Rising Sea Level: An Amphibious Community for the Dartmouth Cove

by

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Submitted in partial fulfilment of the requirements for the degree of Master of Architecture

at

Dalhousie University
Halifax, Nova Scotia
March 2012

DALHOUSIE UNIVERSITY

SCHOOL OF ARCHITECTURE

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled “Rising Sea Level: An Amphibious Community for the Dartmouth Cove” by Justin Cormier in partial fulfilment of the requirements for the degree of Master of Architecture.

Dated: March 19, 2012

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DALHOUSIE UNIVERSITY

Date: March 19, 2012

AUTHOR: Justin Cormier

TITLE: Rising Sea Level: An Amphibious Community for the Dartmouth Cove

DEPARTMENT OR SCHOOL: School of Architecture

DEGREE: MArch CONVOCATION: May YEAR: 2012

Signature of Author

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ABSTRACT

To respond to the global issue of sea level rise, this thesis examines architectural adaptation strategies by focusing on a low-lying coastal community in Dartmouth Cove in Halifax, Canada. Without a comprehensive adaptation strategy, these residents, along with 75% of the properties surrounding the harbour, will be forced to abandon their homes, resulting in a massive retreat from the coast. This project explores ways to build that can accommodate the future rise in sea level and population growth but are sensitive to the natural environment. It includes designs for urban organizations and amphibious housing blocks. The findings presented in this thesis suggest that amphibious architecture could become a viable solution for coastal environments in urban areas.

ACKNOWLEDGEMENTS

Thank you to my thesis committee, Steve Parcell and Brian Lilley.

I would also like to thank my grandpa for inspiring me to pursue this thesis; without him, this project could not have been possible. Thank you to Katie for her untiring support, my sister Jaymi and of course, my Mom and Dad for all of your enduring patience and generosity.

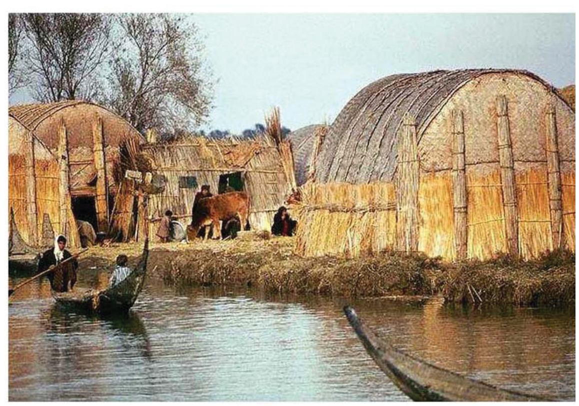
CHAPTER 1: INTRODUCTION

The delicate balance that governs the future of our planet has been disrupted. A substantial increase in carbon emissions from irresponsible human activity is deemed the catalyst for this environmental calamity. As a result, today we find ourselves in the midst of yet another transition era: a changing climate. Although our oceans have been consistently rising for nearly a hundred years, the pressures exerted by global warming are predicted to accelerate annual rates by as much as five times during the next century (Roaf and Crichton 2009, 80). These unprecedented changes are resulting from a combination of thermal expansion and the melting of polar ice caps and glaciers (Watson and Adams 2011, 44-50). In addition, projections indicate sea levels will continue to rise beyond the year 2100 as a result of delayed climate response, regardless of any attempt to stabilize global greenhouse emissions. Tom Agnew, a research meteorologist with the Meteorology Service of Canada, stated: “This change is already taking effect; the whole system is very slow to start and also very slow to stop” (Zevenbergen 2011, 33). Our current circumstances therefore suggest that we should not only consider using environmentally friendly alternatives for the sake of our atmosphere, but we should prepare to plan for the future consequences of our rising seas.

With 50 per cent of the world’s population living in urban metropolises and as much as 80 percent of the largest cities situated near water, rising sea level challenges the future growth of the majority of our built environment (Olthius and Keuning 2010, 24). Sea level rise has the potential to exacerbate flooding in coastal areas, resulting in the possible mass abandonment of buildings, communities, and cities worldwide. In addition to the effects on our cities, the IPPC’s Third Assessment Report outlines the current and future impacts of sea level rise on our natural environment as “increased coastal erosion, higher storm-surge flooding, inhibition of primary production processes, more extensive coastal inundation, changes in surface water quality and groundwater characteristics, increased loss of property and coastal habitats, increased flood risk and potential loss of life, loss of nonmonetary cultural resources and values, impacts on agriculture through decline in soil and water quality, and loss of tourism, recreation, and transportation functions” (Zevenbergen 2011, 96). Although climate change presents several new challenges with the sea, many of the above symptoms are recurring themes from our past.

Throughout history, city developers have overcome the challenges presented by the sea in a variety of ways. The Dutch have long been the leaders of this field, ultimately reclaiming half of their country from the sea, exemplifying the saying: “God created the Earth, but the Dutch created the Netherlands” (Royal Netherlands Embassy 2009, 6). Originally for agricultural purposes, the Dutch drained many of their lakes – a process known as poldering - and reclaimed a significant portion of land through sophisticated dike and windmill technology (Hoeksema 2006, 55-60). As their reach extended and was enabled by technological progress, they were forced to develop engineered floodgates and robotically controlled megastructures to prevent the country from drowning. The Venetians were also accustomed to negotiating with the sea after situating their entire city on wood driven piles in a marshy lagoon (Keahey 2002, 76). A combination of the city’s weight, a rotting foundation and the depletion of underground aquifers has now resulted in an irreversibly sinking city (Keahey 2002, 77). A more common strategy used by less privileged countries such as Thailand, Cambodia and Vietnam has been floating and stilted villages of woven reed mats and bamboo elements (Nordenson 2010, 20). These floating communities are able to rise and fall with the fluctuating water levels, whereas stilted villages (similar to Venice) rely on a fixed distance above the water to keep their foundations dry. In addition to these international examples, a local response to the sea has been developed here in Nova Scotia through the Acadian *aboiteau*. The *aboiteau* was a dike system influenced by early Europeans used to reclaim land for agricultural purposes (Bleakney 2004, 30-34). The use of the *aboiteau* decreased after the deportation of the Acadians in 1755; however, the legacy of this sophisticated technology remains at various locations throughout the province today (Bleakney 2004, 30-34).

Historic construction of the Acadian *aboiteau* (Bleakney 2004)



Floating reed mat villages in Iraq (Olthius and Keuning 2010)

As contemporary cities now face flooding on a global scale, various responses are being developed: from purely ecological solutions and building-by-building designs to engineered and infrastructural approaches. Although many of these modern reactions suggest advanced technologies and new ideas, they remain deeply rooted in historical precedent. As sea level rises and urban populations expand, architects from around the world face an important challenge: is it possible to avoid the mass migration and desertion of our coastal environments?

Passive Tactics

Many countries are beginning to shift towards a more passive technology or natural approach to sea level rise. A number of current proposals for the United States, India and even the Netherlands are suggesting the use of green infrastructure – the recovery and encouragement of coastal ecologies such as salt marshes, mangroves, and dunes - as the most efficient means for adapting to a fluctuating coastal environment (Nordenson 2010, 51). The underlying strategy of green infrastructure is to soften the hard edge between the land and sea and to create a porous boundary which is able to absorb the excess waters of climate change (Mathur and Cunha 2009, 30-40). It thus suggests using nature to combat nature. The challenge of this approach is to develop an efficient method to incorporate these types of ecologies into an urban context. If successful, green infrastructure would provide a way to gently merge cities with the water and transform a previously hard boundary into a continuum or smooth transition (Mathur and Cunha 2009, 30-40). It proposes to abandon the compulsive control of water and instead to generate flexible living environments that accept climatic influences, tides and seasons, while taking full advantage of the relationship between land and sea (Berman 2010, 66-73). This creates an edge which is resilient to, rather than fortified against, the sea. Although few cities have fully embraced this approach, the waterfront in Charleston, South Carolina illustrates a passive response. A broad buffer of wetlands lines the edge of the city, along with flexibly programmed buildings to accommodate periods of inundation on the ground floor. This creates a certain amount of elasticity, allowing floodwaters to inundate and recede from the city without causing considerable disturbance (Helmer 1996, 30).

Soft infrastructure approach along the Charleston waterfront in South Carolina (Fisher 2004)

New York's Rising Currents proposal for sea level rise (Nordenson 2010)

In addition to flood mitigation, these natural ecologies are capable of performing a number of beneficial functions, including buffering storm surges, filtering polluted run-off, providing public places for leisure and recreation, contributing to habitat generation, remediating polluted lands, slowing of water infiltration and reducing the heat island effect (Nordenson 2010, 88). Green infrastructure is therefore a sustainable approach which does not require constant maintenance and costly expenditures. Instead, these coastal ecologies are capable of growing with the sea, as described by the World Wildlife Fund of the Netherlands: "Our estuaries, dunes, marshes, lagoons and peat bogs have a natural capacity to grow in response to rising sea levels. At the moment they lack the space to do so, but there are many places where this can be remedied. Large natural areas which can grow with the sea are ultimately our best means of protection against flooding" (Helmer 1996, 35). Although the strengths of this strategy are notable, the weaknesses cannot be ignored. Unfortunately, a purely ecological approach does not satisfy or provide a complete remedy for the built environment. It would serve as an efficient buffer between our cities and the sea and provide many benefits to the surrounding environment, but it focuses on a resilient landscape, not a waterproof city. Also of concern is how to successfully integrate these initially delicate environments into an urban context. What type of plant species can tolerate a contaminated environment with harsh seasonal variation and human disturbance? How will these ecologies alter water transportation and access to the urban waterfront? As a result of the limitations associated with the use of green infrastructure, it is unlikely that this strategy alone will provide a complete remedy for coastal cities vulnerable to rising sea level.

Building-by-Building Initiatives

Rather than attempting to solve the issue of sea level rise at the scale of the city, many architects are focusing on a building-by-building response. Three recurring types have been established: floating structures, stilted structures and, more recently, amphibious buildings. The only essential difference between these water related designs and regular land based dwellings lies in the construction of their foundations.

Floating buildings are situated solely in water. Their foundations most often consist of expanded polystyrene encased in a concrete shell (Fenuta 2010, 66). This concept was adapted from the historical use of reed mats and bamboo elements. With the proper ratio of buoyancy volume to the overall weight of the structure, the foundation is submerged while the upper portion of the building floats above the surface. With sea level rise, floating buildings are able to rise and fall with fluctuating water levels. Thus, floating designs offer many benefits to our current predicament by allowing cities to grow beyond the waterfront. As cities grow and sea level continues to rise, living on water is a useful option (considering the scarcity of land for development). In this instance, sea level rise is seen as an opportunity where water could serve as a new urban ground for building. This permits "scarless" development and the mitigation of urban sprawl onto previously undeveloped land (Olthius and Keuning 2010, 15-20). It also suggests flexibility in the arrangement and configuration of buildings and communities (since floating components rarely occupy a permanent or fixed location). As difficult as it may seem to visualize a future on water, we are already witnessing modern projects with this initiative. For example, the Maldives (in collaboration with Dutch architects) is currently designing an entire floating country in response to sea level rise (Olthius and Keuning 2010, 60). In addition, the Netherlands are undergoing a process of "de-poldering" - re-introducing water onto previously reclaimed land - to create floating communities and also to relieve the additional pressures from sea level rise exerted on their defensive infrastructure (Olthius and Keuning 2010, 61). Although this strategy is an effective solution for adapting our cities to rising water levels, living on water is not a desirable option for much of the population, who are accustomed to living on dry land. For instance, how could floating buildings and developments provide enough stability to avoid the sensation of living on a boat and the experience of wave turbulence? In addition, how would supporting infrastructure such as sewage, road networks and electricity be incorporated into such a fluid terrain? Furthermore, this strategy would not be applicable to the existing coastal land-based cities, which are currently incapable of floating.

The New Water project illustrating the idea of “de-poldering” in the Netherlands (Olthius and Keuning 2010)

Floating wood villages along the Amazon River in Peru (Olthius and Keuning 2010)

Buildings on stilts are situated both on land and over water. The approach behind stilted structures is to elevate the building to an appropriate height, thereby allowing water to pass beneath. Unlike the flexibility of floating buildings, stilted designs depend on a fixed height above predicted future flood levels to remain dry. More recent designs for stilted foundations consist of friction piles - posts which rely on the texture of their surface to create friction with the surrounding soil to hold them in place - to prevent sinking, which is a modern improvement over historic cities such as Venice (Feireiss 2009, 14). Concrete grade beams tie these friction piles together to prevent lateral movement and also provide a base for the columns or pilotis which support the building (Feireiss 2009, 70). As far as sea level is concerned, stilted designs seem to create more problems than they solve. On one hand they provide a temporary, but effective short-term solution for flood mitigation. The design also makes use of land that otherwise might be unsuitable for building, such as swamps, lagoons and marshes. However, as witnessed in the Make it Right project for New Orleans’ Lower Ninth Ward, these elevated designs hinder the sense of community and vital porch culture of the area while also hindering accessibility (Feireiss 2009, 75). In addition, it is difficult to determine the appropriate height of the building above the ground surface. These estimates are typically based on historical flood events, but with sea level continuing to rise there is no definite height which is truly considered safe (Zevenbergen 2011, 38). Stilt designs are static and can only accommodate a predicted water height which is calculated at the time of their construction. In this sense they lack flexibility and resilience to future events.

Bamboo stilt villages in Cambodia (Olthius and Keuning 2010)

Stilt house in the Lower Ninth Ward of New Orleans by Kieran Timberlake (Feireiss 2009)

In contrast to floating and stilt designs, which have been developed and modified based on historical precedent, amphibious buildings are a contemporary manifestation. “Amphibious” comes from the Greek term *amphi-bios*, meaning double-sidedness of life or living that is adaptable to both land and sea (Berman 2010, 69). This architectural concept, recently developed by the Dutch, but now present also in Louisiana, Great Britain and India, combines both floating and stilted structures in a more dynamic relationship. Amphibious designs consist of buoyant foundations that are secured to mooring posts, allowing the building to rise and fall in a controlled manner in response to fluctuations in water level. These hybrid structures allow buildings to rest on dry ground or to float on water. Similar to an umbilical cord, the services (sewage, electricity, etc.) necessary for the functioning of the dwelling are able to adjust to the rising and falling of the building (Nillesen and Singelenberg 2011, 44). The 36 amphibious homes by Dura Vermeer on the Maas River in Maasbommel are a convincing example of the concept (Nillesen and Singelenberg 2011, 46). These houses, which are situated within the riparian zone of the river, rose as much as twenty feet during a flood and slowly descended to settle back on dry ground (Fenuta 2010, 62). In addition, the Buoyant Foundation Project in Louisiana has developed a plan which simplifies the retrofitting of existing shotgun houses into amphibious homes (Fenuta 2010, 63). The dual ability of amphibious structures to sit on dry land and float (in a controlled manner) in floodwaters suggests these designs are a viable and resilient solution to rising sea level. However, we must bear in mind that this potential solution is merely at the scale of a building. Would it be possible also to develop an entire supporting city infrastructure which embraces these amphibious qualities?

Amphibious houses along the Maas River in the Netherlands (Nillesen and Singelenberg 2011)

The amphibious LIFT house in India (Fenuta 2010)

Defensive Barriers

While the responses above adopted a collaborative approach with the sea, many contemporary designs seek to defend against it. These defences have taken many different forms, but fall generally into two categories: temporary and fixed. Recent proposals for temporary defences consist of inflatable barriers, as seen in both California and New York (Create Space 2008). These mechanisms rest on the ocean floor at the smallest opening into a bay until a storm surge or extreme tidal event occurs. Once activated, these inflated mechanisms float to the surface to inhibit the entrance of higher sea levels. Mechanical temporary storm surge barriers also exist in London (the Thames Barrier) and the Netherlands (the Maeslantkering robotically controlled megastructure) (Create Space 2008). The intent behind these temporary barriers is not to provide a permanent solution to sea level rise, but instead to defend against exceptional events associated with climate change, such as storm surges, elevated tidal levels, and hundred year floods. Fixed defences, on the other hand, are static, permanent constructs such as levees, dikes and sea walls. These structures are erected to form a permanent barrier between land and sea. Around the world, fixed defences are the most common response (Baca Architects 2009, 27). However there exists a superior sense of sophistication in specific locations such as the levees built by the Army Corps of Engineers bordering the Mississippi and the array of dikes constructed by the Dutch to separate the Netherlands from the North Sea (Mathur and Cunha 2001).

The Thames Barrier in Great Britain (Nordenson 2010)

The Maeslantkering in the Netherlands (Nordenson 2010)

The benefits of fixed and temporary defences are outweighed by their disadvantages. On a positive note, they allow for additional land to be temporarily reclaimed from the sea, making potential space for agriculture and urban growth. They also provide a line of defence for the built environment against destructive storms, and in some cases catastrophic flooding. However, as Dilip da Cunha suggests, “Hard edges are the historical product of a determined effort to imagine lines where none exist and then to make them survive in the face of an aqueous terrain which constantly defeats their materiality” (Mathur and Cunha 2001, 65). In other words, as engineers continue to construct defences to keep the water out, they are waging a losing battle with the sea, which will require an indefinite amount of labour, maintenance, expenditures and brainpower over time. In addition to the enormous amount of energy in their undertaking, defensive responses to sea level rise are harmful to both the natural and human environment. The containment of much-needed fresh water and alluvial sedimentation has led to the deterioration of fragile ecosystems and accelerated coastal erosion, while diminishing the natural regenerative potential of these marginal territories (Berman 2010, 70). As witnessed in the Lower Ninth Ward, our reliance on a single line of defence has cost homes and human life (Feireiss 2009, 36). This should question the permanence, security and prosperity that designed defences have promised (Mathur and Cunha 2001, 65).

Because most major cities are located on or near the ocean - for transport, trade and tourism – the imminent sea level rise will have a potentially catastrophic impact (Berman 2010, 72). In response, various strategies continue to be developed, from entirely

Levee failure in Japan during the recent tsunami (Zevenbergen 2011)

Levee failure in New Orleans following Hurricane Katrina (Feireiss 2009)

passive tactics and built initiatives to defensive barriers. However, it is evident that no single method offers a complete solution for the future of our coastal environments. Many planning responses and guidelines have taken a broad-brush approach, without considerating architectural or urban design options. A current response identifies property at risk of flooding and adjusts land use to mitigate these risks. Architects can contribute an additional perspective by considering three-dimensional, spatial and adaptive building solutions to consider inhabiting places subject to sea level rise and flooding scenarios. This would generate more radical, more diverse and more contextually specific solutions than an approach that relies solely on land use controls.

