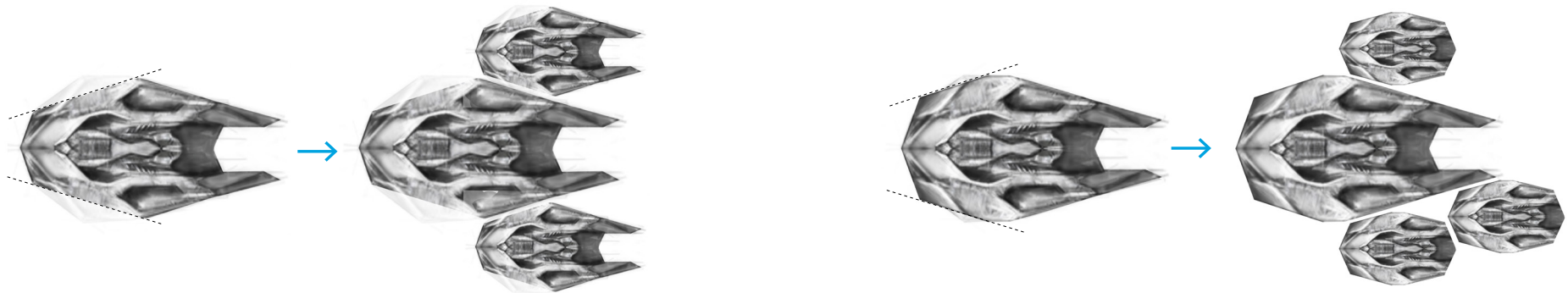


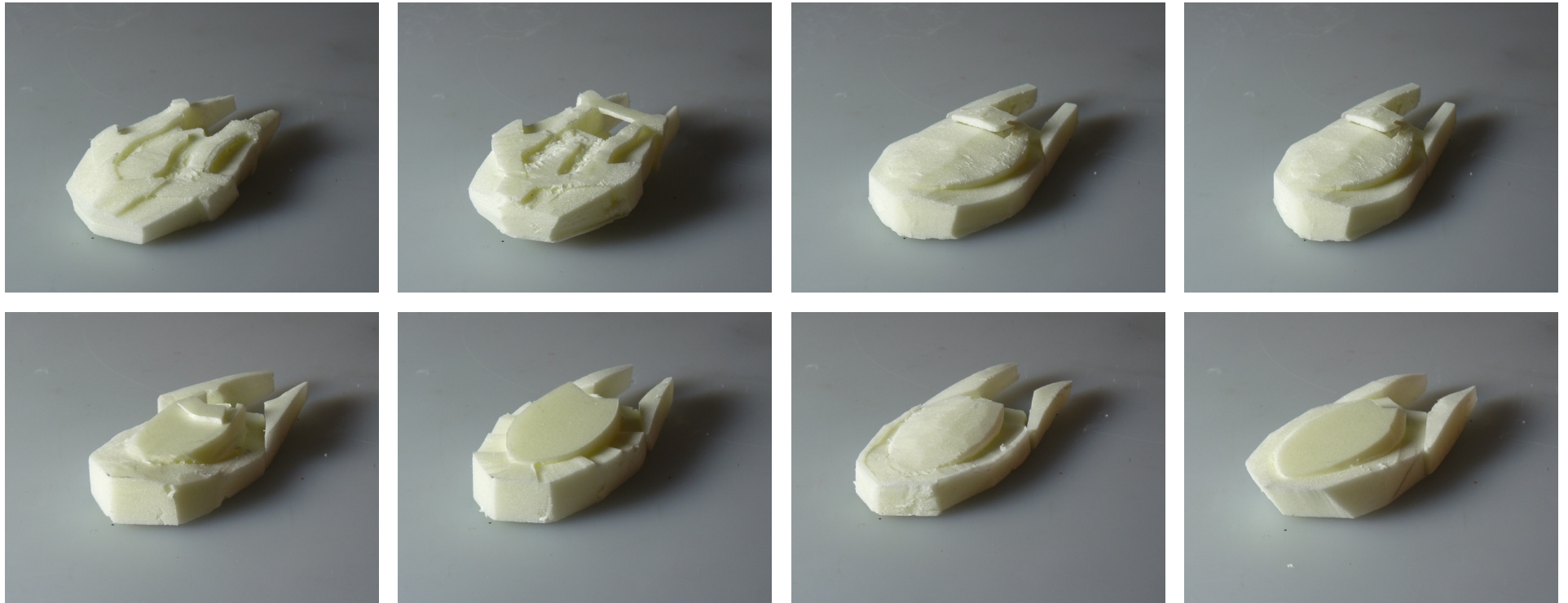
Figure 93: Converting Selected Aesthetic into Preferred Geometry



Figures 94, 95: Allowing for Efficient Tessellation

When developing an aesthetic, focus was given to objects and organisms which have evolved to withstand the unforgiving littoral environment. Attention was drawn to the bi-valve shell, which can be found amongst the rocks throughout the shores of Evans Bay. Similarities can be drawn between the bi-valve shell and that of a floating home such as, protecting the occupant through a thick shell, and that the asymmetrical shell is also very hydrodynamically efficient, given its tapered form, allowing the shell to easily travel through water currents from one point to another.<sup>65</sup> Over twelve progressive iterations the shell was abstracted into a sleek and more futuristic looking form. The most appealing design was then selected and transformed into an extended octagon shape, deemed most successful in earlier experiments, and then tessellated to form an aesthetic which could be taken into a three dimensional model.

### 5.1.10 ITERATIVE MODELLING



Figures 96 - 103: Developing Conceptual Form Through Iterative Modelling

With the basis of a design aesthetic, a model of the design was then produced. Upon reviewing the first model, the form was criticized for being overly complex and challenging to manufacture, increasing the final cost of the dwelling solution for the residents of Kilbirnie. An iterative modelling process was then undertaken to simplify the design and develop it into a sleek form which embodies the movement of the environment in which it inhabits. After seven progressive iterations an appropriate form which fulfils these requirements was produced and developed into a realised concept for permanent ocean dwelling.

### 5.1.11 FLOATING DWELLING CONCEPT

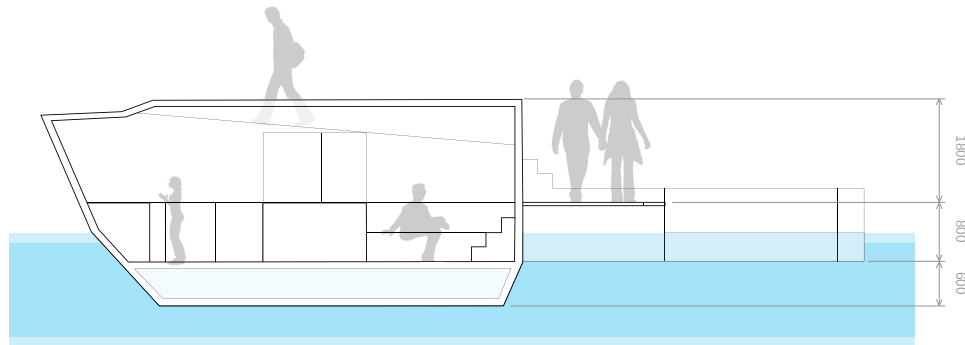


Figure 104 : Longitudinal Section

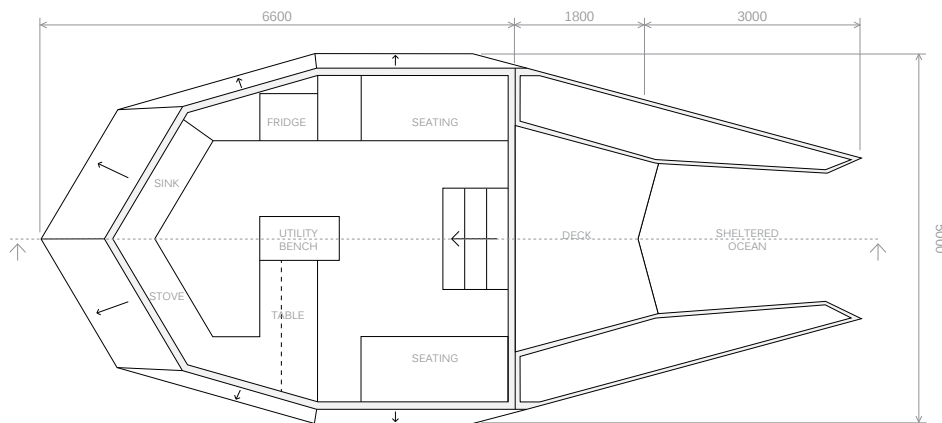


Figure 105 : Living Module Floor Plan

Living Module : 25sqm  
Private Module : 10sqm  
Exterior Space : 45sqm  
Total (1L+2P) : 90sqm

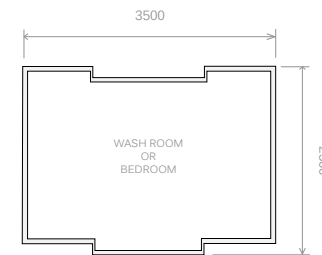


Figure 106 : Private Module Floor Plan

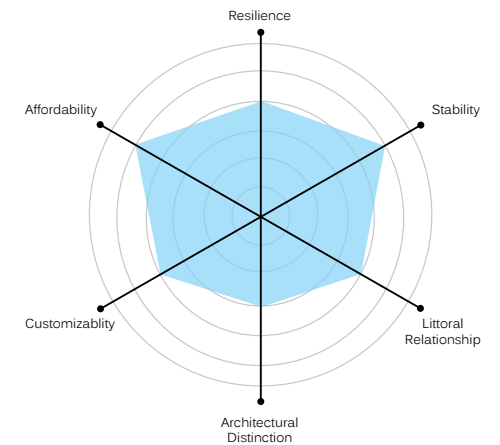


Figure 107 : Concept One's Achievement of Key Criteria

The floating dwelling's larger living module, inspired by the bow (front) of a yacht and a stern (rear) of a catamaran, allows for waves to be calmly dispersed around the form whilst ensuring a sheltered body of water is created between the arms of the deck for safe recreation, see Figures 105 and 108 - 111 . The private modules on either side of the living module are able to articulate both vertically and horizontally, similar to shock absorbers in an automobile, ensuring that the deconstructed dwelling is stable and comfortable for its occupants, despite the constantly changing littoral environment. A large number of these dwellings would be connected together through a system of gangways to allow simple access from the existing community out to the new resilient floating community. From a review of this floating dwelling concept against the design criteria it is clear that the design still requires further development because it fails to meet a number of the design criteria, see Figure 107.

### 5.1.12 DESIGN CRITIQUE

3 Month Design Review - 9th May 2013

After three months of design research my first attempt at a floating dwelling solution to mitigate the impact of sea level rise on the coastal city was formally critiqued by international professors from both architecture, landscape architecture and urban design as well as practicing architecture, all with expertise in waterfront and or in water design.

#### Positives:

- "An interesting concept for an effect of climate change which does not seem to be getting a lot of media attention"
- The articulation system is very unique when compared to previous water dwelling examples
- Providing the user with a variety of possible arrangement options through interchangeable components should assist in the difficult transition from land to sea dwelling

#### Negatives:

- It is unlikely that Kilbirnie residents will be willing to live at sea unless they absolutely have to, could an amphibious solution be more appropriate?
- The scale of the deconstructed dwelling may also be too small, efficiency and affordability is important but so too is comfort

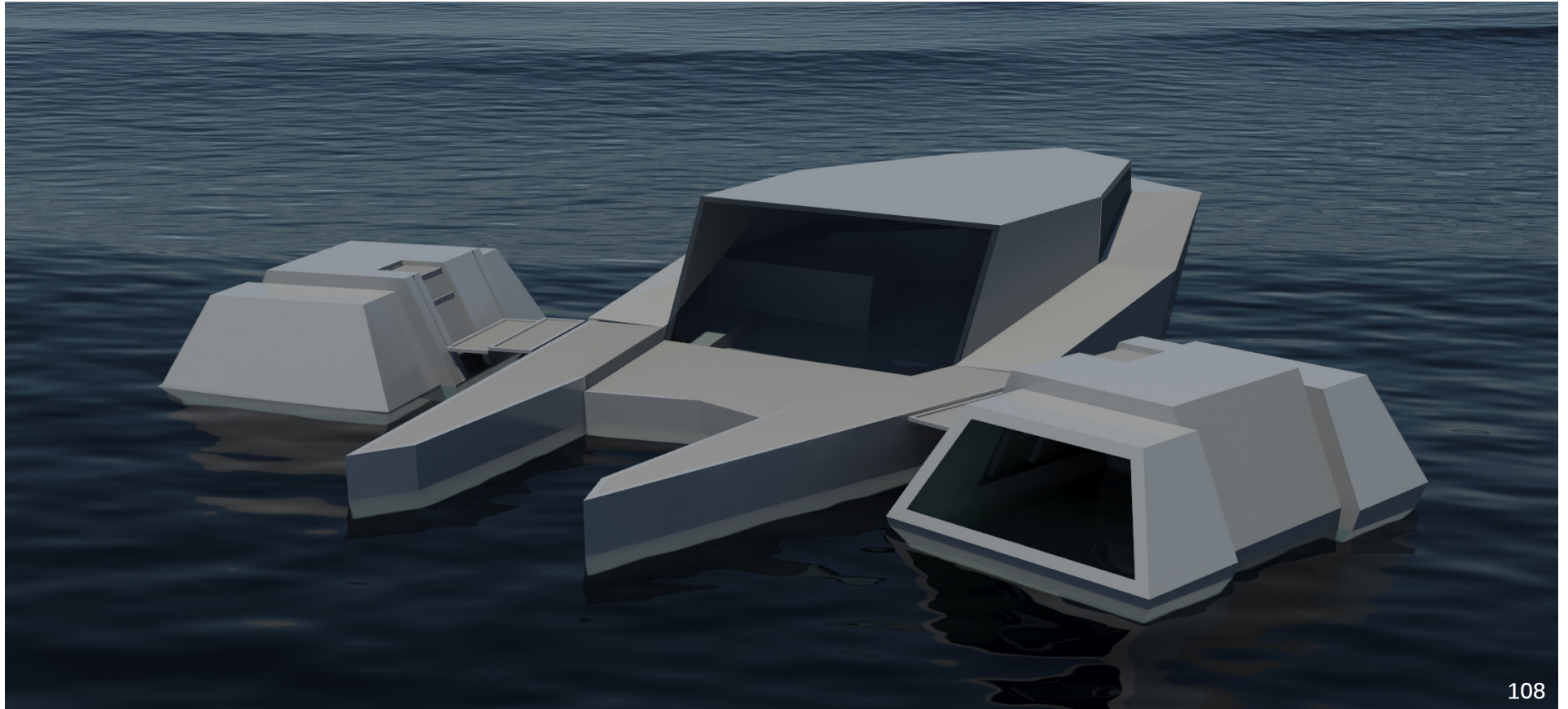
#### Moving Forward:

- As it stands the design is not attractive enough to motivate at risk residents to want to live in a floating dwelling, this will need to be rectified in future design developments
- Infrastructure and services need to be considered and resolved, especially given the fact that the floating dwellings are constantly in a state of flux
- Could the roof tops of the floating dwellings be publicly inhabited with private spaces below?
- Consider constructing the dwellings out of a material which allows for easy replication to reduce the cost of the solution for the Kilbrinie resident

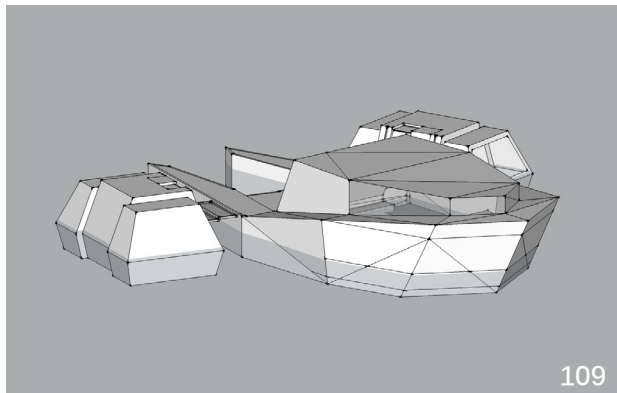
Figures 108, 109 - 111: (Opposite)

Rendered Ocean Inhabitation Concept

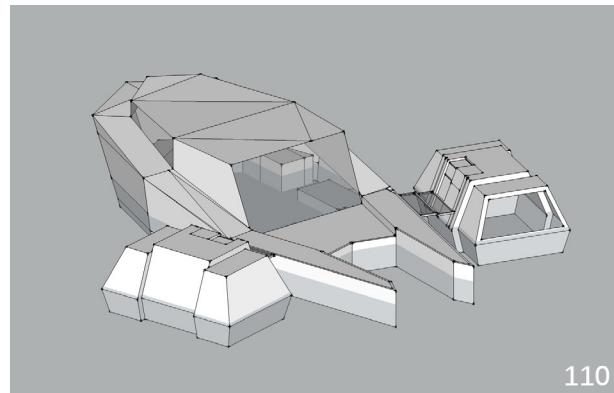
Multiple Perspectives of First Design Concept



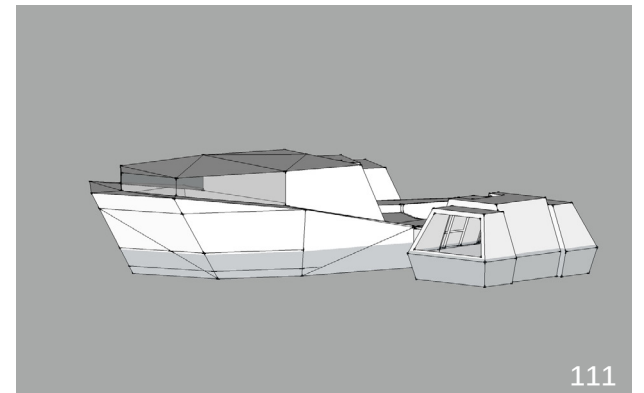
108



109



110



111



### 5.1.13 SUMMARY & REFLECTION

This first design phase has produced a residential dwelling solution to sea level rise in the form of a deconstructed ocean dwelling consisting of a larger living module and a number of smaller private modules. This dwelling is neither a house nor a boat but a hybrid of the two, specifically designed to articulate and move with the changes in the littoral environment rather than attempting to control the unforgiving ocean. The dwelling design will be more comfortable and stable than most other ocean inhabiting residences.

When reflecting upon this first design phase it has been identified that it is unreasonable to expect residents of an established community, such as Kilbirnie, to sell their traditional homes and begin living at sea, purely because the city is at risk of becoming inundated in the next fifty years. It is as if there has been a large jump to the final situation, when the city is completely inundated, rather than considering that sea level rise is an incremental occurrence and that an appropriate dwelling solution would need to be able to cope with varying water levels rather than simply floating from the very start. It has been clearly identified that a more practical strategy would be to introduce amphibious dwelling solutions, capable of inhabiting both land and sea, into the existing community over the coming decades so that when the city is inundated the community would be able to rise and float with the inundation.

- 
- 61 Sussman, P. "Bouyant Market: Are Floating Homes the Future of Housing." 2013. CNN.com/technology. <[http://edition.cnn.com/2013/TECH/science/08/20/floating\\_houses/](http://edition.cnn.com/2013/TECH/science/08/20/floating_houses/)>. par 6
  - 62 Olthuis, K. & D Keuning. Float: Building on Water to Combat Urban Congestion and Climate Change. Amsterdam: Frame, 2012. pg 40
  - 63 Olthuis, K. & D Keuning. Float: Building on Water to Combat Urban Congestion and Climate Change. Amsterdam: Frame, 2012. pg 65
  - 64 Matveev, K and N Kornev. "Dynamics and Stability of Boats with Aerodynamic Support." 11th International Conference on Sea Transportation (2011): 829 - 836.
  - 65 Olivera, A and W Wood. "Hydrodynamics of Bivalve Shell Entrainment and Transport." PALAIOS, American Geological Institute (2013): 203 - 209.





## 5.2 Design Phase Two

After the apparent failings in the approach of the first design phase, I was fortunate enough to be able to travel to the village of Koh Panyee in Thailand, one of my previously selected case studies, see page 18, in order to reconsider how a resilient residential dwelling could be designed to mitigate resident displacement in the coastal city as a result of climate change driven sea level rise. Whilst visiting the tidal community, it became clear that as sea level rise is incremental, a solution which aims to mitigate the impact of sea level rise must be able to accommodate significant tidal fluctuation. It was therefore discovered that an amphibious dwelling, which had the potential to adapt and float when inundated, would be a far more appropriate solution to sea level rise than the previous design approach which quickly jumped to the final situation of ocean inhabitation.

An amphibious dwelling solution could be introduced when coastal city residents believe they will soon be at risk of inundation. The conventional home would be removed in order for a new resilient dwelling solution to occupy the same site. When the sea inevitably does inundate the community the amphibious dwelling would simply rise and float with the ocean environment, as shown in Figure 112. With this new design direction focus in this design phase emphasis will be placed on resolving an amphibious dwelling system rather than finalising a dwelling form. The tapered octagonal form identified as successful in the previous design investigation will be used as a place holder until a new design is developed.

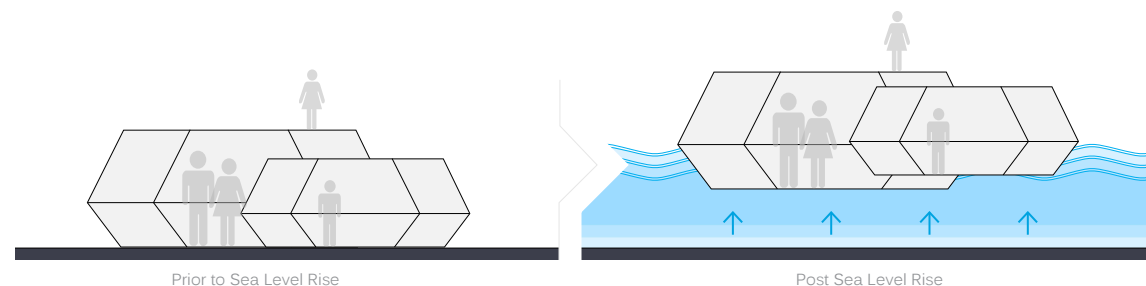
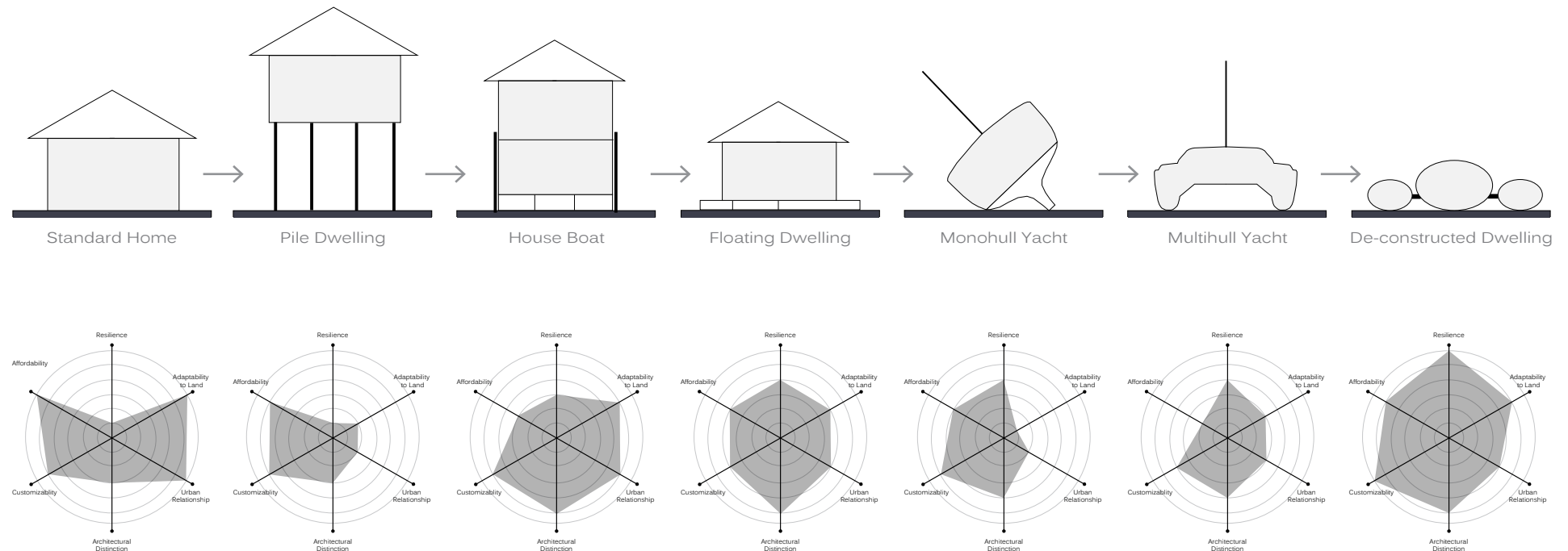


Figure 112: Amphibious Dwelling Diagram

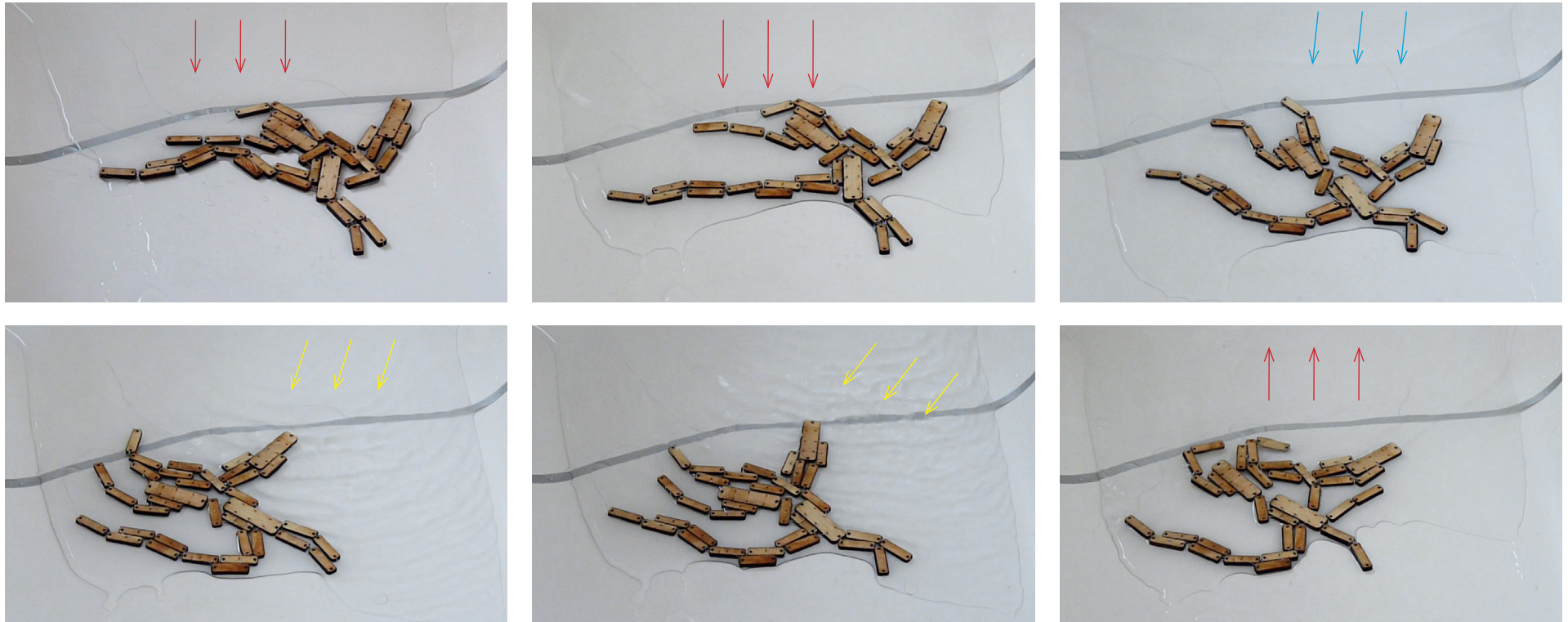
## 5.2.1 COMPARING AMPHIBIOUS DWELLING SOLUTIONS



With this new design approach it was necessary to re-evaluate whether the deconstructed dwelling was still an appropriate solution for amphibious dwelling in the coastal city. To be amphibious, a dwelling must be capable of successfully operating on land and on water.<sup>66</sup> Therefore each of the possible dwelling solutions have been compared against the design criteria relating to both land and sea, see Figures 113 - 120. From analysing these images it was clear that a number of the water based options would struggle to be successful dwellings on land and vice versa. Of the seven dwelling options, a deconstructed dwelling was again identified as the most appropriate choice to minimise the impact of sea level rise on the coastal city as it meets the design requirements of land and sea dwelling the most successfully.

Figures 113, 114 - 120:  
Current Amphibious Dwelling Solutions  
Comparing Solutions Against Design Criteria

## 5.2.2 INTERTIDAL AMPHIBIOUS COMMUNITY SIMULATION



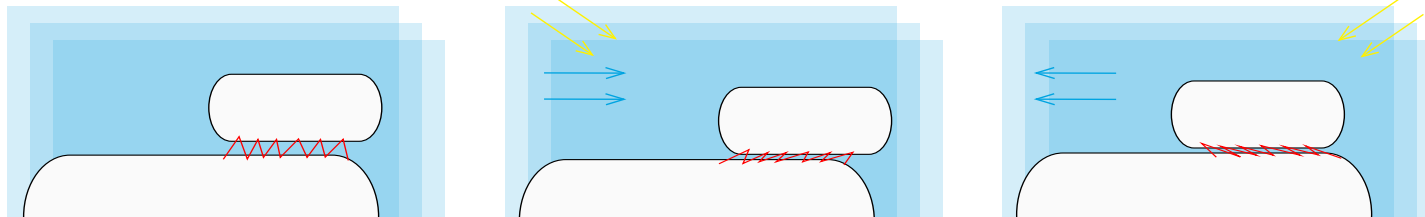
Figures 121 - 126: Intertidal Amphibious Community Simulation

Key:  
 → Tide Direction  
 → Wave Direction  
 → Wind Direction

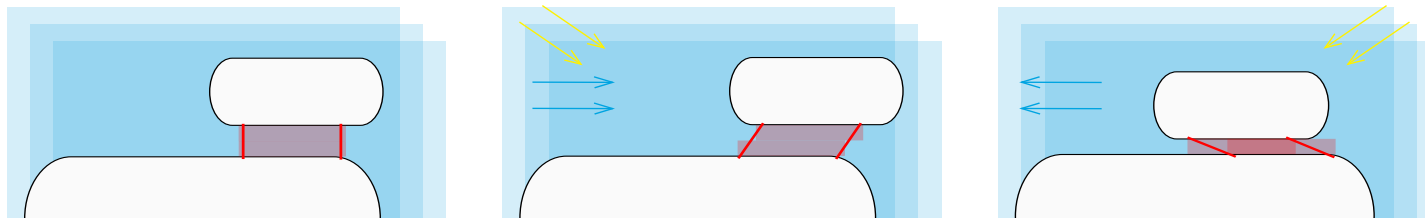
When the coastal city of Kilbirnie is first inundated it would only be for a very brief period of time during high tide. As sea levels continue to rise so too will the duration of inundation until the depth of ocean flooding at mid tide increases above half the tidal range of Wellington Harbour, 0.8m,<sup>67</sup> and from then on the community of Kilbirnie will be permanently inundated. The above simulation illustrates how an amphibious dwelling community would alter with the changing tides prior to complete inundation over a twelve hour period. As the tide rises the community would become inundated and the amphibious community would begin to float with the rising water levels. Once the community is floating the spatial relationships between the dwellings will constantly alter with the changing ocean environment. When the tide lowers the amphibious community would rest again frozen in their new arrangement, like seaweed caught on a rock until the next rising tide.



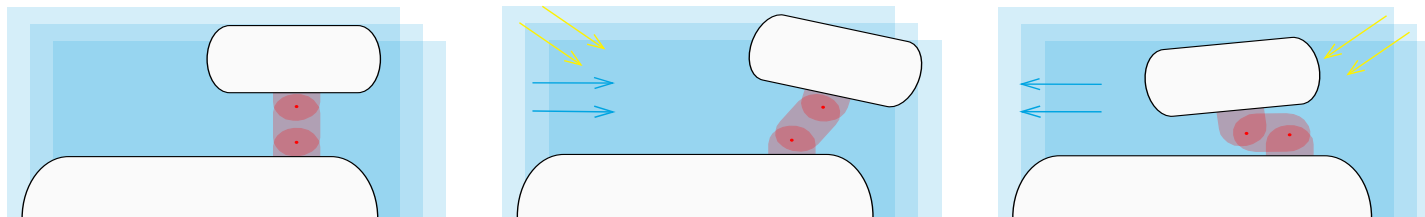
### 5.2.3 DWELLING CONNECTION STRATEGIES



Figures 127 - 129: Tethering Connection



Figures 130 - 132: Sliding Connection



Figures 133 - 135: Rotating Connection

After undertaking another community simulation the next investigation analysed the possible connection strategies which could be used to link a single dwelling, commonly consisting of a number of individual modules, as well as strategies to connect multiple households together. In order for a connection strategy to be considered appropriate it must allow for articulation with the changing environment whilst also ensuring safe circulation and serviceability throughout the community. Tethering connections will not be utilised due to the fact that the units are able to drift apart if the rope stretches, potentially making circulation through the community unsafe, see Figures 127 - 129. Sliding connections have instead been selected to connect individual dwelling modules, as it allows ease of circulation and a platform for the occupant to walk on, see Figures 130-132. Rotating connections have also been selected to connect entire dwelling households to maximise the influence of the changing littoral environment on the arrangement of the community through full articulation, see Figures 133-135.