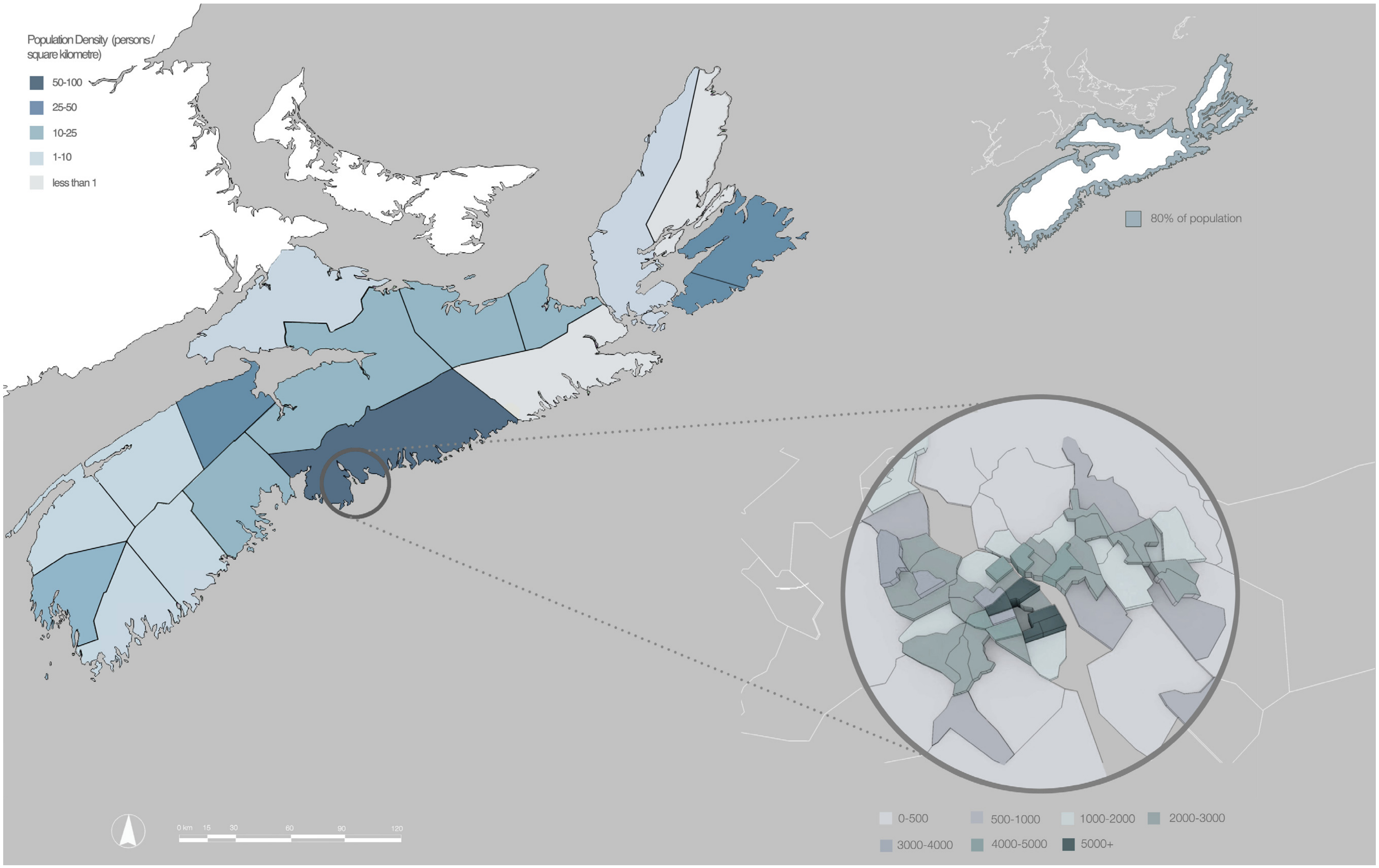
This thesis suggests a hybrid approach that uses these multiple perspectives – ecological, engineering, urban design and architectural - in an integrated, fluid response that is able to adjust and shift as sea level continues to rise. Rather than defending or retreating from the sea, the study will propose a way in which homes and communities can adapt. It suggests the implementation of amphibious architecture as an alternative to the abandonment of our coastal environments and as a way of coping with the inevitable effects of sea level rise. In this instance, sea level rise is perceived as an opportunity rather than a catastrophe. The ambition for the work is that this new architectural approach will provide an alternative to the mass migration and desertion of our coastal homes and communities, and will serve as a model for future growth and floodplain development in other vulnerable areas around the world.

CHAPTER 2: SITE SELECTION

Context

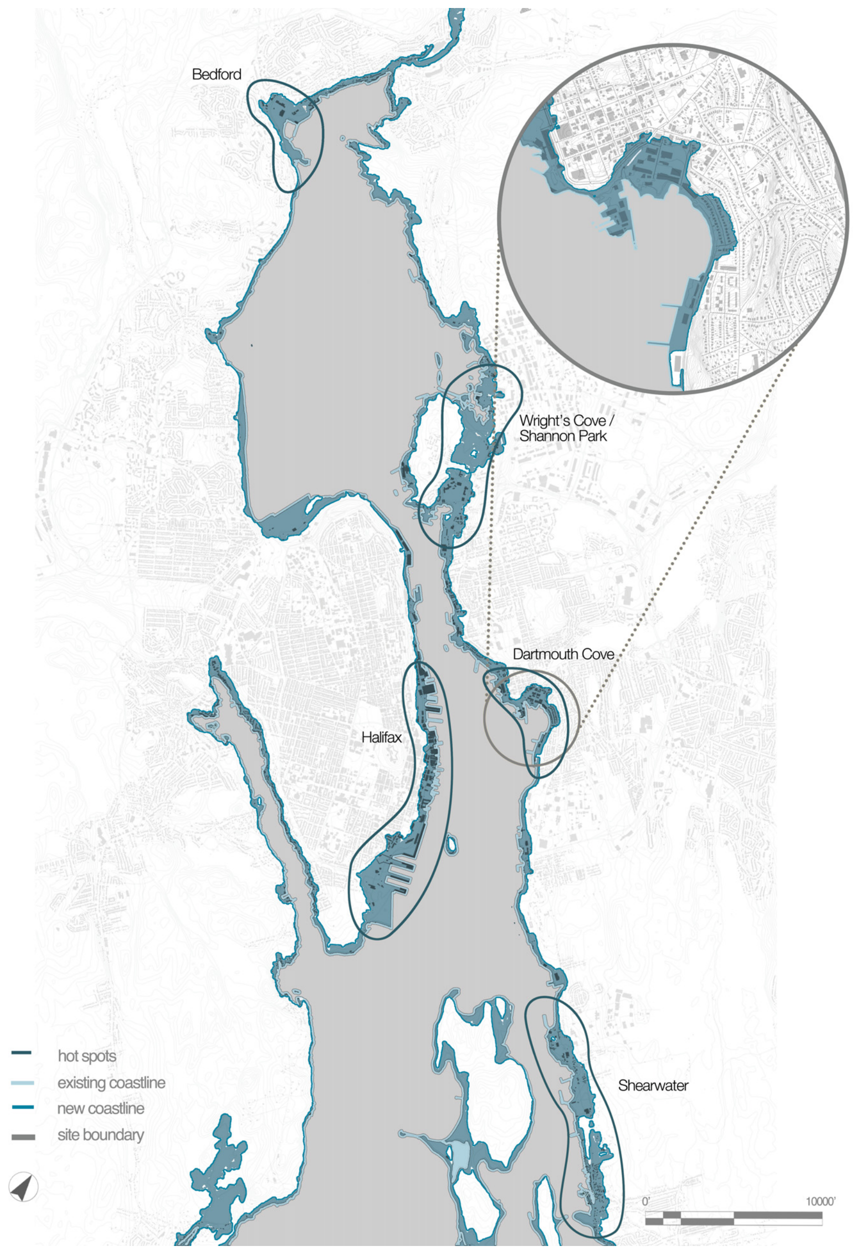
In Canada, the Maritimes are especially vulnerable to the future effects of sea level rise. Not only is 80 percent of the Maritime population situated within 20 kilometres of the ocean, but land subsidence along the Atlantic coast of Nova Scotia is accelerating the effects of climate change (Atlas of Canada 2011). The Government of Canada's sensitivity index ranges from 0 (low sensitivity) to 60 (high sensitivity), with Halifax Harbour located at the higher end of this spectrum.

Sea level rise sensitivity for Canada, highlighting Halifax Harbour (Atlas of Canada 2011)



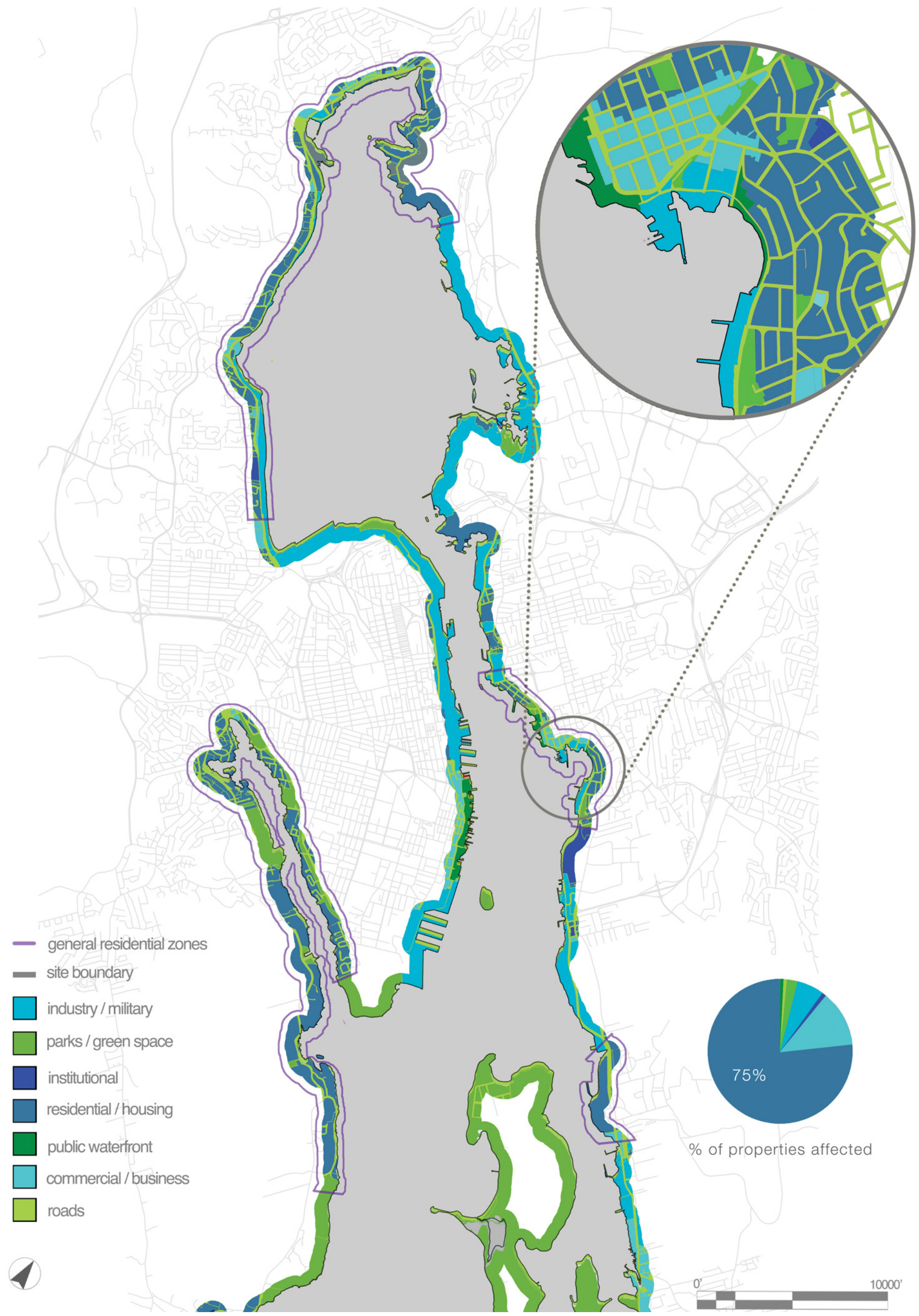
Map illustrating population density for Nova Scotia and Halifax Harbour. Notice that most densely populated areas occur along the coastline and will thus be most vulnerable to the effects of sea level rise.

Based on the one hundred year sea level rise scenarios produced by the Bedford Institute of Oceanography, there are five major low-lying “hot spots” surrounding Halifax Harbour. Each scenario is based on a combination of factors, including global sea level rise, land subsidence, storm surge events and tidal fluctuations (Environmental Planning Studio 2009). The resulting hot spots are places with high human, social and economic activity that are vulnerable to the effects of sea level rise. They include the Shearwater coast, Dartmouth Cove, Halifax waterfront, Wright’s Cove and Bedford Basin.



Hot spots surrounding Halifax Harbour that are vulnerable to effects of sea level rise. The highlighted area illustrates the thesis site.

In the coastal buffer (200-300m from the shoreline) around the harbour 75% of the total properties at greatest risk of flooding are residential (Desai 2010). Developing an adaptation strategy for these residential areas may alleviate the need for a massive retreat from the harbour's edge. The densely populated residential zone surrounding Dartmouth Cove will serve as the site for this thesis.



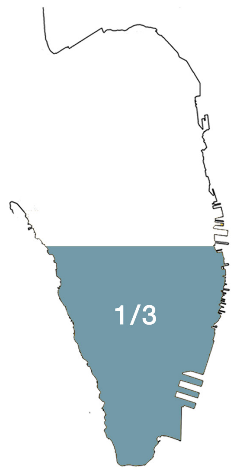
Zoning map of the coastal buffer for Halifax Harbour, highlighting Dartmouth Cove

Dartmouth Cove

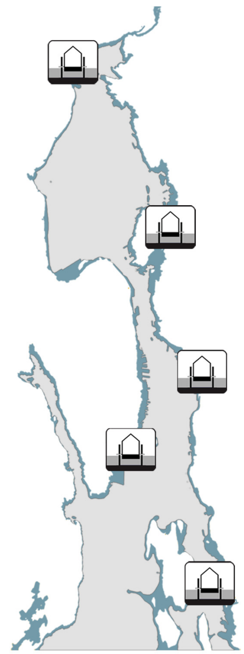
Within Dartmouth Cove, the thesis site is bounded by the existing coastline and the high water line in the worst-case scenario from the sea level rise data. It is currently occupied by fifty homes. The goal is to “re-house” the affected residents and provide additional homes for the future population in a manner which is accepting and resilient to the potential effects of sea level rise. Although Dartmouth Cove is merely a small portion of Halifax Harbour, it can serve as a significant example which could be applied to other areas along the waterfront.

Extent of sea level rise in Dartmouth Cove, highlighting the thesis site

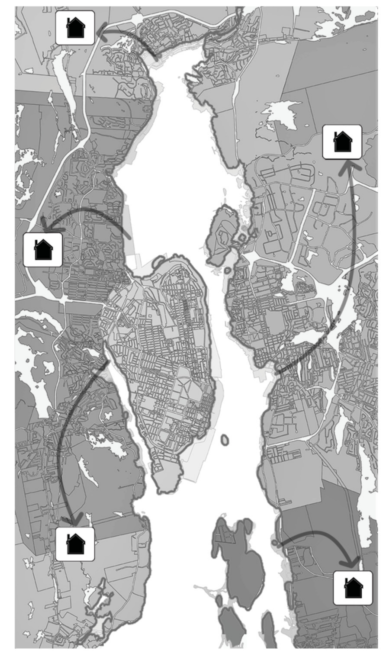
Area of the Halifax harbour flooded by sea level rise ~ 600+ hectares



Flooded area is roughly equivalent to 1/3 of the area of the Halifax peninsula (1850 hectares)

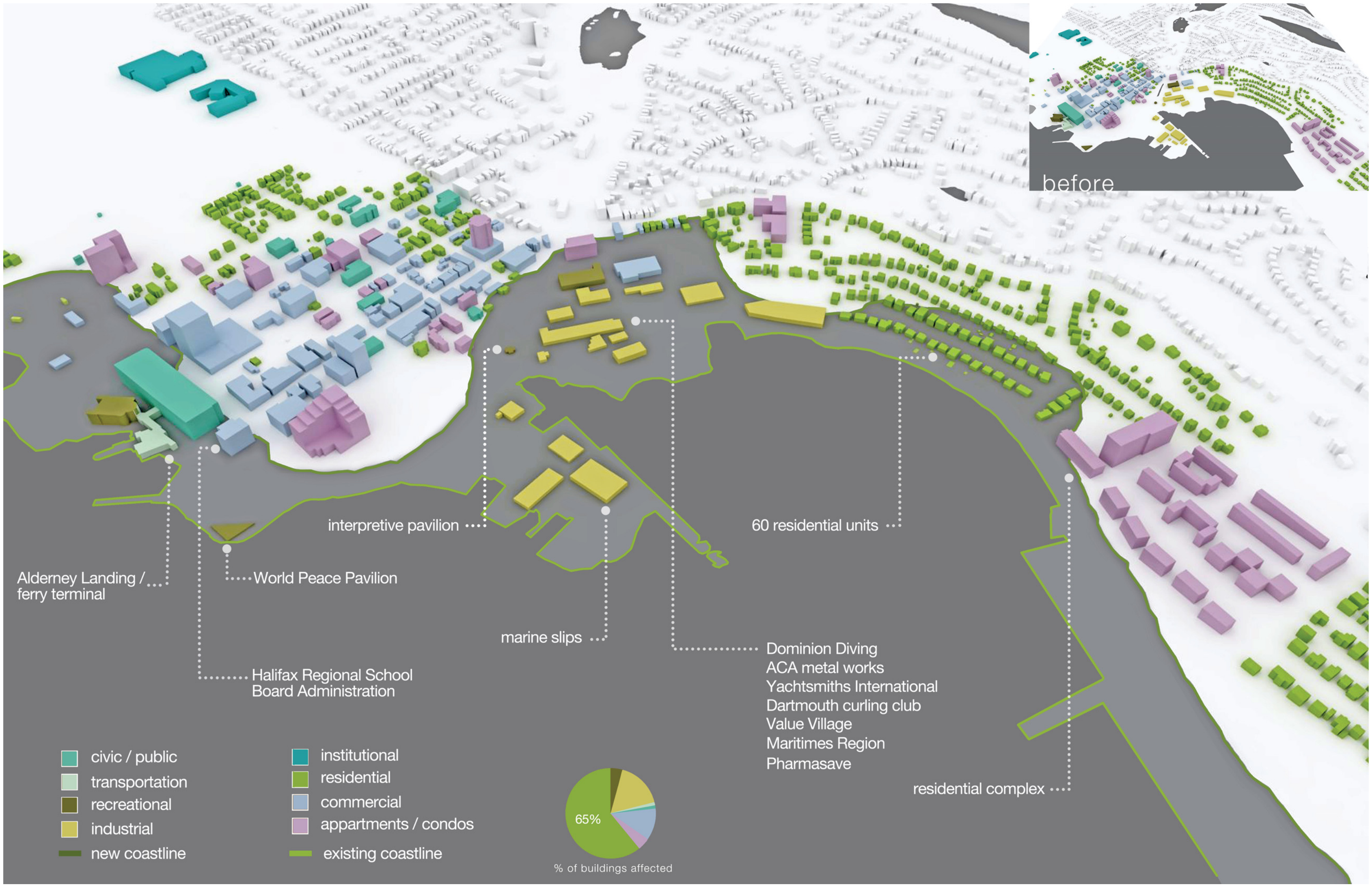


Encourage the design of amphibious communities in areas at risk

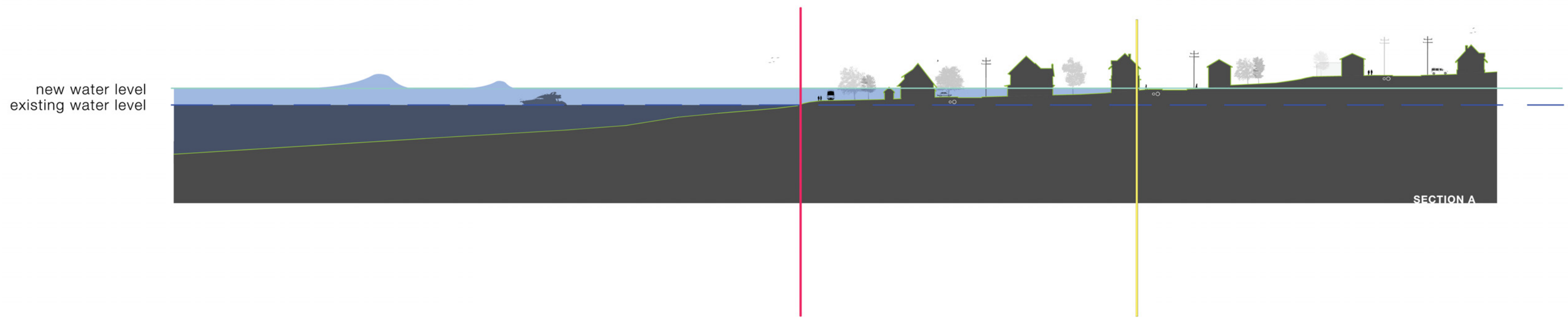


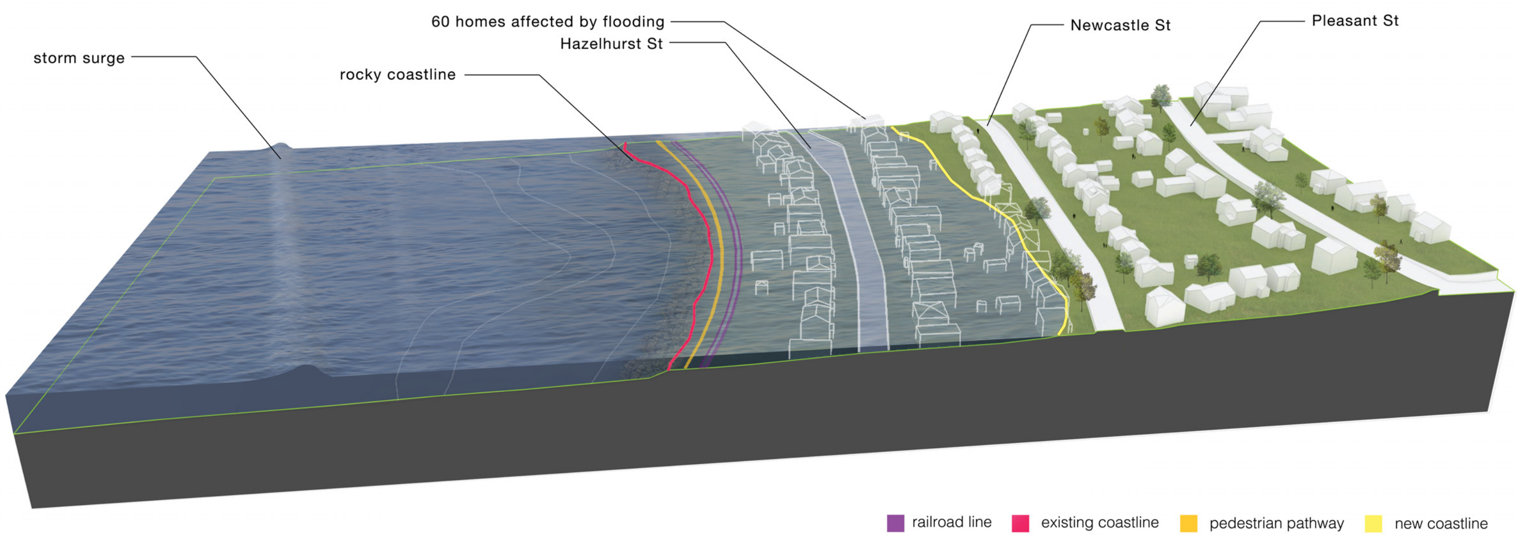
Avoid retreat and sprawl onto previously undeveloped land

The successful implementation of amphibious communities in flood sensitive areas could alleviate the pressures of sprawl onto previously undeveloped land and densify the urban core of the Halifax Regional Municipality.