## 5.2.4 VISUALISING THE INTERTIDAL AMPHIBIOUS COMMUNITY

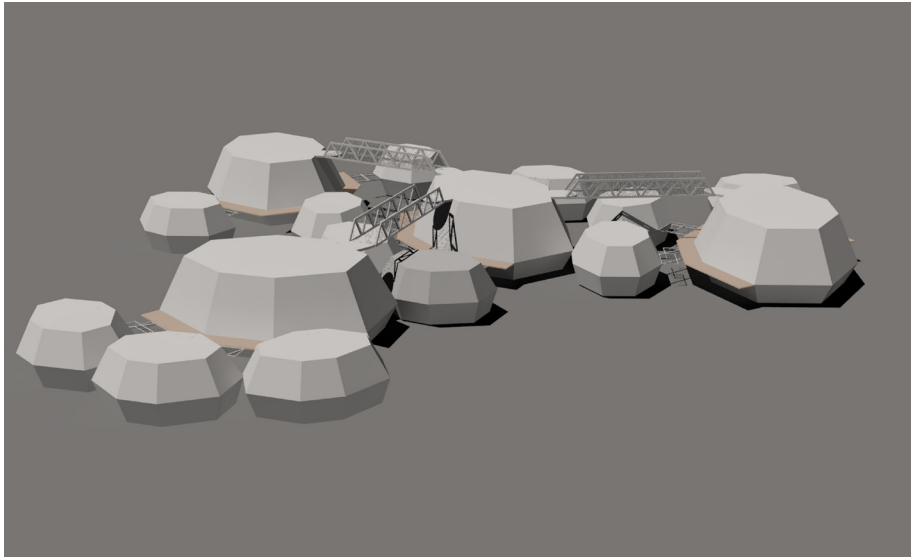


Figure 136: Prior to Inundation - Community Sits on Land

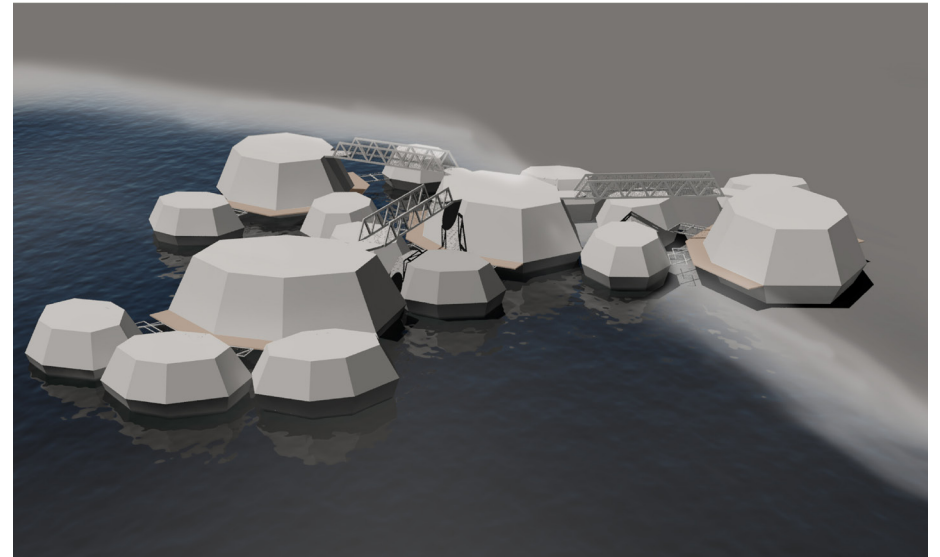


Figure 137: Intertidal (Low Tide) - Community is Inundated But Does Not Float

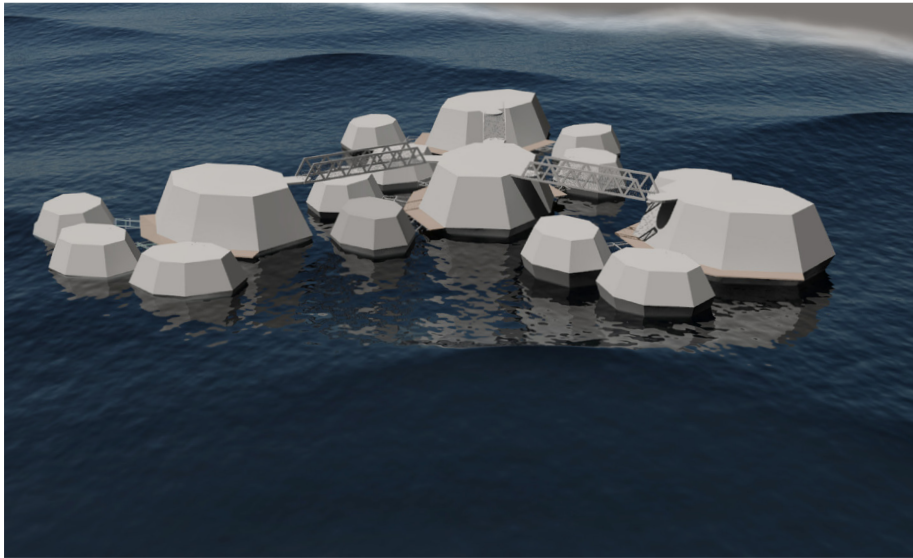


Figure 138: Intertidal (High Tide) - Sea Levels are High Enough for Community to Float

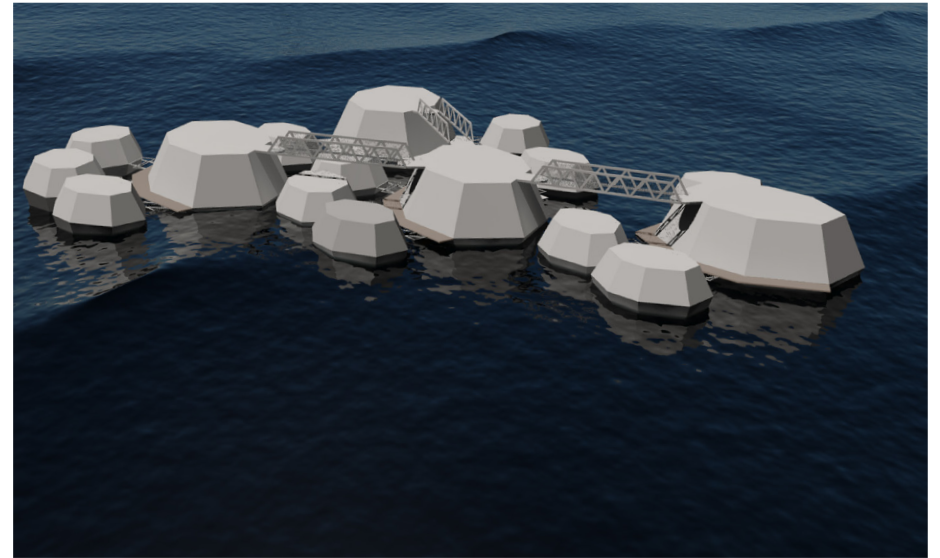
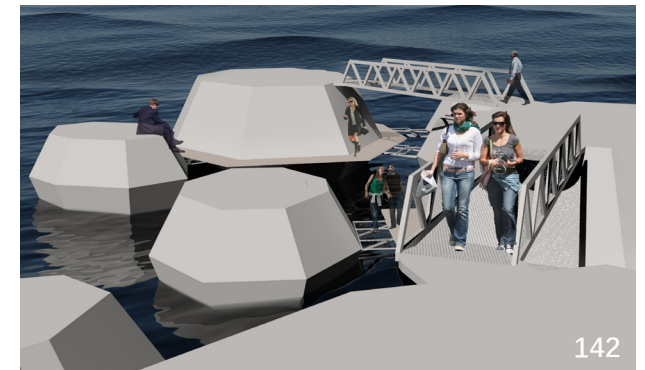
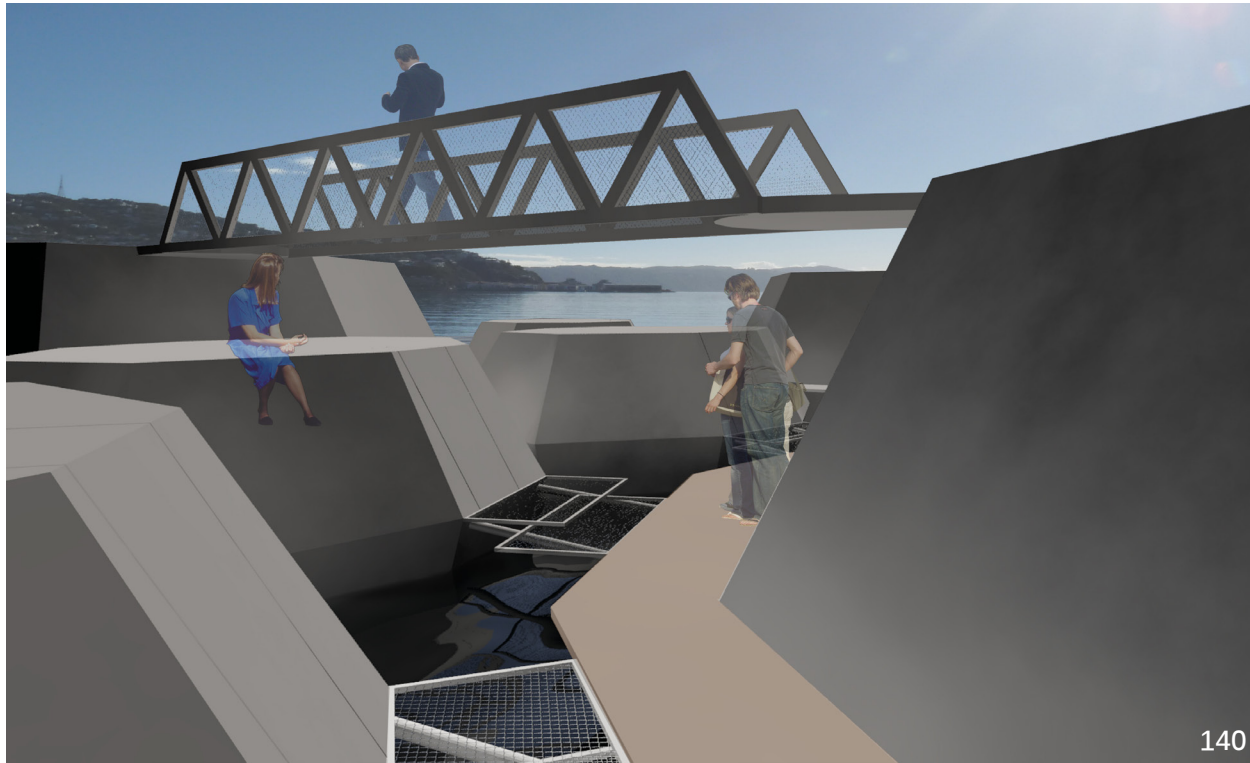


Figure 139: Full Inundation - Community Arrangement Changes with Littoral Environment



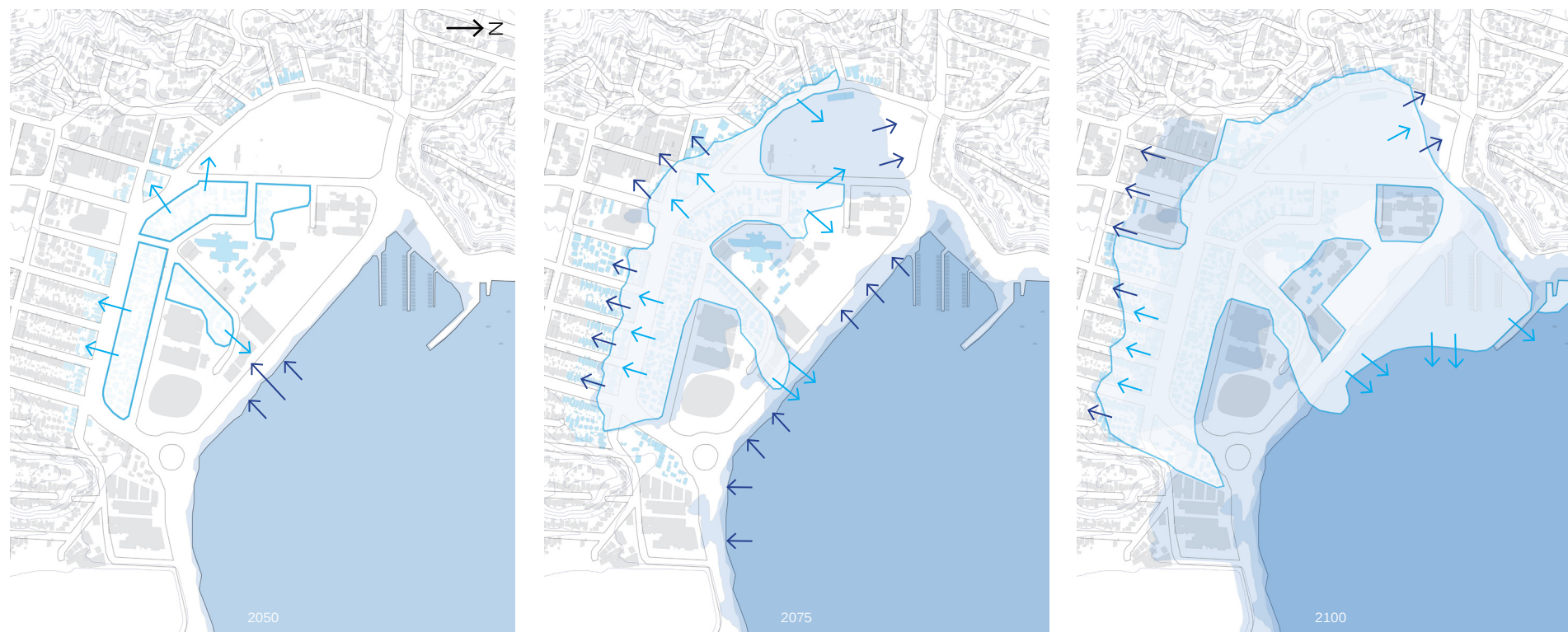
Figures 140 - 142:

An Amphibious Dwelling Community In Evans Bay  
Post Inundation

Using the selected connection strategies and the octagonal placeholder forms, identified at the introduction of this design phase, a series of renders have been produced to illustrate how the amphibious community would change over time from resting on land, to rising and falling with the tide, to permanently floating and moving with the changing littoral environment, see Figures 136 - 139. The above images demonstrate how residents may occupy the amphibious community with public circulation occurring above, semi-public circulation between a households individual dwelling modules provided below and private dwelling occurring within the amphibious modules.









## 5.2.5 INCREMENTAL DEVELOPMENT OF THE AMPHIBIOUS COMMUNITY



Figures 143 - 145: Incremental Development of the Amphibious Community

Key:

	Sea Inundation		Remaining Buildings		Future Inundation
	New Community		Removed Buildings		Future Growth of Community

Amphibious dwellings would be initially introduced into the domestic areas surrounding Tacy and Kemp Street which have been previously identified at high risk of inundation. This community of land based resilient dwellings would steadily expand to replace traditional dwellings as the risk of inundation draws near. By 2075 most of North Kilbirnie will be underwater and the amphibious community will begin to float. By the end of the century the entire amphibious community could be floating and steadily changing its arrangement as the littoral environment changes. From here there would be a potential to expand out to sea and even move entire households from one site to another by tugboat.

5.2.6 CONSTRUCTION ANALYSIS

Construction Material Analysis



Timber

Cost: Average  
Strength Load: Average  
Strength Collision: Poor  
Weight: Average  
Maintenance: Average  
Life Expectancy: Average  
Environmental: Average  
Thermal Properties: Average  
Construction Method: Fabrication



Fibreglass

Cost: Average  
Strength Load: Average  
Strength Collision: Poor  
Weight: Average  
Maintenance: Average  
Life Expectancy: Average  
Environmental: Average  
Thermal Properties: Average  
Construction Method: Moulding



Carbon Fibre

Cost: Poor  
Strength Load: Great  
Strength Collision: Average  
Weight: Great  
Maintenance: Average  
Life Expectancy: Average  
Environmental: Average  
Thermal Properties: Average  
Construction Method: Moulding



Plastic

Cost: Average  
Strength Load: Average  
Strength Collision: Great  
Weight: Average  
Maintenance: Great  
Life Expectancy: Average  
Environmental: Great  
Thermal Properties: Average  
Construction Method: Rot Moulding



Aluminum

Cost: Average  
Strength Load: Average  
Strength Collision: Great  
Weight: Average  
Maintenance: Average  
Life Expectancy: Average  
Environmental: Poor  
Thermal Properties: Poor  
Construction Method: Fabrication



Concrete

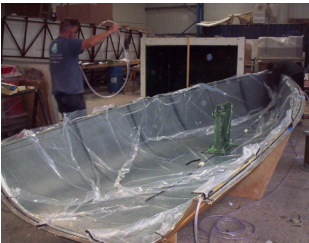
Cost: Average  
Strength Load: Great  
Strength Collision: Great  
Weight: Poor  
Maintenance: Average  
Life Expectancy: Great  
Environmental: Poor  
Thermal Properties: Average  
Construction Method: Casting

Construction Method Analysis



Fabrication

Replication: Poor  
Automation: Poor  
Design Restrictions: Average  
Complex Forms: Average  
Start Up Cost: Great  
Cost Per Unit: Average  
Time Per Unit: Poor  
Health Risks: Average



Moulding

Replication: Average  
Automation: Average  
Design Restrictions: Average  
Complex Forms: Average  
Start Up Cost: Average  
Cost Per Unit: Average  
Time Per Unit: Average  
Health Risks: Poor



Rotational Moulding

Replication: Great  
Automation: Great  
Design Restrictions: Average  
Complex Forms: Average  
Start Up Cost: Poor  
Cost Per Unit: Great  
Time Per Unit: Great  
Health Risks: Average

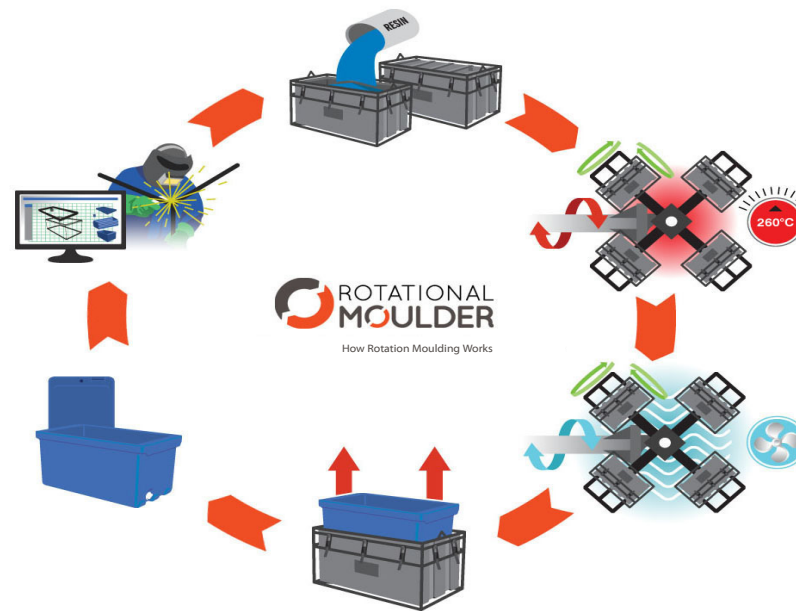
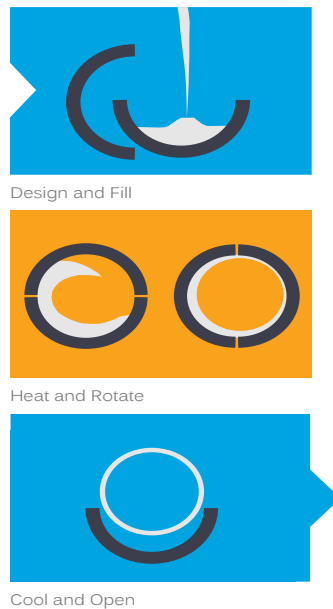


Casting

Replication: Average  
Automation: Average  
Design Restrictions: Average  
Complex Forms: Average  
Start Up Cost: Poor  
Cost Per Unit: Average  
Time Per Unit: Poor  
Health Risks: Average

Figures 146 - 151, 152 - 155:  
Possible Construction Materials For An Amphibious Dwelling  
  
Possible Construction Methods That Could Be Used To Manufacture An Amphibious Dwelling

### 5.2.7 ROTATIONAL MOULDING PLASTIC

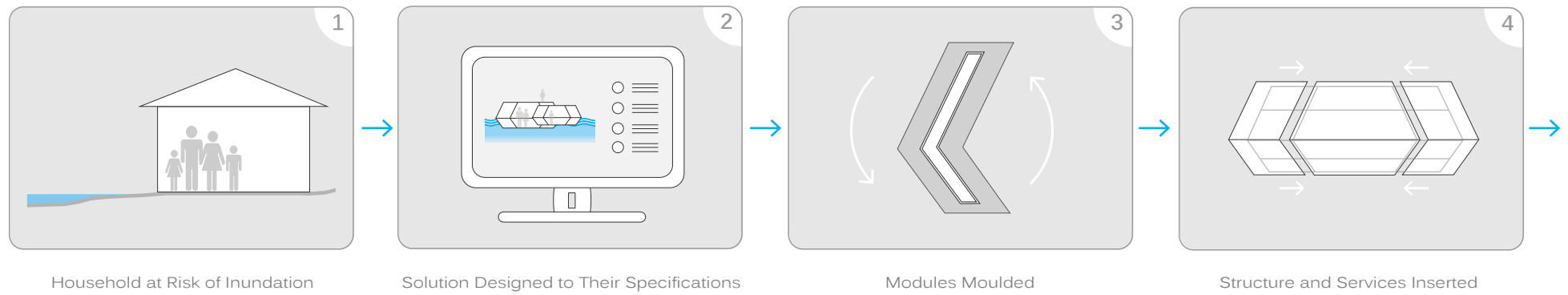


Figures 156, 157: The Rotational Moulding Process

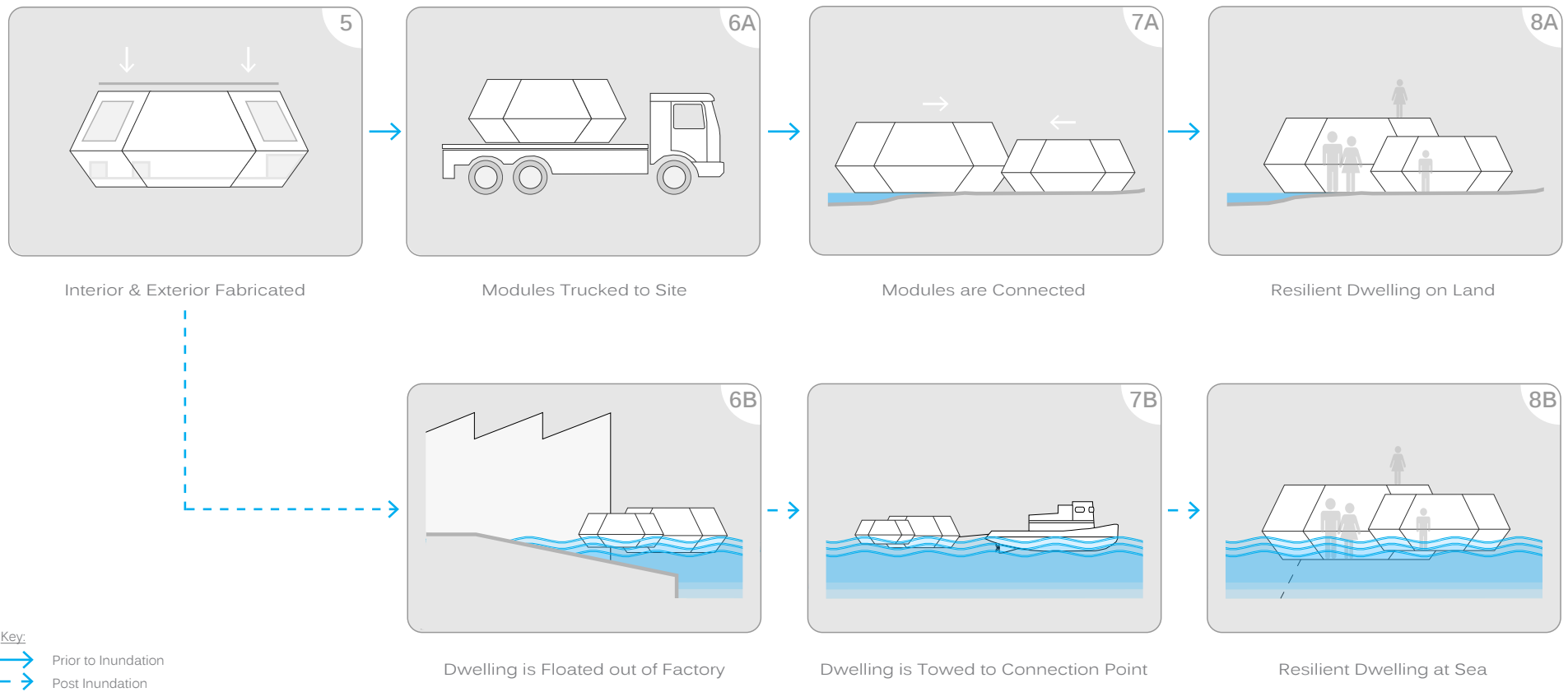
After developing a successful dwelling system the next issue was to resolve what construction method and materials should be used when manufacturing these amphibious solutions. From comparing the cost, strength, life expectancy and thermal properties of all of the possible construction materials it was discovered that plastic would be the most appropriate choice for an amphibious dwelling. Typically used in a wide array of household materials, riot shields and small dinghies. High-density polyethylene or HDPE is an extremely strong material which is UV, salt water and mould resistant making the material perfect for a water-bound dwelling.<sup>68</sup> HDPE can also be made from recycled plastic, so pollution such as the gigantic floating plastic island in the Pacific Ocean could be reused to form resilient dwellings for communities at risk of inundation.

Of the construction methods it was discovered that rotational moulding, one of the most common forms of producing large items from plastic, would be the most appropriate as it would allow for components up to ten metres in length to be quickly mass produced with minimal labour required.<sup>69</sup> In the rotational moulding process plastic resin granules are poured into a mould which is rotated and heated until the plastic has taken the shape of the mould, before being cooled and removed from the mould. Depending on the size of the mould the entire process can take as little as an hour, see Figures 156 - 157.<sup>70</sup> Based on the likely number of components required that means that an amphibious dwelling could likely be constructed in a number of days not months. The following images illustrate the process of construction from moulding through to assembling and transporting to site.

## 5.2.8 PROCESS OF CONSTRUCTION







Figures 158 - 169: Process of Construction - Prior to Sea Level Rise v.s. Post Inundation

### 5.2.9 SERVICING THE AMPHIBIOUS COMMUNITY

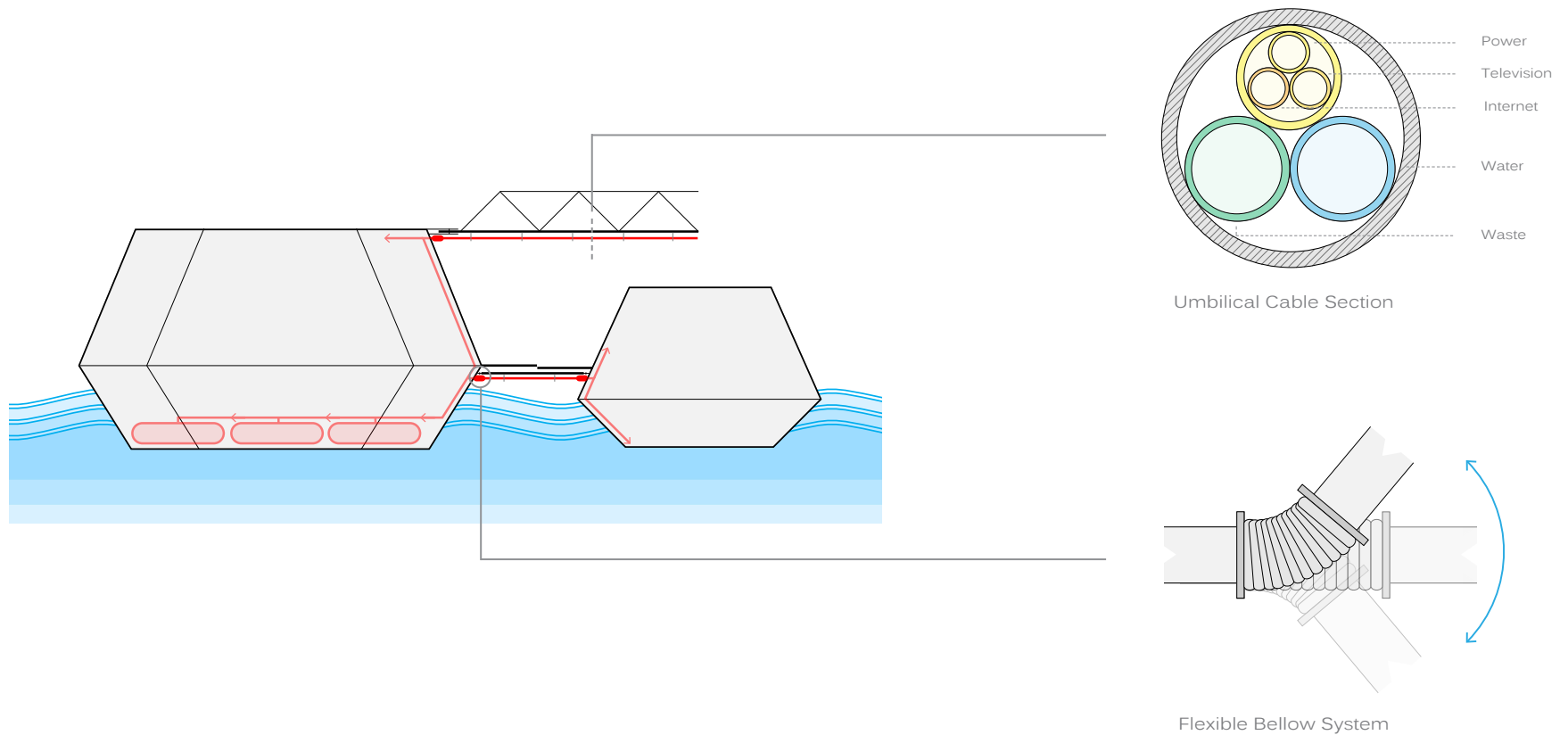


Figure 170: Flexible Services System

Services will be provided to each dwelling unit through a system of umbilical cables, similar to those used in the offshore industry, containing power, water, gas, digital television and internet. Waste will be sucked out of the dwellings through a separate compartment of the same cable. After exiting the module these cables will be fixed to the base of the pedestrian bridges. In order to allow the services to articulate with the moving modules, flexible bellows will be used at each connection point. In the event of any problems with this new services system, each dwelling will have three large tanks for the storage of fresh water, grey water and black water in order to comply with NZS 5465 : Providing for Self Containment.

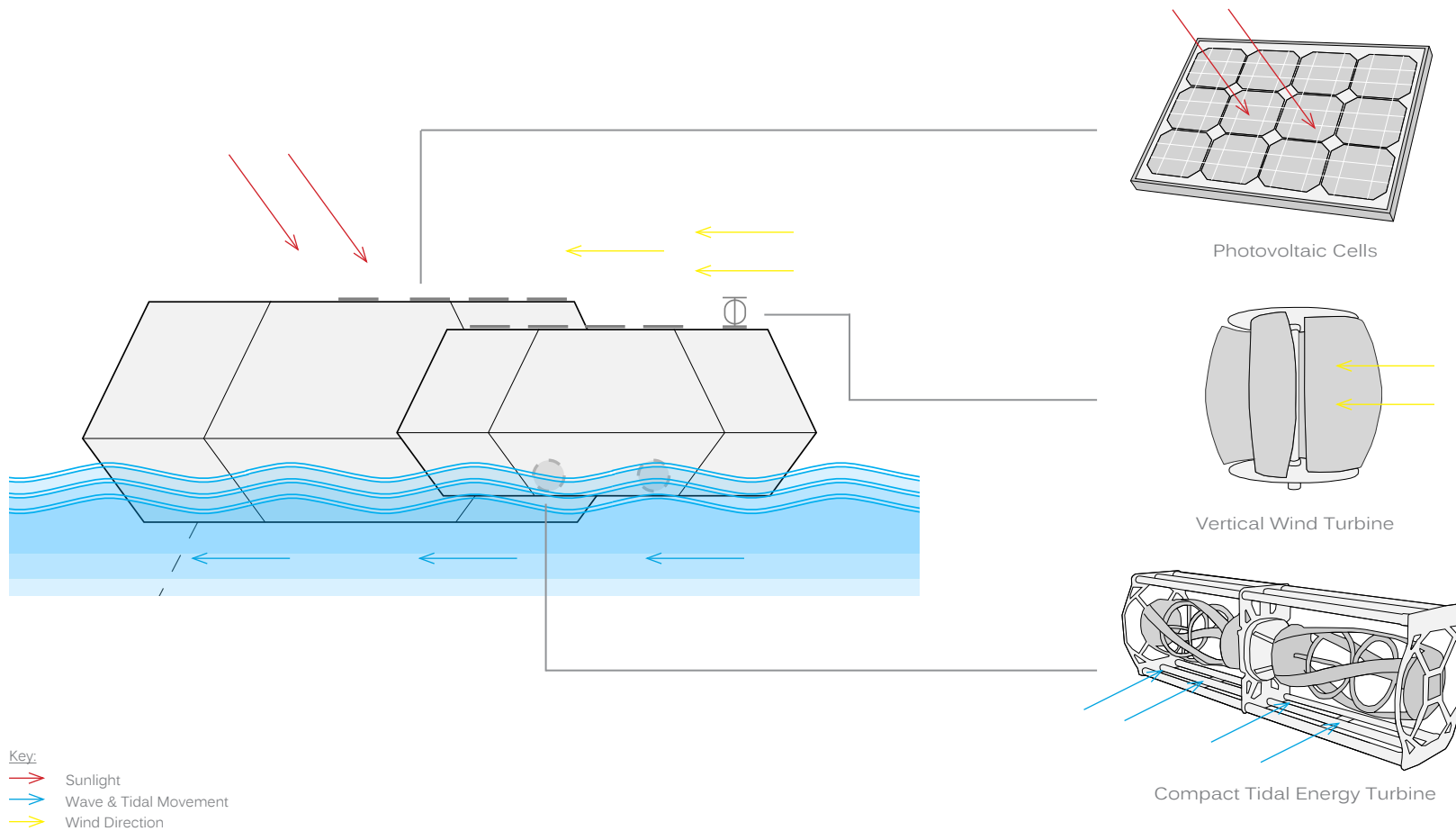


Figure 171: Green Energy Solutions

Upon purchasing an amphibious dwelling, residents will have the option to install a number of passive energy solutions to improve their own carbon footprint and restrict further climate change. Solar panels and small vertical wind barrels could be used to generate renewable energy. Once the dwelling is inundated there is also a strong potential to use the oceans movement as a source of power generation through the implementation of small water turbines or alternator fins. Residents may choose to install one or even all of these systems and when combined with a dwelling constructed from renewable materials residents would be able to live in a truly green dwelling solution.

### 5.2.10 DESIGN CRITIQUE

#### 5 Month Professional Review - 24th July 2013

After five months of design research my second attempt at a resilient dwelling solution for sea level rise in the coastal city was formally critiqued by an internal and external expert reviewer each with architectural and boat building backgrounds.

#### Positives:

- Both reviewers agreed that an amphibious dwelling solution would be far more appropriate for a coastal city at risk of inundation than that of the first design phase
- Similarities between exposure to others and exposure to the elements. The public space above is completely open and exposed, down to semi-private and semi-sheltered space and down further to a private and sheltered dwelling space
- An innovative solution to servicing a community which when floating will be in a constant state of flux

#### Negatives:

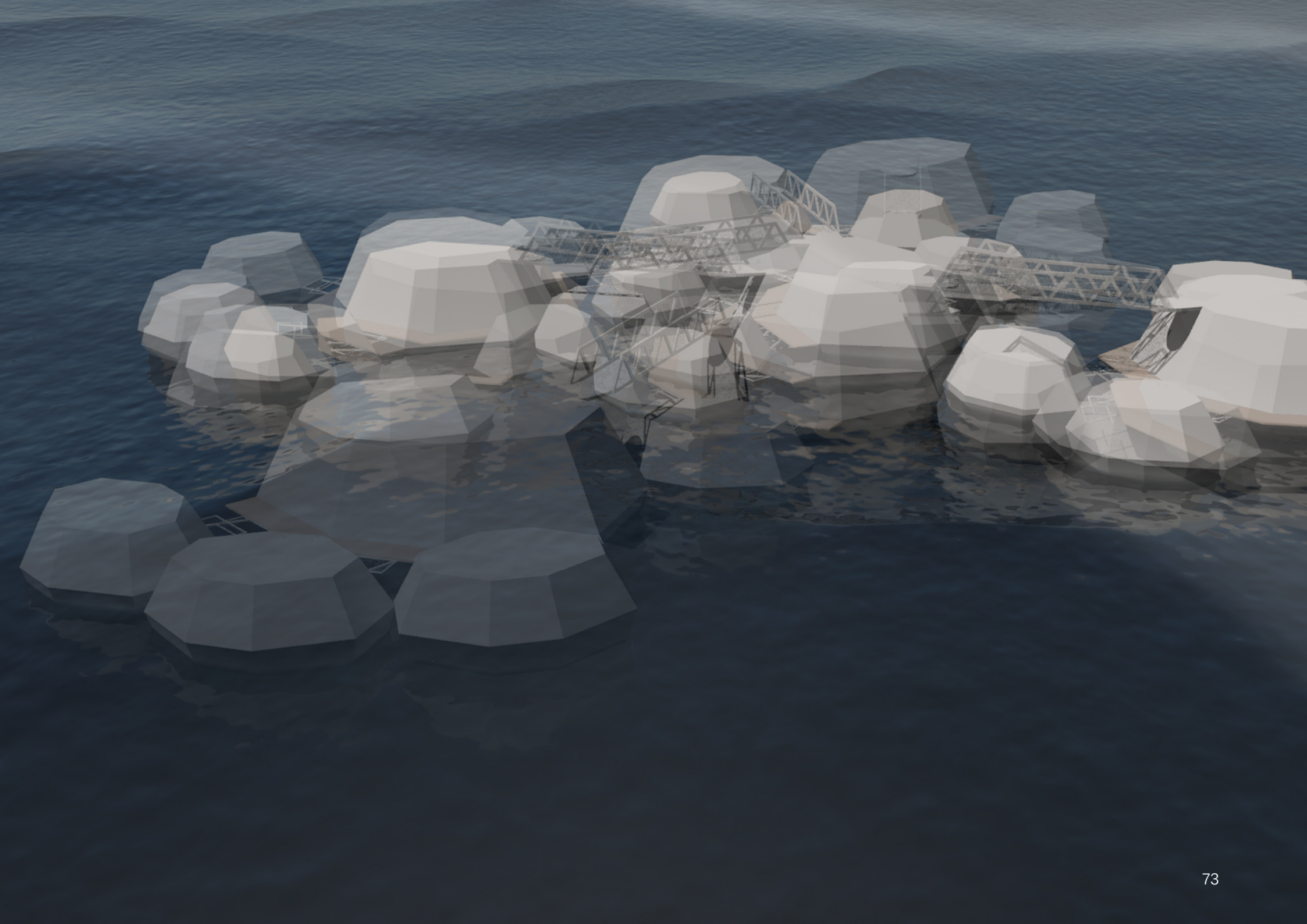
- The current forms are very simplistic and pod like, its currently an engineering solution rather than an attractive architectural solution.
- The octagonal shape is a placeholder but the final form needs to interact with the changing littoral environment as opposed to purely attempting to ensure user safety and comfort

#### Moving Forward:

- Can marine technology be introduced to improve areas of the design, is it worth approaching experts in the marine industry for their opinions?
- Begin considering the interiors of these dwellings. How will the user perceive the different conditions, floating vs. grounded, high tide vs. low, calm vs. storm, Northerly vs. Southerly?
- The user should also be able to control the amount of articulation that the dwelling incurs in order to adjust the dwelling connection set up for different conditions.

Figure 172: (Opposite)

Amphibious Community in a Constant State of Flux





### 5.2.10 DESIGN CRITIQUE (Continued)

#### Design Discussion with Experts in the Field of Marine Design- 31st July 2013

Following on from the advice from the design critique, I arranged to discuss my amphibious dwelling concept with two experts in their respective fields of the marine industry. An ethics application was made and approved prior to these discussions, see Appendix 4. The first meeting was conducted with Phillip Furr, Marine Engineer at Transfield Worley and most recently the chief designer of the Yolla A oil rig accommodation platform for the Bass Strait, one of the roughest patches of ocean in Australasia, see Figure 173. The second meeting was undertaken at Fitzroy Yachts, one of New Zealand's premier super yacht manufacturers, with their head Naval Architect Michael Stuart, see Figures 174 - 176. The feedback from both experts has been combined below.

#### Positives:

- Fixing anything permanently to the sea bed is very expensive, creating a floating system with minimal anchor points will be a cost effective solution
- Wellington Harbour experiences 8 million waves a year. If the system was rigid it would fatigue very quickly and break apart in less than a year regardless of its construction. By allowing the design to articulate with the littoral environment, the forces applied to the structure and its joints will be dramatically reduced, therefore significantly increasing the life span of the dwelling solution
- When floating at sea there is a huge potential to utilise the dynamic ocean environment as a source of power generation

#### Negatives:

- The toilets need to be in the same module as the bedrooms. Residents would not be safe going to bathroom through an open walkway in to a separate module in the middle of the night. Guest bathrooms and laundries could be provided for in a wider community module similar to arrangements used in motel campsites
- The units will be constantly bumping into one and other. A rubber bumper system similar to that of an inflatable dingy should be incorporated.

#### Moving Forward:

- Could yacht technologies be re-appropriated to assist in the design and construction of the amphibious dwelling?
- Could consider looking back to earlier design work to re-inspire a new form design

Figures 173, 174 - 176: (Opposite)

Yolla A Platform in Australia's Bass Strait

Zefira - Designed and Constructed at Fitzroy Yachts  
New Plymouth, New Zealand (2010)



173



174



175



176

### 5.2.11 SUMMARY & REFLECTION

After acknowledging the failures of the first design phase, this second approach developed a residential dwelling which is a far more appropriate solution to the design problem, in the form of an amphibious dwelling which could be implemented over the coming decades to allow the community to adapt when sea levels do inundate the coastal city of Kilbirnie.

This design phase has focused primarily on developing an amphibious dwelling system including, identifying connection strategies, appropriate materials, construction methods and resolving how the flexible community would be serviced, rather than attempting to produce an aesthetically appealing final form. The next stage in the development process will be to take on board the advice of the reviewers and marine experts and begin producing a more attractive dwelling solution which will be able to convince Kilbirnie residents currently at risk of inundation to purchase a resilient and adaptable amphibious dwelling solution.

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66 Oxford Dictionaries. Definition of Amphibious in English. 2013. <http://oxforddictionaries.com/definition/english/amphibious>. par 1

67 Land Information New Zealand. Tides Around New Zealand. 2013. <<http://www.linz.govt.nz/hydro/tidal-info/tidal-intro/nz-tides>>. par 2

68 Dynalab Corp. Plastic Properties of High Density Polyethylene (HDPE). 2012. <[http://www.dynalabcorp.com/technical\\_info\\_hd\\_polyethylene.asp](http://www.dynalabcorp.com/technical_info_hd_polyethylene.asp)>. par 2-3

69 D&M Plastics Inc. The Rotational Moulding Process. 2014. <<http://www.rotationalmoulding.ca/process.htm>>. par 1

70 D&M Plastics Inc. The Rotational Moulding Process. 2014. <<http://www.rotationalmoulding.ca/process.htm>>. par 1



## 5.3 Design Phase Three

Following the success of the previous design phase where a system of articulating amphibious units was developed, this third design phase focussed on developing the concept further alongside the advice of the architectural reviewers and marine experts. The most common advice was to consider incorporating aspects of marine technology into the amphibious dwelling concept, see Figure 177. In comparison to land technology, which is largely about rigid fixing and fastening, marine technology is about catering for flux, for example having an elongated hull shape to adjust to the ocean's constant movement, or trimming a sail though a system of pulleys and cleats to adjust to the new wind direction.

Unfortunately most examples of floating or amphibious architecture to date have largely employed traditional principles of land-based technologies to inhabit a site which is anything but traditional, rather than incorporating simple aspects of marine technology which have been specifically designed to cope with permanent occupancy of the water. As a result most architecturally designed water residences have major issues with stability and durability and as such are often not fit to occupy the untamed littoral environment.

In contrast, building upon the knowledge gained from years of competitive sailing, my resilient dwelling solution will be specifically designed to occupy the exposed ocean. A number of aspects of marine technology could be successfully reappropriated into this designed solution in order to ensure greater stability and durability whilst also providing the user with the ability to control a variety of mechanisms which would influence their dwelling environment, such as the degree of articulation, vertical movement and level of exposure.

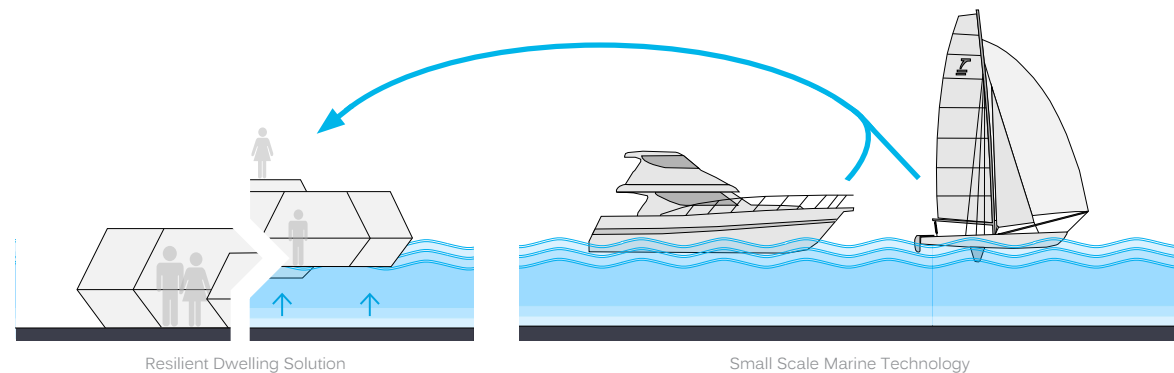
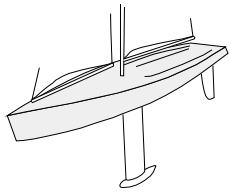


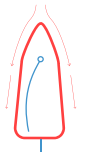
Figure 177: Reappropriating Marine Technology into the Resilient Dwelling Solution



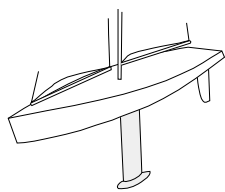
### 5.3.1 REAPPROPRIATING MARINE TECHNOLOGY



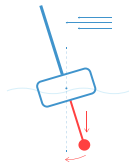
Hull



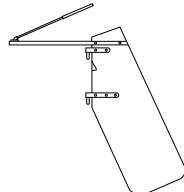
Possible Reappropriation  
- Create a resilient dwelling module capable of occupying land and sea



Keel



Possible Reappropriation  
- A counterbalance system to ensure stability even in high seas



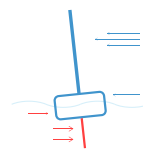
Rudder



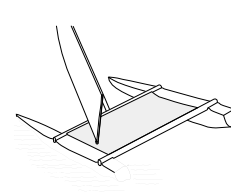
Possible Reappropriation  
- Pieces of the module could rotate independently



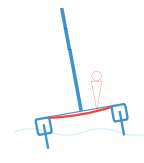
Centre Board



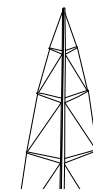
Possible Reappropriation  
- A board could be lowered to adjust susceptibility to the littoral environment



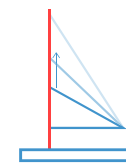
Trampoline



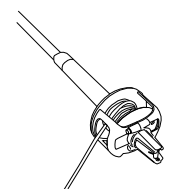
Possible Reappropriation  
- Allow easy circulation between modules



Mast



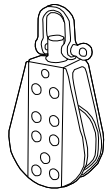
Possible Reappropriation  
- Support system for external shade canopy



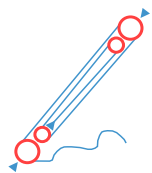
Furler



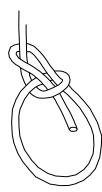
Possible Reappropriation  
- Storing smaller shade canopy



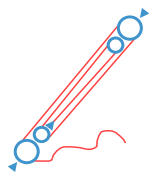
Pulley



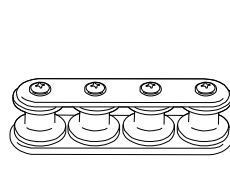
Possible Reappropriation  
- Lifting and pulling objects through a pulley system



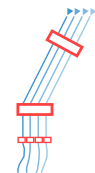
Rope



Possible Reappropriation  
- Mechanised system to lift, pull and rotate objects



Deck Organiser



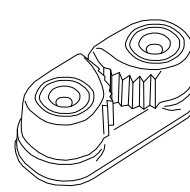
Possible Reappropriation  
- Displaying the functionality of the system for maintenance



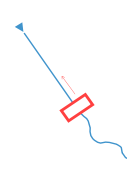
Winch



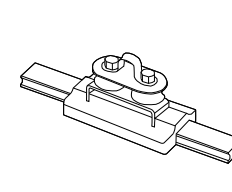
Possible Reappropriation  
- Rotating, lifting or moving objects with less effort



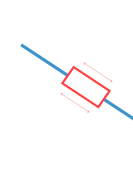
Cleat



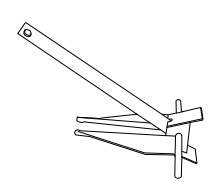
Possible Reappropriation  
- Temporarily restricting movement of a designed system



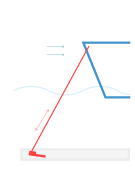
Traveller Car



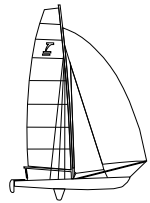
Possible Reappropriation  
- Track for internal furniture and partitions to slide along



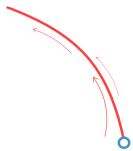
Anchor



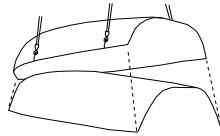
Possible Reappropriation  
- Connecting modules to the sea floor once floating



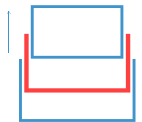
Dacron Sails



Possible Reappropriation  
- Creation of an extended external shade canopy



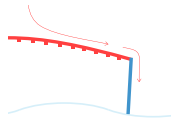
Moulded Hulls & Foils



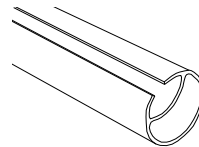
Possible Reappropriation  
- Prefabricating modulated dwelling components



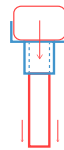
Teak Decks



Possible Reappropriation  
- Creating warm feeling weather resistant exterior floor surface



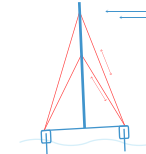
Extruded Spars



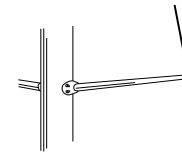
Possible Reappropriation  
- Creating extended metal objects such as tracks and poles



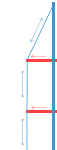
Stay



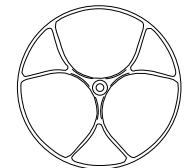
Possible Reappropriation  
- Support system for external shade canopy



Spreader



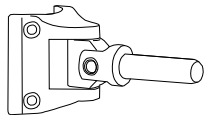
Possible Reappropriation  
- Support system for external shade canopy



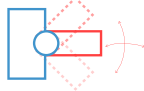
Wheel



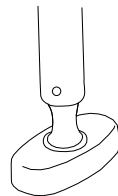
Possible Reappropriation  
- Manual user control of dwelling systems



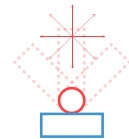
Gooseneck



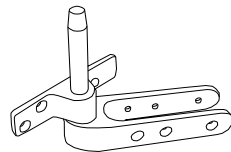
Possible Reappropriation  
- Pivoting circulation system between modules



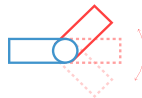
Universal Joint



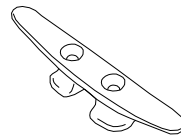
Possible Reappropriation  
- Connecting fenders to external faces of modules



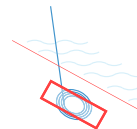
Gudgeon



Possible Reappropriation  
- Pivoting large module components



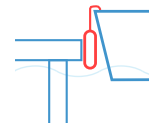
Open Based Cleat



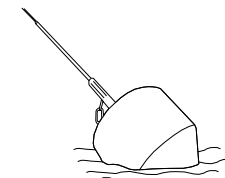
Possible Reappropriation  
- Tether multiple modules together



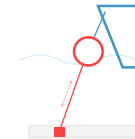
Fender



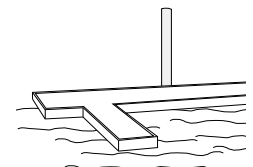
Possible Reappropriation  
- Creating a bumper system around all modules



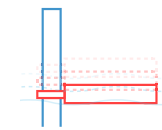
Mooring Bouy



Possible Reappropriation  
- Identify mooring locations



Marina



Possible Reappropriation  
- Creating floating walkways

### 5.3.2 MODELLING POSSIBLE REAPPROPRIATIONS

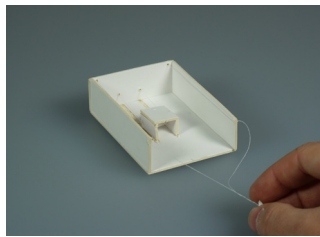


Figure 206 - 208: Rope, Pulleys and Track Utilised to move Internal Components

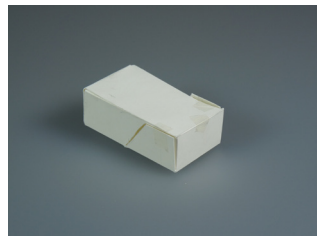


Figure 209 - 211: Gudgeons, Rope and Cleats Utilised to Create Unfolding Recreation Space

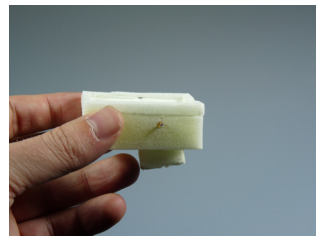


Figure 212 - 214: Keel Mechanism Rotated To Provide Stability at Sea and Flush on Land

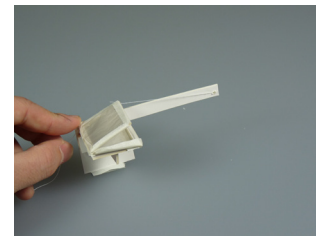
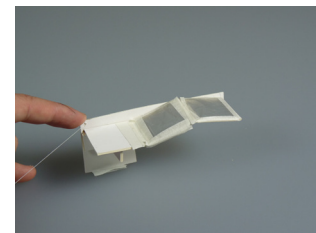
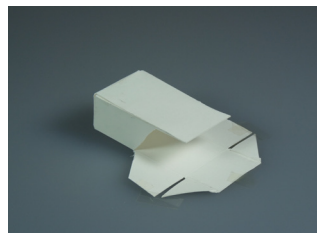
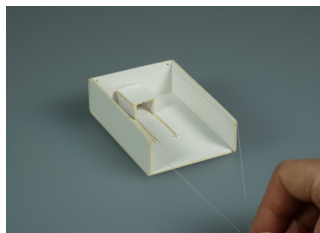
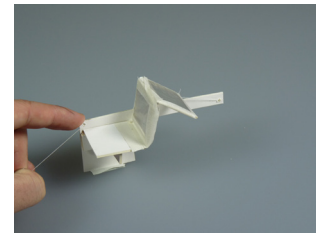
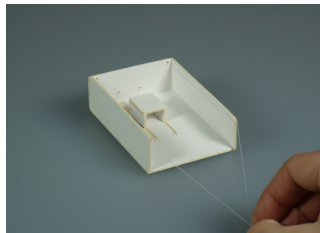


Figure 215 - 217: Rope, Mast and Gudgeons Utilised to Create Expanding Shade Canopy



In order to design a seaworthy amphibious dwelling solution capable of facilitating flux, an extensive selection of marine technology has been compiled, analysed and broken down to its most basic function, see Figures 178 - 205. An example of how this technology could be reappropriated into the design of an amphibious dwelling has been provided for each piece of marine technology, ranging from hull shape and material specifications to methods of moving internal furniture and retractable shade sails. The above images illustrate a number of examples of how marine technology could be employed in the design of the resilient dwelling through basic kinetic models.

With the possible reappropriations identified, emphasis will be placed on iteratively developing forms, layouts and design systems which employ this marine technology and critique them against the established design aims in order to resolve an attractive and seaworthy architectural solution which would increase the appeal of an accommodative resilient dwelling to the residents of the coastal community of Kilbirnie.

Figures 178 - 191: (Previous)

Functions of Marine Technology and Possible Reappropriations

Figures 192 - 205: (Opposite)

Functions of Marine Technology and Possible Reappropriations

### 5.3.3 DESIGN ITERATION ONE

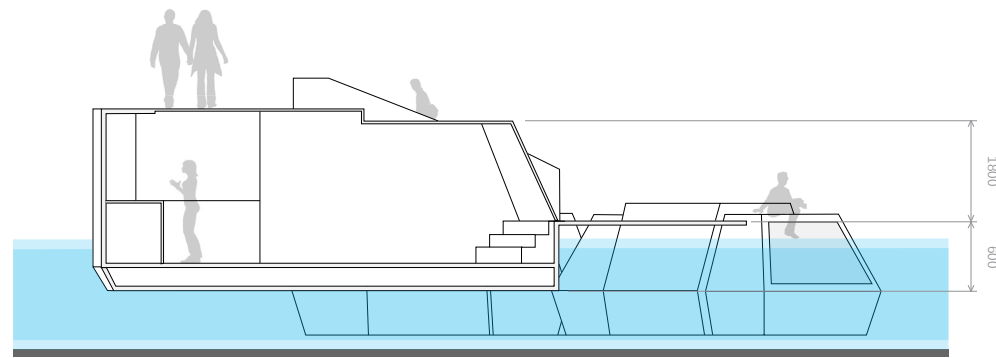


Figure 219 : Longitudinal Section - Once Inundated

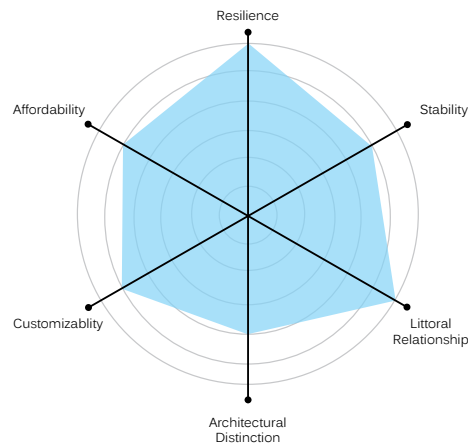


Figure 218 : Iteration One's Achievement of Key Criteria

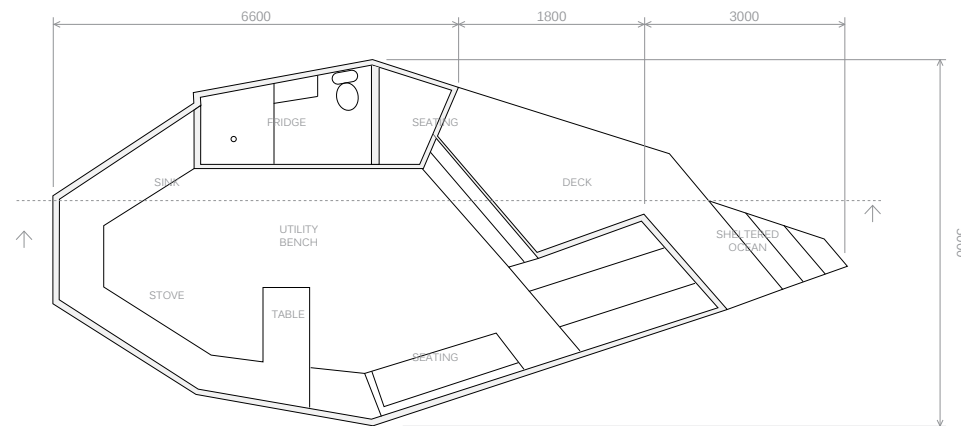
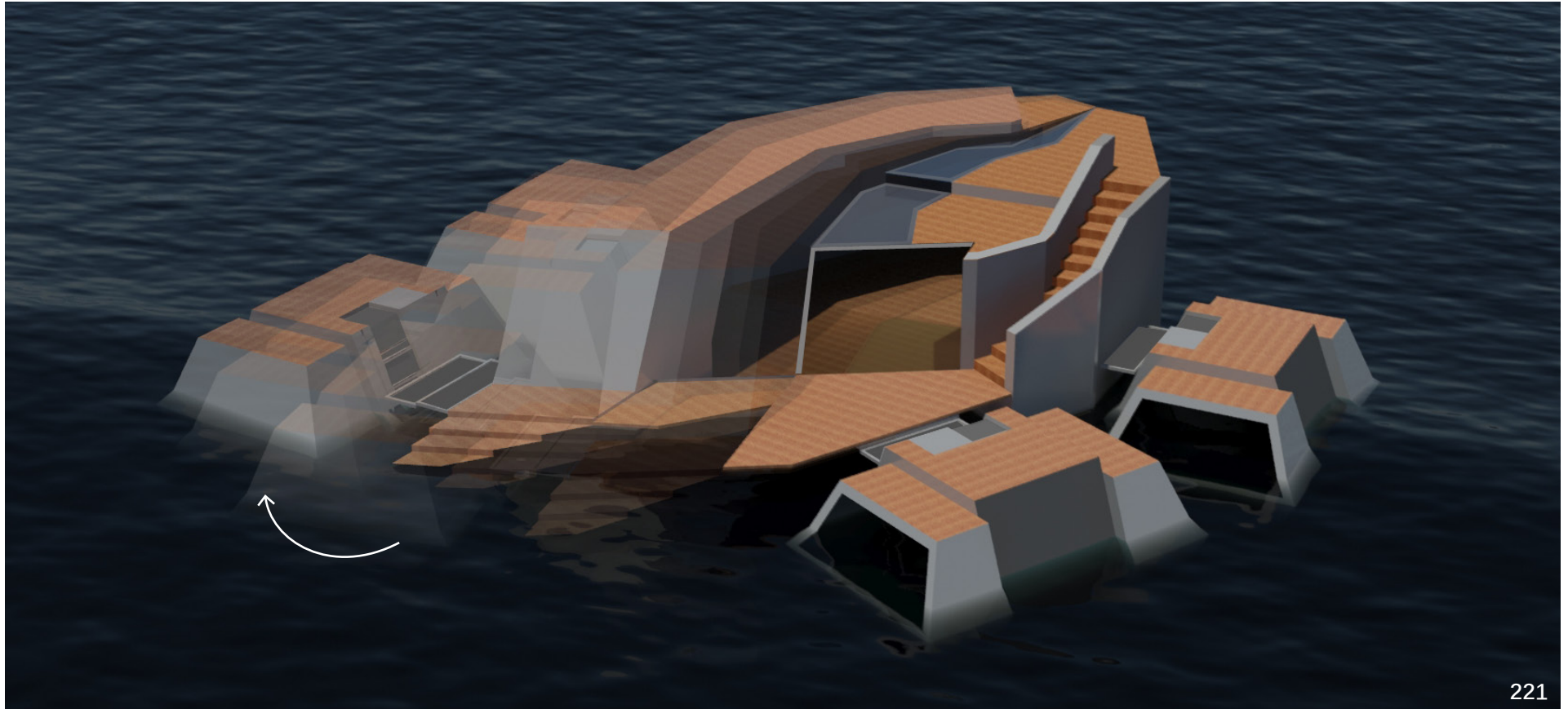


Figure 220 : Living Module Floor Plan

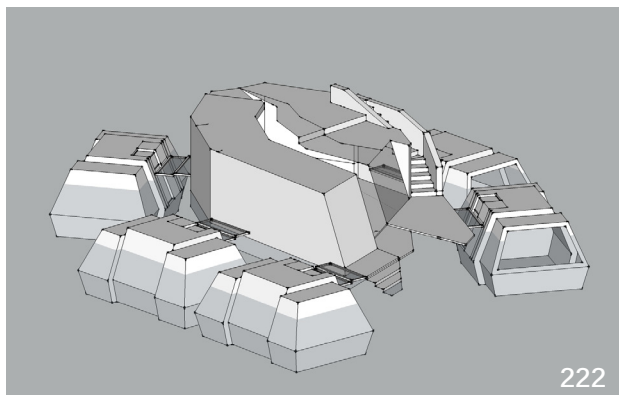
Living Module : 30sqm  
Private Module : 10sqm  
Exterior Space : 55sqm  
Total (1L+1P) : 95sqm

Figures 221, 222 - 224: (Opposite)  
Rendered View of Design Iteration One  
First Design Iteration from Multiple Perspectives

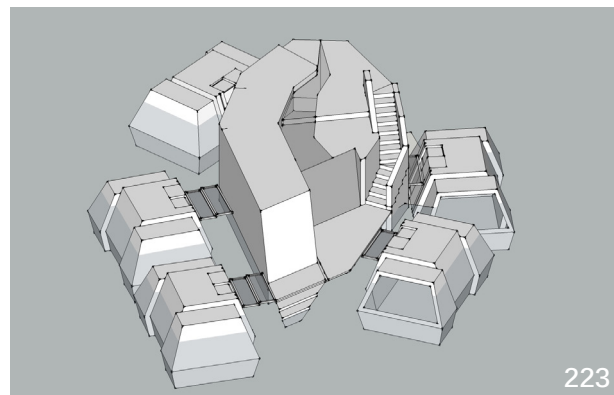
This first design iteration focussed on incorporating selected marine technologies into a developed version of the previous octagonal dwelling concept. Gudgeons, pulleys, travellers and cleats have all been employed in the design of the larger living module. This technology allows the user to control their level of exposure to the elements, but more importantly it also allows for them to control the susceptibility of the dwelling to the dynamic littoral environment depending on the conditions. When the form is opened the surface area exposed to the environment increases, similar to a spinnaker on a racing yacht. This allows for the littoral environment to apply a greater force to the dwelling, causing it to articulate further with the same environmental conditions applied and therefore enhancing the relationship between the occupant and their environment.