Buildings within Dartmouth Cove that would be affected by sea level rise during the next hundred years. Note that 58 of the 95 buildings, or 60% of the total building count, are residential.





Section and sectional perspective indicating the effects of sea level rise on the existing homes on the thesis site

Unlike the existing land-based homes at Dartmouth Cove, an amphibious community must adapt to a constantly fluctuating aquatic environment. More frequent flooding from sea level rise, land subsidence and severe rainfall will influence the entire foundation of the community. Harsh coastal conditions such as strong winds and storm surges associated with hurricanes and “Nor’easters” will require elements such as wind barriers and breakwaters, in addition to flood resilient homes. Living on or near the sea also affects haptic qualities such as light and sound. Both are reflected by water, so building facades must accommodate them accordingly. Accessibility to amphibious dwellings cannot rely on automobiles, and may require different forms of transportation such as boats, bicycle paths and boardwalks. The Old Ferry Road and a pedestrian pathway along the waterfront currently provide the only means of access to the site. With severe flooding from climate change, these access points will be completely inundated, so alternate routes must be provided. Services to the site, such as sewage, electricity and gas, will also be affected by sea level rise. Therefore, the community must be linked to the existing service lines and city infrastructure.

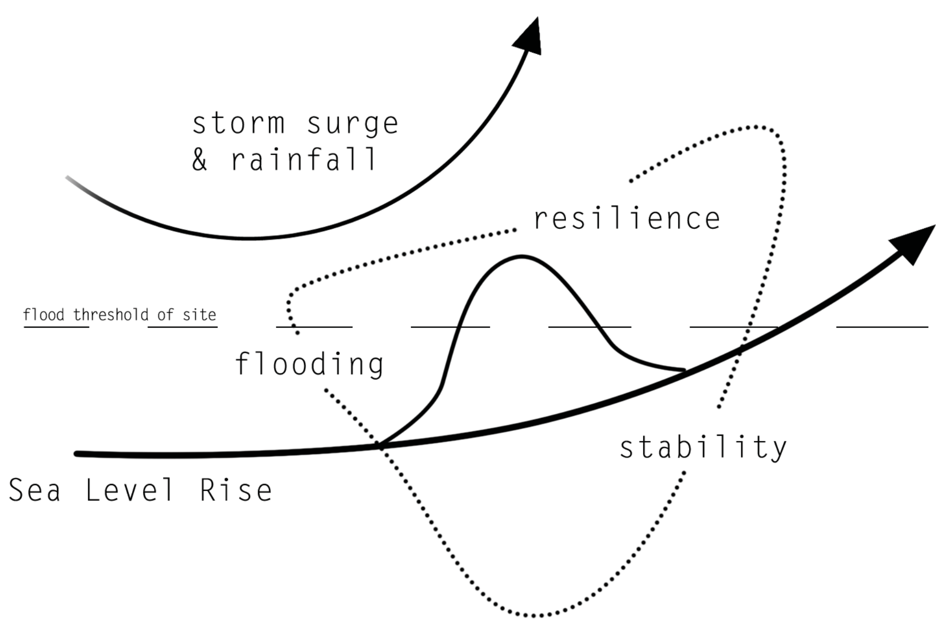
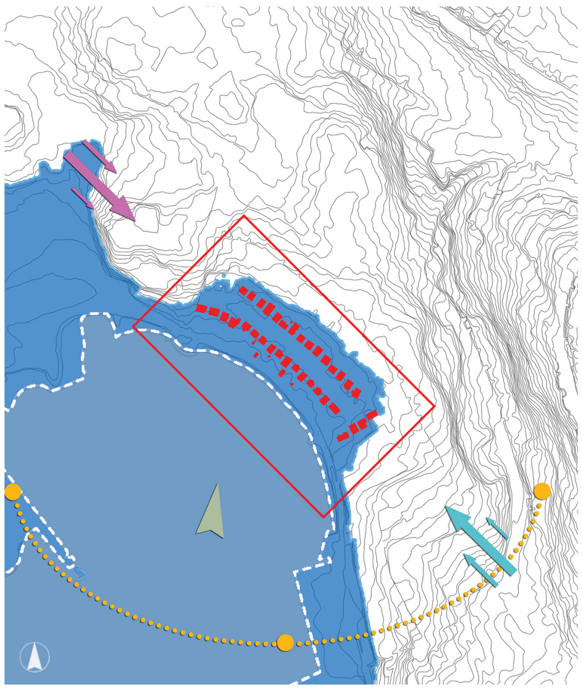
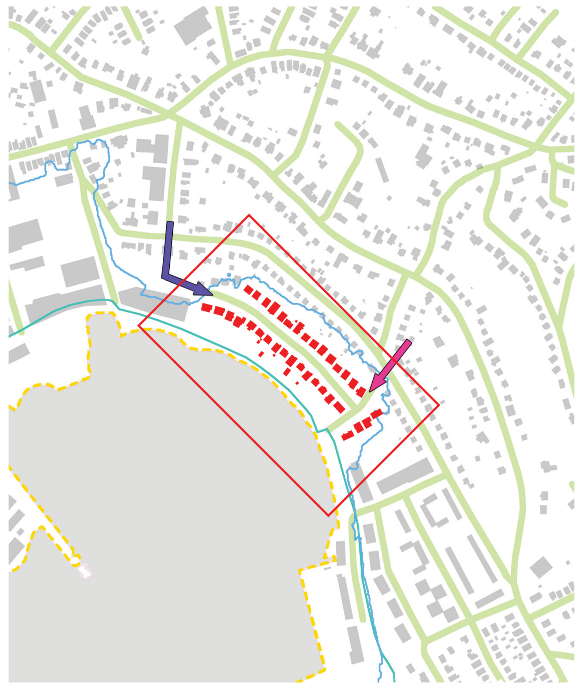


Diagram illustrating the energies of the site as they relate to water. Sea level rise is a constant, whereas periodic flooding from storm surge and rainfall events is temporary. As disturbances cause flooding, the site adapts to reach a state of stability.



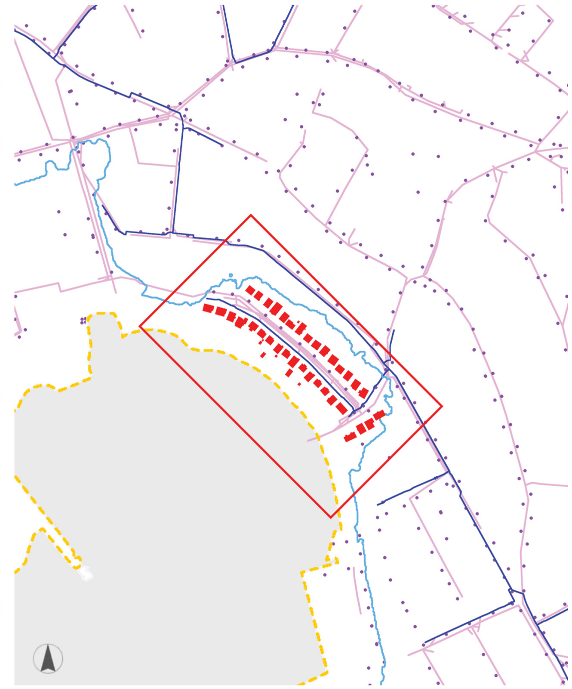
Natural Forces

- thesis site and affected homes
- sea level rise scenario
- new coastline
- existing coastline
- sun path
- prominent storm surge direction
- dominant summer winds (SE)
- dominant winter winds (NW)
- 1m contour lines



Accessibility

- thesis site and affected homes
- existing roadways
- existing access to site
- potential access to site
- existing coastline
- new coastline
- pedestrian pathway
- existing buildings



Services

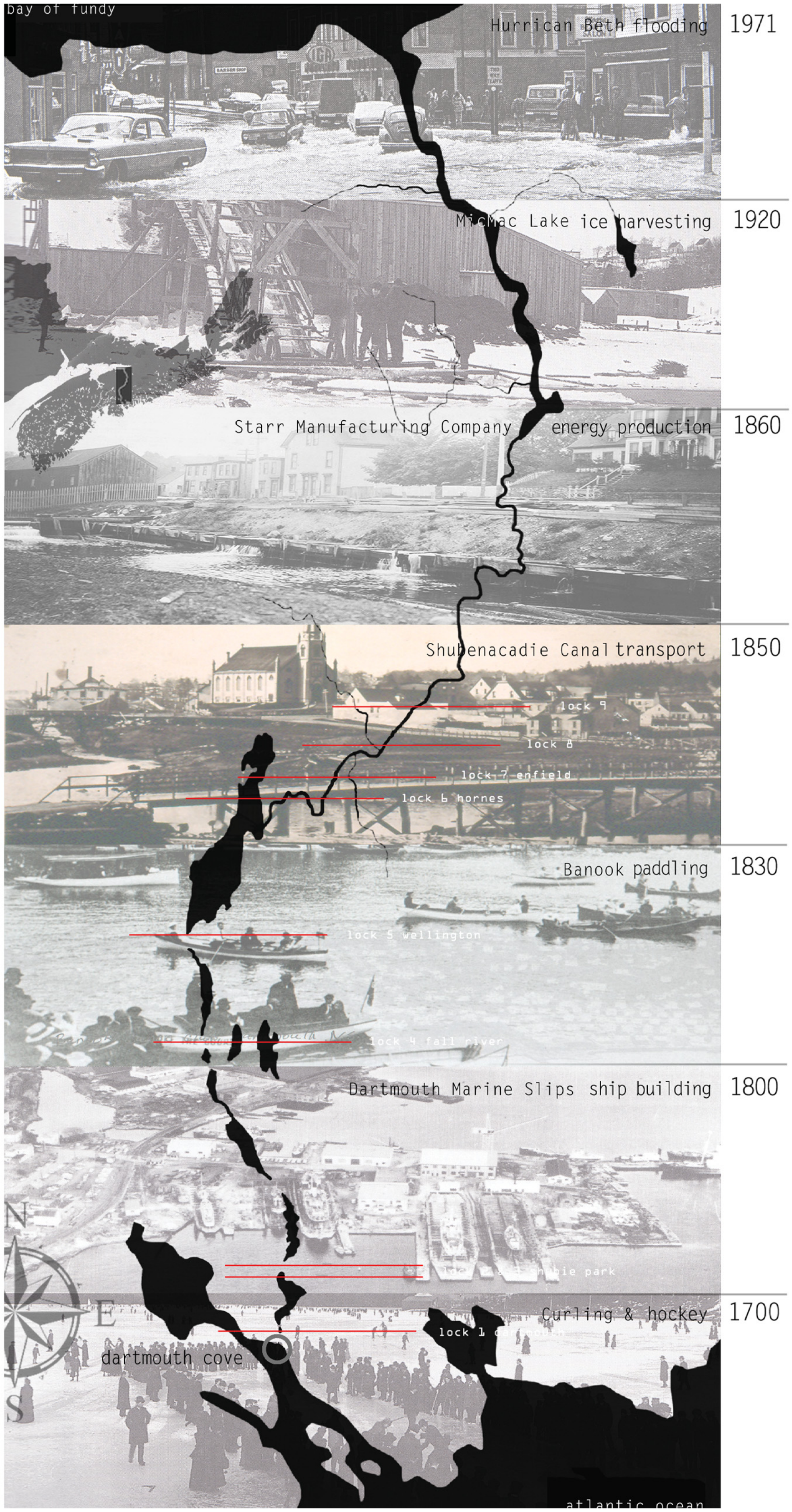
- thesis site and affected homes
- sewage pipes
- new coastline
- utility points
- natural gas line
- existing coastline

Elements of Dartmouth Cove which will need to be considered as a result of sea level rise.

History and Existing Strategies

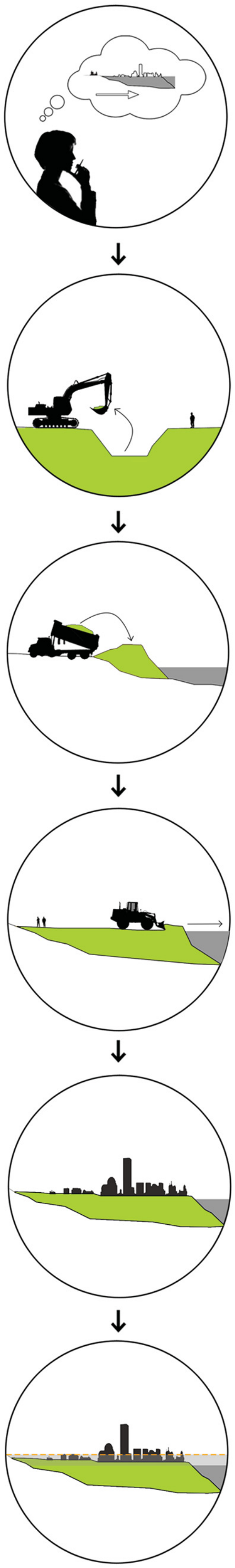
Although Dartmouth faces a new challenge due to climate change, it has enjoyed a valuable relationship with water. Historically, Dartmouth was the end of the Shubenacadie Canal (an inland waterway, linking Halifax Harbour to the Bay of Fundy), a shipbuilding port, a node for ice harvesting, and a city which embraced water recreation (Chapman 2000, 15). Water has helped shape the culture of Dartmouth and should be an important consideration in the future.

Current strategies for building along the harbour's edge are based on ideas of land reclamation, a process of creating new land from sea or riverbeds (Olthius and Keuning 2010, 33). Newly reclaimed land is known as reclamation ground or landfill. By reclaiming land from the sea, we can essentially extend beyond the existing coastline to gain new ground for agriculture (similar to the Dutch and Acadians), industry or human habitation. Many areas around Halifax Harbour, including Dartmouth Cove, have been reclaimed. The new King's Wharf project on Dartmouth Cove continues this practice. Unfortunately, land reclamation projects destroy animal habitats and disrupt water currents (Olthius and Keuning 2010, 36). In addition, these projects create a static, low-lying settlement that is vulnerable to flooding and erosion. All of the flood vulnerable areas around Halifax Harbour were reclaimed from the sea. Land reclamation is unsustainable due to sea level rise and therefore should be avoided in the design of an amphibious community.



Historic and cultural forces at Dartmouth Cove as they relate to water (Images edited from Chapman 2000)

Land reclamation for Dartmouth Cove from 1860 to 2011, followed by the proposed King's Wharf development in 2020 and the effects of sea level rise in 2100 (Images edited from Chapman 2000)



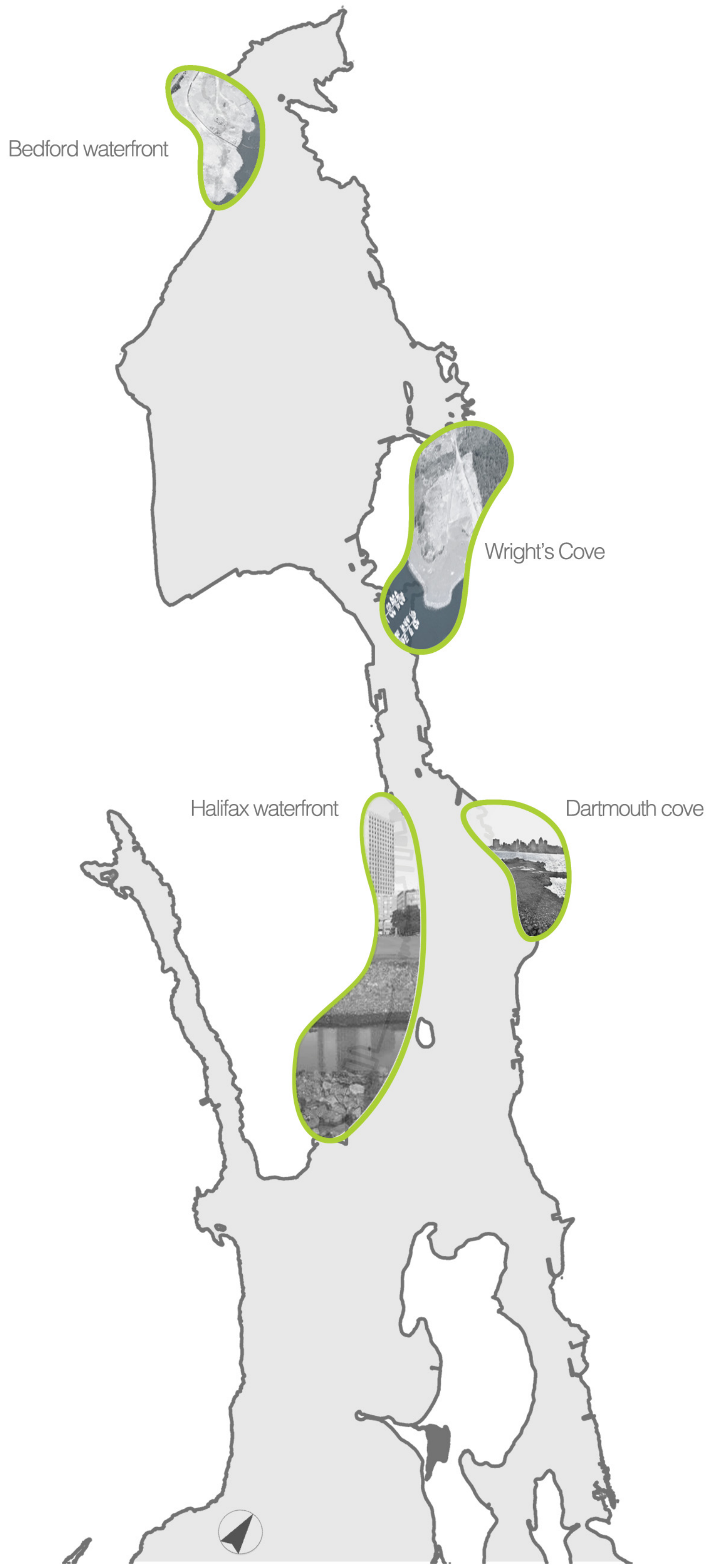


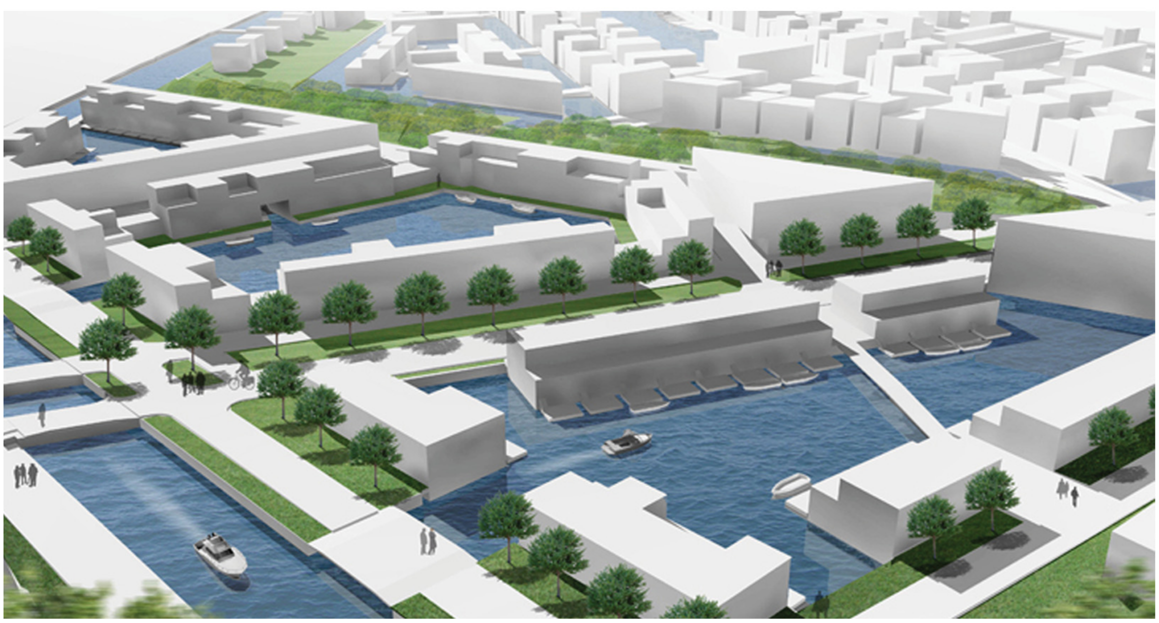
Diagram illustrating the process of land reclamation

Reclaimed land around Halifax Harbour as it relates to the flood vulnerable areas (Images edited from Google Maps)

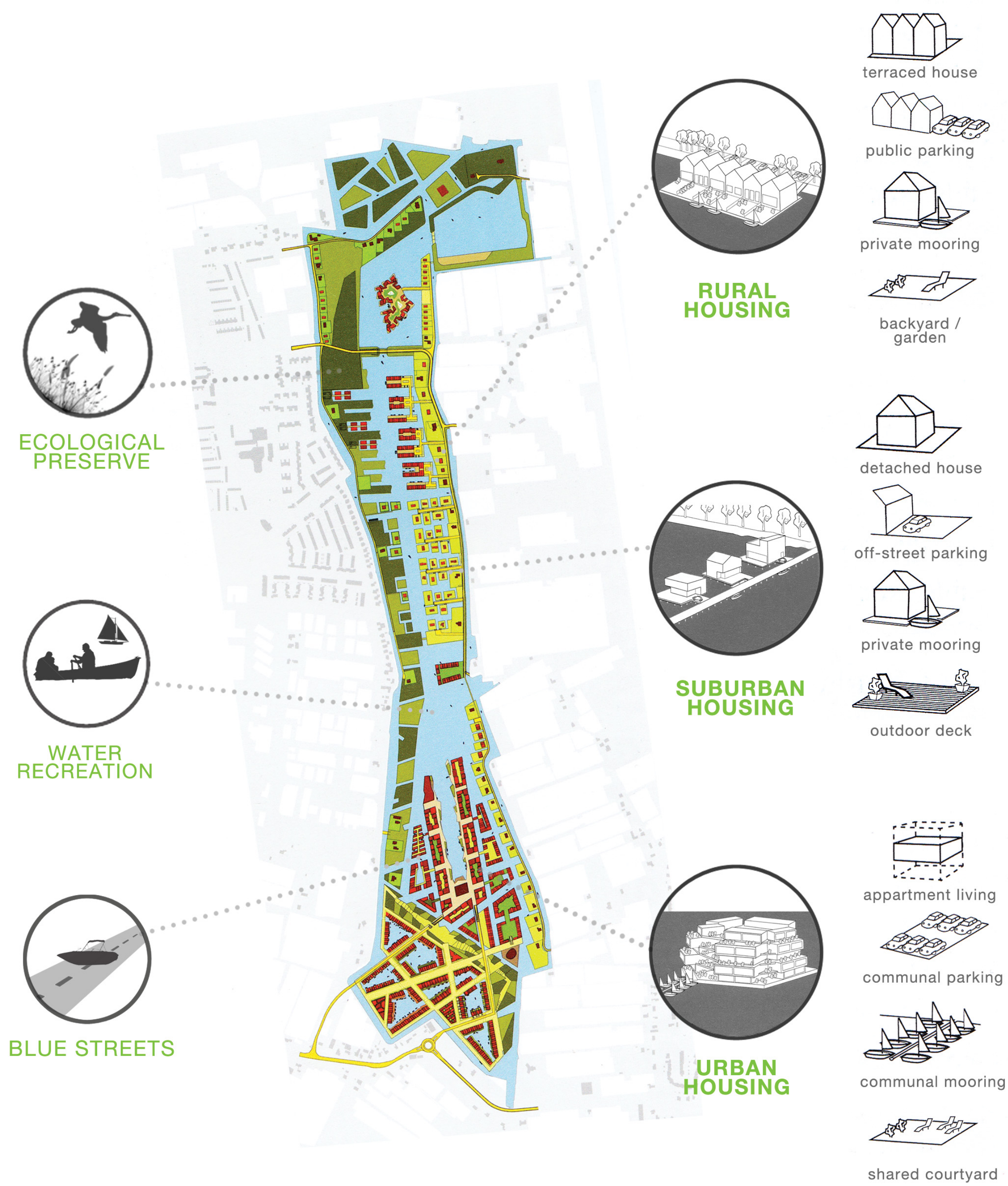
Precedents

The New Water Project
Westland, Netherlands
Waterstudio Architects 2011-2019

The New Water Project is an 80-hectare, 1200-house amphibious neighbourhood currently being constructed in the Netherlands. The planned area of the polder consists of separate sections which will be filled with water after the houses are built, a new process known as “de-polderization.” The open water serves both ecological and recreational functions and celebrates living on water. The western part of the site combines ecological and recreational zones and amphibious homes with a suburban density whereas the south-eastern part of the site is more urbanized with greater density. In general, the buildings in this area are closed residential blocks with shared interior spaces and rows of terrace houses. Canals run between the blocks. The northern part of the site, where the density is lower, has a floating, three-storey complex of flats (Olthius and Keuning 2010, 55).



Rendering of amphibious courtyard configurations and blue streets of the New Water Project (Olthius and Keuning 2010)

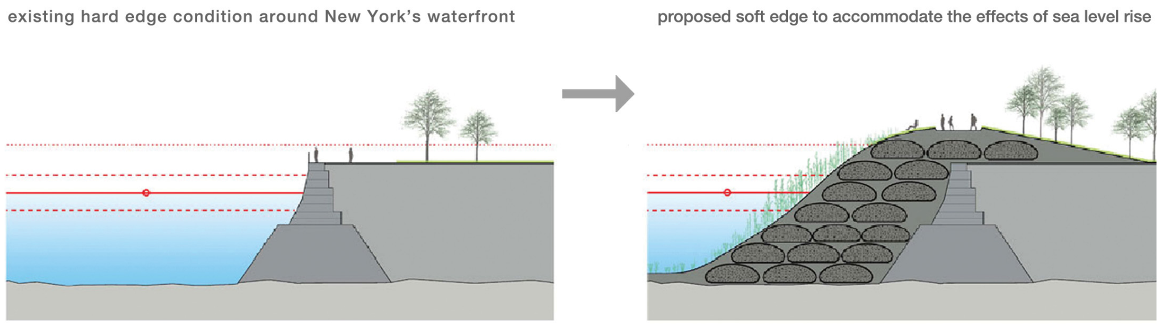


Site plan emphasizing the different zones and corresponding configurations (Image edited from Olthius and Keuning 2010)

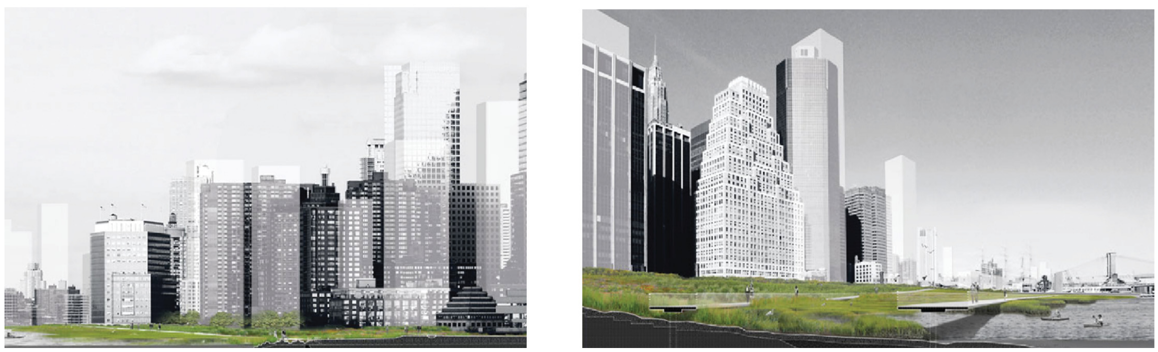
Rising Currents: Projects for New York's Waterfront
Manhattan, New York
Architecture Research Office 2010

The Rising Currents project involves a rethinking of New York's harbour and coastline in response to rising sea level. Although the project may never be realized, it consists of many thought-provoking ideas and possible adaptation strategies for dealing with sea level rise. New York harbour was divided into five zones for the project, addressed by a multidisciplinary team that included architects, engineers, landscape architects and students. They developed schemes for each zone by imagining new ways to occupy the harbour and adjacent coastline. Many of the ideas were based on the concept of "soft infrastructure," which would re-introduce natural wetlands and return the harbour to its original state as an estuary. The wetlands would provide a more natural buffer between the city and the harbour, eliminating the hard edge between the built and natural environment. Wetlands also provide many benefits, including protection against storm surge, natural filtration of polluted run-off from the built environment and the restoration of habitats for numerous species. This enhances human interaction with nature and increases the qual-

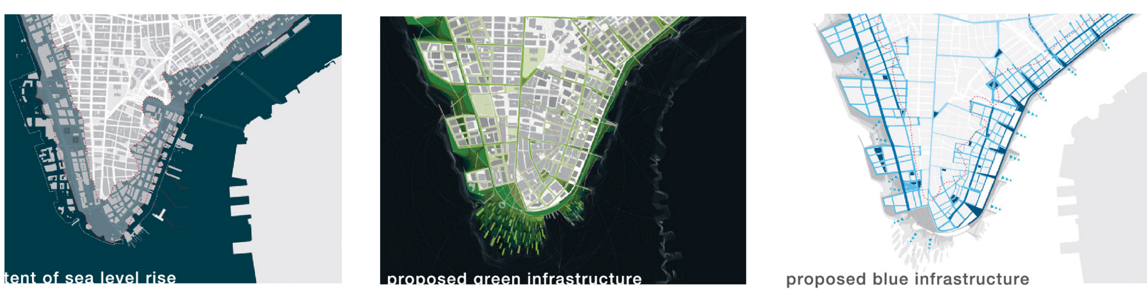
Perspective of proposed "soft infrastructure" for Lower Manhattan (Bergdoll 2011)



Sections illustrating the proposed edge transformation. The red lines indicate high and low tide as well as storm surge water levels. (Image edited from Bergdoll 2011)



Sectional perspectives illustrating possible haptic qualities and habitation potential (Bergdoll 2011)



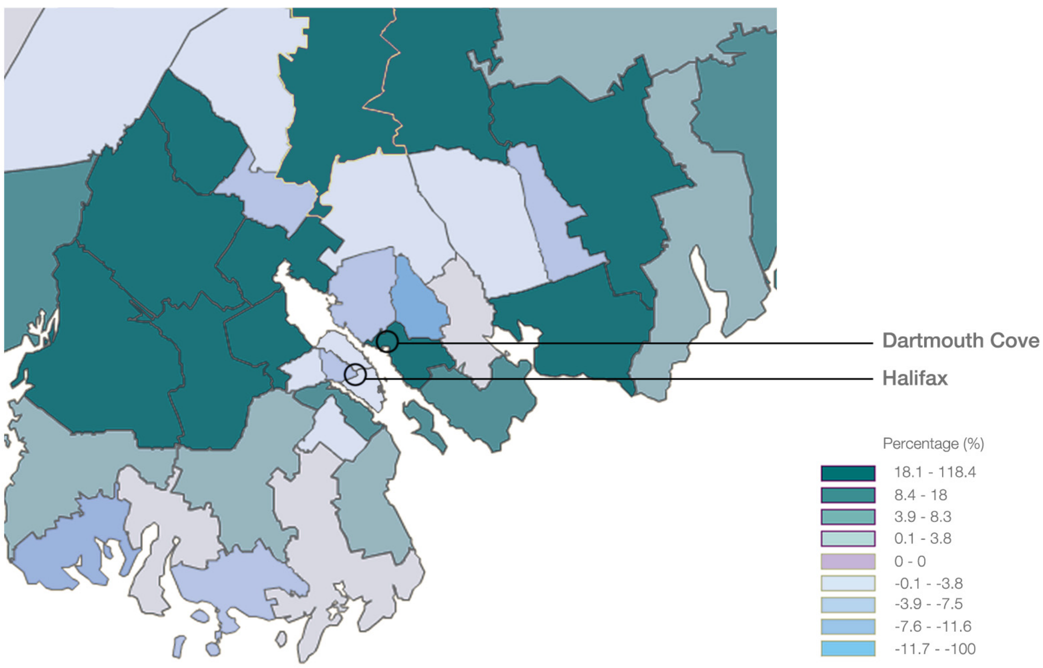
Series of site plans illustrating the layers of the site (Images edited from Bergdoll 2011)

ity of life in an urban setting. Many of the schemes nestle the built environment within this soft infrastructure; however, the focus is mainly at an urban scale, without investigating the scale of a building (Nordenson 2010, 60).

CHAPTER 3: PROGRAM DEVELOPMENT

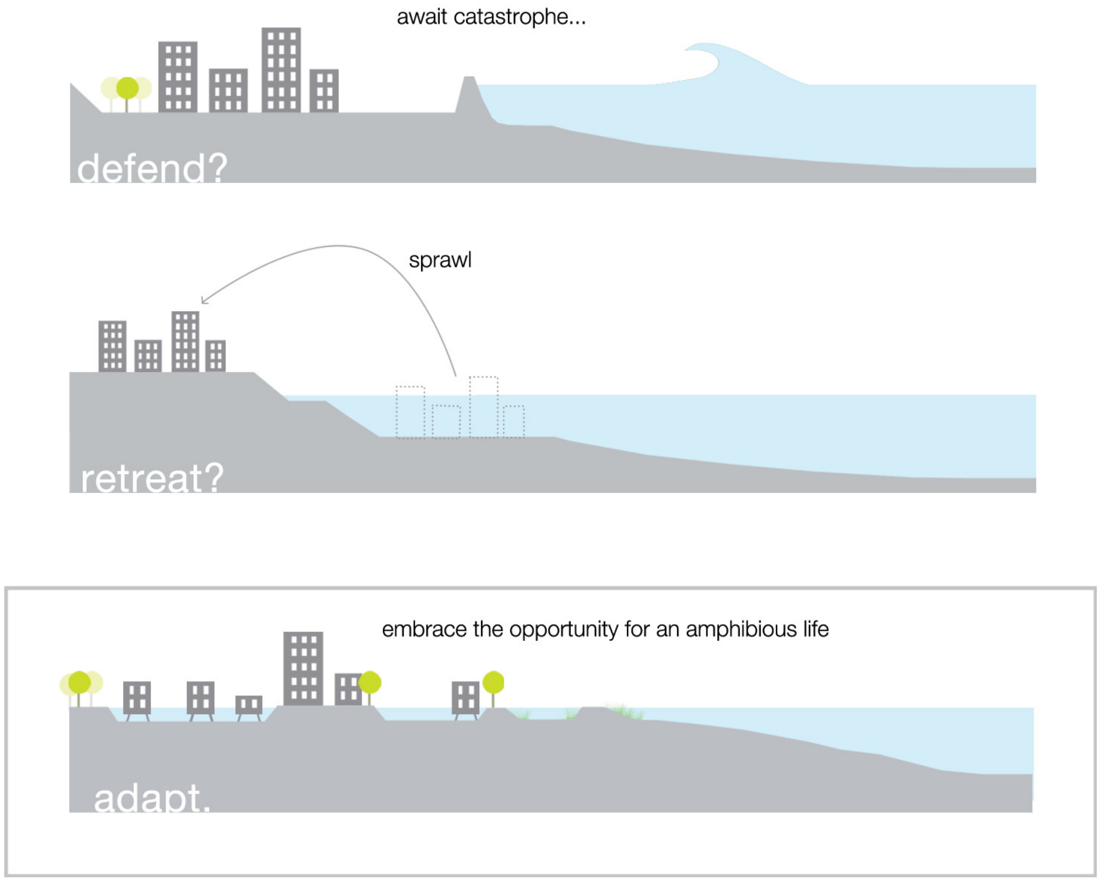
Amphibious Communities

The urban core of the Halifax Regional Municipality in recent years has witnessed a general decline in population, with growth in suburban and rural areas (Government of Nova Scotia 2011). Without a comprehensive strategy for climate change, the added pressures of sea level rise could increase sprawl.



1990-2006 population change in HRM, showing sprawl (Image edited from Government of Nova Scotia 2011)

Rather than erecting temporary defence structures or retreating from the coastline, the vision for this thesis is to respond to rising sea levels through the development of amphibious communities that would be adaptable to both dry and wet conditions. Sea level rise in Halifax Harbour threatens to inundate 600+ hectares of land, which is approximately equivalent to 1/3 of the area of the Halifax peninsula (1850 hectares). Amphibious communities in these areas could avoid a massive retreat from the coast and allow for further densification along the harbour's edge. Future growth in these flood zones could alleviate additional sprawl onto previously undeveloped land. The development of amphibious communities would also transform the harbourfront from a largely industrial zone to an area for



Possible coastal responses to sea level rise, including an amphibious option

living and public space. The harbour can become the connective tissue which joins areas along the waterfront (Dartmouth, Halifax, Shearwater, Bedford, etc.), rather than a body of water that separates them.

The program for the thesis is motivated by two important aspects: education and living, the awareness of rising sea level and a relaxing place to live. Sea level rise has typically been perceived as a threat associated with catastrophe and destruction (Roaf and Crichton 2009, 68). This mentality has resulted in a general tendency to retreat or defend against the sea. Instead of a disconcerting problem, is it possible to regard rising sea level as an opportunity to develop a new relationship with the water? Can sea level rise serve as a catalyst to generate a calm, relaxing and peaceful living environment?