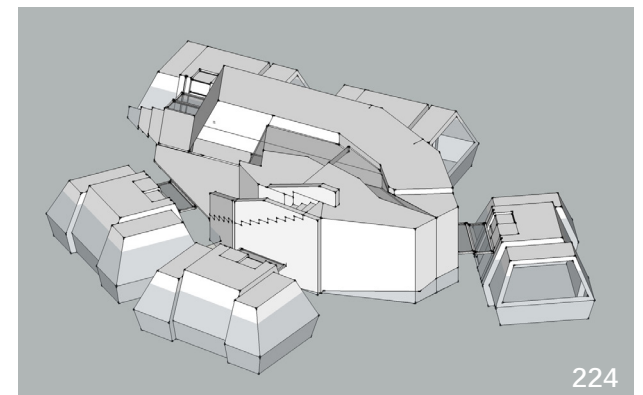
221



222



223



224



### 5.3.4 DESIGN ITERATION TWO

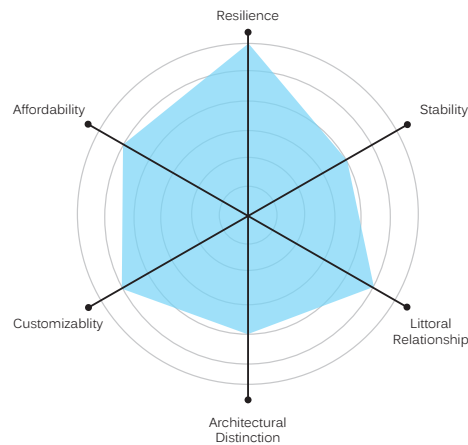


Figure 225 : Iteration Two's Achievement of Key Criteria

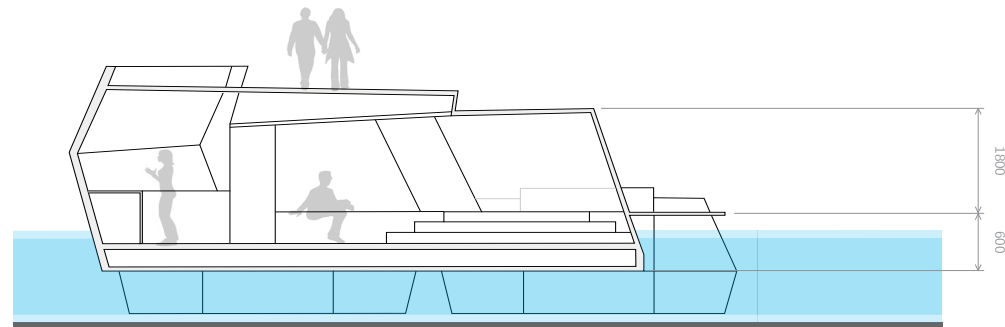


Figure 226 : Longitudinal Section - Once Inundated

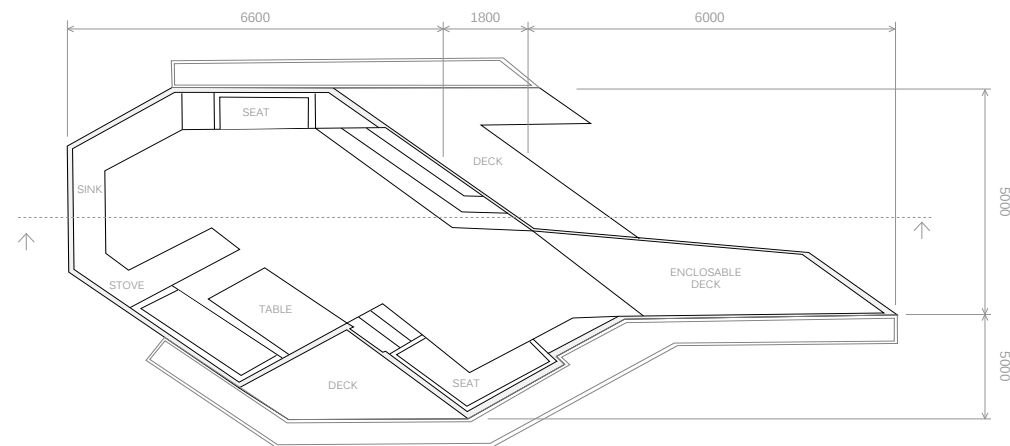
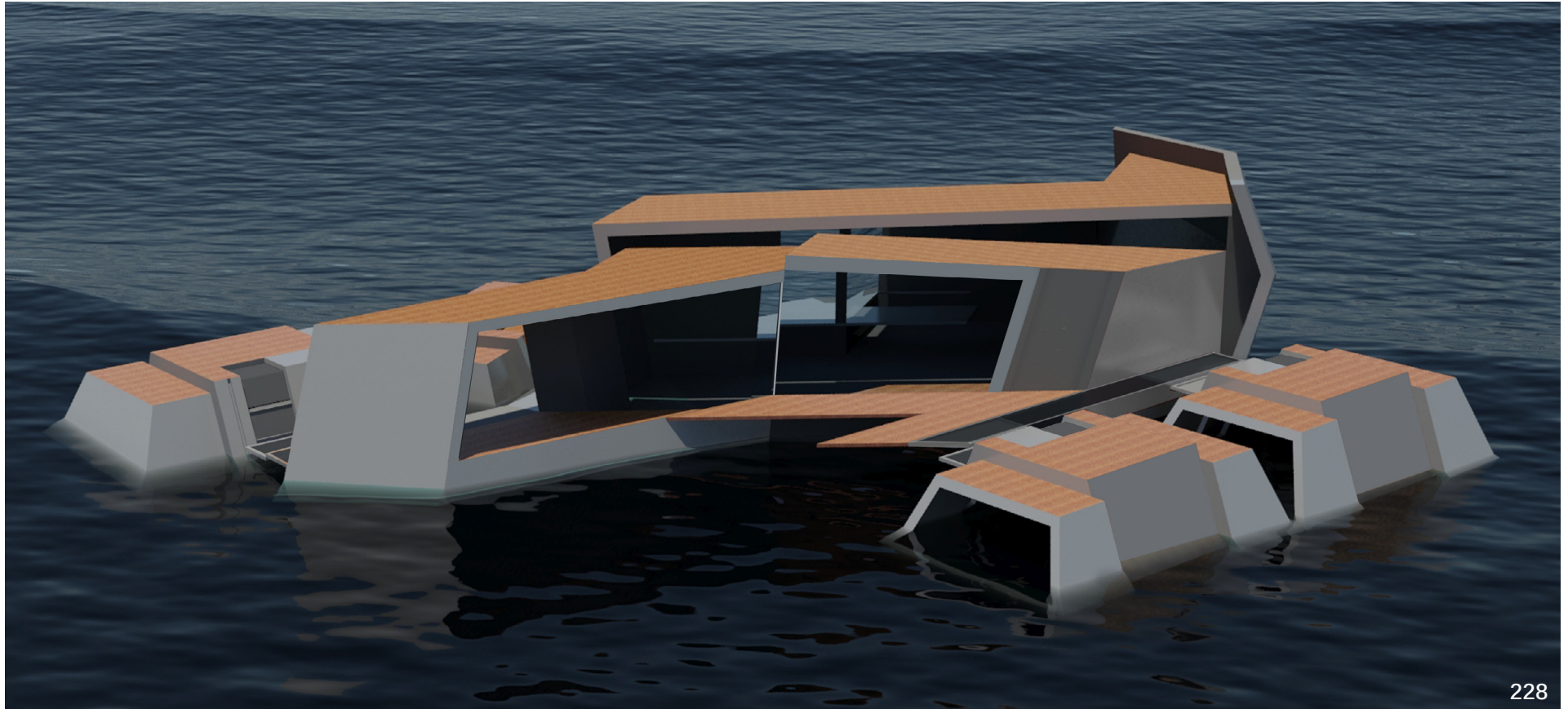


Figure 227 : Living Module Floor Plan

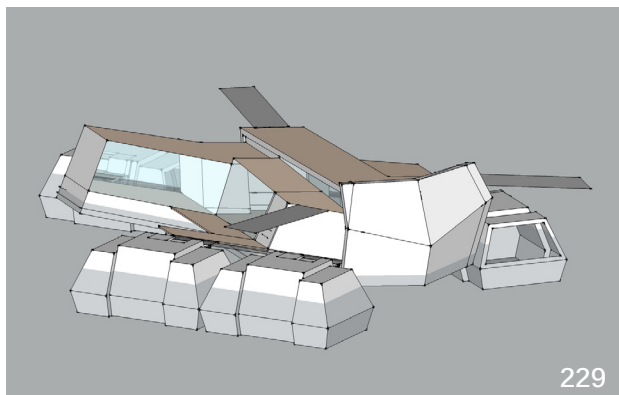
Living Module : 20sqm  
Private Module : 12sqm  
Exterior Space : 48sqm  
Total (1L+1P) : 80sqm

Figures 228, 229 - 231: (Opposite)  
Rendered View of Design Iteration Two  
Second Design Iteration from Multiple Perspectives

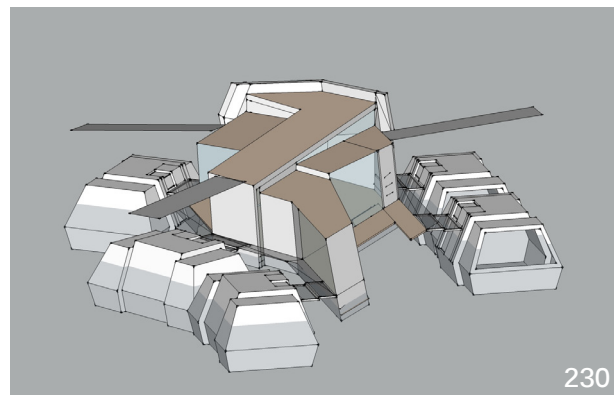
After reviewing all of the previous dwelling design concepts, it is clear that the sleek, elongated and futuristic shell aesthetic which was illustrated in the first design phase has not yet been realised, see page 50. This second design iteration aims to return to those themes. Focusing mainly on the larger living module, the previous octagonal design has been heavily manipulated to remove the similarities between the resilient dwelling and an escape pod and provide an asymmetrical dwelling design, similar to the bivalve shell in plan, which can be occupied on multiple levels with a variety of different levels of user controlled exposure. Unfortunately, attempting to produce an attractive dwelling solution that will entice the Kilbirnie residents has come at the cost of safety and stability. Once inundated this design would be highly unbalanced as the centre of buoyancy is much closer to the left hand side of the dwelling, given the unusual module shape, and would therefore have a strong potential to capsize in rough seas if a number of private modules were not



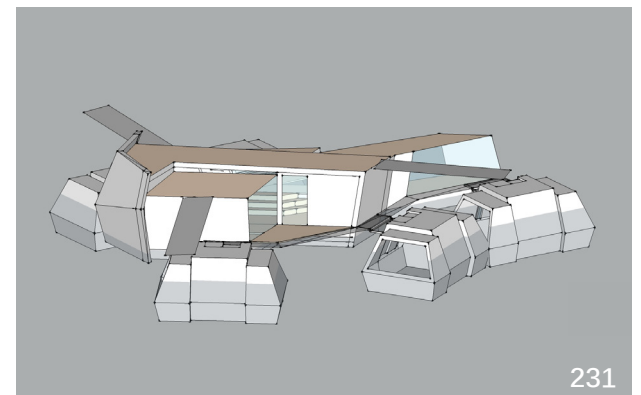
228



229

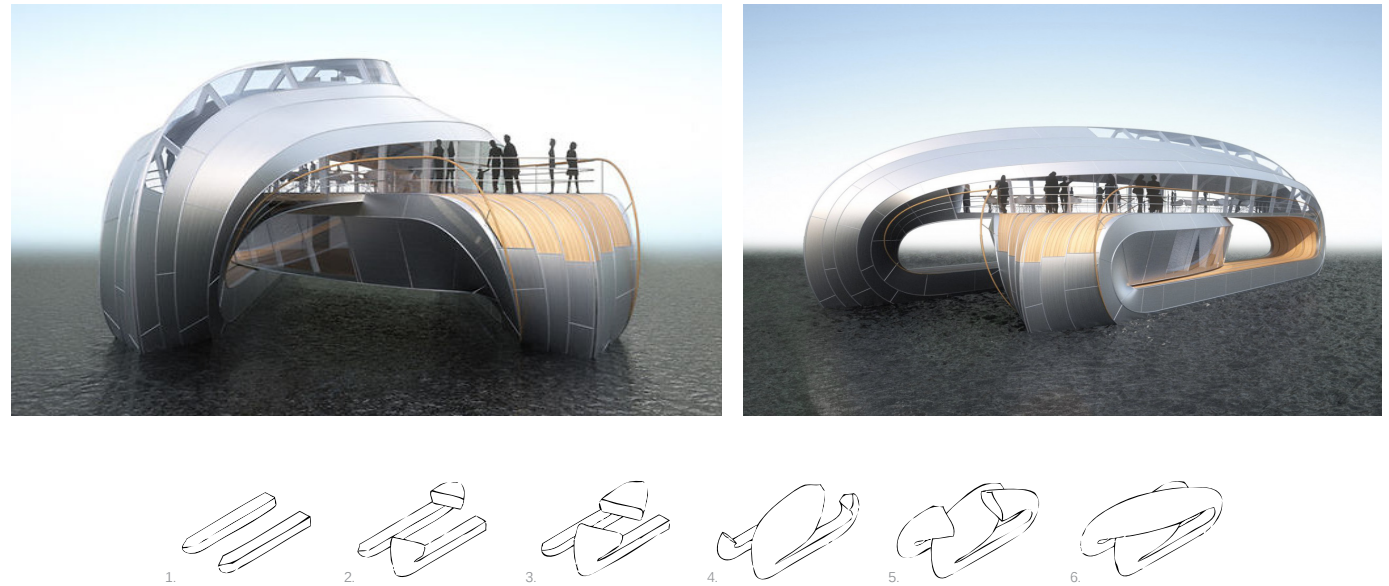


230



231

### 5.3.5 FROM A MONOHULL TO A CATAMARAN



Figures 232 - 234: River Boat for River Loire, France - Thomas Heatherwick (2012)

After designing a resilient dwelling that had an aesthetic appeal but was far too unstable for the unpredictable environment of Wellington Harbour, it was time to once again return to the drawing board. In designing a deconstructed dwelling, what was essentially created was a flat based monohull yacht with a number of outriggers attached to each side. Anyone who has ever sat in a dingy can testify that small monohulls are unstable and uncomfortable especially in a short ocean chop.

Thomas Heatherwick recently encountered similar issues when designing an ultra-modern river boat for a very wealthy client in Nantes, France. His solution to instability was simple, make it a catamaran, see Figures 232 - 234. In comparison to a monohull, a catamaran, a boat consisting of two hulls, is very stable as the righting arm, or the distance between the points of buoyancy, is much greater. Catamarans are also typically a lot lighter and sit higher on the waterline allowing them to float with a smaller body of water beneath the hulls.<sup>71</sup> When designing his architectural solution for the River Loire, Heatherwick asked the question, can a whole boat be made entirely of its hull?<sup>72</sup> This question and Heatherwick's resulting solution convinced me that the answer to ensuring stability whilst maintaining aesthetic appeal may be as simple as moving to two hulls for the main living module rather than one.

### 5.3.6 NEW FORM DEVELOPMENT

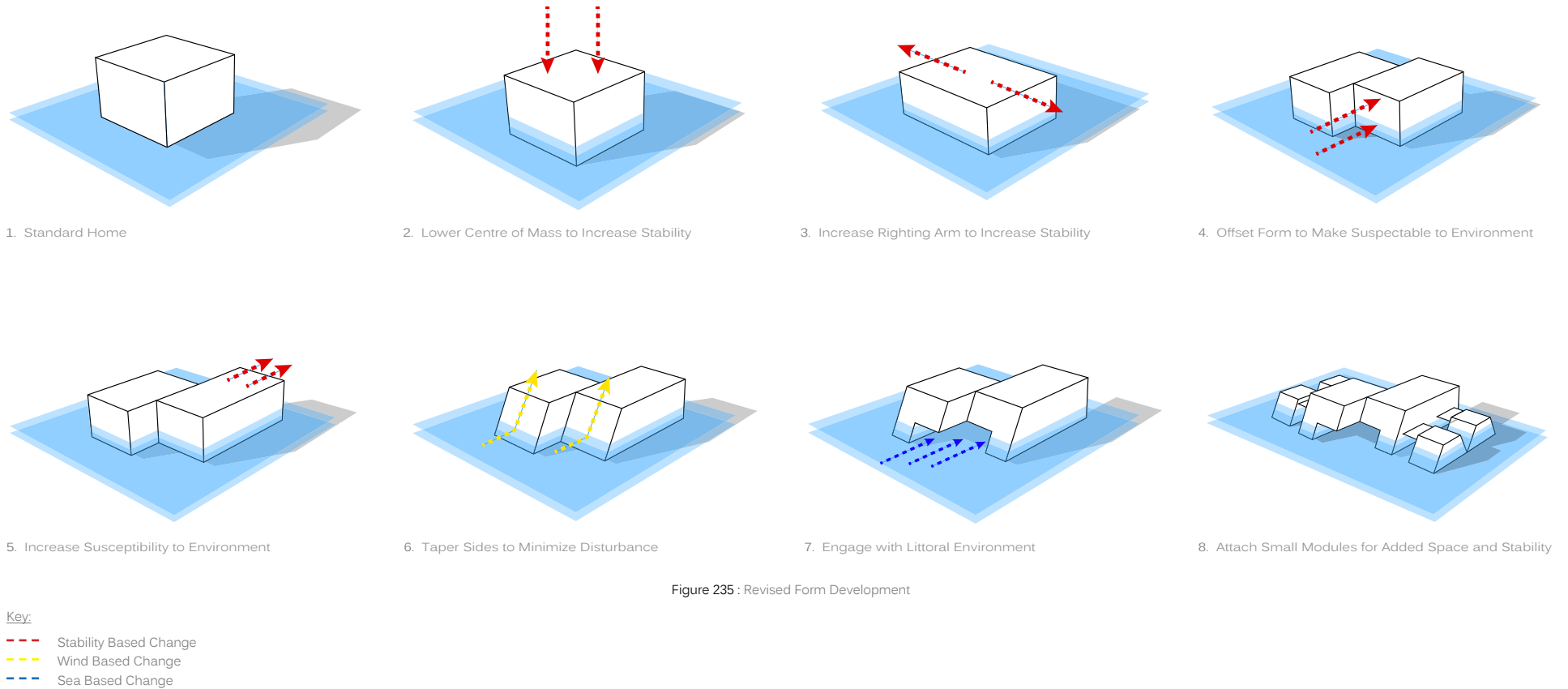


Figure 235 : Revised Form Development

The design of the new deconstructed dwelling occurs in eight steps. Starting with a simple floating cube, the design is lowered into the water and widened to increase stability for the residents within. The design is then split in half, offset and lengthened to become asymmetrical and increase its susceptibility to the changing environment and improve the relationship between the resident and the littoral environment once inundated. The form is then tapered to improve its aerodynamics and minimize unnecessary disturbance. The most recent step is then to carve a void through the dwellings centre to form a stable catamaran. Water will now be able to flow through the design rather than force its way around it. The final step is then to attach the private modules with the sliding circulation bridges to increase stability and provide for greater residential dwelling space.

### 5.3.7 DESIGN ITERATION THREE

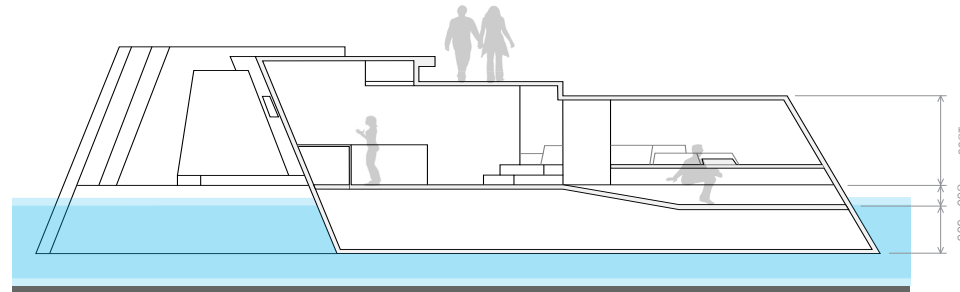


Figure 237 : Longitudinal Section - Once Inundated

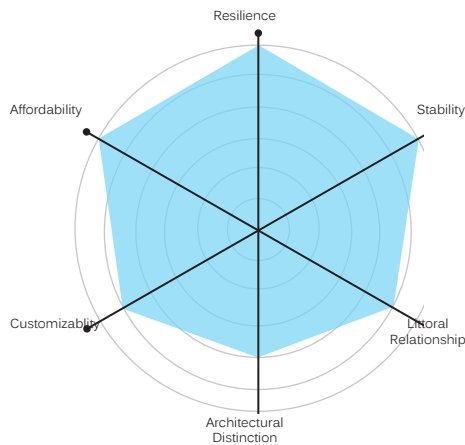


Figure 236 : Iteration Three's Achievement of Key Criteria

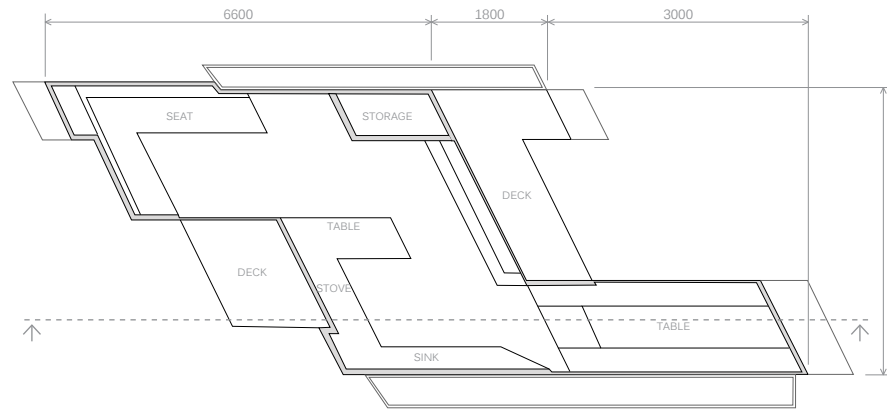


Figure 238 : Living Module Floor Plan

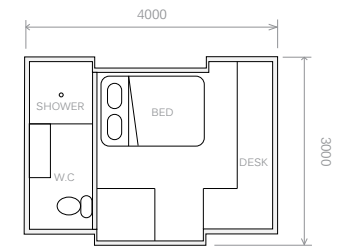


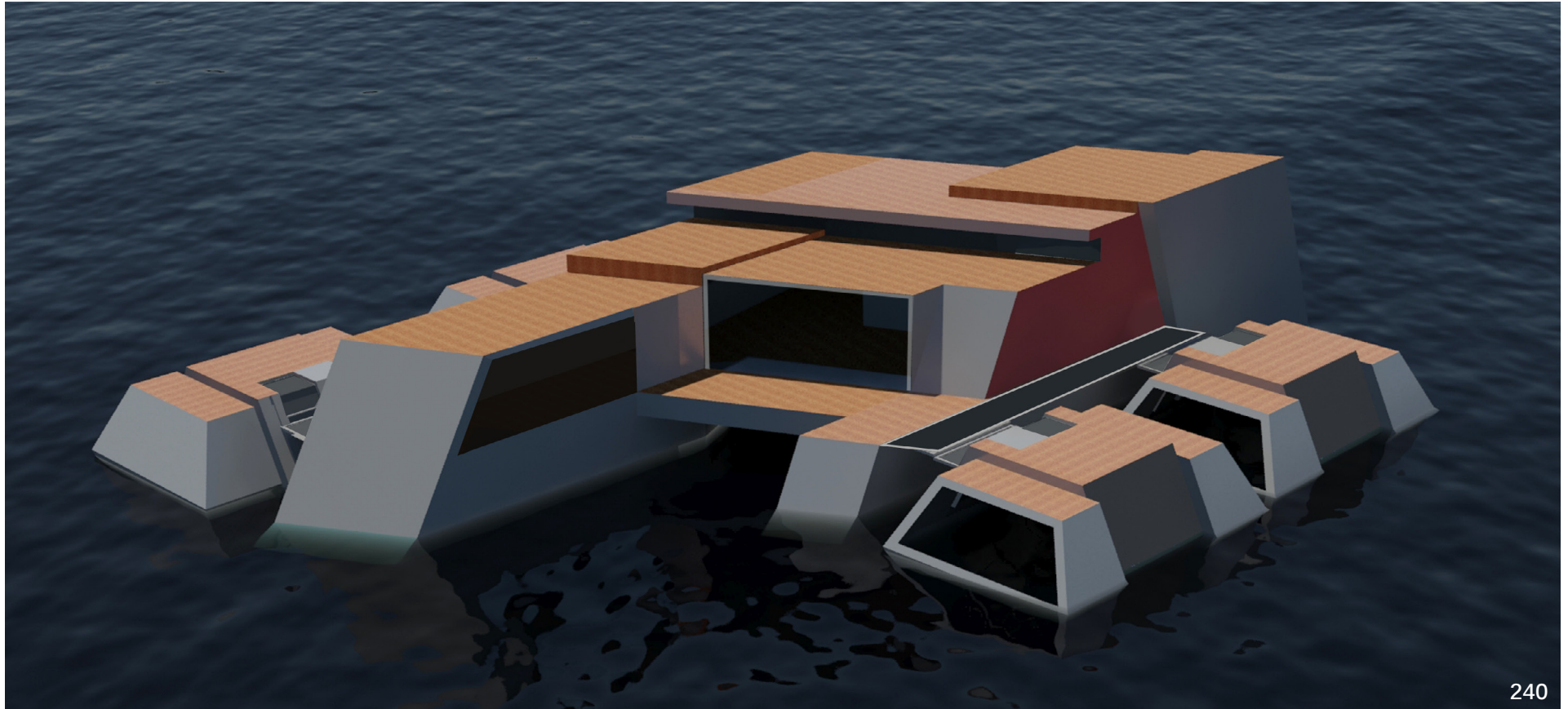
Figure 239 : Private Module Floor Plan

Living Module : 30sqm  
Private Module : 12sqm  
Exterior Space : 62sqm  
Total (1L+1P) : 104sqm

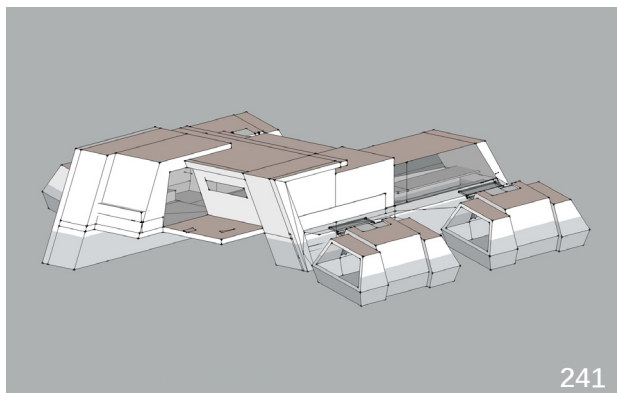
Employing the new form development process, this third design iteration aimed to produce a dwelling solution which finds a middle ground between aesthetics and function. Designed to embellish the movement of the littoral environment, the living modules have skewed hulls. This design gesture has caused for the users line of sight to be partially restricted regardless of their location therefore allowing semi-private dwelling to occur, even in the relatively compact space. When four private modules are attached to the base living module the combined dwelling would be 18m wide by 12m long, with a total internal floor area of 78sqm and a further 100sqm of external dwelling area, when four private modules are attached. A typical Kilbirnie home is considerably larger at 110sqm with a 300sqm section,<sup>73</sup> and as a result the size of this design iteration would need to be significantly increased in order to improve the appeal of a resilient dwelling solution to the Kilbirnie resident at risk of inundation. This iteration is the most stable, appealing, customisable and with the strongest littoral relationship of any of the previous designed dwelling concepts. This third design iteration will therefore be developed further to provide a resilient dwelling solution which can successfully achieve all of the design criteria.