Users and Spaces

The primary population for this community would be the existing residents of Dartmouth Cove. According to the household demographics for Dartmouth (Government of Nova Scotia 2011), the existing residents include working class middle-age married couples with both young and teenage kids, as well as working middle-age single residents such as young professionals and bachelors. To encourage sustainable development, the amphibious community would accommodate a mix of uses in addition to housing, such as recreation and commercial amenities, so there would also be a number of secondary users, including middle-age recreationists, employees and family tourist groups.

The primary and secondary users would require certain spaces. Primary dwellings would include bedrooms, kitchens, living rooms, studios, gardens, etc. A number of transportation and infrastructural spaces also would be required, such as boat launches for personal vehicles, ferry stops and bus shelters for public transit, gangways, boardwalks and cycling paths for pedestrian circulation, and “blue streets” for boat circulation. Additional spaces for residents would include places for gathering, such as communal gardens, parks and open space. Secondary spaces for visitors would include places for recreation such as fishing, kayaking, sailing, biking, swimming and ecological education.

User Profiles

primary users

family residents

married couple

- age 25 - 55 years old
- 1-4 children
- husband employed full time
- wife employed part time
- interested in short commute to work, but want a waterfront property
- want to provide a natural environment for their kids, but in close proximity to amenities

teenage daughter

- age 14 -19
- attending junior high/ high school
- interested in sports, recreation and places to hang out
- needs to live close to friends, and wants private space of her own

child

- age 2 - 9
- attending pre-school/ daycare
- requires parental supervision at all times
- interested in playgrounds, parks and wildlife
- needs playful places to grow, learn and be inspired

single residents

young professional

- age 25 - 40
- enjoys the night life of the city
- looking to meet other young professionals
- interested in places to exercise and walk her dog
- frequently invites guests over to gather
- prefers private but inspiring studio space for conducting work

recent bachelor

- age 40 - 55 years old
- experienced in the work-force
- looking to socialize with other professionals in the community
- prefers living adjacent to the office and urban core
- wants to own a personal yacht for evening cruises along the harbour and weekend fishing trips

secondary users

recreationist

paddler

- age 18 - 35 years old
- trains 4 times a week
- interested in a variety of workouts including; swimming, biking, kayaking and running trails
- enjoys exercising in fresh air environments along the edge of the city

employee

restaurant manager

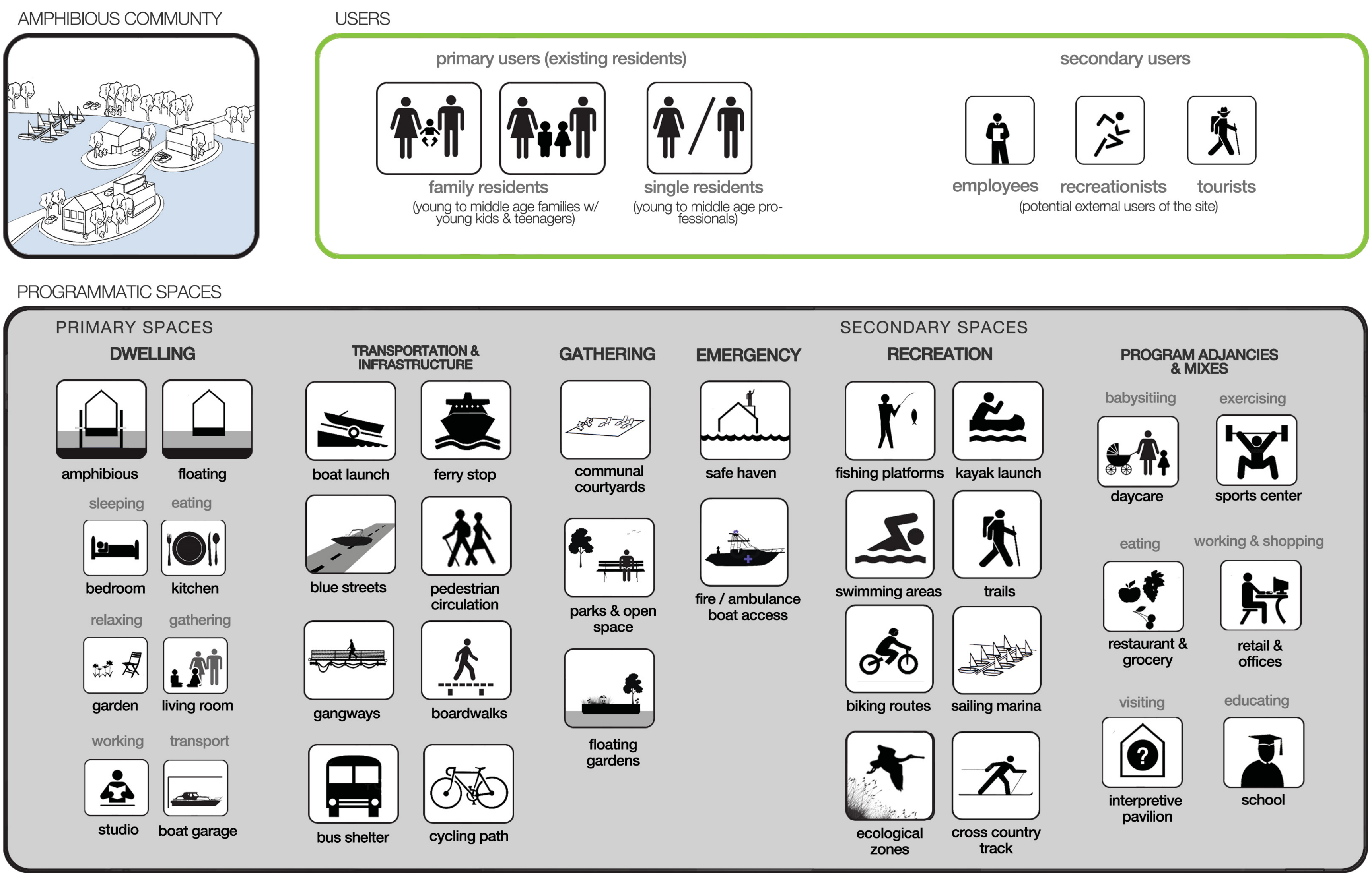
- age 30 - 55 years old
- interested in capturing the harbourfront experience through seaside dining
- wants to work for a restau-rant oriented towards tour-ists and families
- looking for a job, which is a close commute to down-town

tourist

family

- age 25 - 55 years old
- married with kids age 5 -18 years old
- interested in spending the afternoon along the waterfront
- looking to learn about the coastal ecology of the area, but also want to participate in water related activites

Potential user profiles for an amphibious community in Darmouth Cove (Images edited from Flickr Photos)



Required spaces based on the potential user profiles

Design Parameters

Sustainable Urbanism

The design aim for this thesis is not only to adapt to rising sea level, but also to provide a dense living environment. Increasing density alleviates the pressures of urban sprawl, thus preserving previously undeveloped land. Douglas Farr's Sustainable Corridor model suggests a minimum of 7 dwelling units per acre in order to free people from automobile dependence and support local transit (Farr 2008, 18). The model also suggests a mix of building uses in order to achieve a 1:1 job - housing balance (Farr 2008, 20). Although this suggested density is applicable for current development, the design for this thesis is based on a future scenario. With a current population of 403,188 persons in the HRM and a projected growth of 84,400 persons by 2026, the population may triple in the next century (Halifax Regional Municipality 2004). A significant increase in housing will require a rethinking of Dartmouth's current suburban form.

Mixed Use Development

According to Robert Witherspoon, in order to develop an effective mixed-use development the following characteristics must be achieved (Witherspoon 1976, 44):

- three or more significant revenue-producing uses (such as retail, office, residential, hotel/motel, and recreation)

- significant functional and physical integration of project components, including uninterrupted pedestrian connections

- development in conformance with a coherent plan (which frequently stipulates the type and scale of uses, permitted densities and related items)

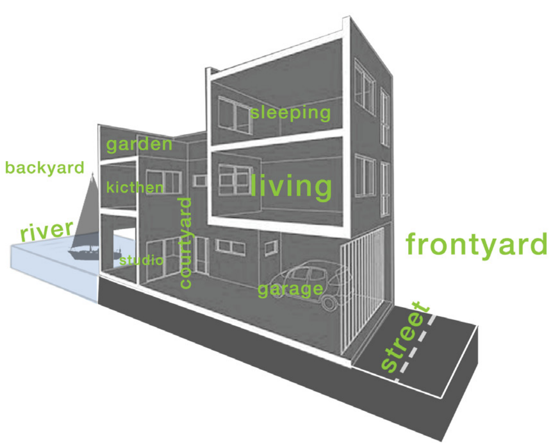
There are currently no revenue-producing uses in Dartmouth Cove. Therefore, additional revenue-producing programs must be incorporated into the new design.

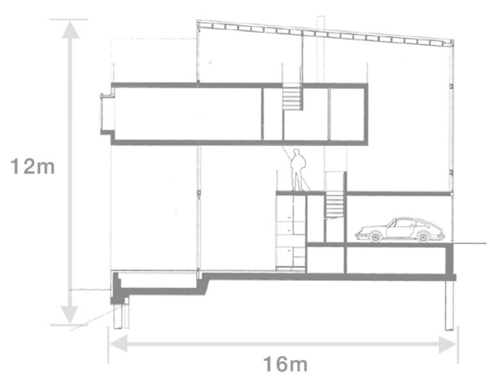
Precedents

Borneo Sporenburg
Amsterdam, Netherlands
West 8 Architects 1996-2000

The Borneo Sporenburg amphibious housing project in the Netherlands consists of 2500 low-rise, high-density dwelling units. Each house has a private realm which is organized around an internal courtyard. It includes living spaces, a kitchen, studio, bedrooms, patio and roof garden. The houses are aligned to create front yard / backyard relationships with both the street and the water. The site is predominantly housing, but shops, institutions, restaurants, offices and sports centres are also included to promote a walkable, mixed-use neighbourhood (Machado 2008, 16).

Photograph of Borneo Sporenburg homes and corresponding mixed-use layout of site plan (Images edited from Machado 2008)



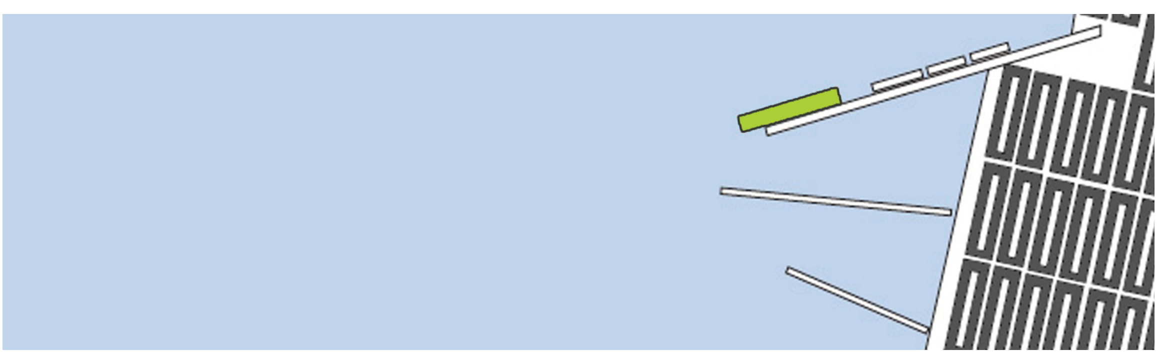


Sectional perspectives illustrating frontyard / backyard relationship as well as internal program of a typical housing unit (Images edited from Machado 2008)

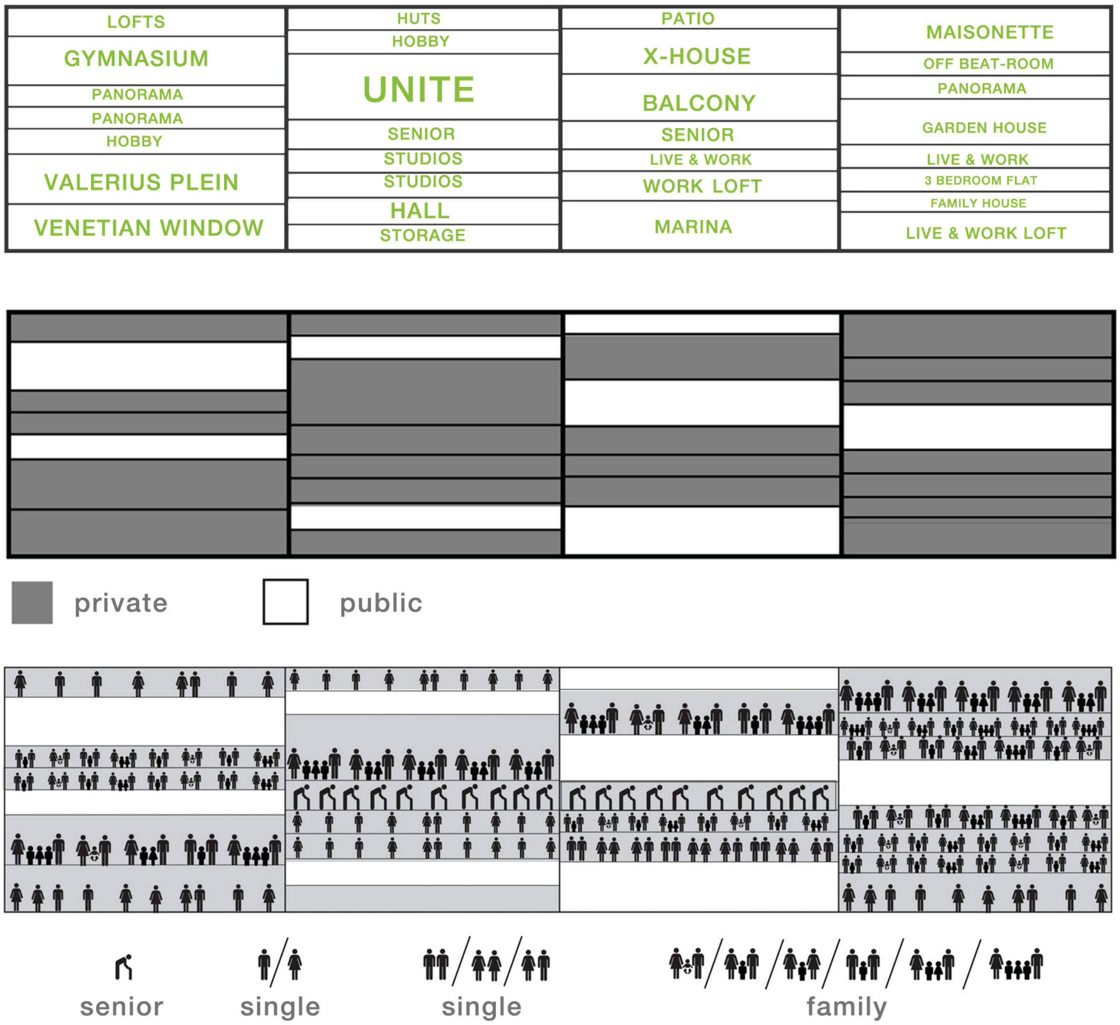
The Silodam
IJ River, Netherlands
MVRDV 1994-2007

The Silodam is an amphibious community housed in a single building. The building consists of 157 units (apartments, houses, offices and commercial) and public spaces, all within a 10-story-high and 20-meter-deep urban envelope. The housing units are stacked in internally connected “neighbourhoods” of 4 to 8 houses for a range of users, including seniors, singles and families. The “houses” differ in both orientation and size; they can be half a block, a whole block, or diagonal over two floors, some having a terrace or balcony. Mixed uses support the community, making the building not only a place to live, but a place to work and play. Silodam provides high density living in proximity to Amsterdam and accommodates a transition from land to aquatic living (Ryan 2010, 18). Although the building is located over water, it is incapable of floating and thus not resilient to the future rise in sea level.

Photograph of the Silodam on the IJ river (Ryan 2010)



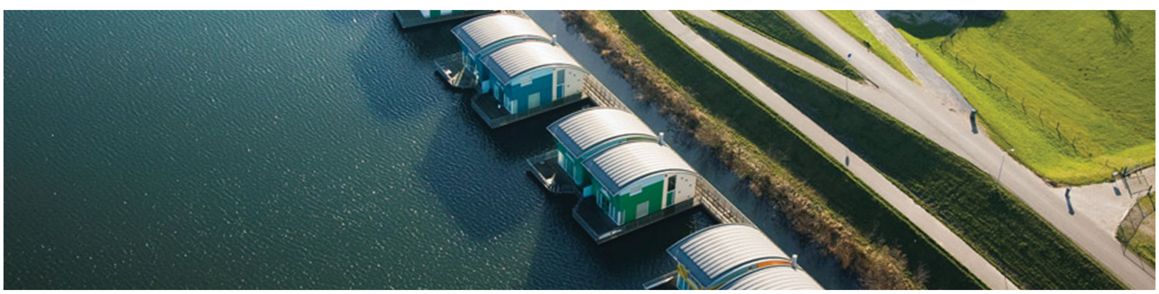
Site plan illustrating Silodam’s high density housing program in relation to the urban core (Image edited from Ryan 2010)



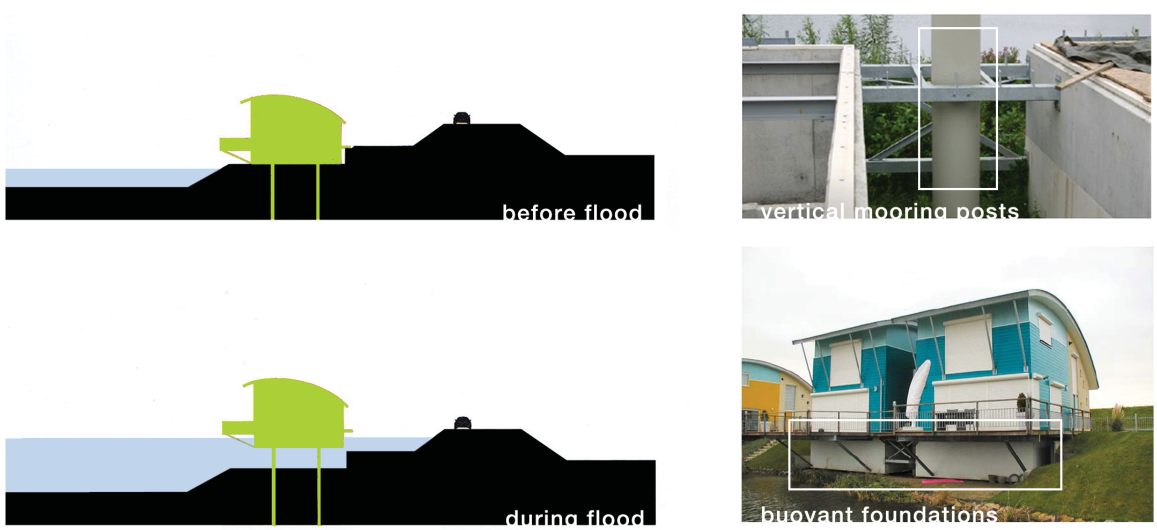
Programmatic relationships, public and private spaces and internal neighbourhoods of the Silodam (Image edited from Ryan 2010)

Amphibious Homes
Maasbommel, Netherlands
Dura Vermeer 2008

The very first fully engineered amphibious homes were designed and built by Dura Vermeer at Maasbommel on the Maas River in the Netherlands as a response to river flooding. The Maasbommel project consists of 34 amphibious houses, which are capable of floating with rising water levels. Each house is built on a watertight hollow concrete and polystyrene basement that becomes a buoyant foundation for the house when it floats. The houses can rise to a maximum of 18 feet by sliding along two vertical mooring poles that are permanently inserted into the ground between each pair of houses. These poles restrict horizontal movement to ensure the houses do not float away when the water levels are high. In addition to the amphibious houses, the Maasbommel project has 14 continuously floating homes (Nillesen and Singelenberg 2011, 35).