Figures 240, 241 - 243: (Opposite)  
Rendered View of Design Iteration Three  
Third Design Iteration from Multiple Perspectives

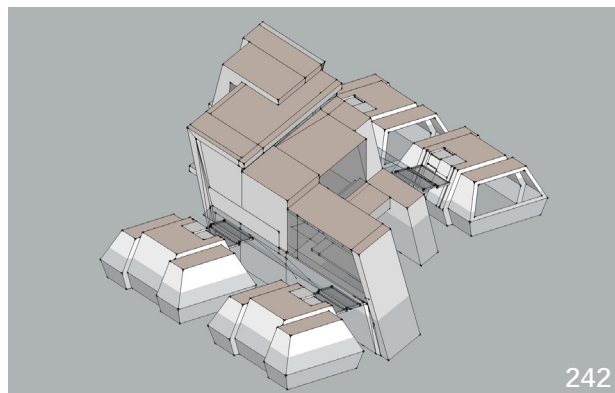




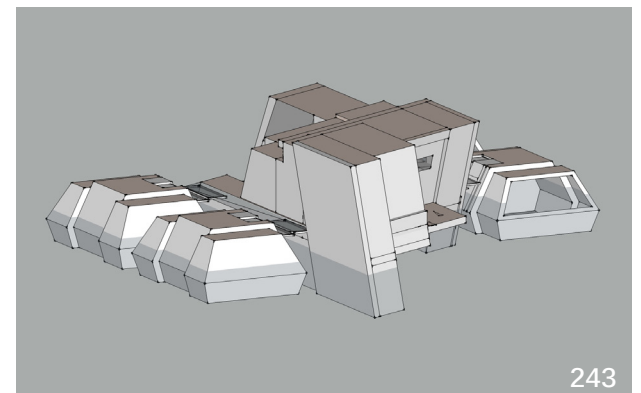
240



241



242



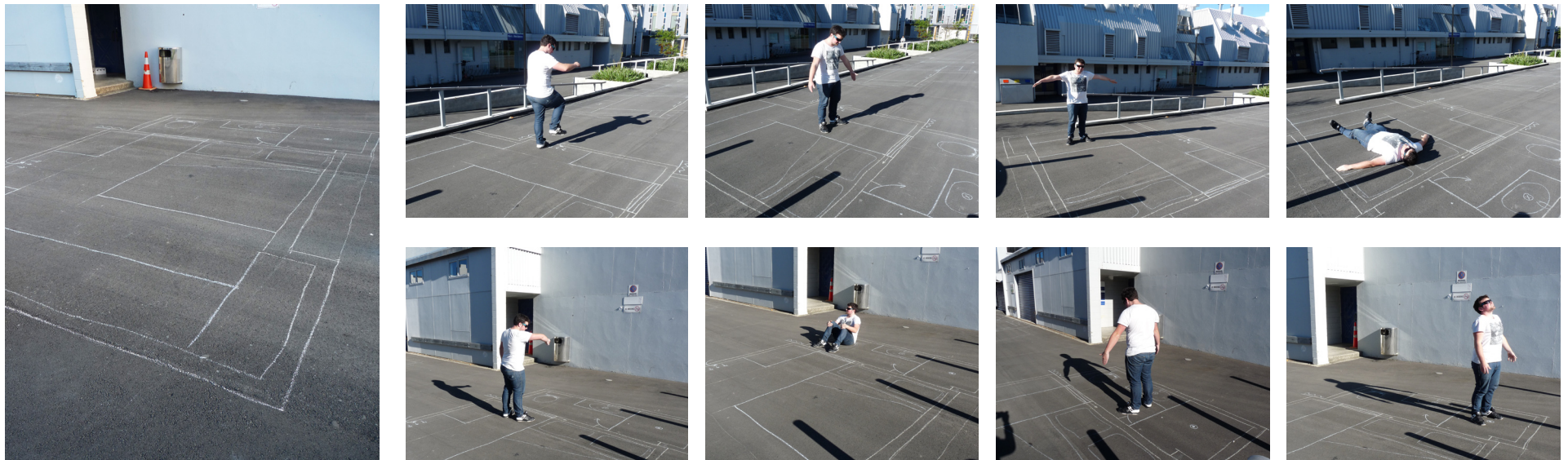
243

### 5.3.8 TESTING SCALE AT 1:1



Figures 244 - 252: Living Module Ground Floor Scale Testing

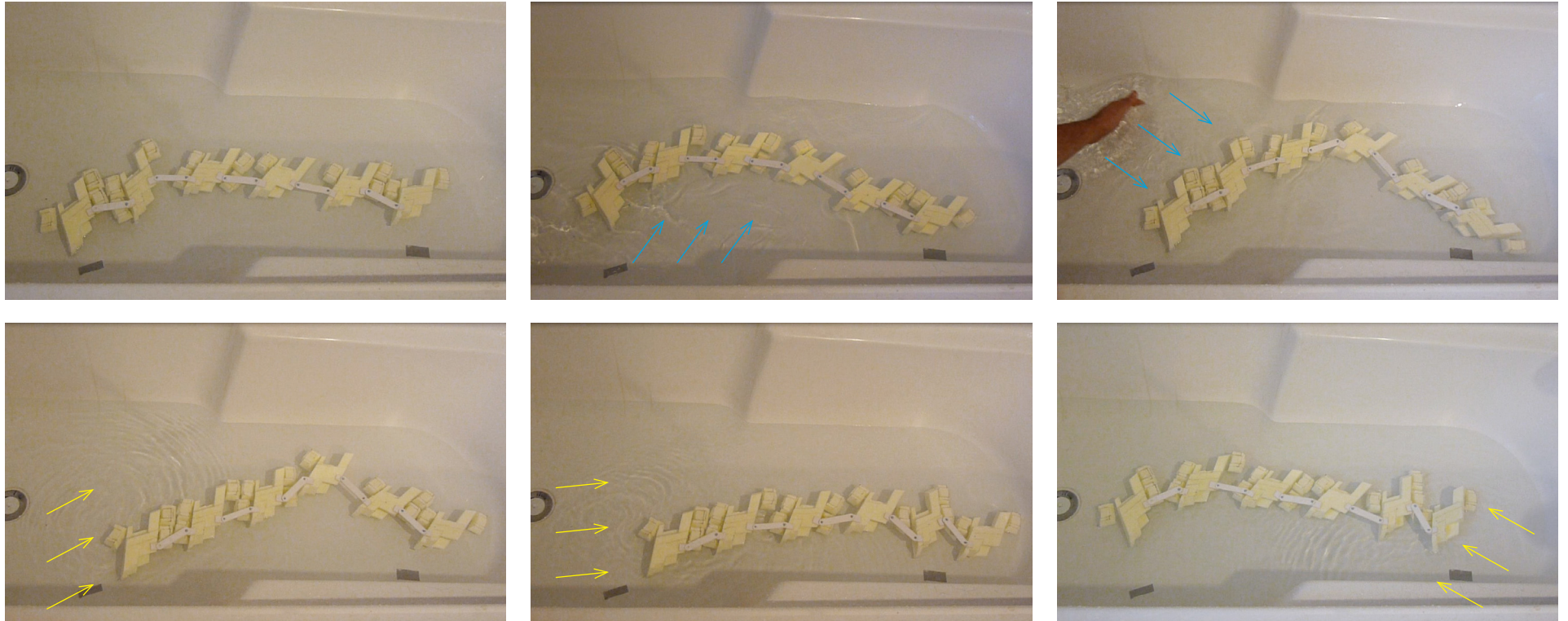




Figures 253 - 261: Private Module Ground Floor Scale Testing

After identifying that the selected design iteration was significantly smaller than the average Kilbirnie residence, it was decided that the best way to check the size of the dwellings dimensions was to test it at 1:1. The floor plans of both the living module and smaller private module were therefore drawn to scale in chalk on a large asphalt surface. Over the course of a few hours each and every dimension was tested through simulated occupancy. This enabled problematic areas to be identified and changes to be implemented on the spot. The biggest issues seemed to be in the private module, especially in the bathroom. Issues were also discovered in the living area and in the dining area of the living module. These problematic areas have been addressed and the scale of the entire dwelling was also increased to provide a more spacious and overall more comfortable dwelling for the residents of Kilbirnie.

### 5.3.9 RESILIENT COMMUNITY SIMULATION



Figures 262 - 267: Inundated Community Simulation Two Connection Points





Figures 268 - 273: Inundated Community Simulation Three Connection Points

Key:  
 → Wave Direction    → Wind Direction

With a new design solution partially developed, scale models have been utilised in a series of simulations to explore how different connection arrangements impact the resilient community's relationship with the changing littoral environment. These video stills represent the possible arrangements which could occur over a twelve hour period in Evans Bay under a variety of conditions and weather directions. In the first simulation dwellings were connected side to side with two anchor points, see Figures 262 - 267. In the second simulation one dwelling had three connection points with two units attached off the dwelling without an anchor point allowing for a greater variation in the effects of the environment on the floating community, see Figures 268 - 273. The later simulation allowed a greater influence of the littoral environment on the arrangement of the community, having three possible connection points also allows for less linear community configurations to be formed.



### 5.3.10 RESOLVED RESILIENT DWELLING SOLUTION

After an extensive iterative design process, a resilient dwelling solution was developed which successfully meets all of the design aims, see Figure 274. The dwelling solution is adaptable and stable in changing conditions; it is prefabricatable and customizable to meet the needs of a wide variety of users; it allows the user to control the level of articulation to suit the changing littoral environment; once inundated it provides a strong relationship between the occupant and their littoral environment; and finally its rounded asymmetrical form makes the resilient dwelling solution highly desirable to those at risk of inundation in the community of Kilbirnie, see Figure 275. A number of aspects of the traditional Kilbirnie home have been incorporated into the resolved design of the resilient dwelling in order to ease the residents transition from their current homes to the new amphibious dwellings. These aspects include a strong juxtaposition in colour, an abstracted cornice line and a largely timber exterior.

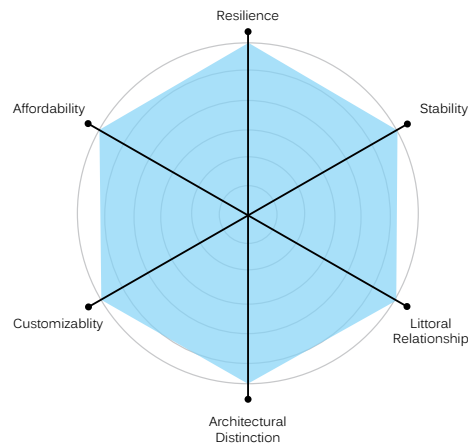


Figure 274: Resolved Resilient Dwelling Solutions Achievement of Key Criteria

Following images illustrate what a community of these resilient dwellings would look like and how it would be occupied when on land prior to sea level rise, see Figure 277, as well as how Kilbirnie may look after sea inundation, when the resilient community would be able to adapt and float together in a now much larger Evans Bay, see Figures 276, 278 and 279. After testing the earlier design concept at 1:1 and realising a number of key areas were far too small, the dimensions of this resolved dwelling have been increased much larger to provide a comfortable dwelling space for a household previously at serious risk of inundation. When two or more private modules are added to a living module, the resilient dwelling will have a total floor area similar to that of a typical Kilbirnie home, see Figure 280.

Figure 275: (Opposite)

A Resilient Dwelling Post Inundation In Evans Bay

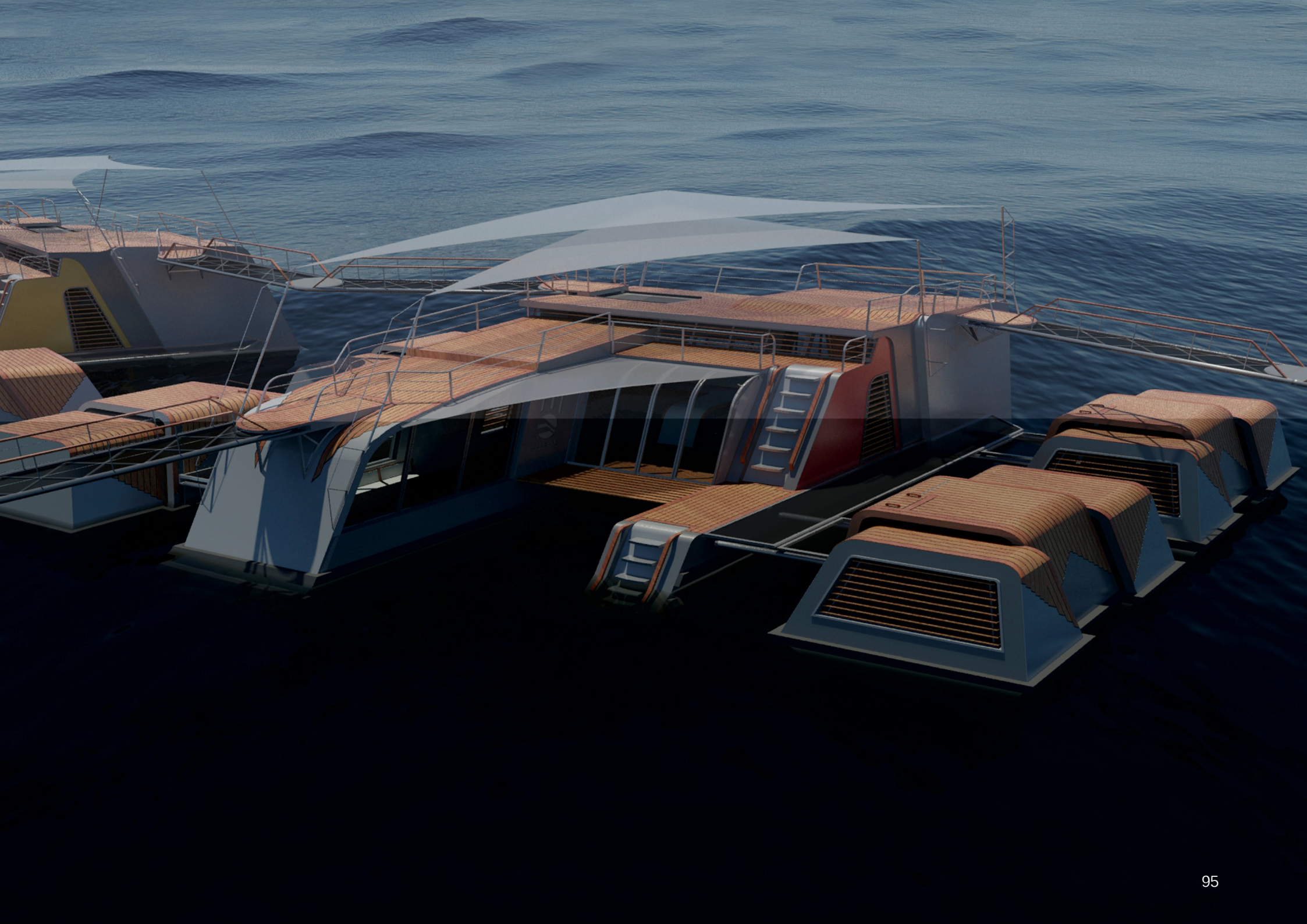
Figures 276, 277, 278, 279: (Following)

Resilient Community Floating in Evans Bay

Resilient Community Prior to Inundation

Community Articulating in a Storm

Dwelling From Water Level







276





277



278



279

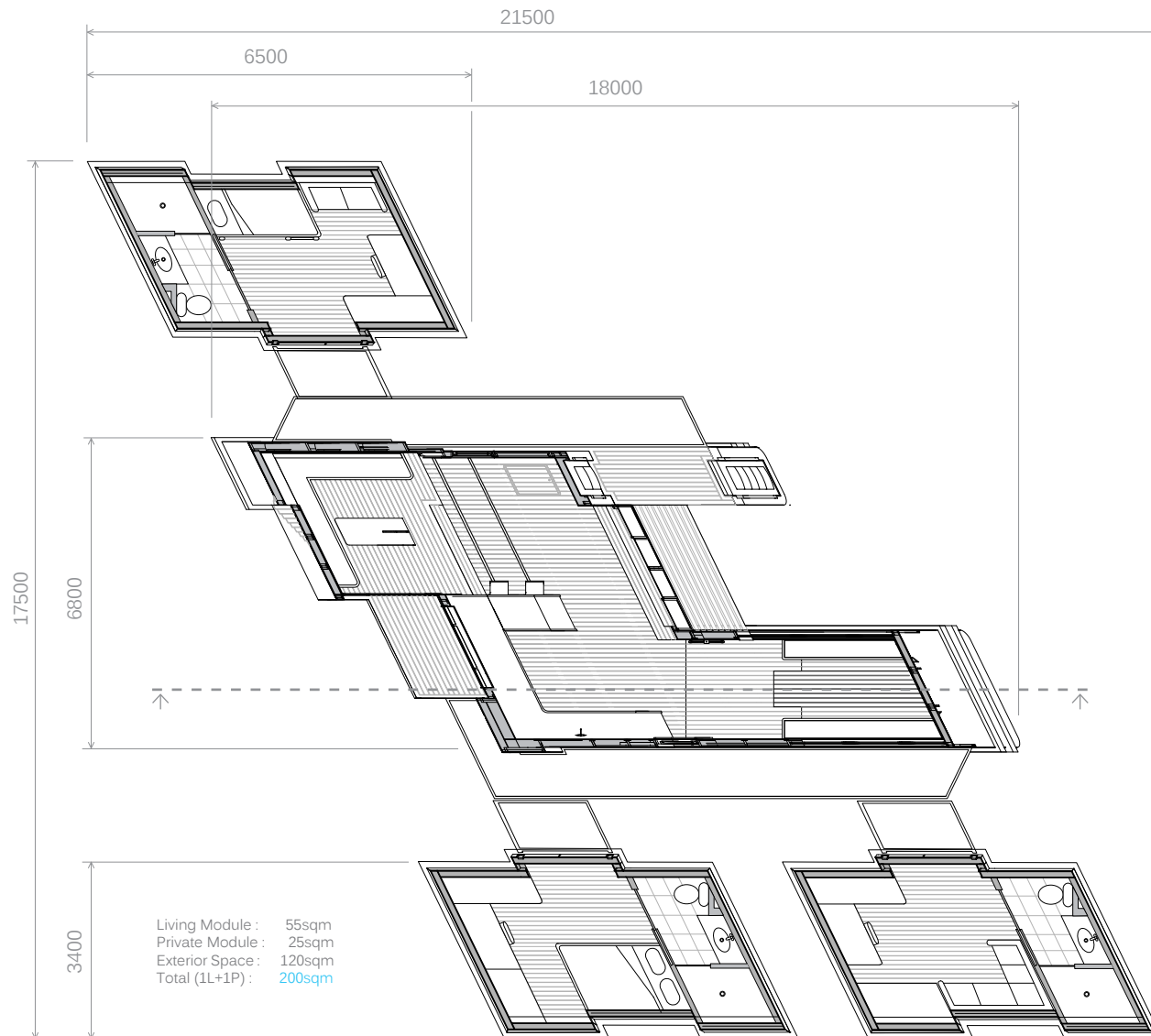


Figure 280: Resolved Resilient Dwelling Floor Plan



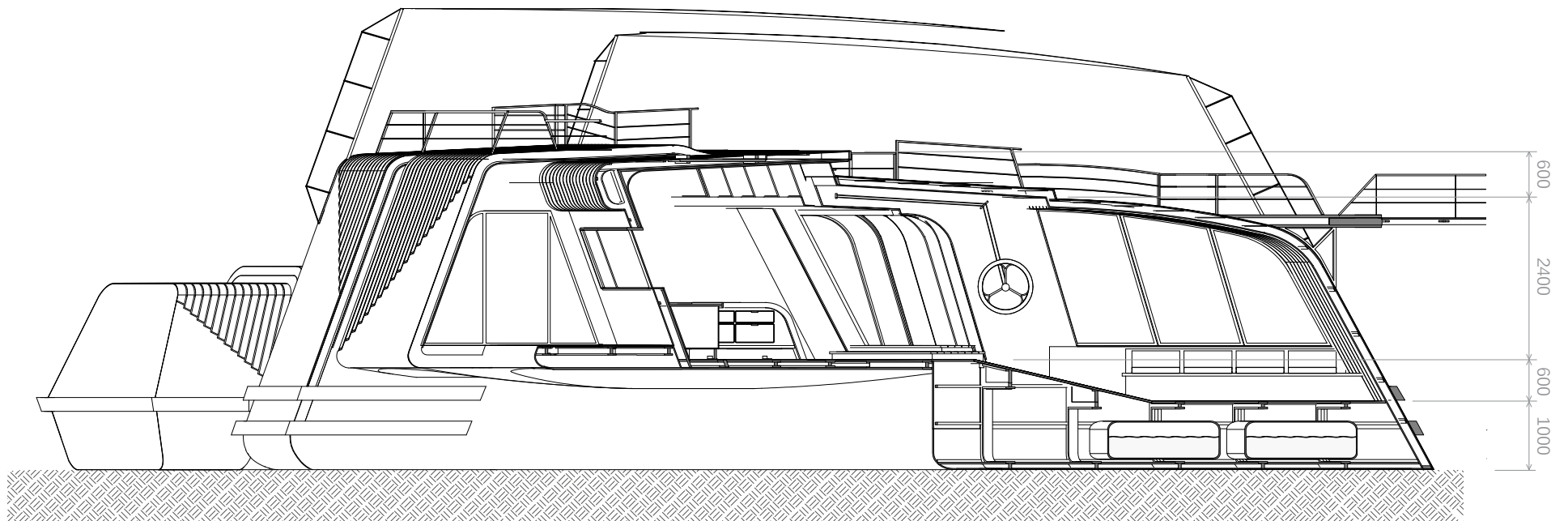
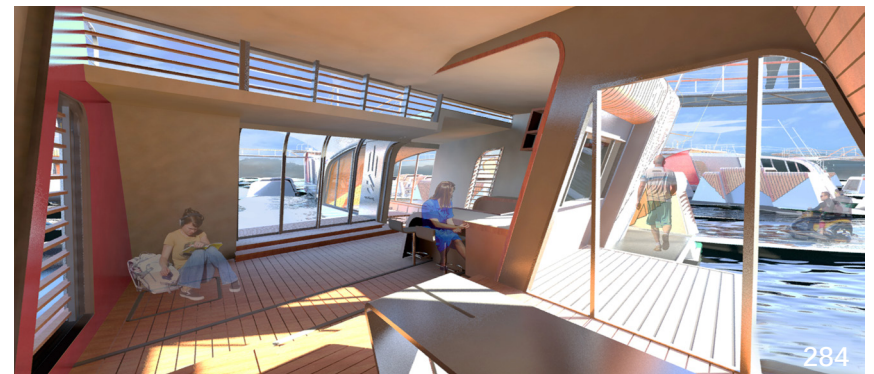
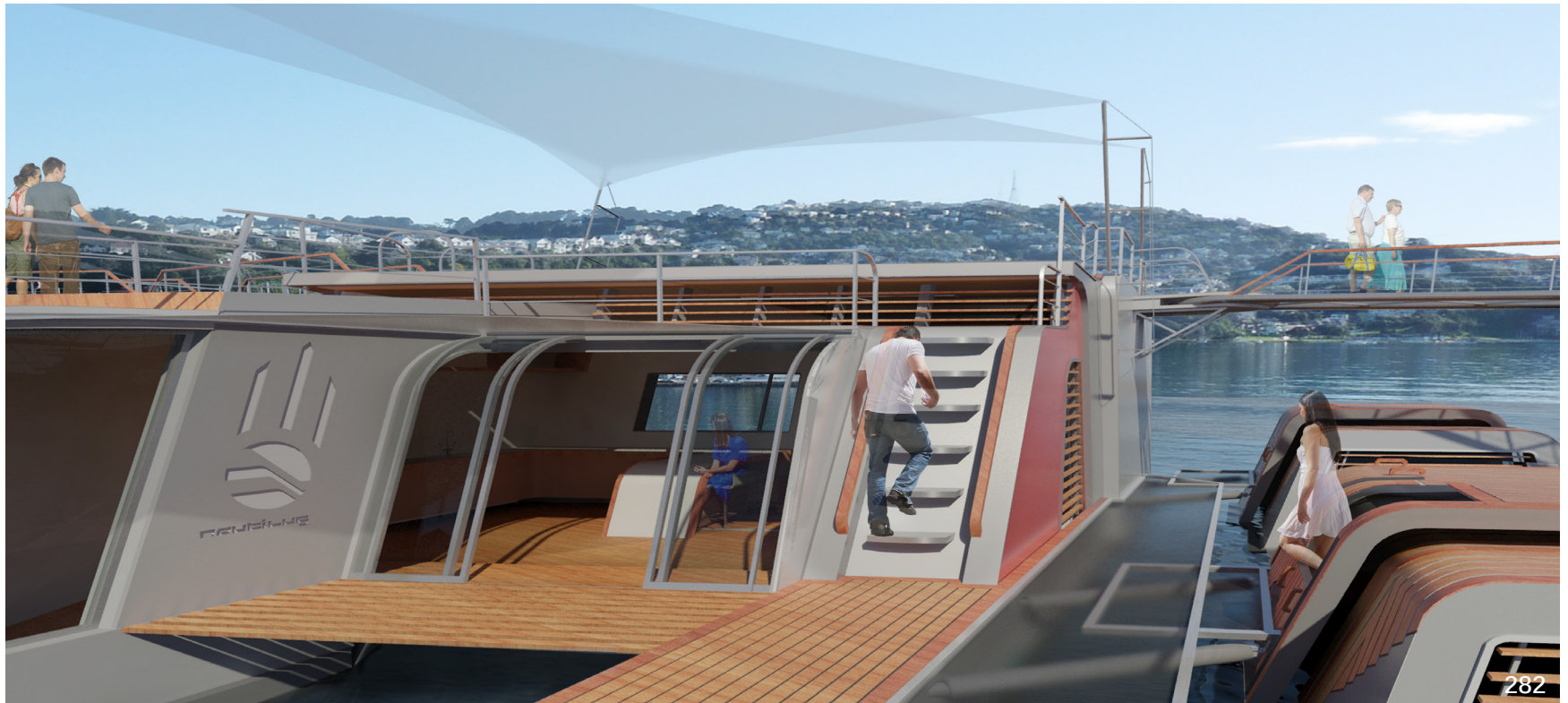
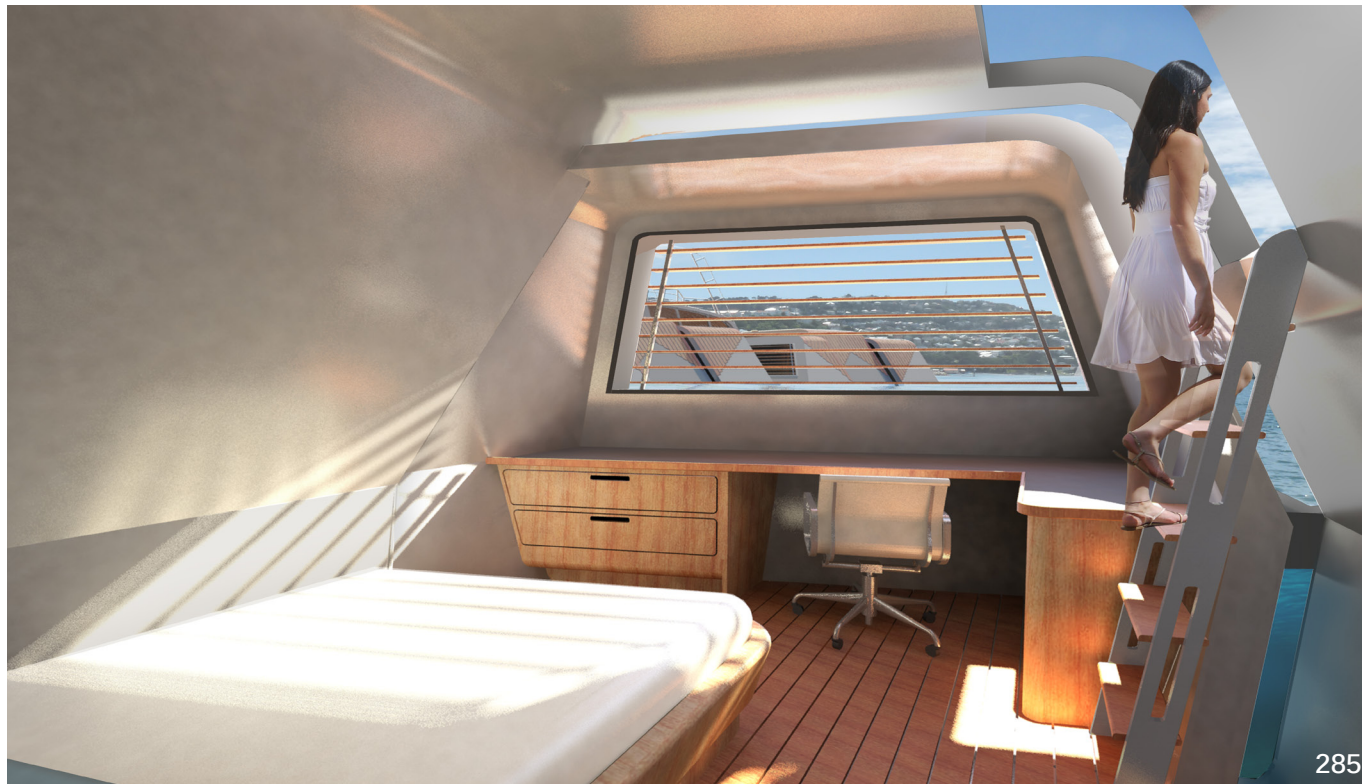


Figure 281: Resolved Resilient Dwelling on Land Longitudinal Section

### 5.3.11 DWELLING IN AN EXPOSED CLIMATE





The dwellings interior has been designed to make the occupants feel safe and warm no matter how rough the weather is outside. Emphasis has been placed on ensuring that the aesthetic of the exterior is not lost in the internal design of the amphibious dwelling. The images shown to the left represent only one of a number of different internal arrangements and material selections which could be implemented to suit the desires of a wide variety of dwelling occupants. The above image shows a typical bedroom arrangement in the smaller private module post inundation.

Large tinted windows have been installed in each of the main spaces within the living module in order to provide the resident with clear views out over the dynamic community whilst maintaining a sense of intimacy and privacy. A number of pieces of furniture are able to move on a system of sliding tracks, ropes and pulleys in order to allow for multiple functions to be catered for in a single space. These pieces include the breakfast table, which can be moved to create a larger kitchen space, the dining table, which can be lowered to create a double bed for a guest and a sliding wall which can be used to divide off the living area.

Figures 282, 283, 284, 285:  
Resilient Dwelling Circulation  
Kitchen Perspective  
Living Room Perspective  
Private Dwelling Perspective



### 5.3.12 DWELLING CONSTRUCTION

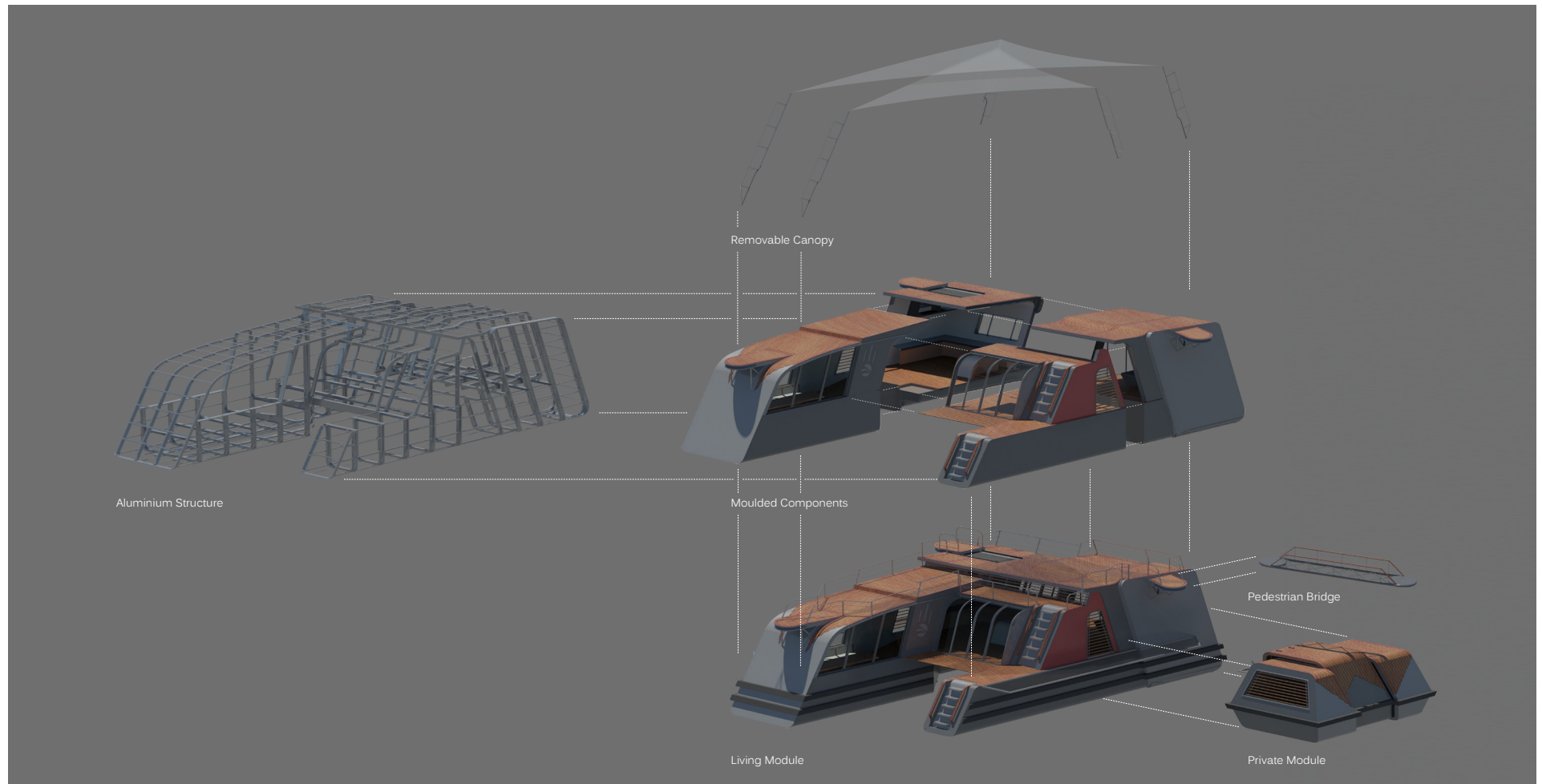


Figure 286: Exploded Diagram of a Resilient Dwellings Construction

The resilient dwelling is constructed from three core components, an extruded aluminium shell structure at 400crs, six 15mm thick high density polyurethane roto-moulded components and a removable shade canopy. Once constructed the dwellings interior, doors and windows, walkways and other fittings and fixtures can be installed. The fabricated modules can now be shipped to site and the services and circulation routes connected.