Aerial view of amphibious houses along the waterfront at Maasbommel (Nillesen 2011)



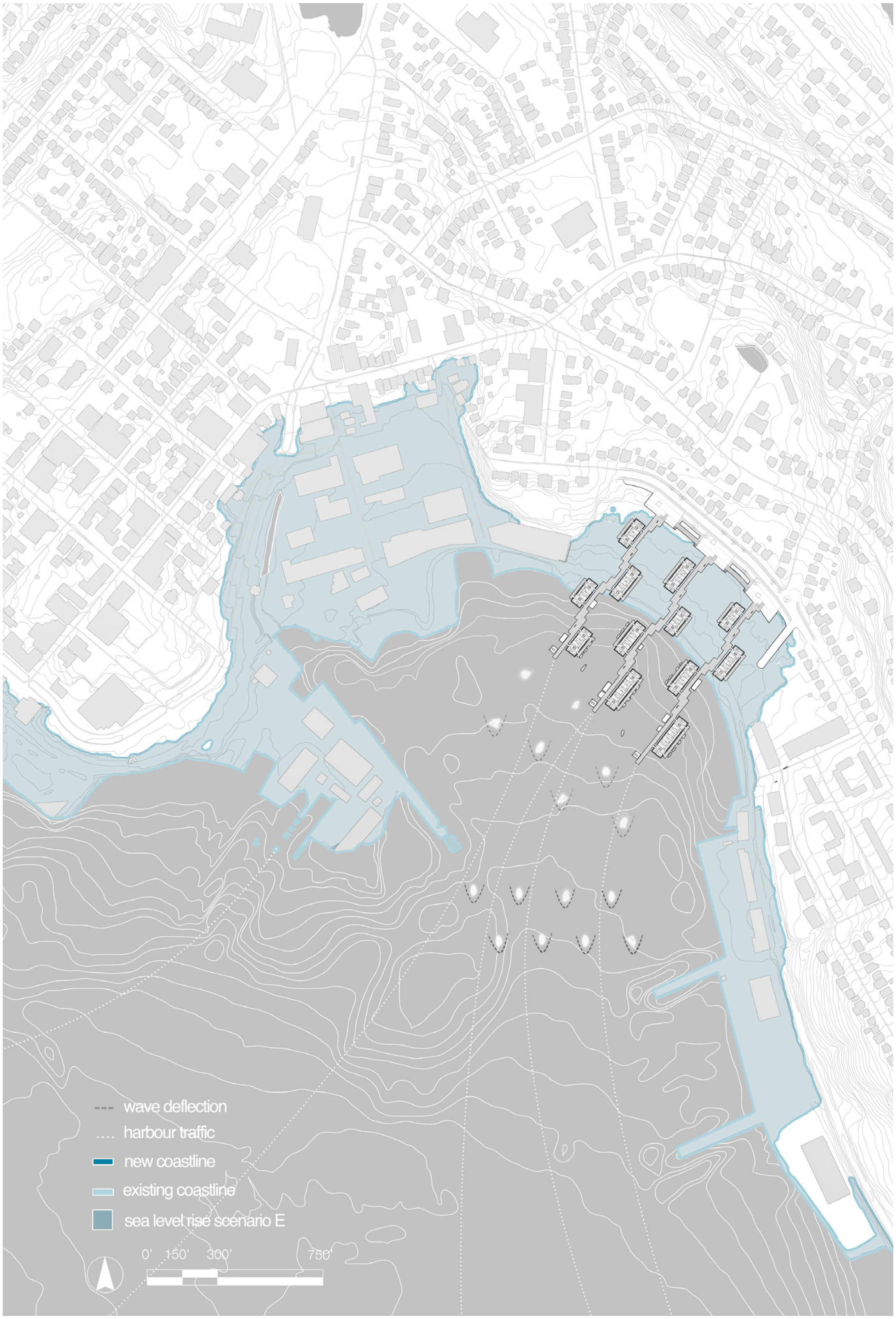
Buoyant foundations and permanent vertical mooring posts allow the amphibious houses to rise in a controlled manner with flood waters. (Image edited from Nillesen 2011)

CHAPTER 4: DESIGN

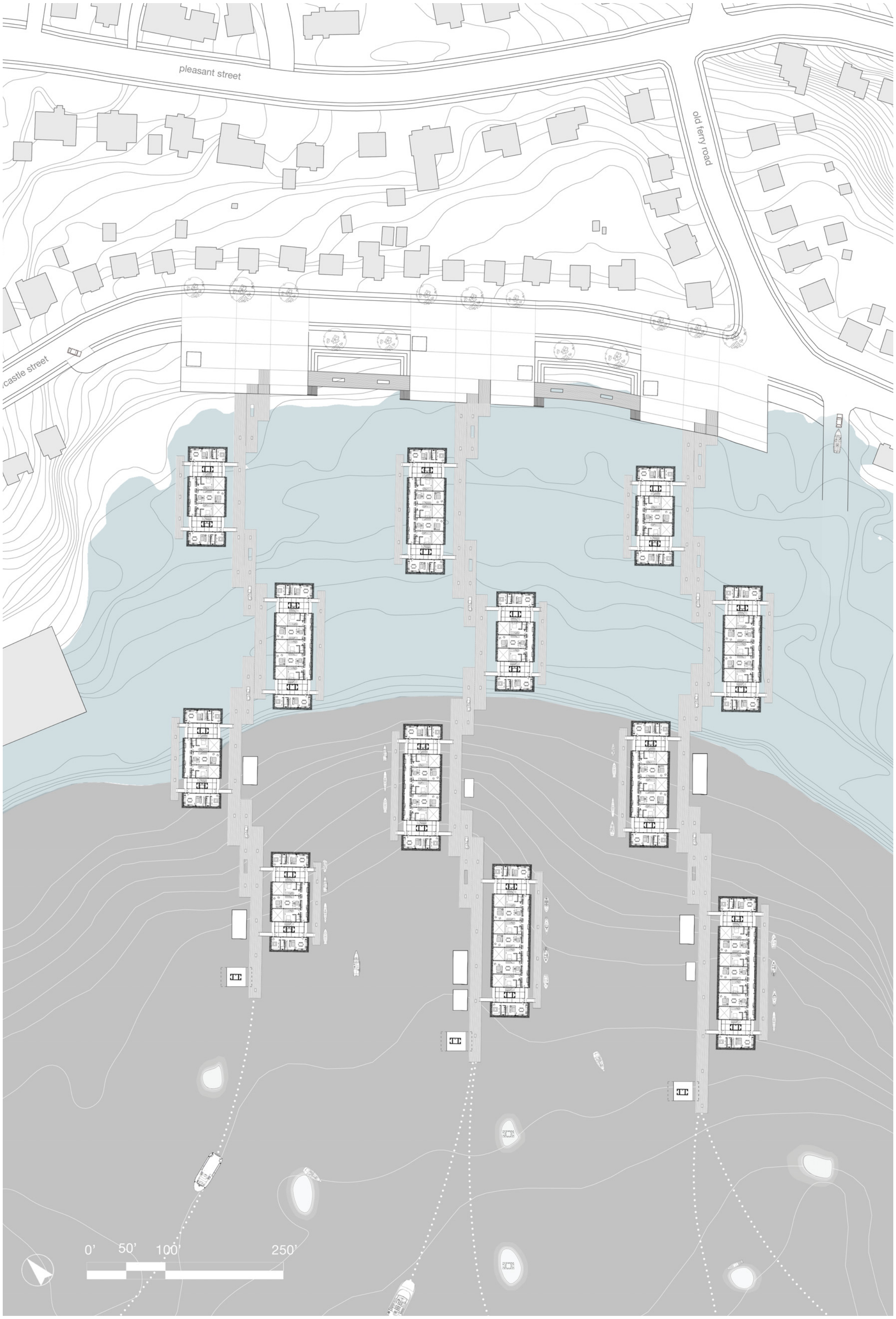
Urban Scale

At the urban scale the thesis design seeks to develop a community that can respond to rising sea level as it accommodates an expected growth in population over the next century. It assumes that the existing homes and infrastructure within the floodplain for Dartmouth Cove will be removed and replaced by an amphibious community.

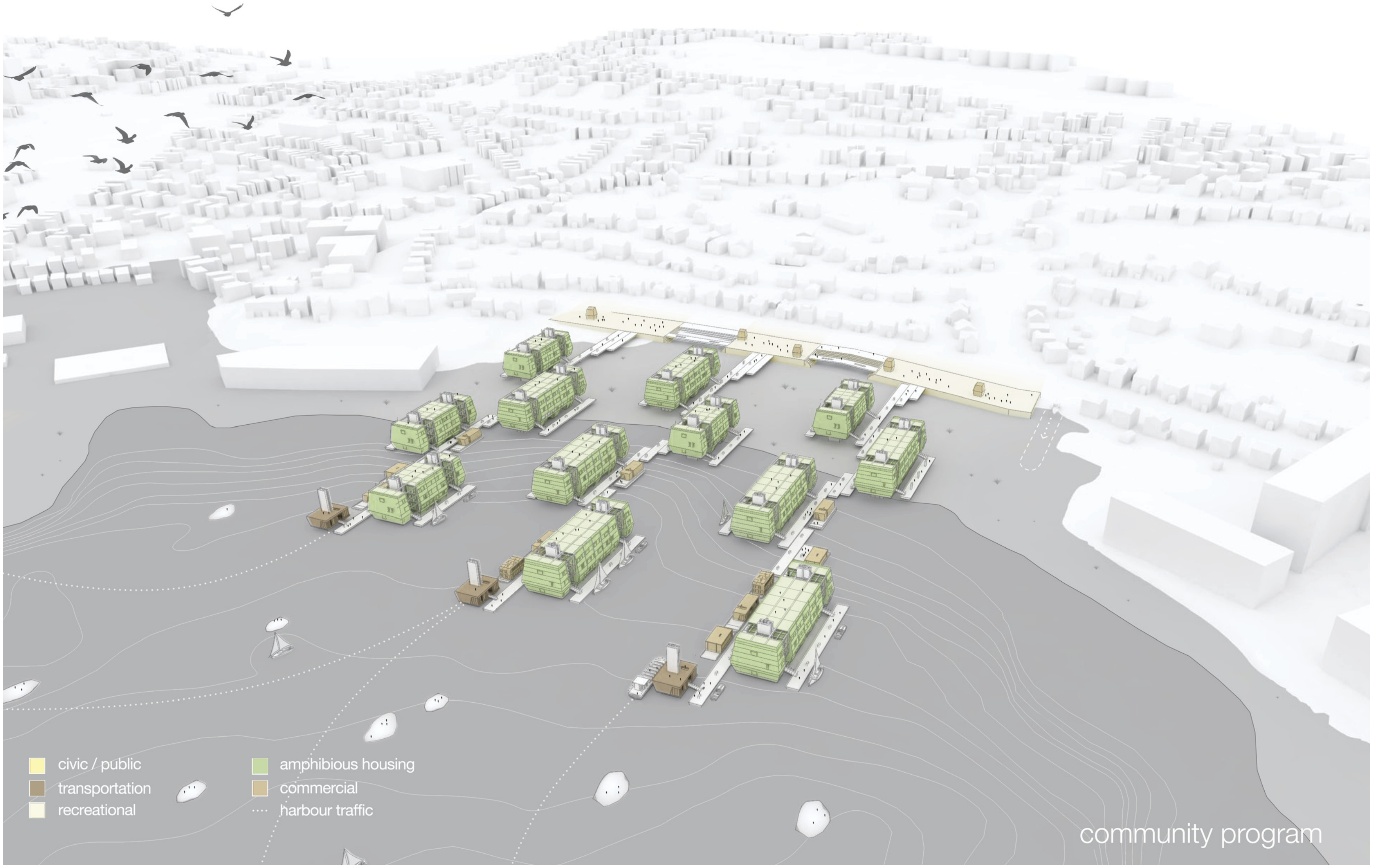
Rather than growing parallel to the existing fabric this new community will be oriented perpendicular to the shoreline. In this sense the city extends into the water, blurring the boundaries between land and sea. A network of amphibious pedestrian piers (supporting housing blocks and public leisure areas) extends the existing city infrastructure, providing docking points for a new harbour oriented transit system. Beyond the piers is an archipelago of man-made islands that encourage silt accumulation, fostering a natural resilience against storm surges and generating destinations for recreation and habitat. At the same time the water extends into the city, transforming the existing landscape into an aqueous terrain that encourages the growth of coastal ecologies. This new amphibious landscape is punctuated by a series of tidal pools, infiltration basins and bioswales that absorb storm water runoff and function as parks in dry weather. The intersection between the amphibious community and the existing suburban fabric is a hard edge or anchor which supports a seaside promenade and provides public space for the city.



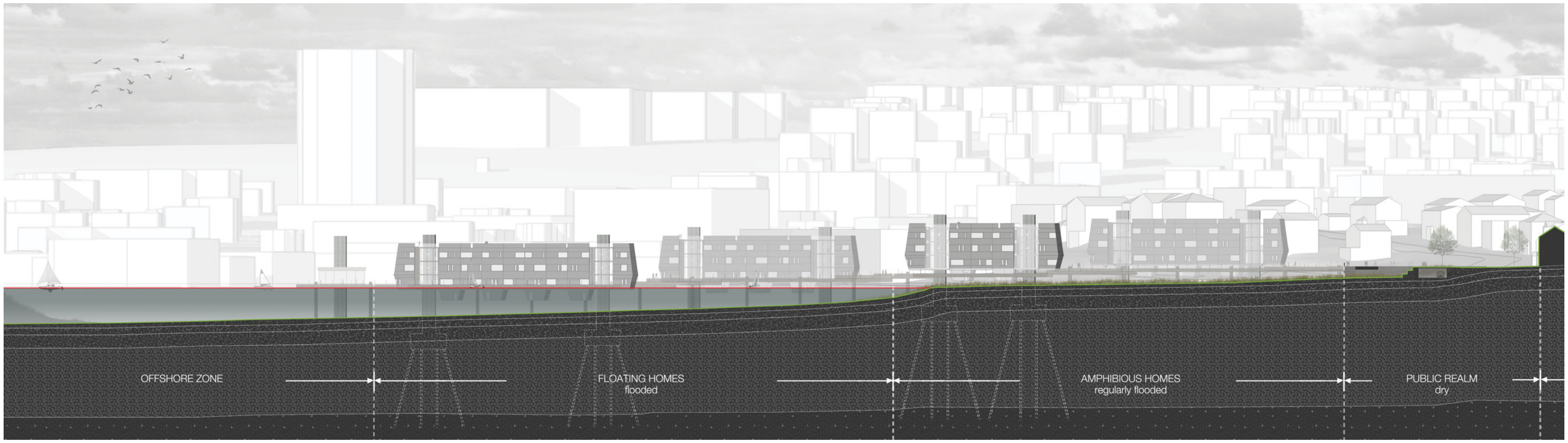
Site plan of the amphibious community in Dartmouth Cove



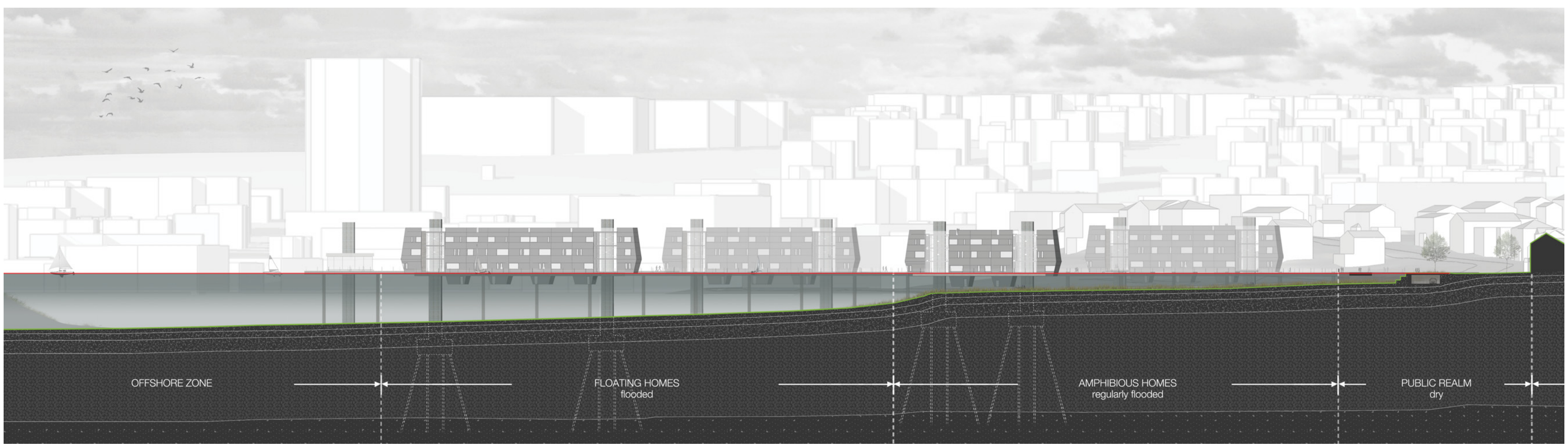
Site plan of the amphibious community in an urban context



Program diagram of the amphibious community

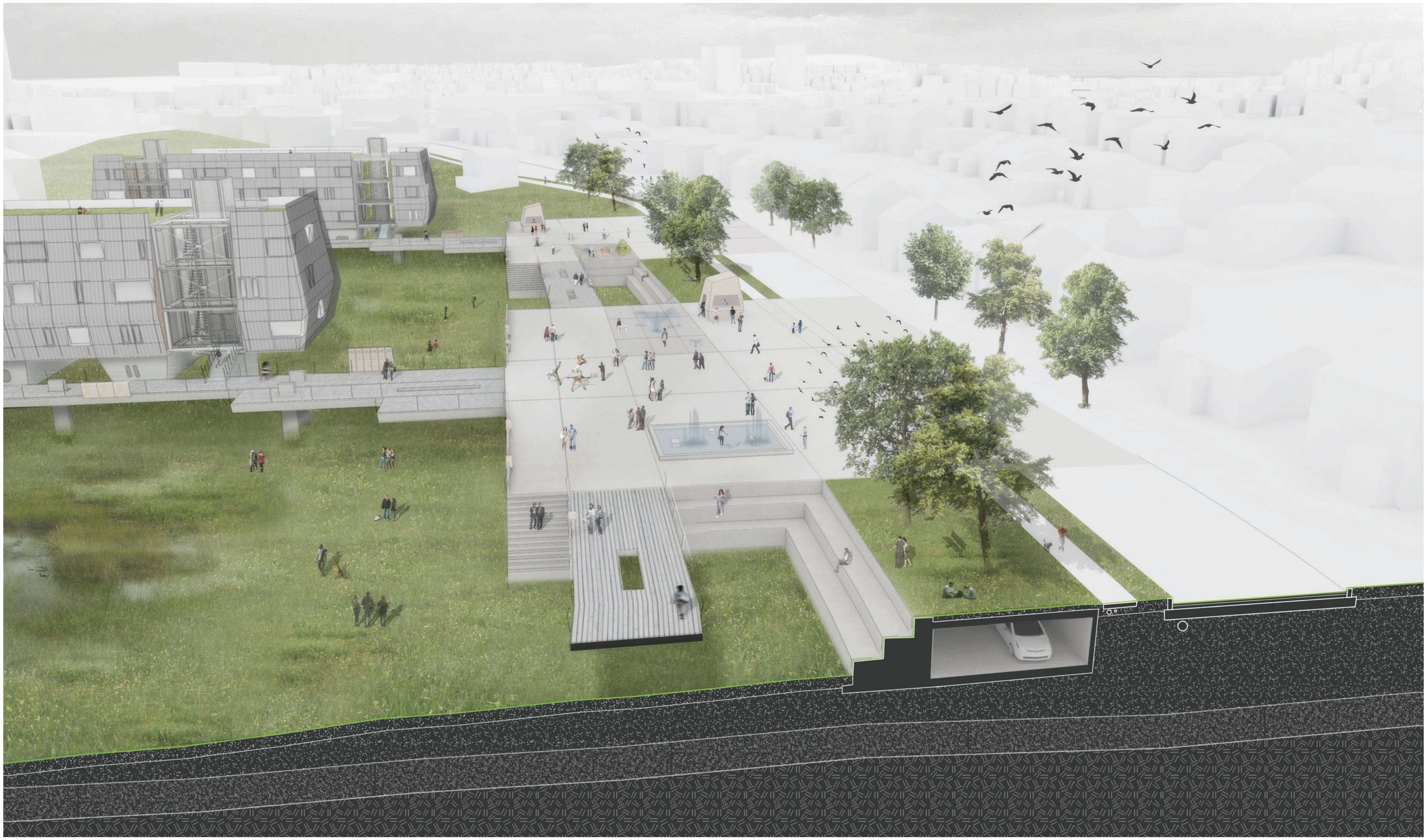


Before flooding

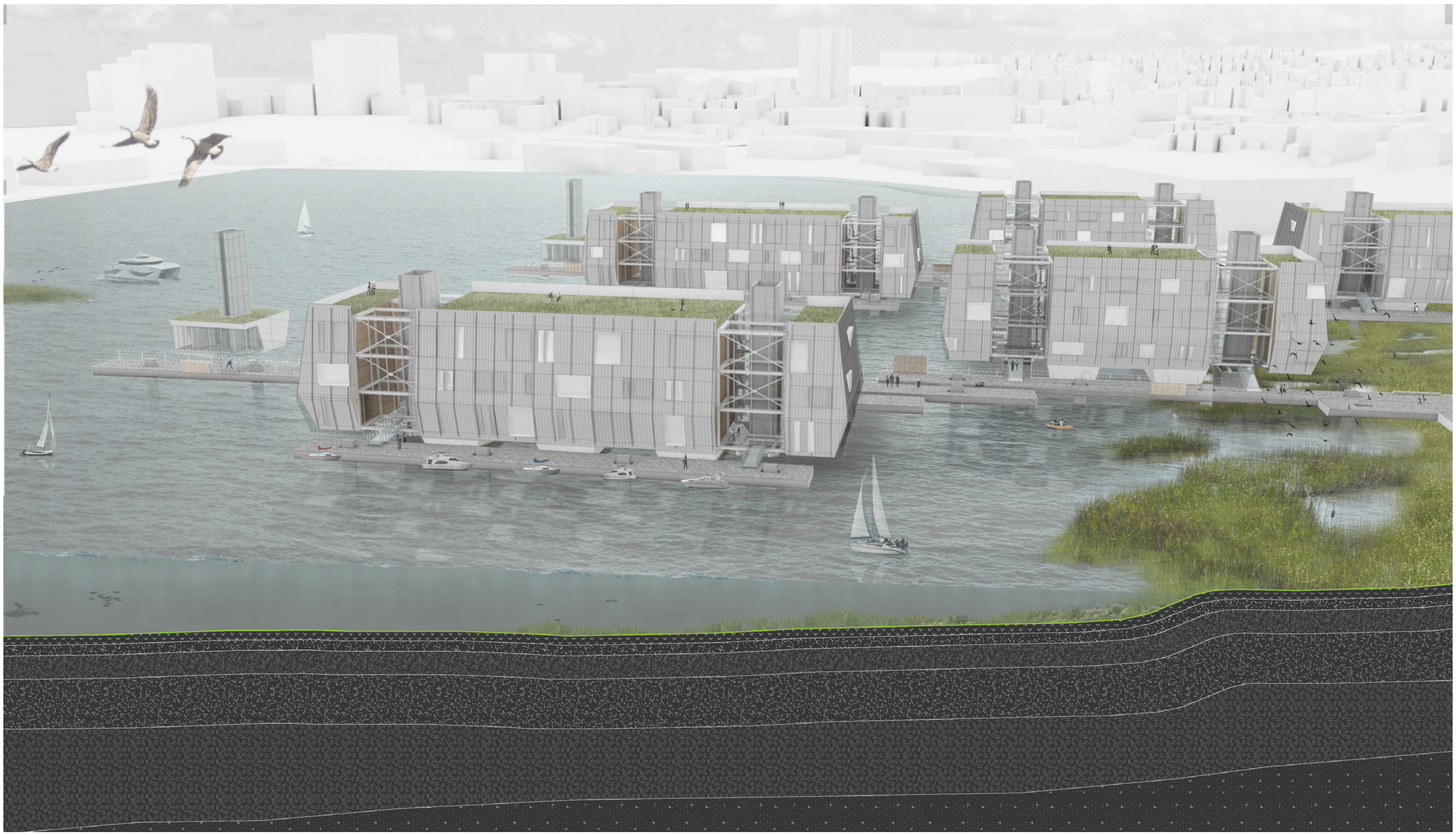


After flooding

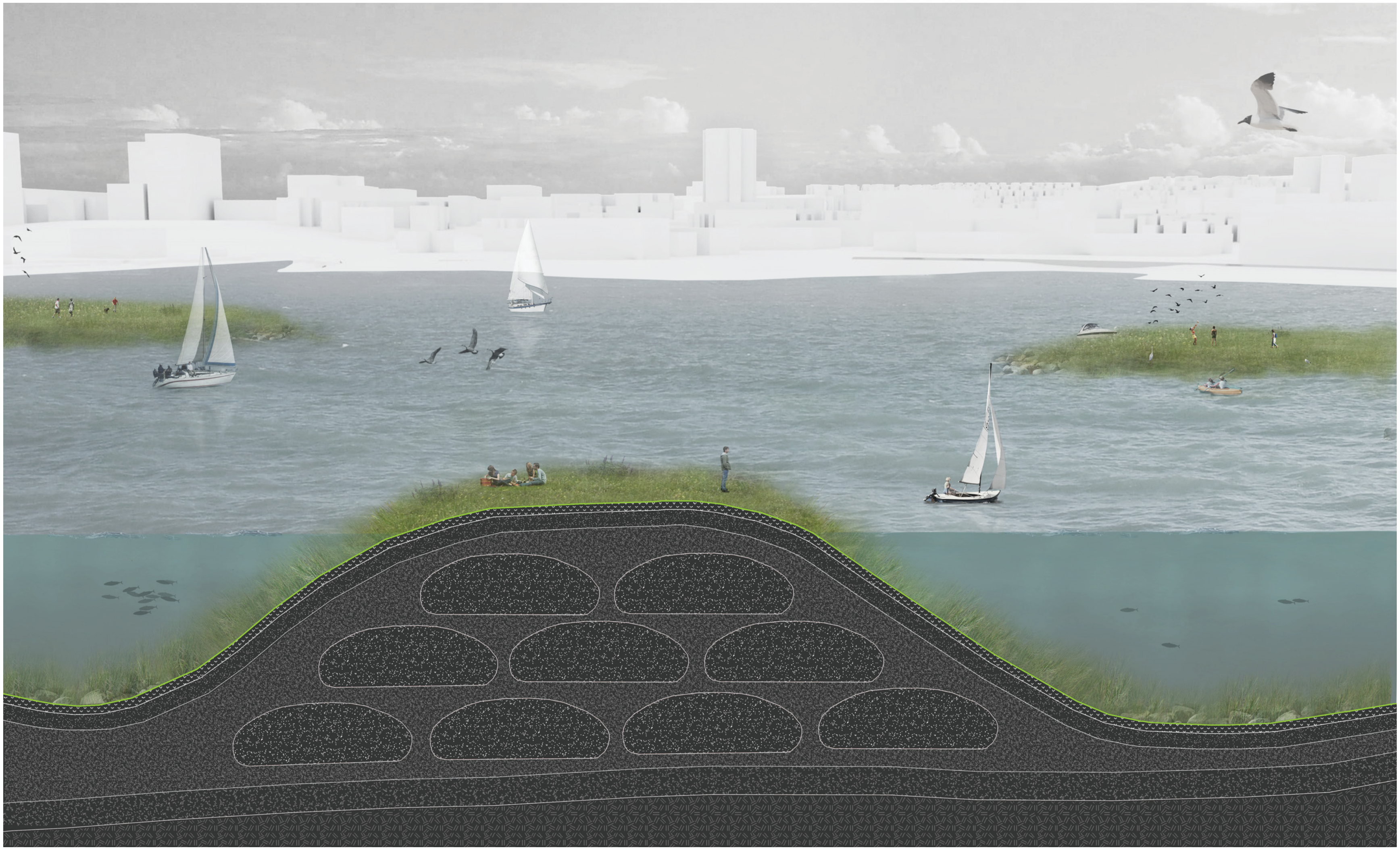
Longitudinal section through the site, illustrating amphibious housing blocks before and after flooding



Sectional perspective of the civic space that links the amphibious community to the existing suburban fabric



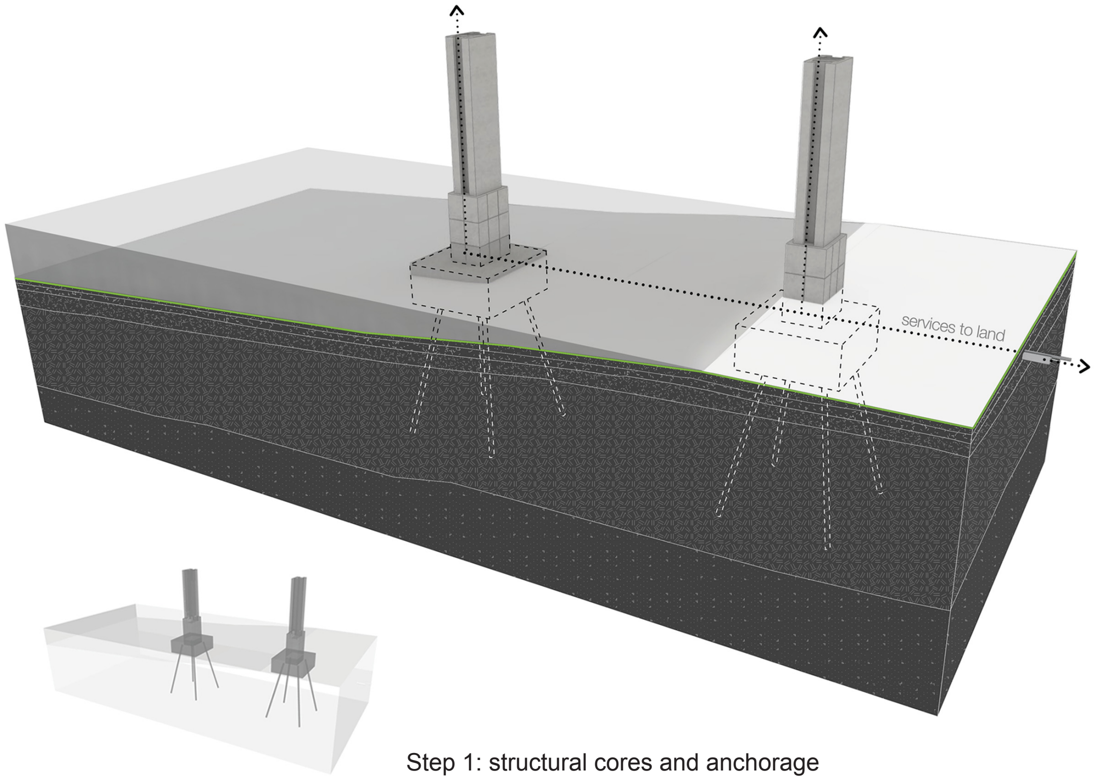
Sectional perspective of the amphibious housing blocks on dry land and in water



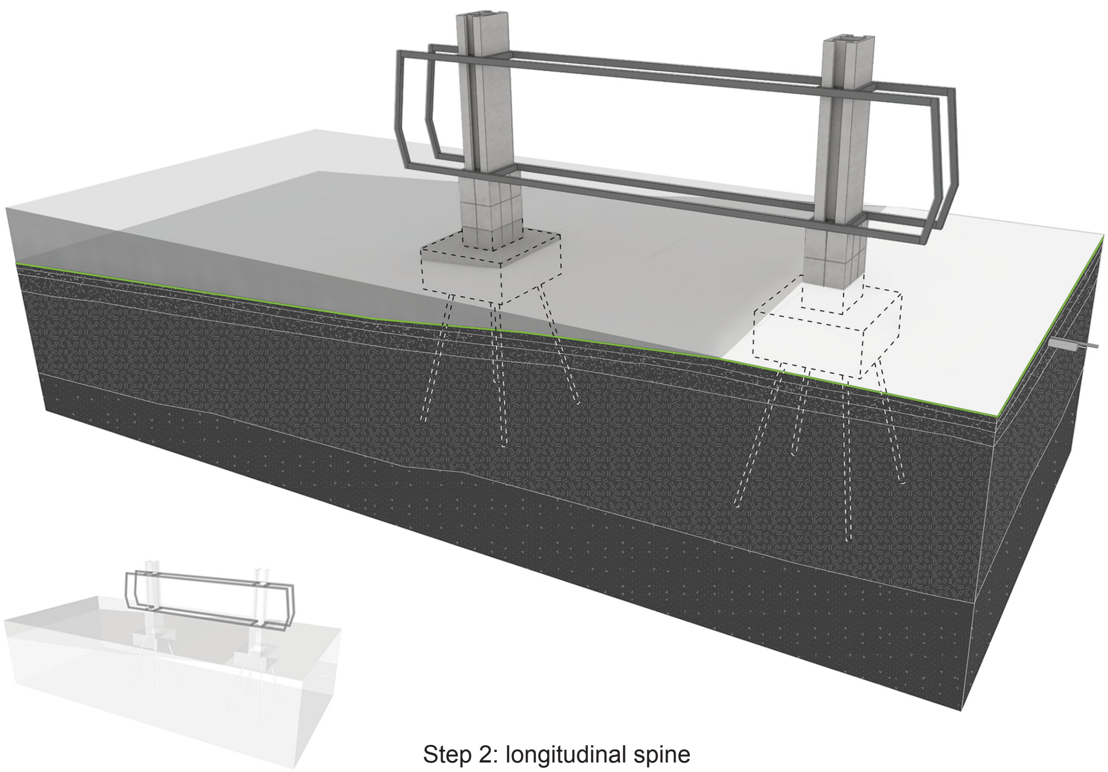
Sectional perspective of the archipelago of man-made islands beyond the amphibious community

Building Scale

Amphibious housing blocks are designed to maximize density (to accommodate population growth) and minimize impact (to allow natural landscapes and ecologies to develop). The general form of the blocks is a hybrid of land and water based elements. Central to their design are the structural cores, which provide services and support to the housing units. On land these cores function as dry docks, suspending the housing blocks above the ground. In water the cores act as mooring posts, allowing the homes to rise and fall with the rhythms of the tide. Each housing block plugs into the amphibious pedestrian piers through a flexible gangway connection which provides access to the blocks. On the opposite side an additional pier serves as the "back porch" for the homes, acting as a viewing and gathering platform on dry land and a mooring station in water. While the underside of the blocks is shaped to maximize buoyancy, the roof serves as a shared community green space and a safe haven in severe storm events.