### 5.3.13 REAPPROPRIATED MARINE TECHNOLOGY

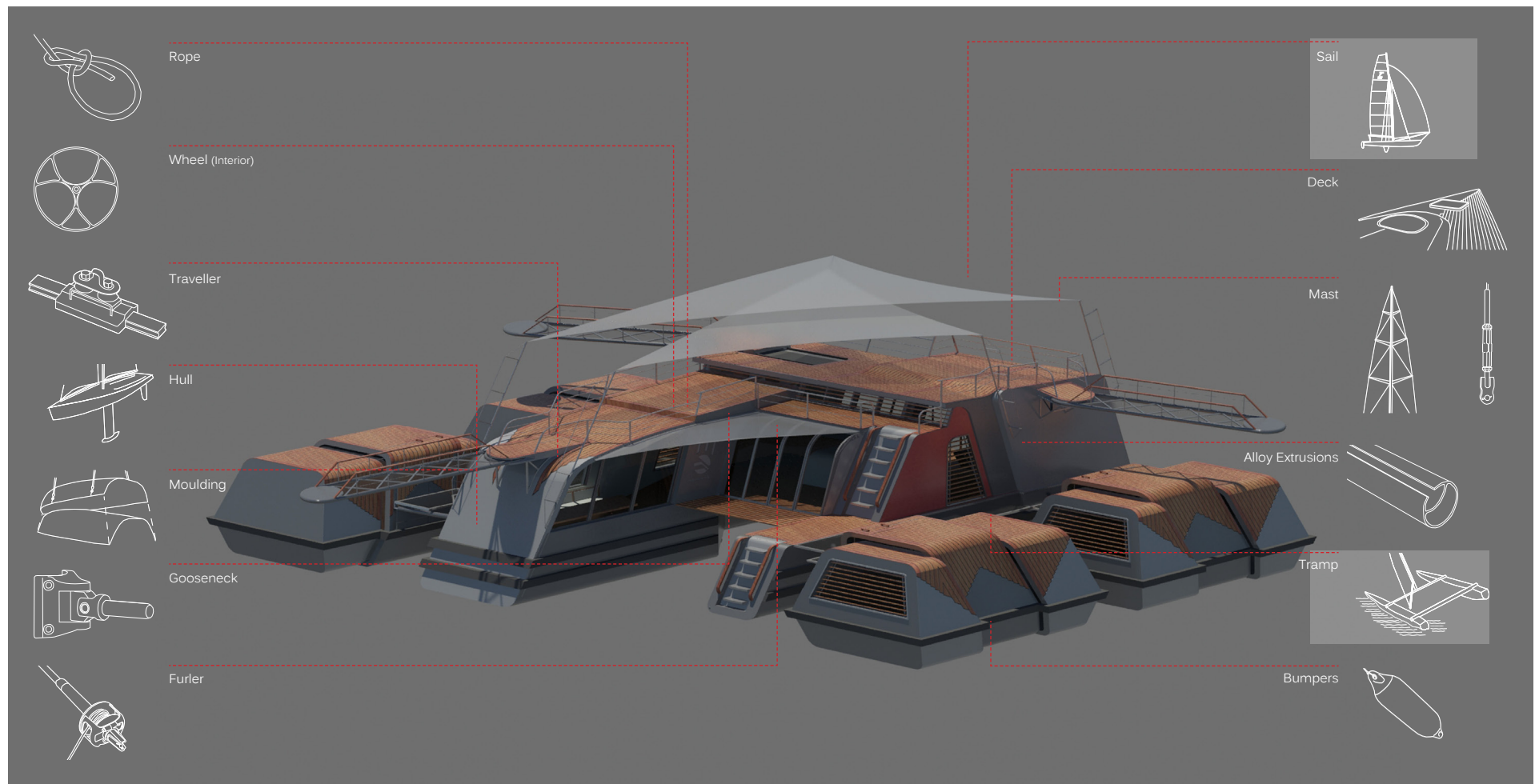
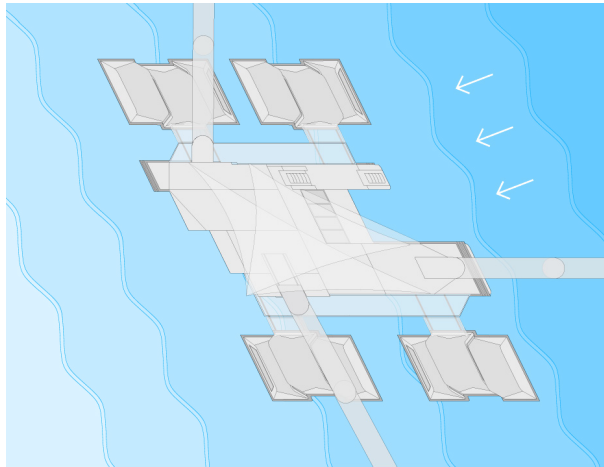


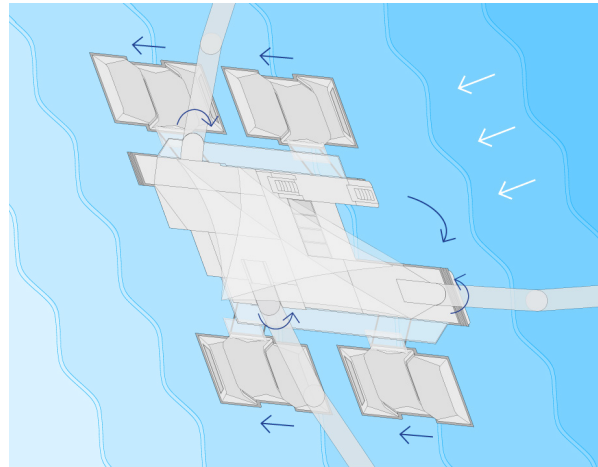
Figure 287: Illustrating Locations Where Marine Technology has been Reappropriated to Assist in Dwelling Function and Resilience

Marine technology has been reappropriated throughout the resilient dwelling design, assisting in basic construction and material specifications, including stainless steel fittings and fixtures, teak decking, alloy extrusions and mylar shade sails. More importantly the marine technology has been reappropriated to allow the dwelling to articulate and adapt to the constantly changing environment with goosenecks, travellers, wheels, pulleys and ropes employed across most of the dwelling.

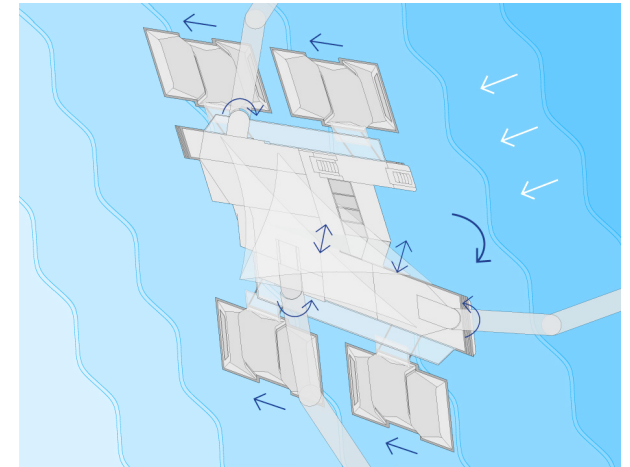
### 5.3.14 ADAPTABILITY THROUGH ARTICULATION



Articulation Restricted

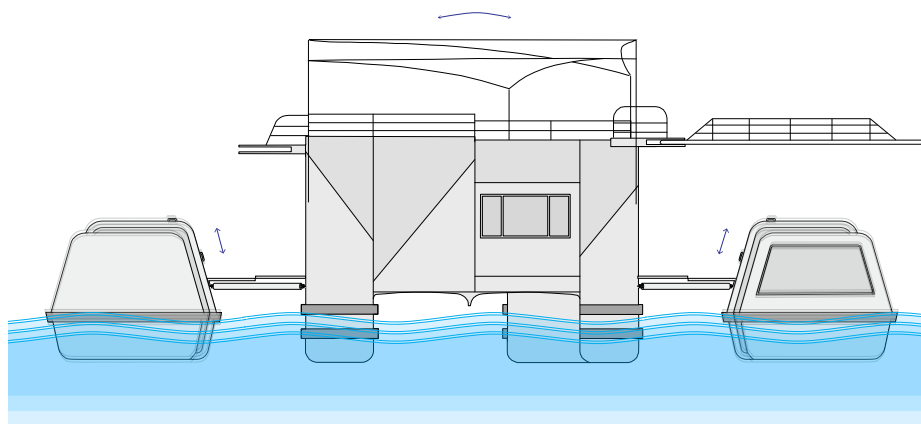


Articulation Allowed

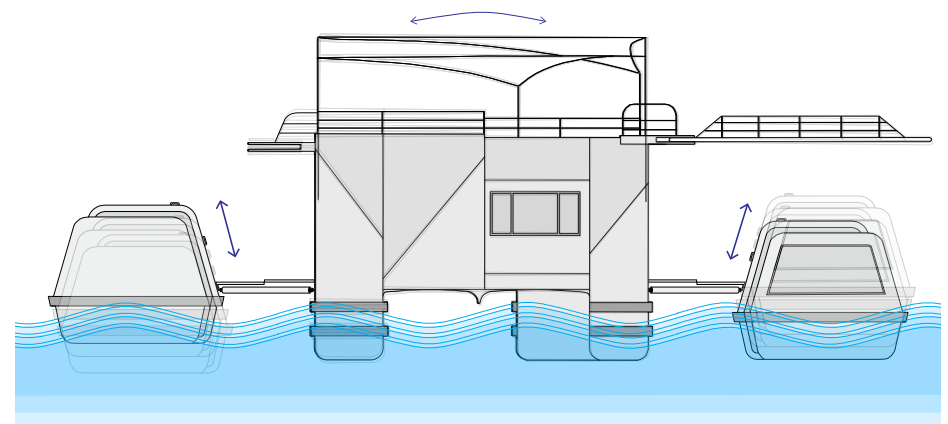


Articulation Allowed and Dwelling Opened

Figures 288 - 290: Horizontal Articulation



Dwelling in Calm Environment



Dwelling in Storm Environment

Figures 291 - 292: Vertical Articulation

One of the largest differences between this design solution and that of the previous design case studies is the dwellings ability to articulate in order to adapt to the changing environment. Through the reappropriation of marine technology, the user will be able to control a dwellings level of articulation to suit the environment and their own dwelling needs. For example on a warm calm day an occupant could open the dwelling to bring in more fresh air whilst also increasing the dwellings susceptibility to the littoral environment, whereas on a stormy day the occupant could close up the dwelling and restrict horizontal articulation to remain as stable as possible in rough seas, see Figures 288 - 290. Vertical articulation allows for the individual modules to move up and down independently with the waves to minimise the total force applied to the combined dwelling, similar to how shock absorbers work in an automobiles suspension, allowing for a safe and comfortable dwelling even in a large swell, see Figures 291 - 292.



Figure 293: Dining with a View - Calm Environment

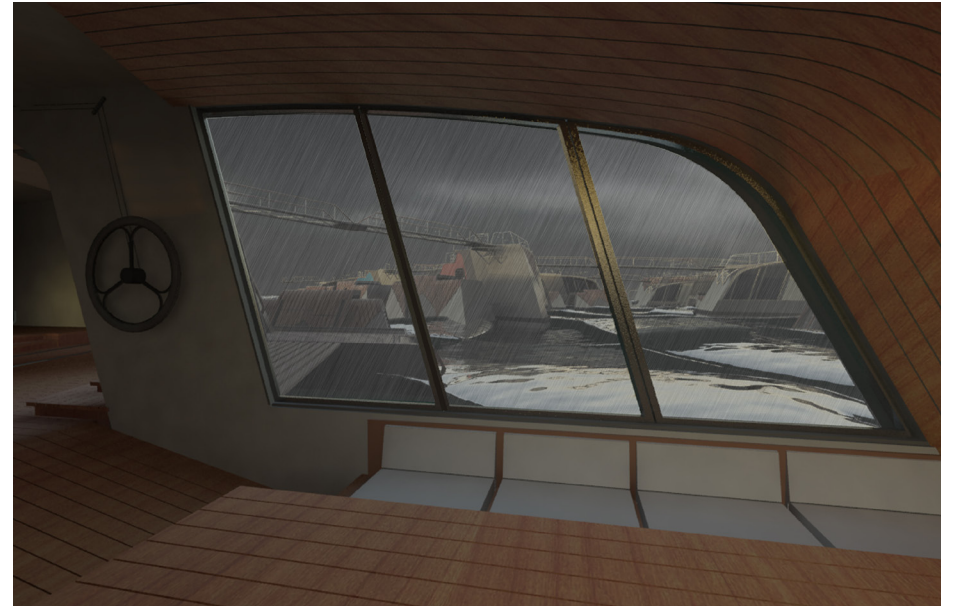


Figure 294: Dining with a View - Storm Environment





Figure 295: Dining with a View - Dusk Environment

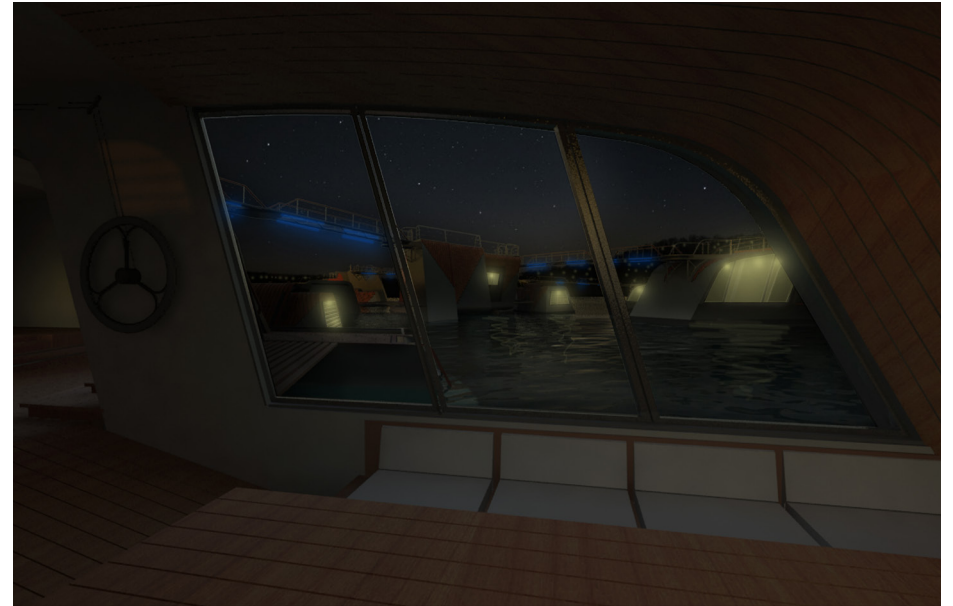
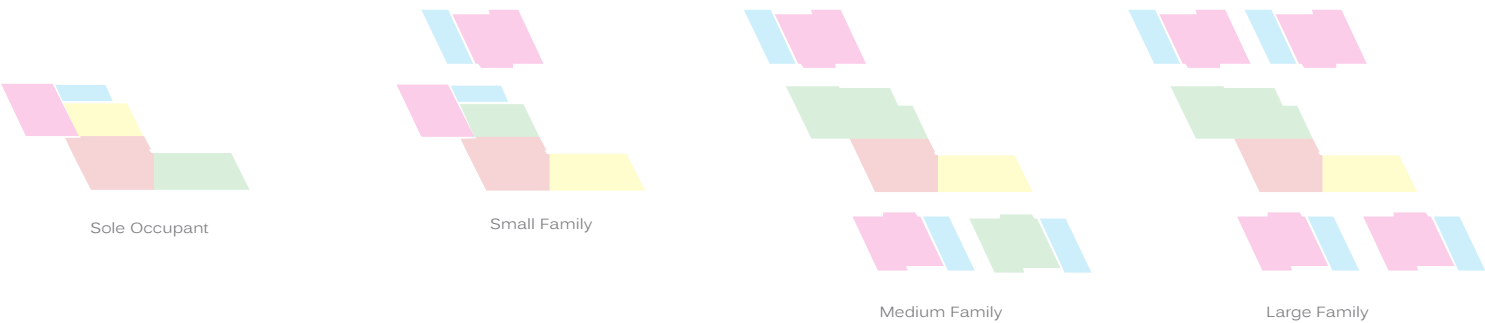


Figure 296: Dining with a View - Night Environment

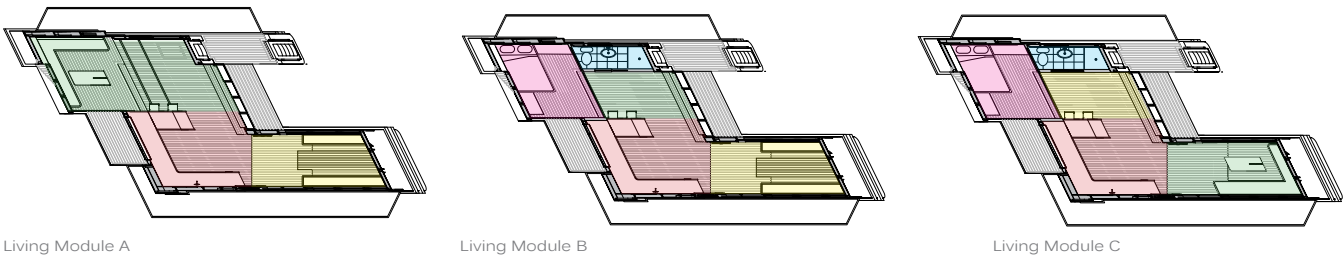
Unlike the urban environment, the littoral environment is frequently changing, and therefore once inundated, the resilient dwelling community will be in a constant state of flux. As a result these resilient dwellings will have very dynamic spatial relationships, with neighbours, view lines, sunlight angles and degree of exposure to the elements progressively changing as the environment in which they occupy alters. The above images illustrate from a single perspective how the spatial relationships may change between a dwelling and the community over the course of a single day in Wellington Harbour, see Figures 293 - 296.

5.3.15 USER CUSTOMIZATION

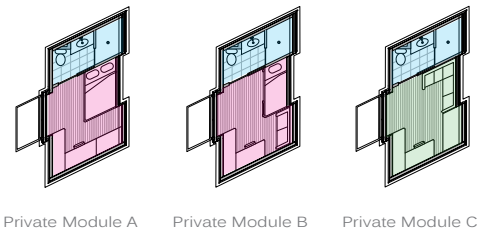
Possible Dwelling Arrangements



Living Module Configuration Options



Private Module Configuration Options



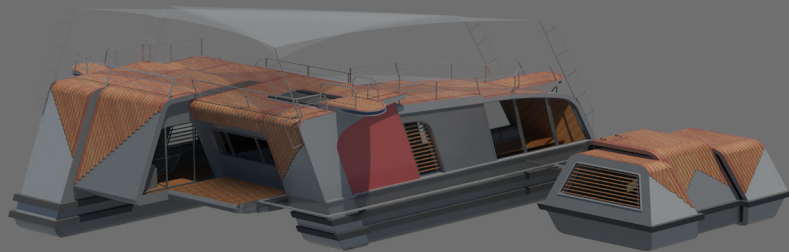
Key:

	Cooking		Eating		Relaxing		Sleeping		Cleaning
--	---------	--	--------	--	----------	--	----------	--	----------

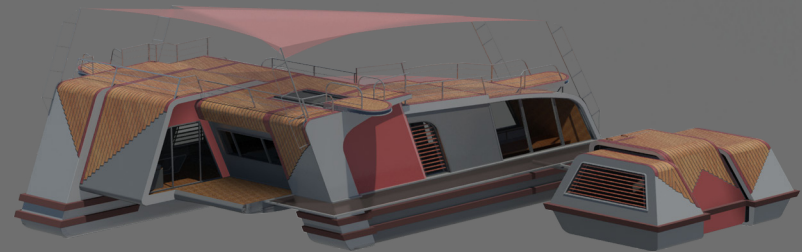
Figures 297, 298, 299:  
Possible Dwelling Arrangements  
Living Module Configuration Options  
Private Module Configuration Options

Figures 300: (Opposite)  
Multiple Colour Scheme Options

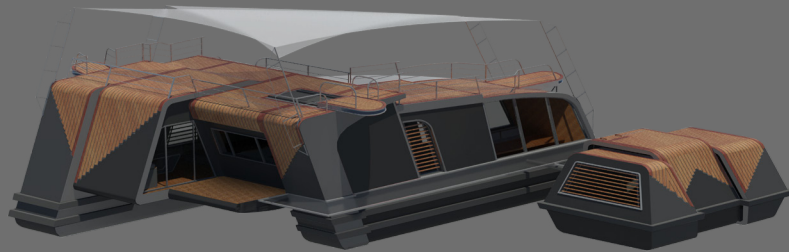
With the unprecedented rise of the iPhone and similar personal technologies, the desire to express our own unique identity to the world has placed mass customization at the forefront of the technological, fashion, automotive and architectural industry.<sup>74</sup> As a community, Kilbirnie is extremely diverse with cultures, incomes and household sizes varying dramatically across the suburb. Adaptability and user customization has therefore been placed as a key aim in the design of this resilient dwelling solution. When purchasing a resilient dwelling, a household will be able to select any number of modules with a variety of different component configurations to choose from to suit their own dwelling needs, see Figures 297 - 299. Cosmetic customization is also available, with a wide variety of different colour and material options, both externally and internally, to suit the tastes and budget of the residents and allow them to represent themselves in their new home, see Figure 300.



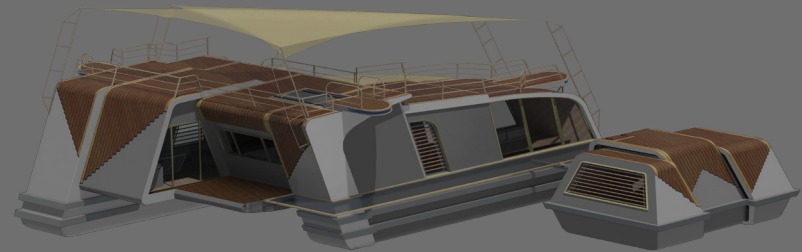
Single Feature Colour Dwelling Scheme



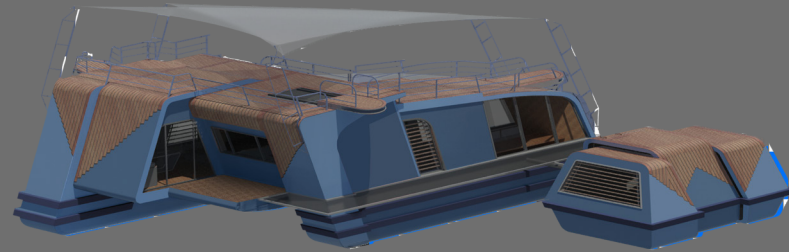
Multiple Feature Colour Dwelling Scheme



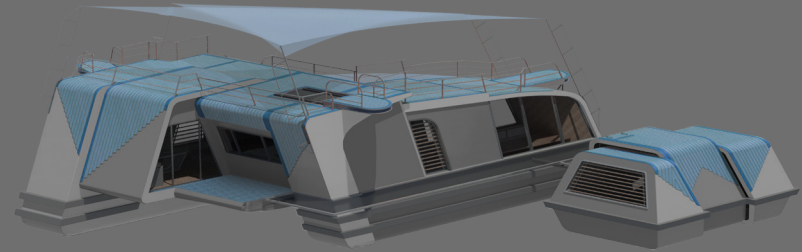
High Contrast Dwelling Scheme - Dark



High Contrast Dwelling Scheme - Light



Single Colour Dwelling Scheme - Module



Single Colour Dwelling Scheme - Decking & Canopy

### 5.3.16 DEVELOPING A BRAND



Figures 301, 302: Nautilus Mollusk on the Ocean Floor

When developing a brand for the resilient dwelling solution it seemed only appropriate to look to the marine environment for a brand name and logo inspiration. Nautilus, the greek term for sailor, is a pelagic marine mollusk originating from the Triassic era,<sup>75</sup> see Figures 301 and 302. Similar to my own design, the animal is able to stretch out to move faster through ocean currents or enclose completely into its shell to protect itself. This ability has allowed the mollusk to survive on the planet for millions of years despite enormous changes in the global climate, making Nautilus an ideal name for this dwelling solution.<sup>76</sup> A logo has been developed from the basic shape of a Nautilus into a circle divided into three sections, land, tide and sea representing the three areas in which the dwelling solution has been designed to occupy, see Figures 303 - 305.

#### Logo Development

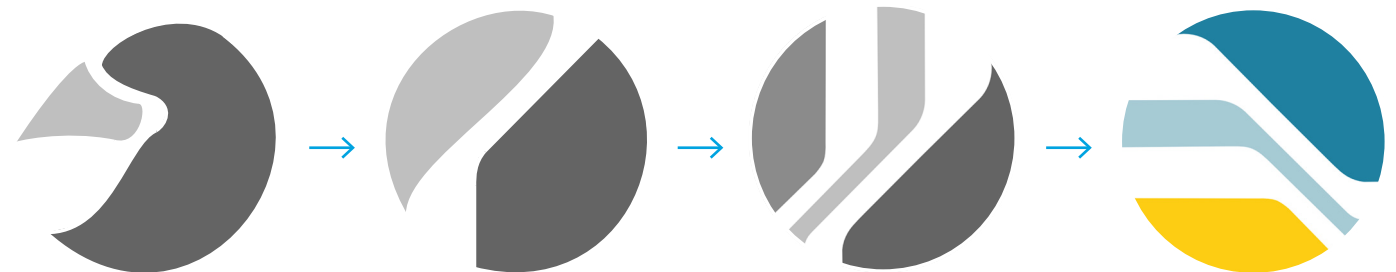


Figure 303: Key Stages in Logo Development



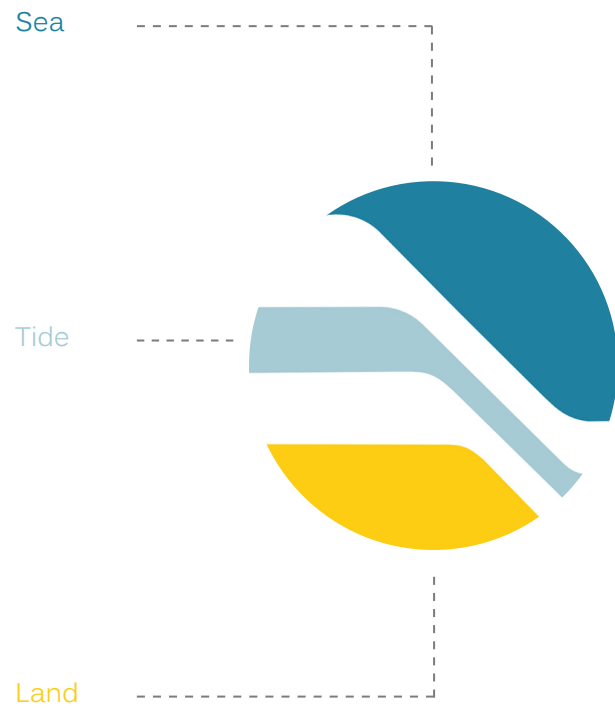


Figure 304: Break Down of Nautilus Logo

Figure 305: (Right)

Final Development of the Resilient Dwelling Brand Nautilus



### 5.3.17 DESIGN CRITIQUE

#### Final Design Review

After producing a successful resilient dwelling solution for sea level rise in the coastal city, my final design was formally critiqued by leading international scholars and academics as well as practicing architects experienced in waterfront and on water design.

#### Positives:

- A very attractive final design, the flexibility of the dwelling community to adapt to changing conditions through the use of marine technology and the fact that the solution can be implemented into the site now to prepare Kilbirnie residents for inundation will make the dwelling solution highly applicable to the design problem
- The design solution takes a positive spin on the global threat of sea level rise and actually makes the looming disaster seem rather manageable

#### Negatives:

- The dwelling solution could be slightly over designed, it is almost at an industrial design level rather than an architectural level. That time could have potentially been used elsewhere in the research project

#### Moving Forward:

- You have designed a resilient dwelling specifically for the residents of Kilbirnie. How could the design be altered to suit another site and or different climate conditions?
- Could a similar design process be utilized for other building types such as larger commercial buildings or recreational facilities?

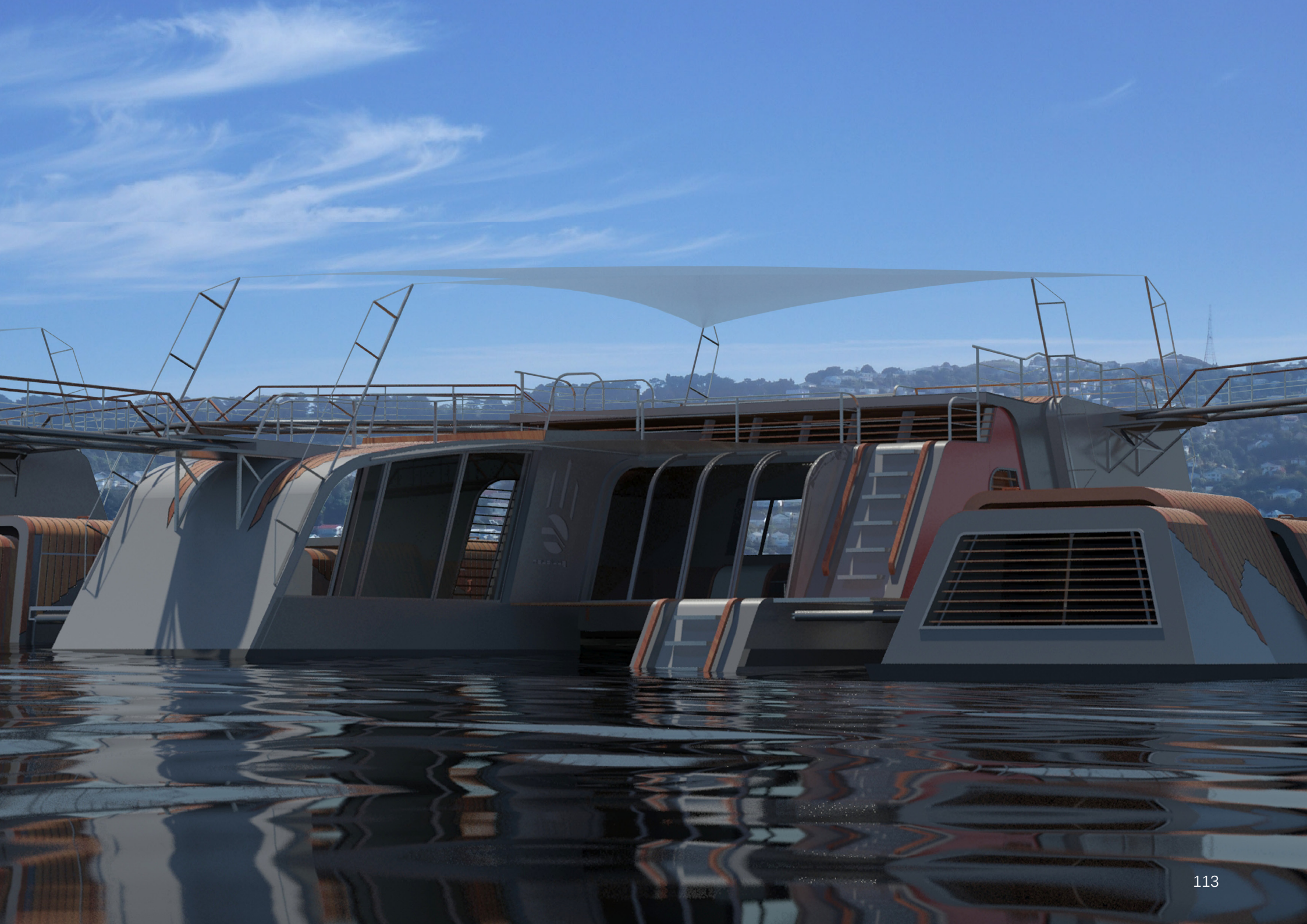
- 
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- 74 Joseph, B. "Mass Customization: The New Frontier in Business Competition." Harvard Business School Press, 2010. pg 5
- 75 Vayner, J. Chambered Nautilus. 2005. Retrieved from <http://www.seasky.org/deep-sea/chambered-nautilus.html>. par 1
- 76 Kemmett, G. Nautilus Pompilius. 2012. Retrieved from <http://marinebio.org/species.asp?id=168>. par 6

Figures 306: (Opposite)

Final Nautilus Dwelling Solution

Figure 307: (Following)

A Resilient Community Floating in Evans Bay













## 6. Conclusion and Discussion





Global sea levels are rising at an unprecedented rate, placing hundreds of millions of people at serious risk of inundation in coastal communities across the globe. In the case of New Zealand's capital city, Wellington, over ten percent of the city's residents are at risk of displacement by the end of this century. This thesis aimed to find a solution to resident displacement in the coastal city, addressing the question, *How can a resilient residential dwelling be designed for the coastal city, in response to the encroaching pressures of climate change driven sea level rise?*

This thesis proposes a connected network of amphibious dwelling solutions with the capacity to accommodate inundation. It is intended that these amphibious dwellings could be brought into the existing community over the coming decades to provide permanent and resilient accommodation for the residents of the coastal city of Kilbirnie. Hereby ensuring the social sustainability of the community, which is currently at serious risk of destruction, through providing the residents of Kilbirnie with the capacity to adapt and thrive in the face of sea inundation, caused as a result of climate change driven sea level rise.

Over the period of research, the design brief developed from the initial requirements contained in the literature and from those solutions proposed in case study examples, into a set of design aims to better suited to the conditions associated with living on and near the exposed ocean.

In the first phase of design development I attempted to resolve a dwelling solution for permanent ocean inhabitation, providing a floating dwelling similar to those discussed in the earlier case study analysis. This design phase had a clear failure in approach, for it is unlikely that Kilbirnie residents would want to live on the ocean purely because there was a risk their homes could be inundated in the next hundred years. Although there were a number of key design moves in the first design phase which provided the basic foundation for the final resilient dwelling solution, such as a deconstructed modular dwelling arrangement, a community which can respond to the changing environment and a shell like design aesthetic. It was instead established that a resilient dwelling which had the potential to float incrementally in accordance with tidal changes as well as gradual inundation would be a far more appropriate solution, given that sea level rise will be an incremental occurrence.

In order to increase the appeal of a resilient dwelling solution, and on water living in general, to citizens at risk of inundation, focus was heavily placed on ensuring that the amphibious dwelling had an attractive form and a unique design aesthetic which contained aspects inspired by the traditional Kilbirnie homes which it would eventually replace, some of these aspects include a strong juxtaposition in colour, an abstracted cornice and a timber exterior. Focus also was placed on making sure that the solution had a similar level of comfort and quality, as well as ensuring a similar dwelling size to that of a typical Kilbirnie home, in order to ease in the transition from the residents currently at risk home to that of a new amphibious dwelling solution.

Given the diverse nature of the Kilbirnie community, one of the biggest challenges in the designs development was producing a dwelling solution which could be easily adapted and customized to meet the needs of a wide variety of dwelling households. Two separate steps were undertaken to resolve this problem. The first was to



deconstruct the typical home into two separate modules, a larger module for cooking, dining and entertaining and a smaller, private module for sleeping and bathing. When a Kilbirnie household is at risk on inundation they could purchase the type and number of modules that they would need to dwell comfortably, rather than providing a one size fits all solution. The next step was to allow for user customization with multiple layout arrangements, colour options and material specifications provided for each prefabricated module to suit the tastes of each dwelling household. A similar approach could be used when adapting this resilient design to suit the community and climate needs of a different site. For example, if the site had a colder climate the same basic form could be used but the thickness of the dwelling modules wall could be increased, or if the dwellings were required in a sheltered deltaic environment dwellings could be constructed with multiple stories due to the fact that maintaining stability will not be as challenging as in an exposed ocean.

It is worth reiterating that most examples of sea level rise accommodating dwellings and floating architecture in general has been designed for sheltered ocean environments. A significant gap in the literature was discovered as sea-ready architecture, or architecture capable of surviving in the exposed littoral environment, appears to have been largely ignored, with the exception of major industrial and marine projects. Alarmingly 75% of coastal cities at risk of sea level rise border the exposed and unforgiving ocean.

Unlike most other floating architecture examples, this amphibious dwelling community has been specifically designed to occupy the untamed ocean. The resilient dwelling has therefore been designed to be as stable as possible, once inundated, in an environment which is constantly changing. Through undertaking a number of littoral environment simulations, reappropriating aspects of marine technology, employing the basic principles of stability, and deconstructing the dwelling to act like the shock absorbers in the car, the designed solution will remain stable and ensure user comfort and safety, even in rough seas. The dwelling has also been designed to articulate horizontally and move progressively with the changing ocean environment in order to minimise the force applied to the dwellings joints as well as provoke a strong relationship between the dwellings occupants, the ocean environment and the new dynamic community of Kilbirnie within which they will soon live.

This design research has resulted in the development of a resilient residential dwelling solution which answers the research question and successfully meets all of the design aims. There is a strong potential to take this research further. Future study areas could include; exploring how other building types could be made resilient; analysing if and how the lives of the occupants differ when on land and when on sea; or to explore how an amphibious dwelling solution could be marketed to those currently at risk of inundation as a result of climate change driven sea level rise.

*'In the end we cannot fight water, we have to learn how to live with it'*

Koen Olthius - Leading Practitioner in Amphibious Architecture

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Documentation provided by the Victoria University of Wellington in June 2013

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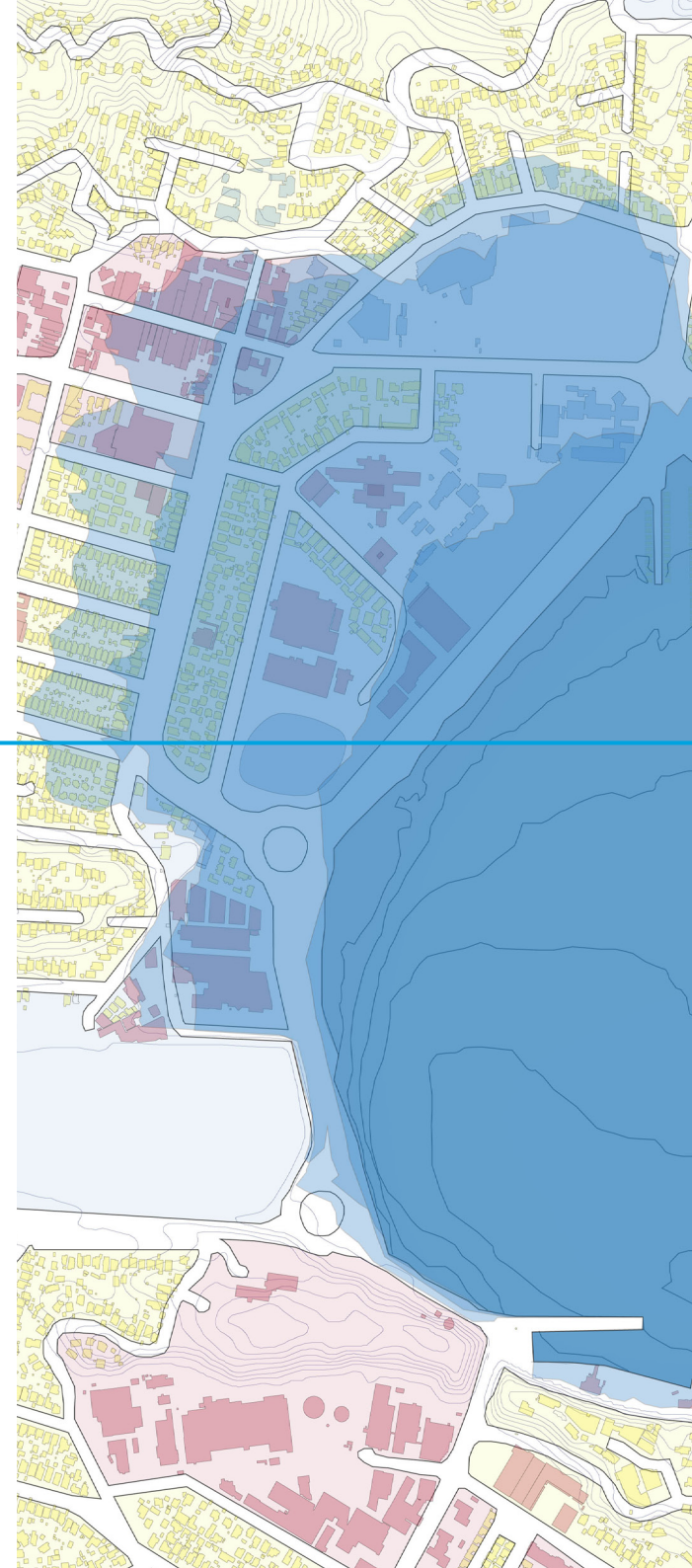
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## A. Appendix

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# A.1 Wellington Inundation Mapping Studies

## OCEAN FLOOR ANALYSIS



Figure A1.1: Kilbirnie Ocean Floor

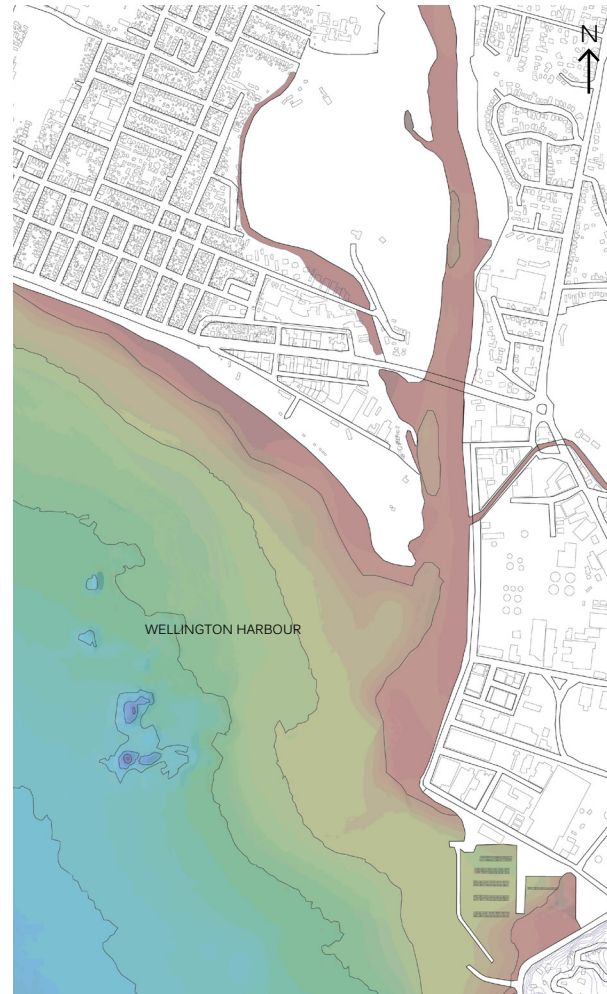


Figure A1.2: Petone Ocean Floor

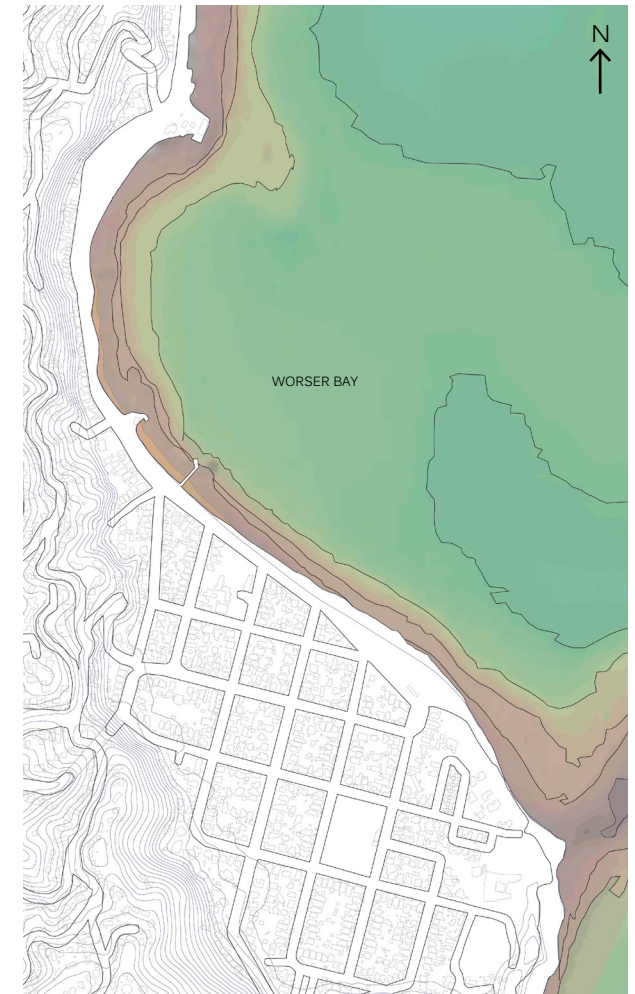


Figure A1.3: Seatoun Ocean Floor

Key:

	< 20m		10 - 15m		4 - 7m
	15 - 20m		7 - 10m		1 - 4m



BUILDING ZONE & VEHICULAR ROUTE ANALYSIS

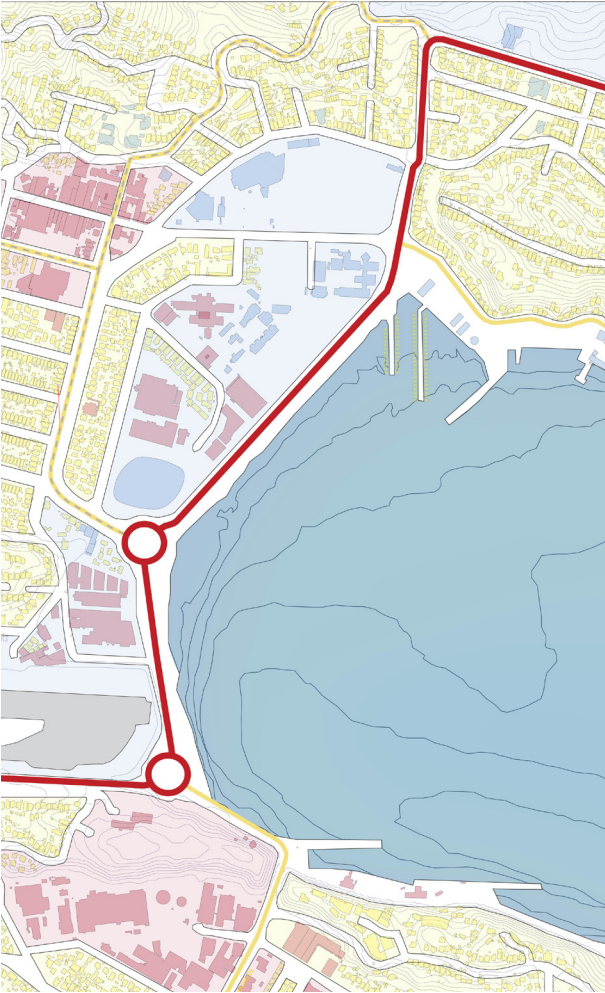


Figure A1.4: Kilbirnie Urban Environment

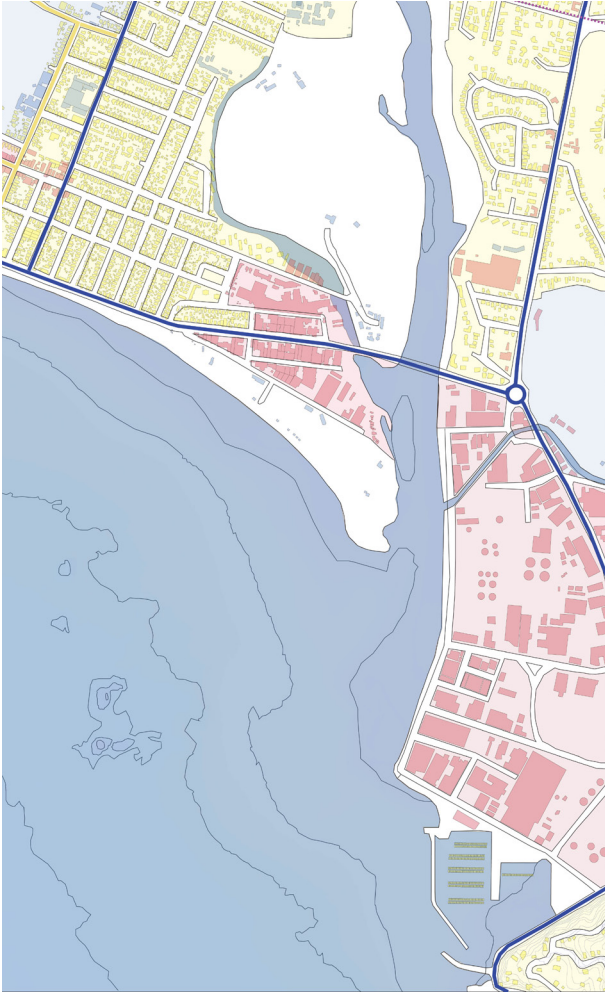


Figure A1.5: Petone Urban Environment

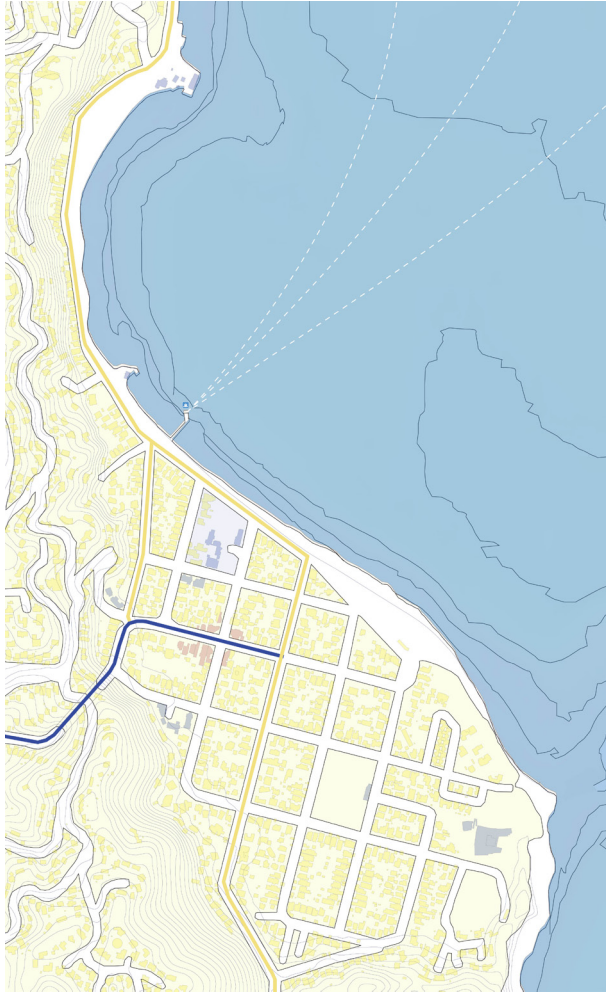


Figure A1.6: Seatoun Urban Environment

Key:

Residential	Institutional	Motorway	Secondary Road
Commercial	Wellington Airport	Main Road	Ferry



LITTORAL ENVIRONMENT - NORTHERLY



Figure A1.7: Kilbirnie Northerly



Figure A1.8: Petone Northerly

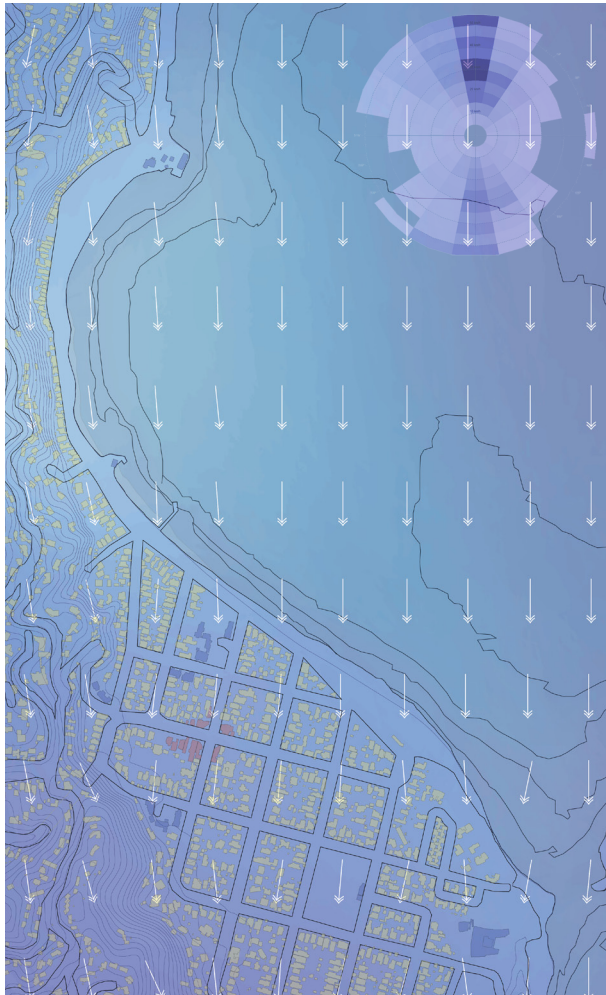


Figure A1.9: Seatoun Northerly

Key:

	Very Exposed		Partially Sheltered
	Exposed		Sheltered
	Strong		Direction of Wind
	Medium		



LITTORAL ENVIRONMENT - SOUTHERLY



Figure A1.10: Kilbirnie Southerly

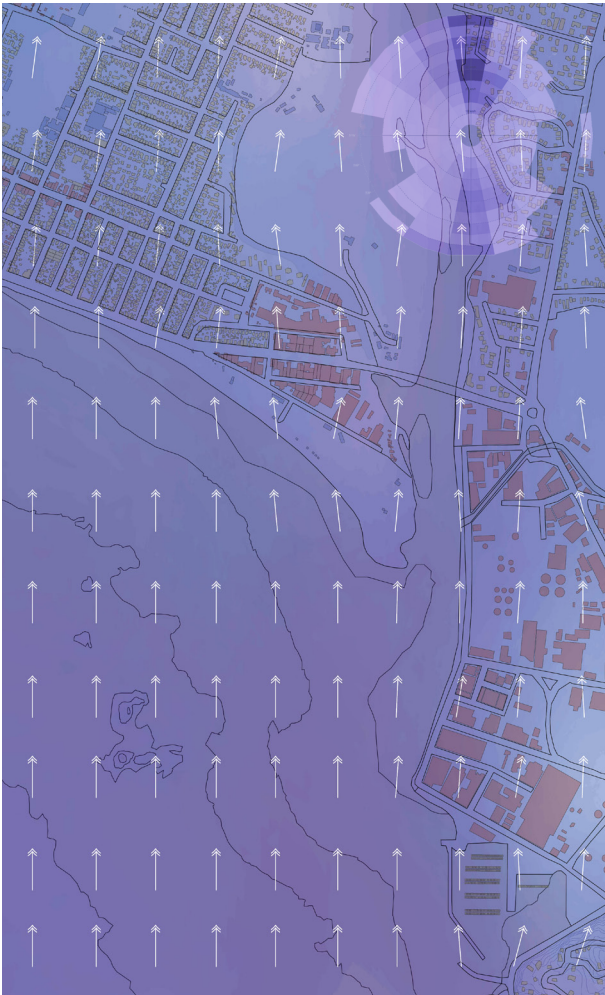


Figure A1.11: Petone Southerly

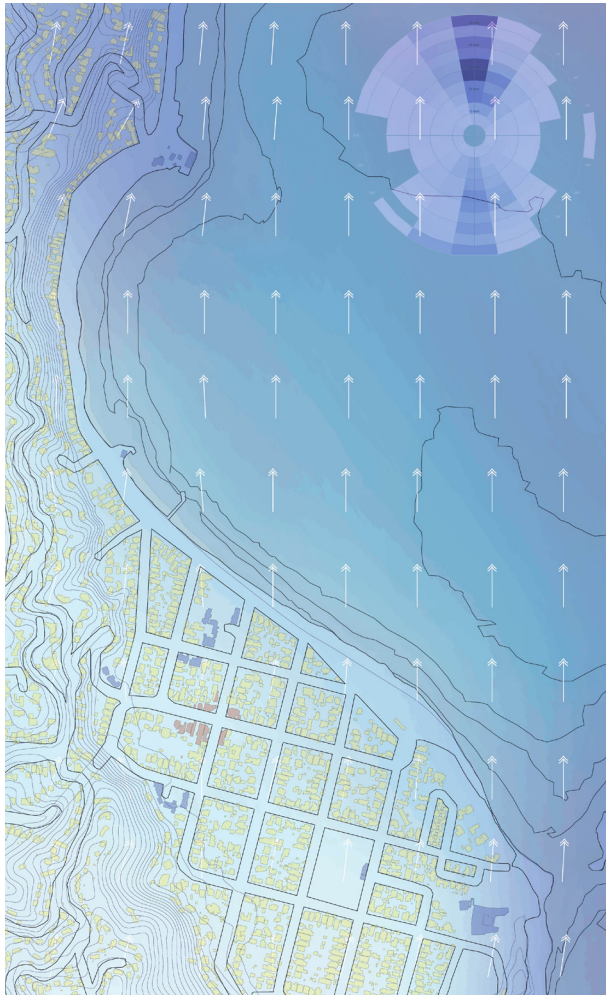


Figure A1.12: Seatoun Southerly

Key:

Very Exposed	Partially Sheltered
Exposed	Sheltered
Strong	Direction of Wind
Medium	



GEOLOGICAL ANALYSIS

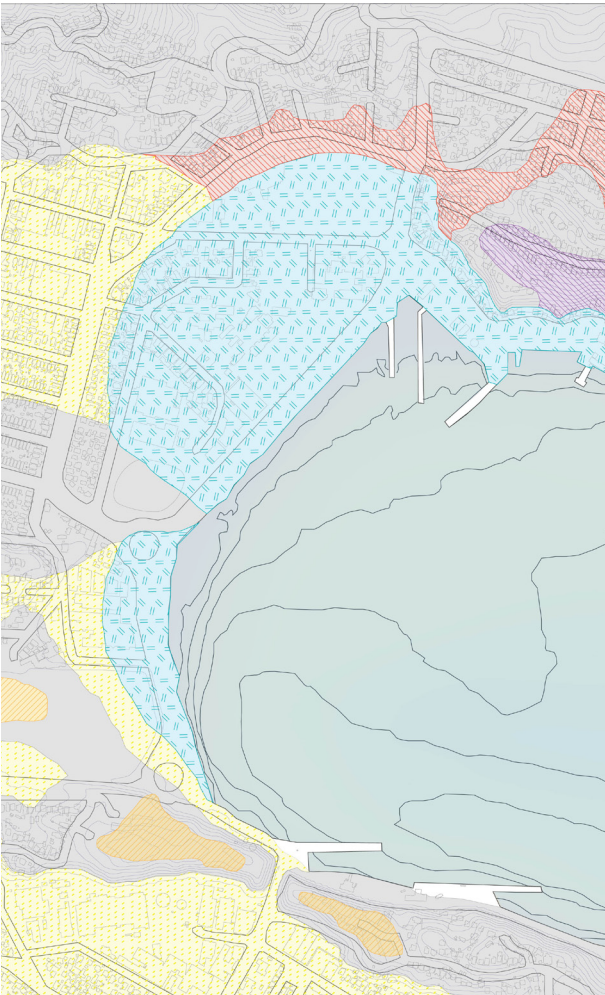


Figure A1.13: Kilbirnie Geology

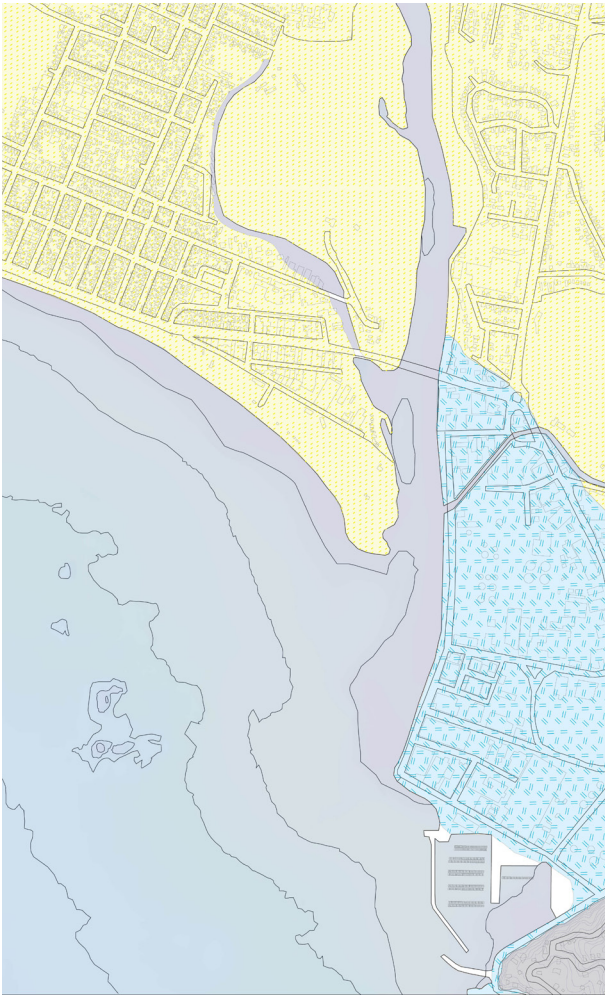


Figure A1.14: Petone Geology

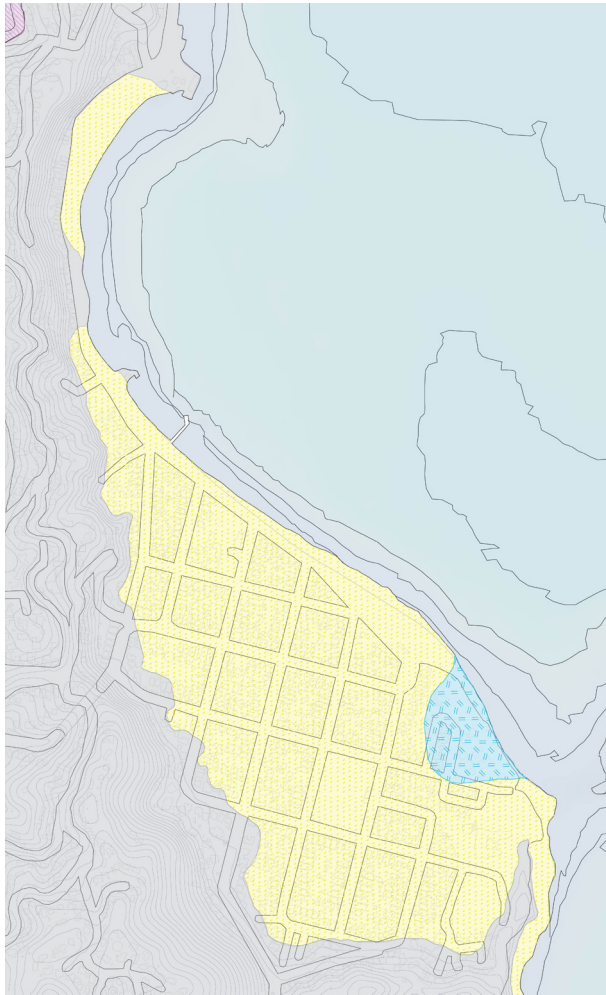


Figure A1.15: Seatoun Geology

- Key:
- |                           |                      |
|---------------------------|----------------------|
| Greywackie                | Sandstone            |
| Holocene Alluvium         | Reclamation Landfill |
| Pleistocene Sediments     |                      |
| Marginal Marine Sediments |                      |

LIQUEFACTION RISK

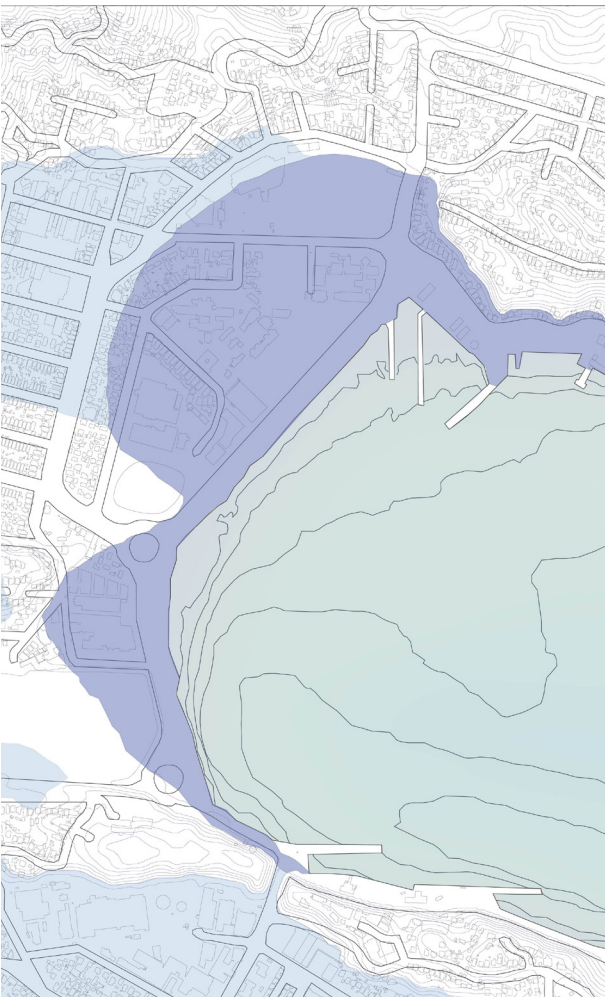


Figure A1.16: Kilbirnie Liquefaction



Figure A1.17: Petone Liquefaction Risk

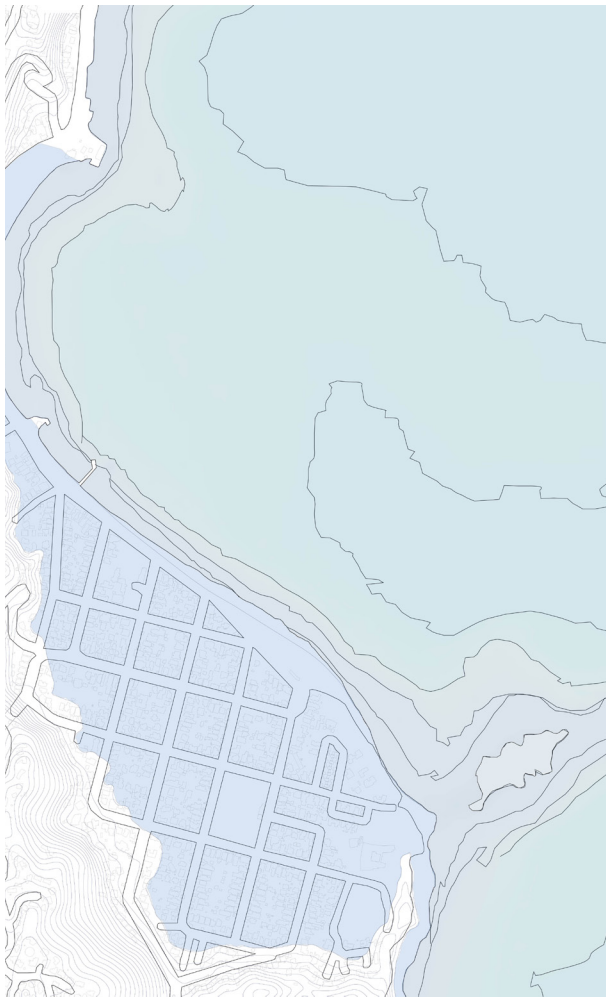


Figure A1.18: Seatoun Liquefaction

Key:

Dark Blue	High Risk
Light Blue	Medium Risk



KILBIRNIE SEA LEVEL RISE

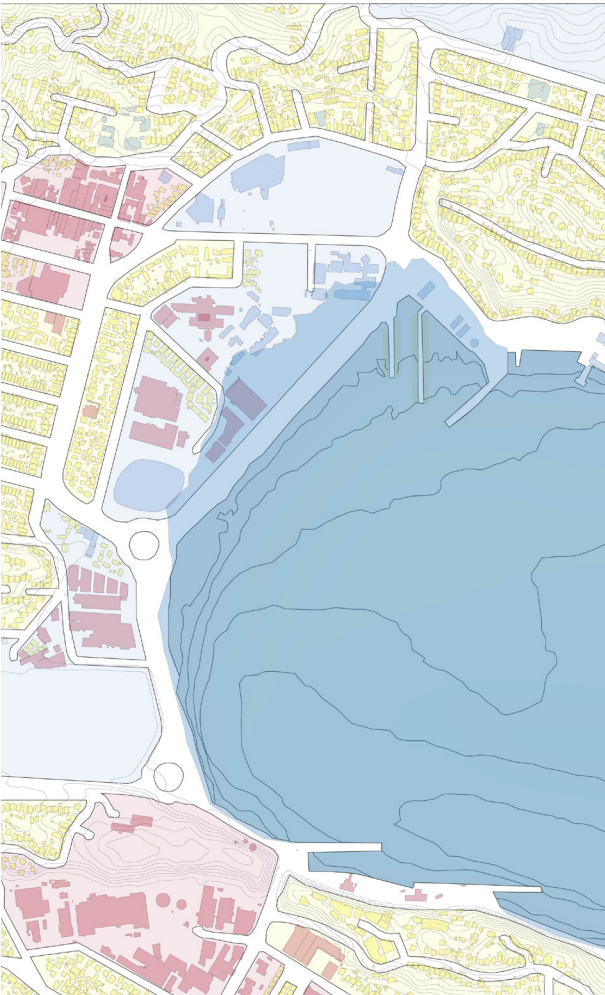


Figure A1.19: 0.75m Sea Level Rise

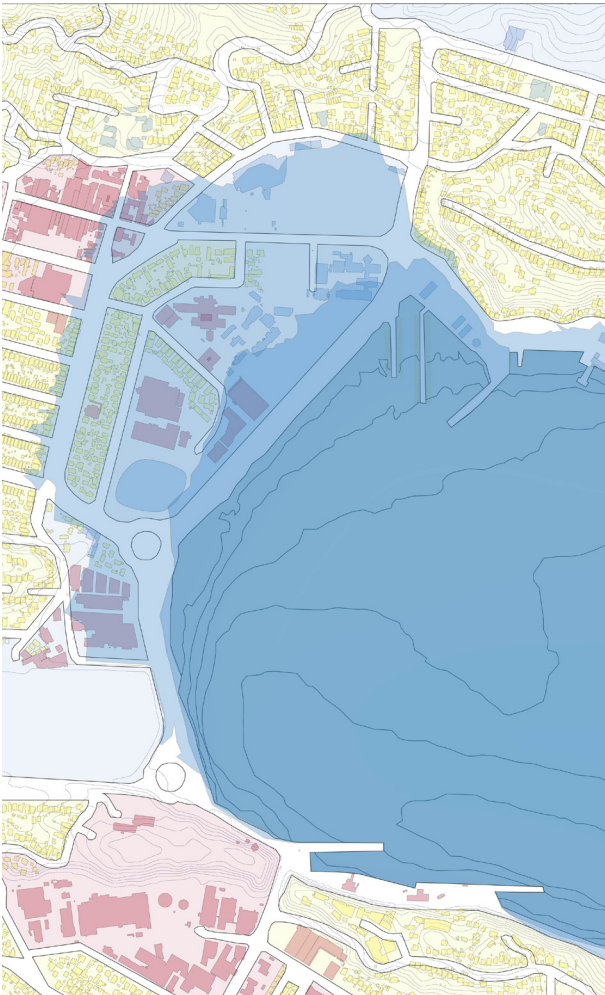


Figure A1.20: 1.2m Sea Level Rise

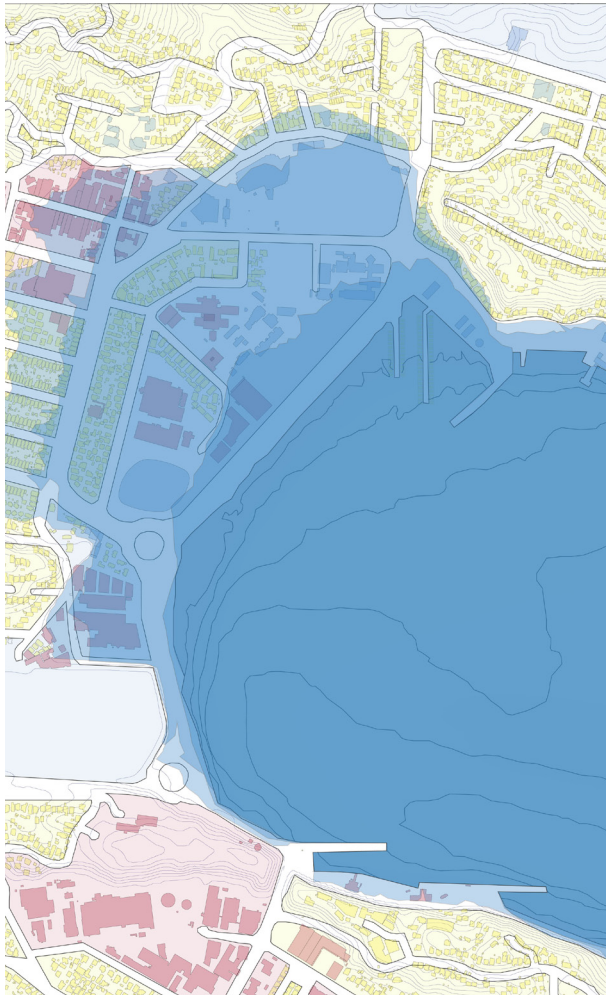


Figure A1.21: 2.0m Sea Level Rise

- Key:
- Residential
  - Commercial
  - Institutional
  - Sea Level



PETONE SEA LEVEL RISE

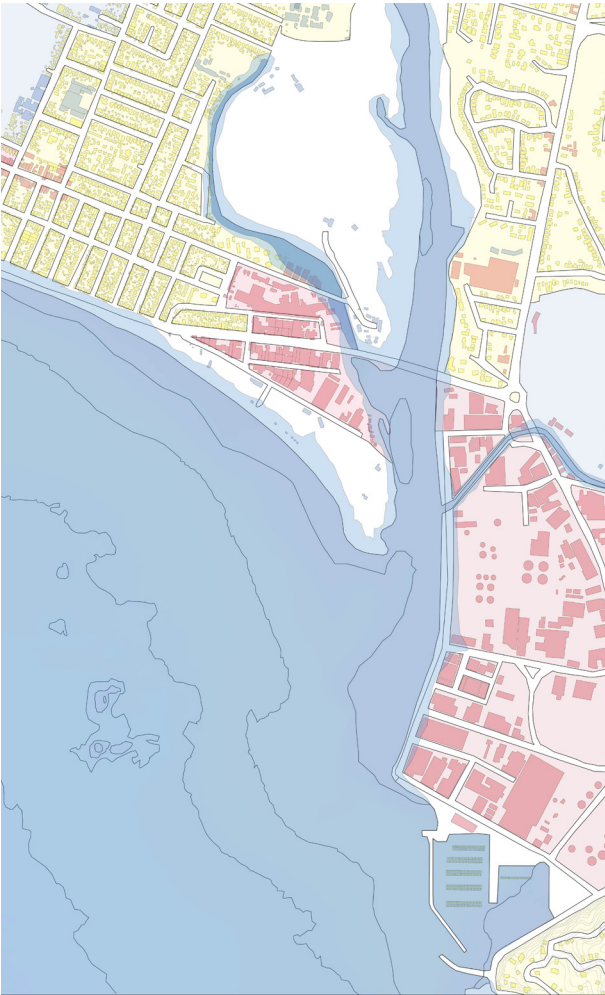


Figure A1.22: 0.75m Sea Level Rise

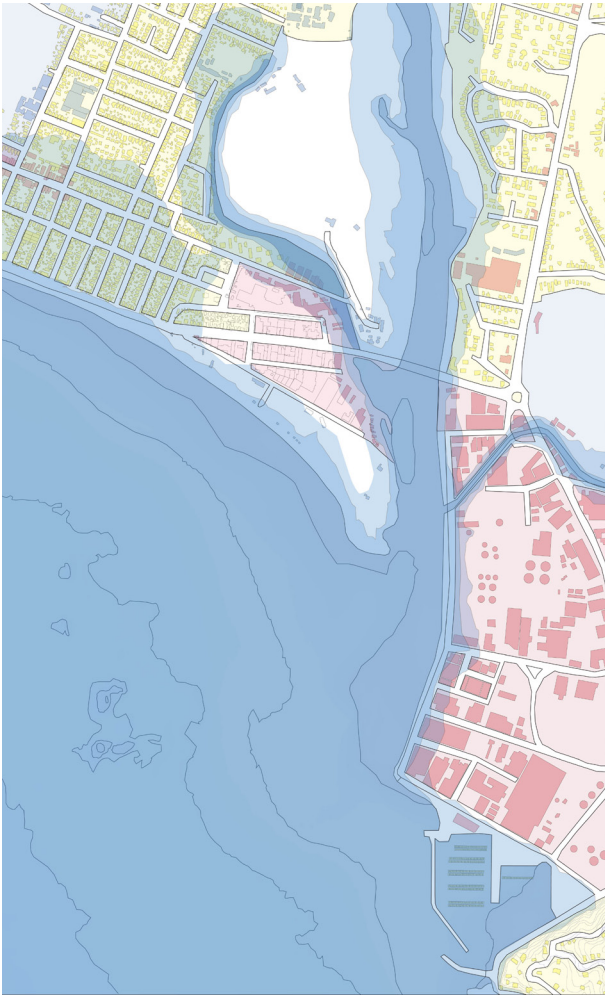


Figure A1.23: 1.2m Sea Level Rise

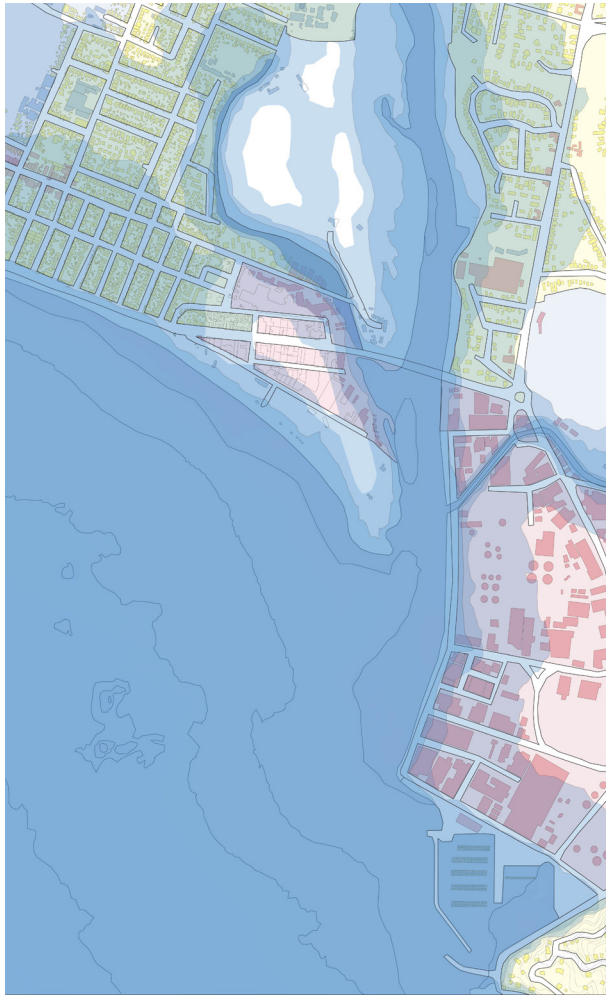


Figure A1.24: 2.0m Sea Level Rise

- Key:
- Residential
  - Commercial
  - Institutional
  - Sea Level

SEATOUN SEA LEVEL RISE



Figure A1.25: 0.75m Sea Level Rise



Figure A1.26: 1.2m Sea Level Rise

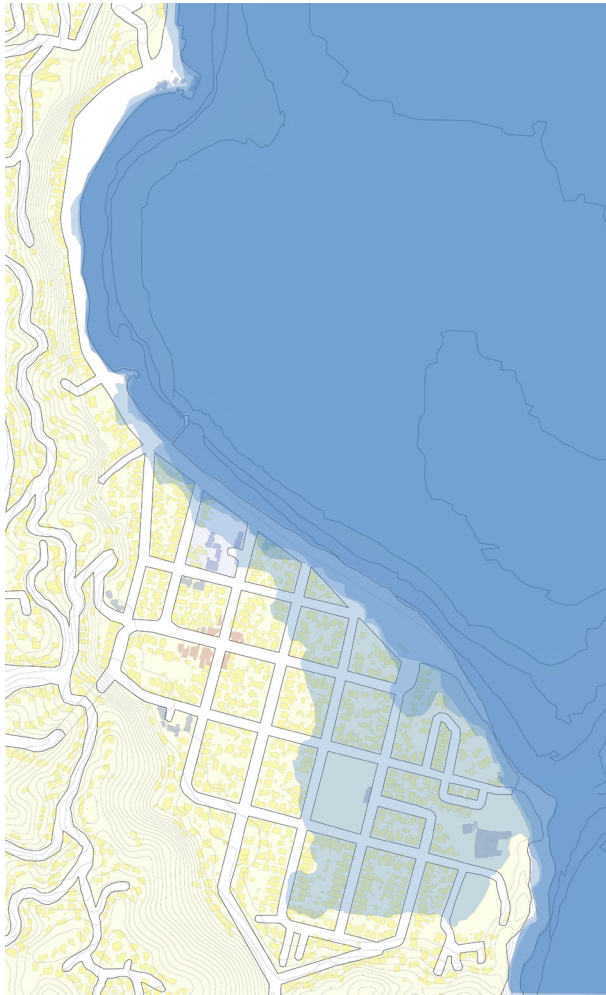


Figure A1.27: 2.0m Sea Level Rise

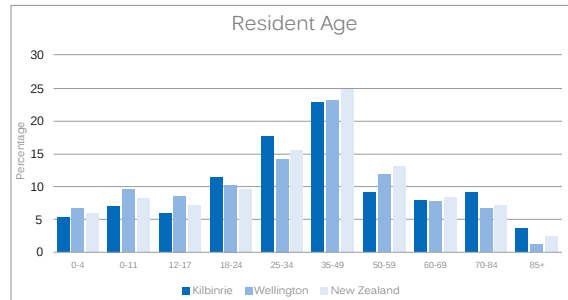
Key:

- Residential
- Commercial
- Institutional
- Sea Level

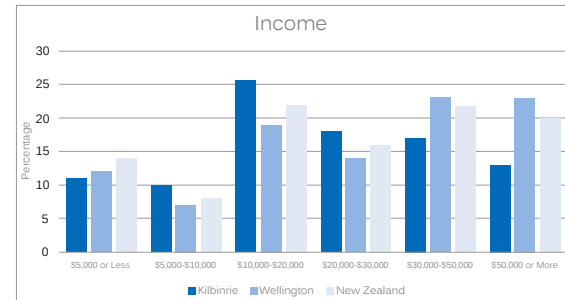


# A.2 Kilbirnie Community Statistics

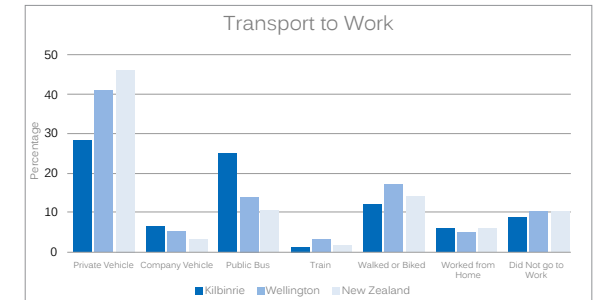
## KILBIRNIE COMMUNITY STATISTICS COMPARED WITH LOCAL & NATIONAL AVERAGES



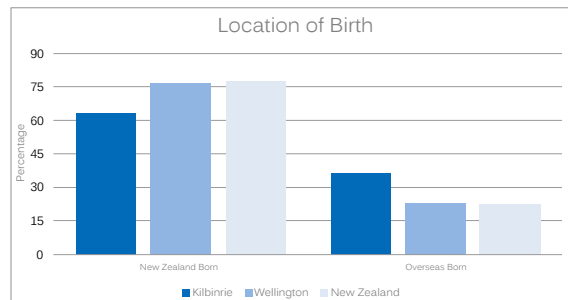
Graph A2.1: Resident Age



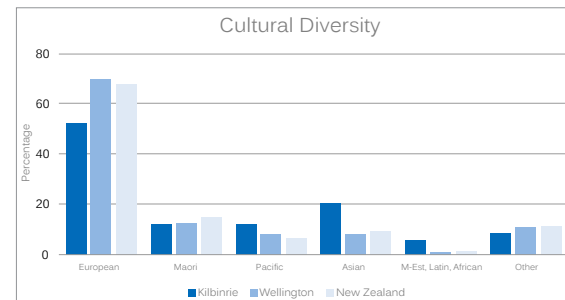
Graph A2.2: Income



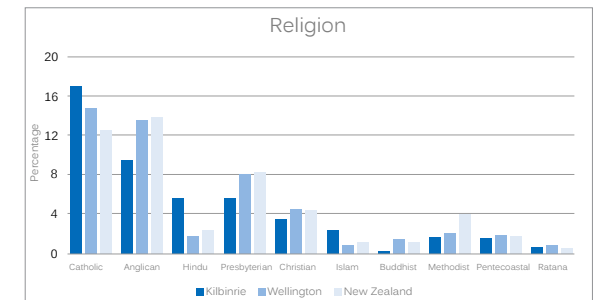
Graph A2.3: Transport to Work



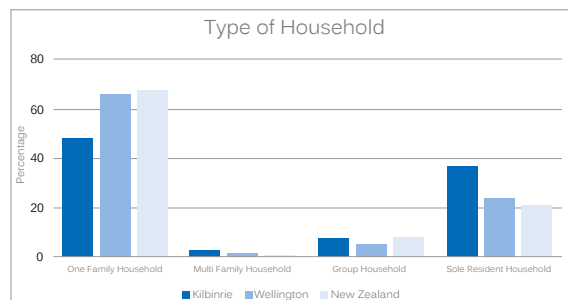
Graph A2.4: Location of Birth



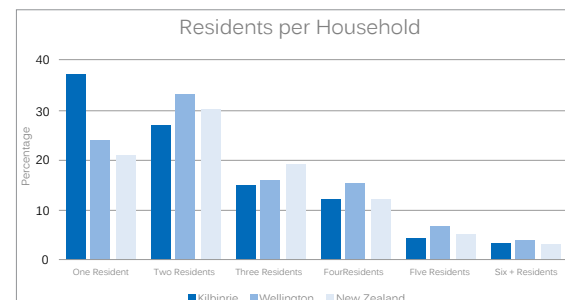
Graph A2.5: Cultural Diversity



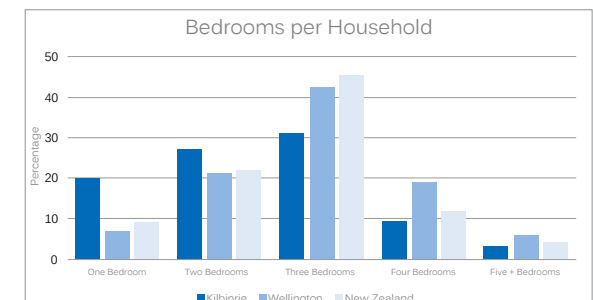
Graph A2.6: Religion



Graph A2.7: Type of Household

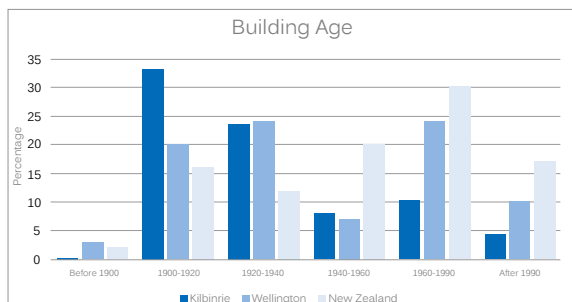


Graph A2.8: Residents per Household

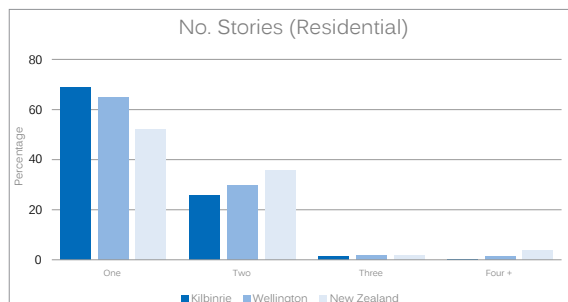


Graph A2.9: Bedrooms per Household

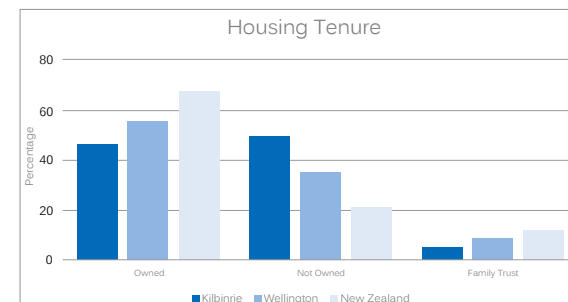




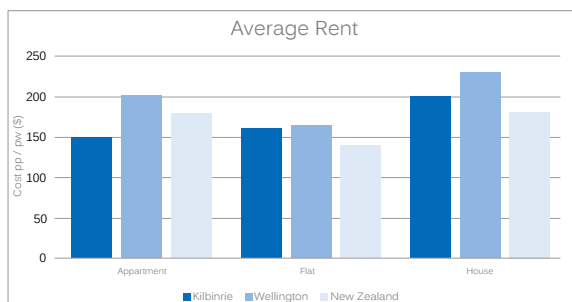
Graph A2.10: Building Age



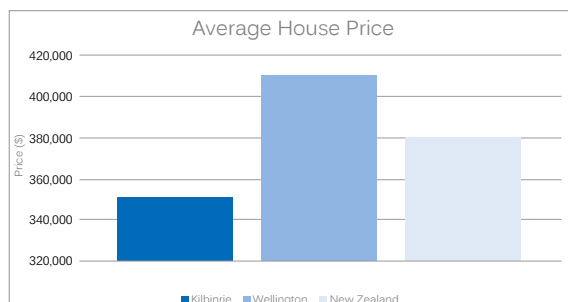
Graph A2.11: No. Stories



Graph A2.12: Housing Tenure

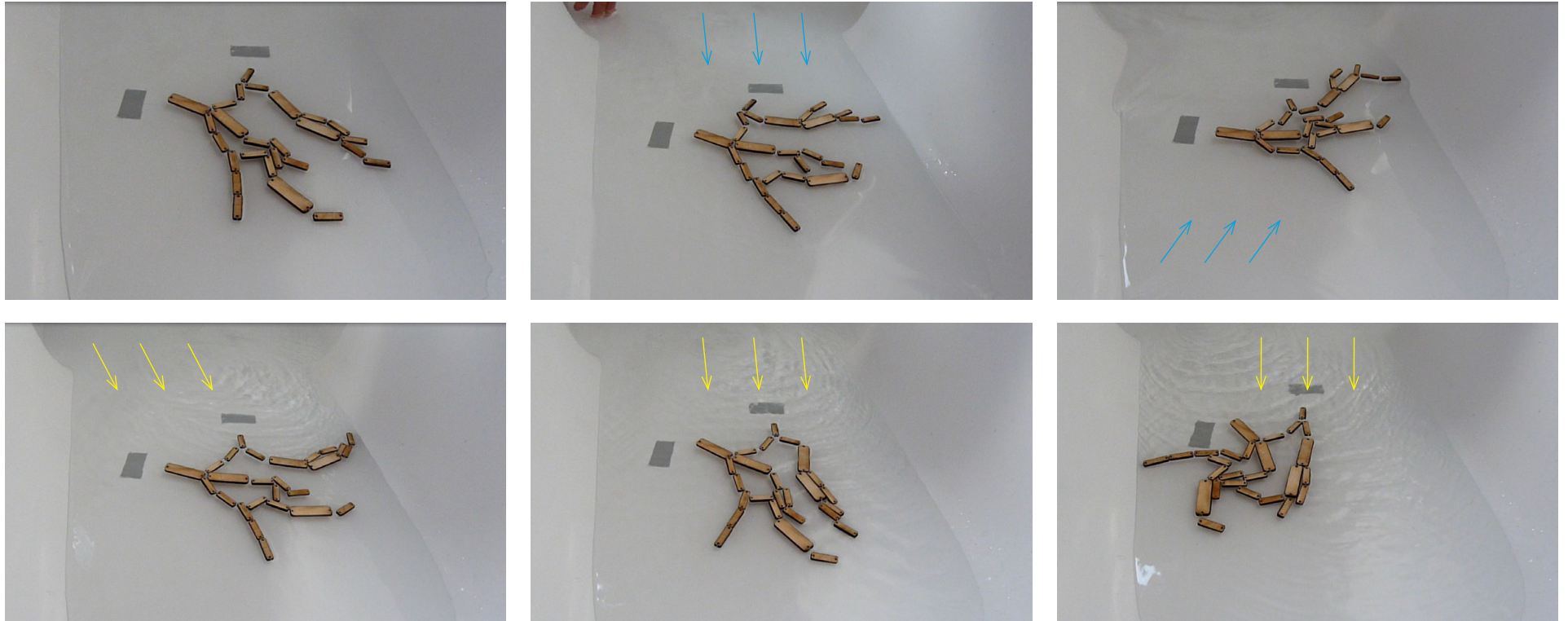


Graph A2.13: Average Rent



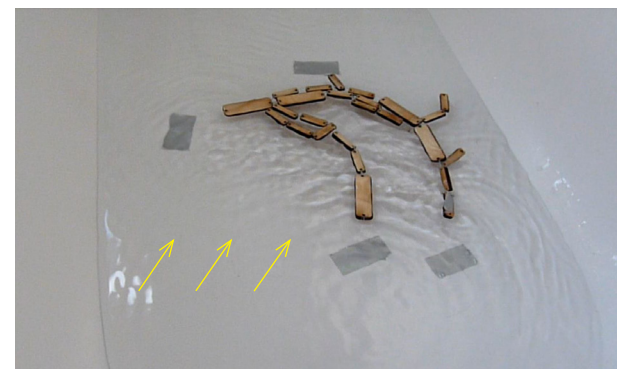
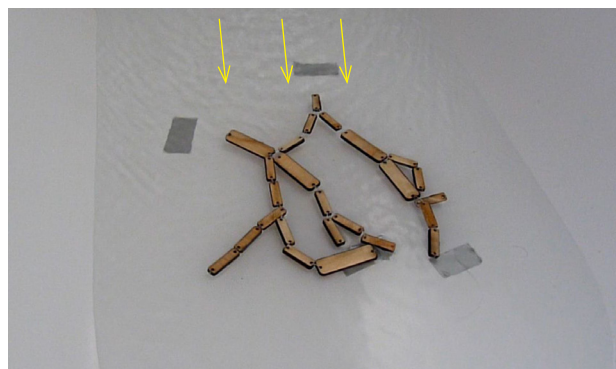
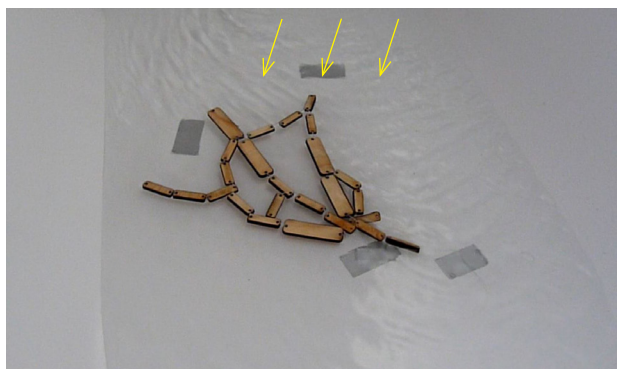
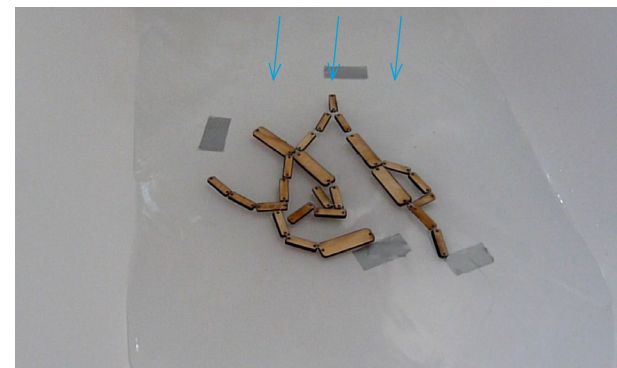
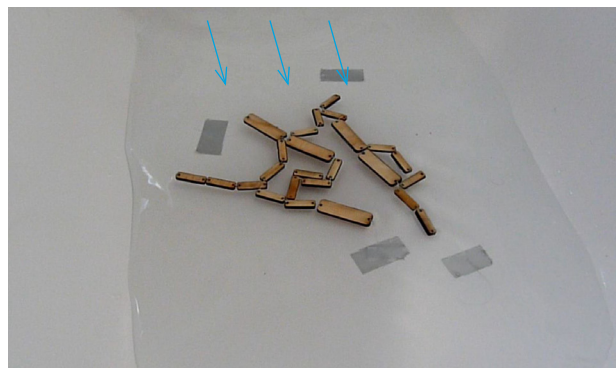
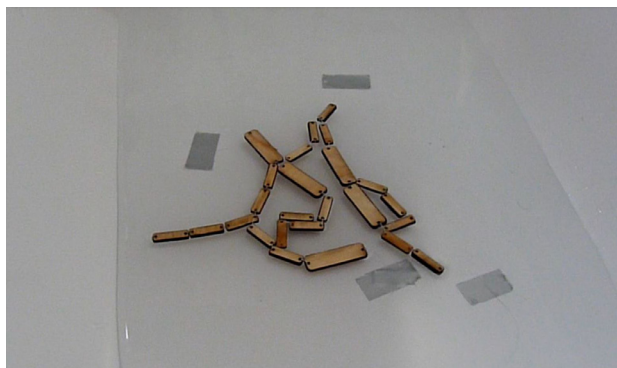
Graph A2.14: Average House Price

## A.3 Floating Community Simulations



Figures A3.1 - 6: Two Anchor Point Floating Community Simulation

Key:  
→ Wave Direction  
→ Wind Direction



Figures A3.7 - 13: Four Anchor Point Floating Community Simulation

## A.4 Ethical Approval For Marine Experts Interviews

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI



### MEMORANDUM

Phone 0-4-463 5676  
Fax 0-4-463 5209  
Email Allison.kirkman@vuw.ac.nz

TO	Michael Hatch
COPY TO	Jacqueline McIntosh
FROM	Dr Allison Kirkman, Convener, Human Ethics Committee
DATE	29th July 2013
PAGES	1
SUBJECT	<b>Ethics Approval: 20181</b> Resilience in the Face of Sea Level Rise

Thank you for your application for ethical approval, which has now been considered by the Standing Committee of the Human Ethics Committee.

Your application has been approved from the above date and this approval continues until 18 February 2014. If your data collection is not completed by this date you should apply to the Human Ethics Committee for an extension to this approval.

Best wishes with the research.

Allison Kirkman  
Human Ethics Committee

A handwritten signature in blue ink, appearing to read 'Allison Kirkman'.

Figure A4.1: Ethical Approval for Marine Expert Interviews