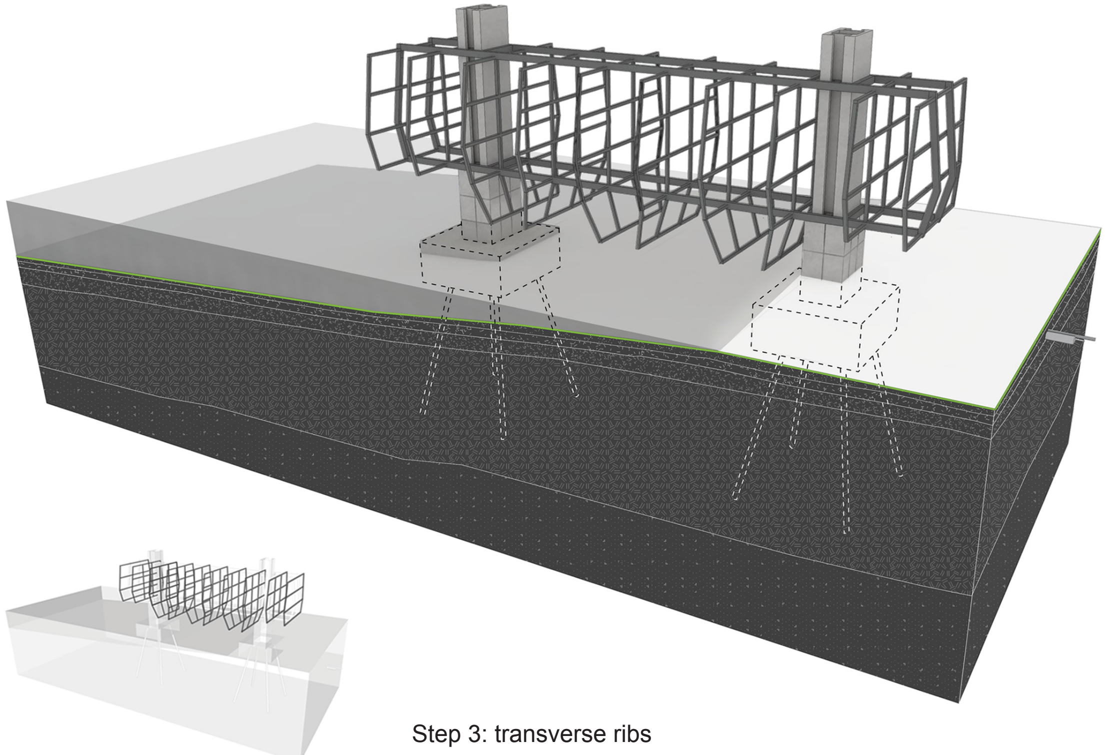


Step 1: structural cores and anchorage

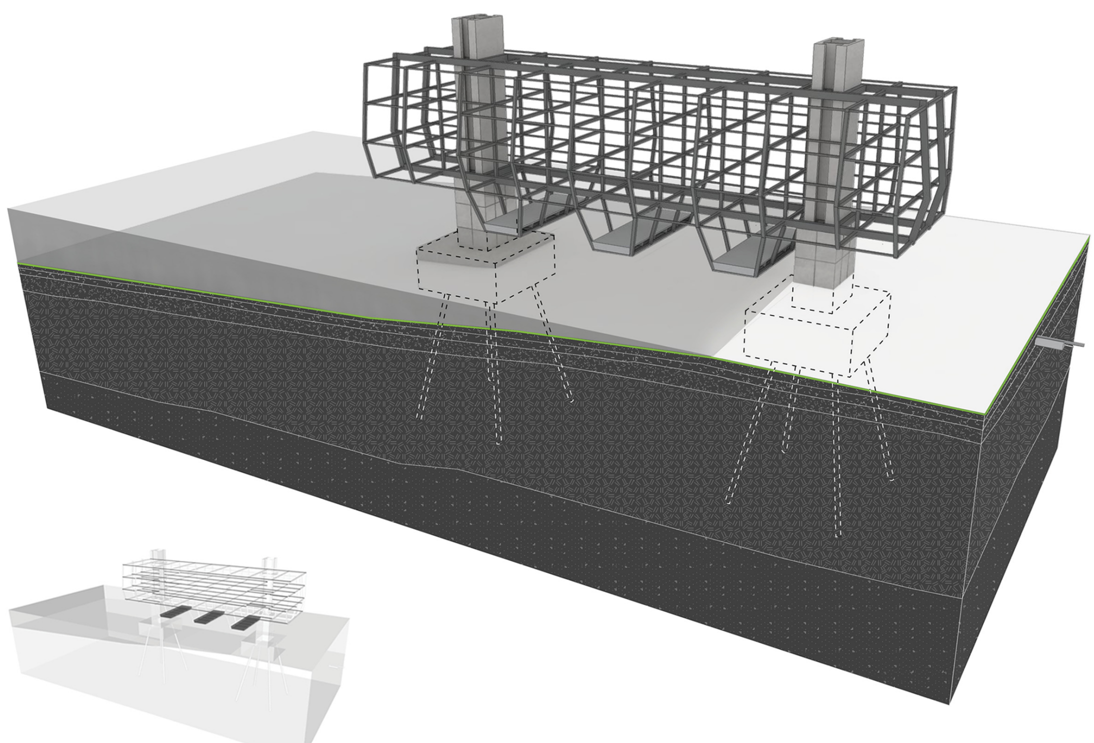


Step 2: longitudinal spine

Steps 1 and 2 of the structural sequence for an amphibious housing block

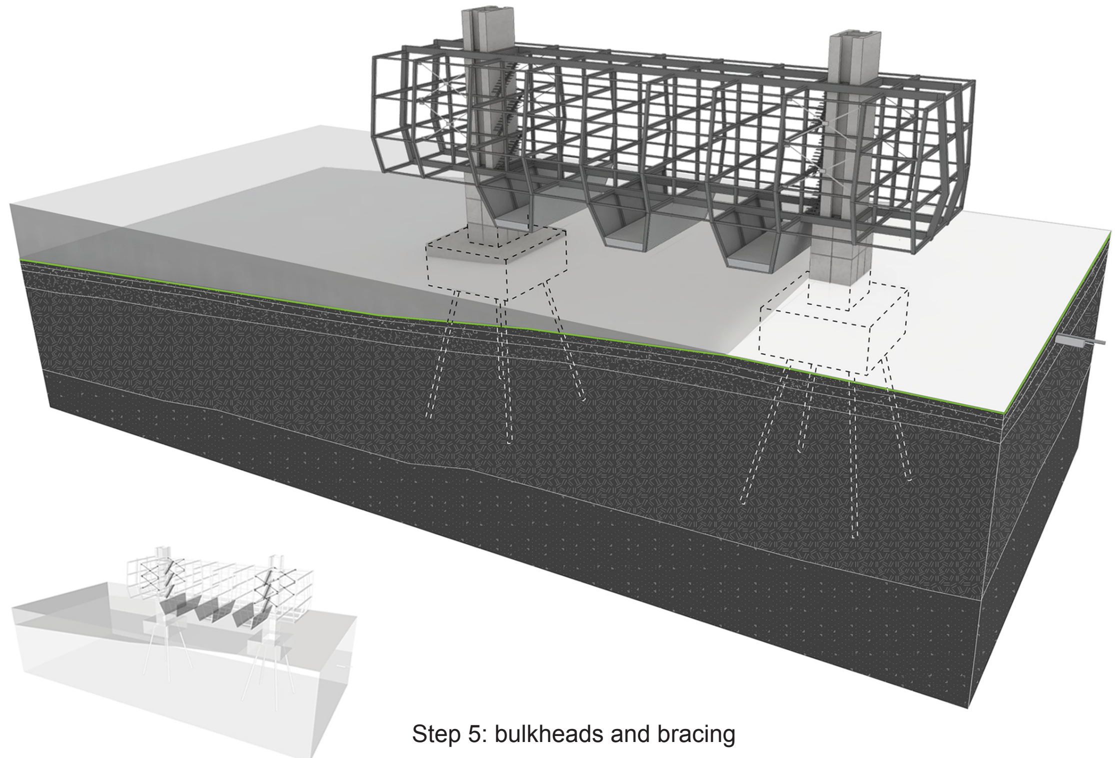


Step 3: transverse ribs

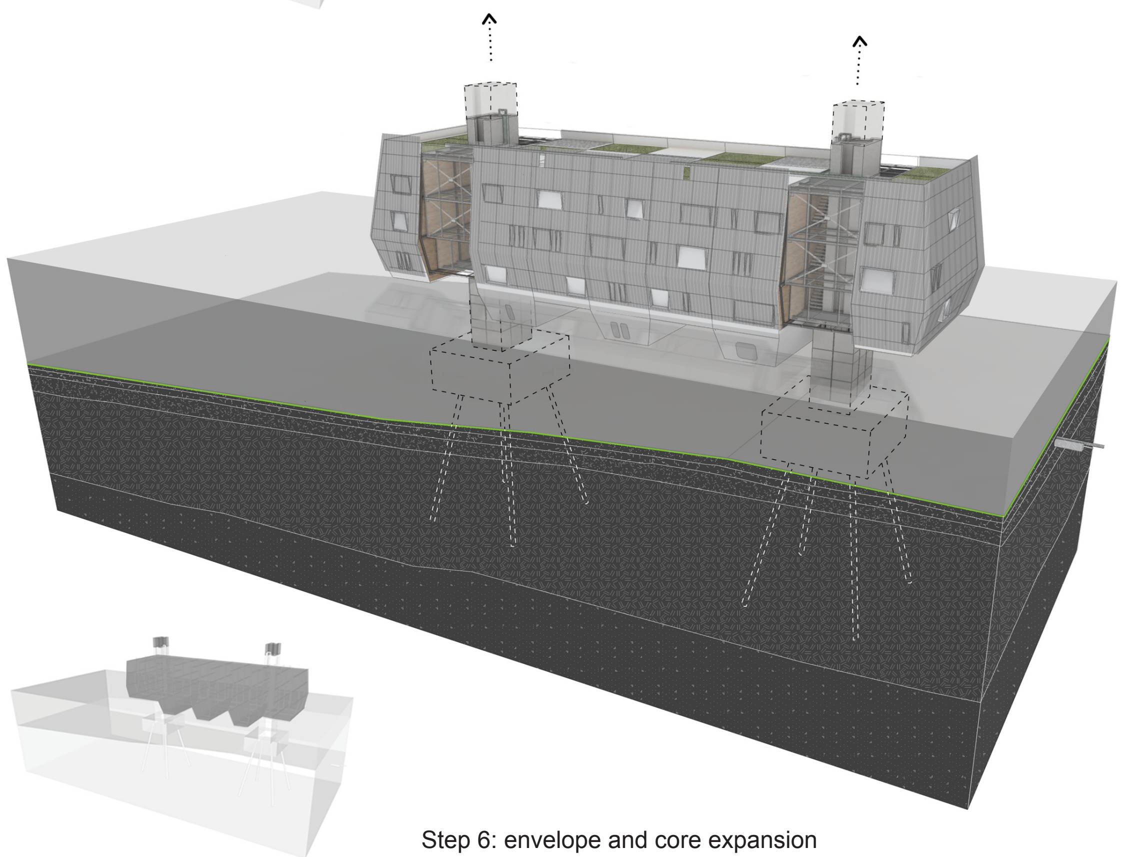


Step 4: ballasts

Steps 3 and 4 of the structural sequence for an amphibious housing block

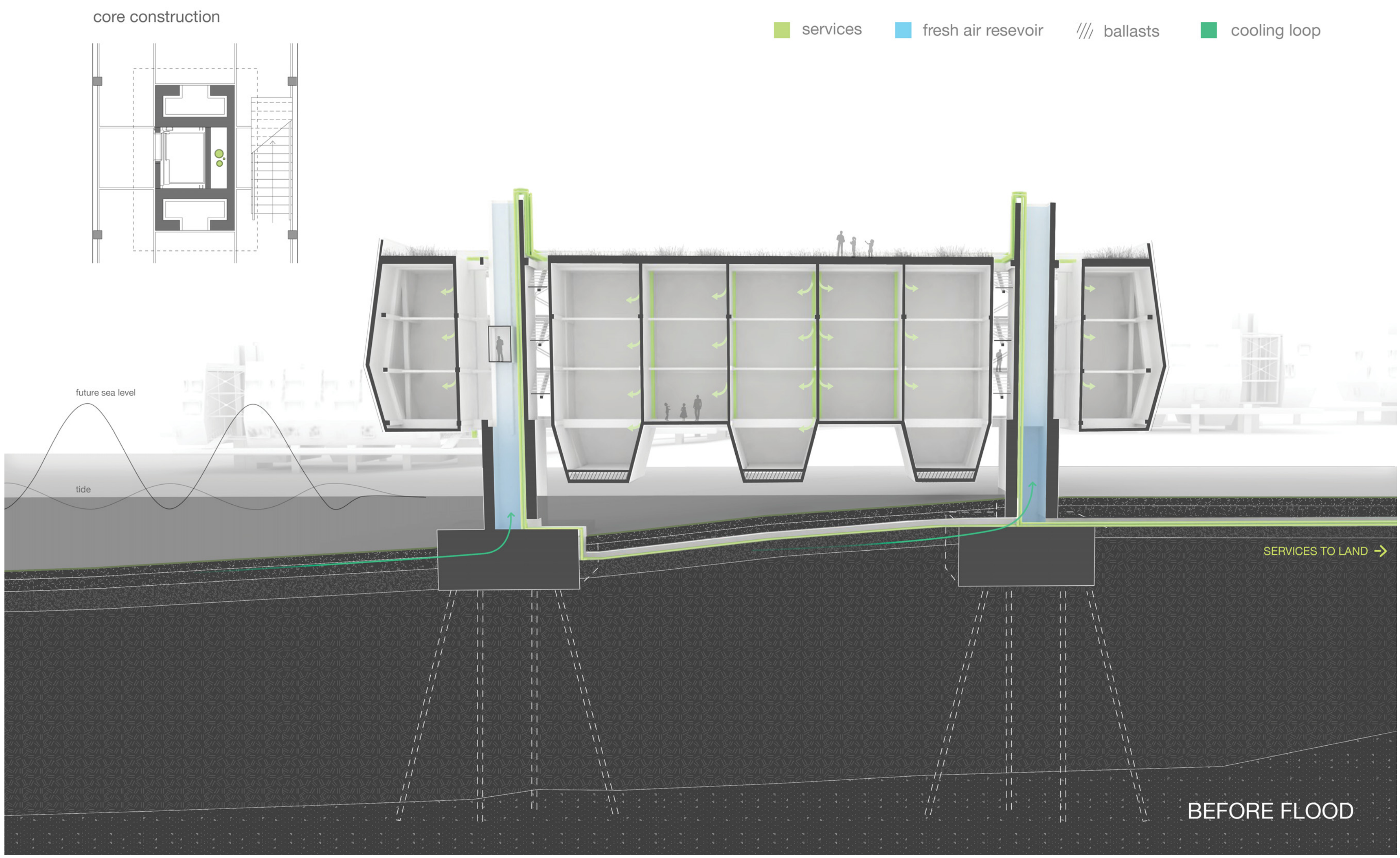


Step 5: bulkheads and bracing

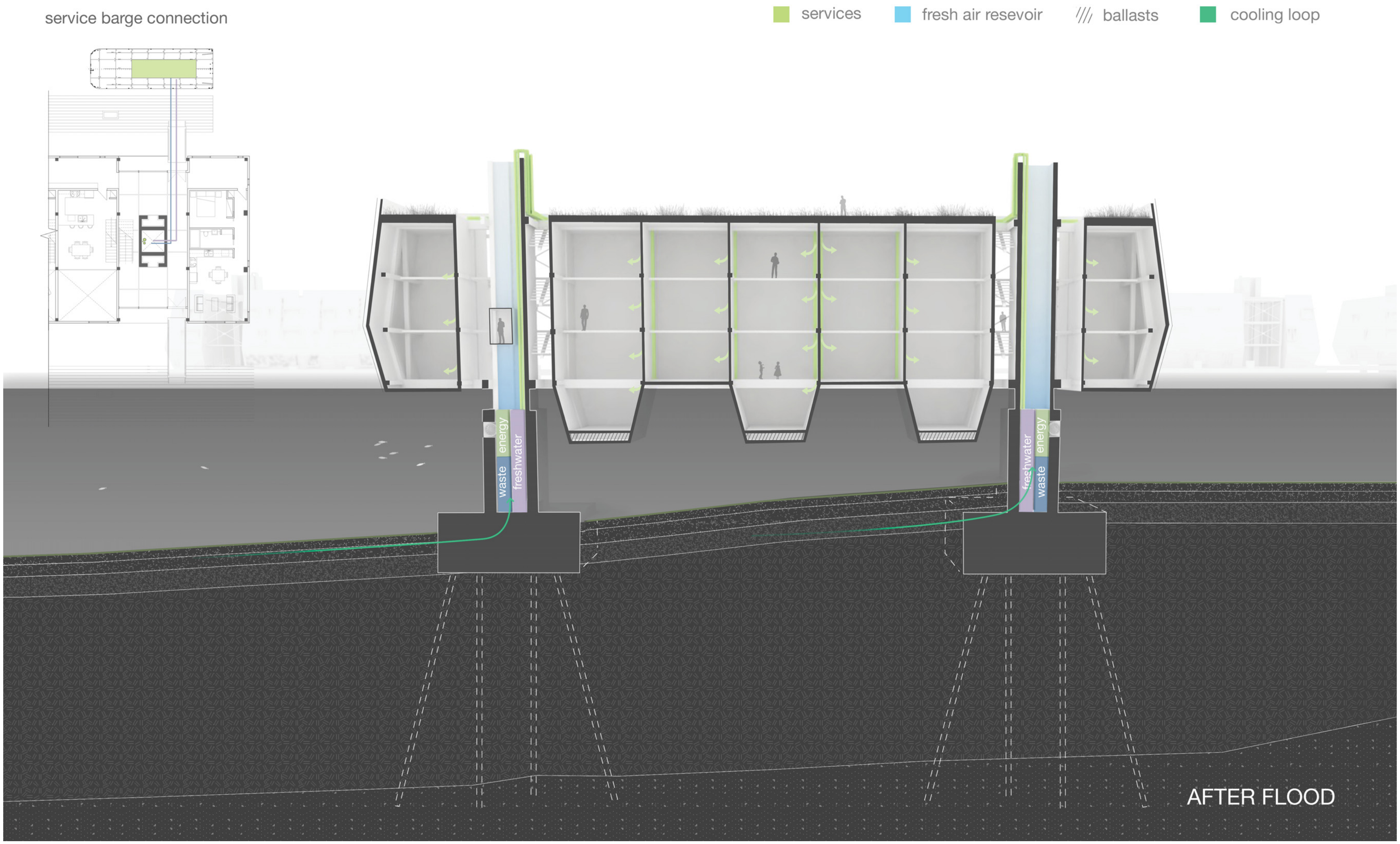


Step 6: envelope and core expansion

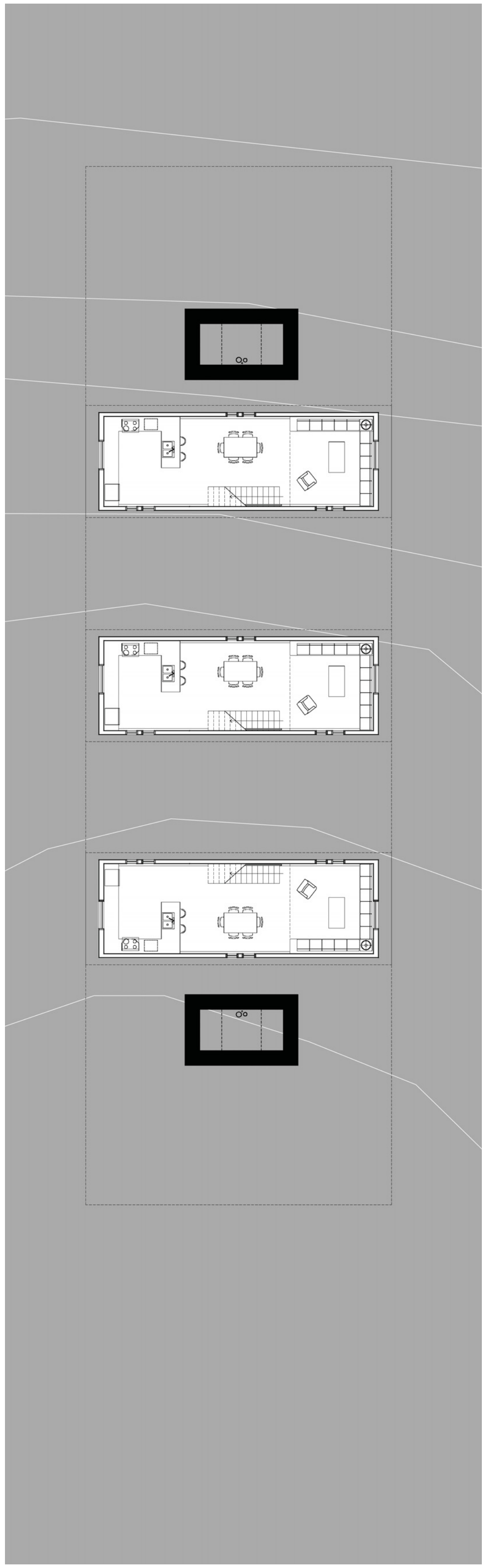
Steps 5 and 6 of the structural sequence for an amphibious housing block



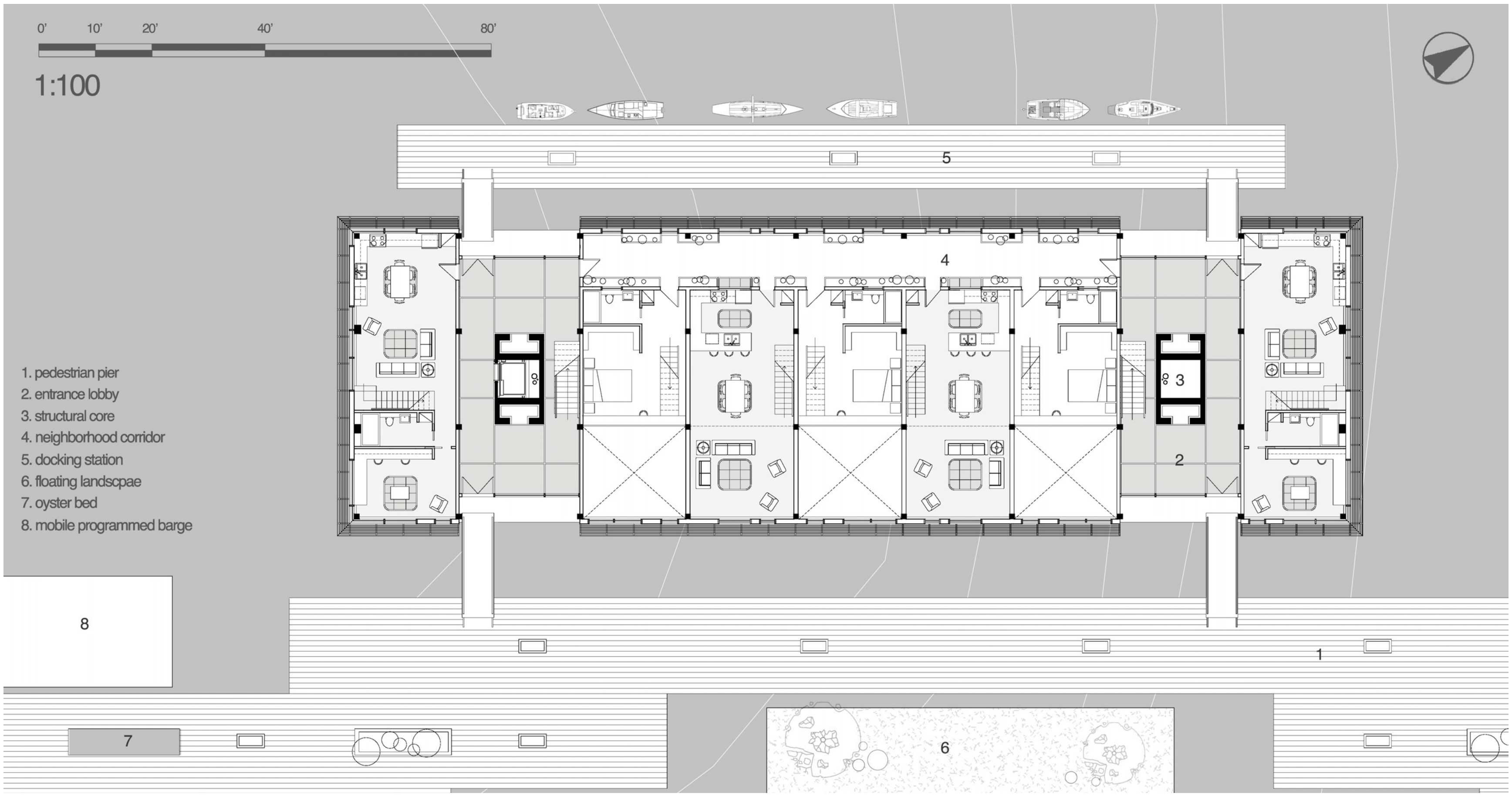
Longitudinal section illustrating land dependent services before flooding



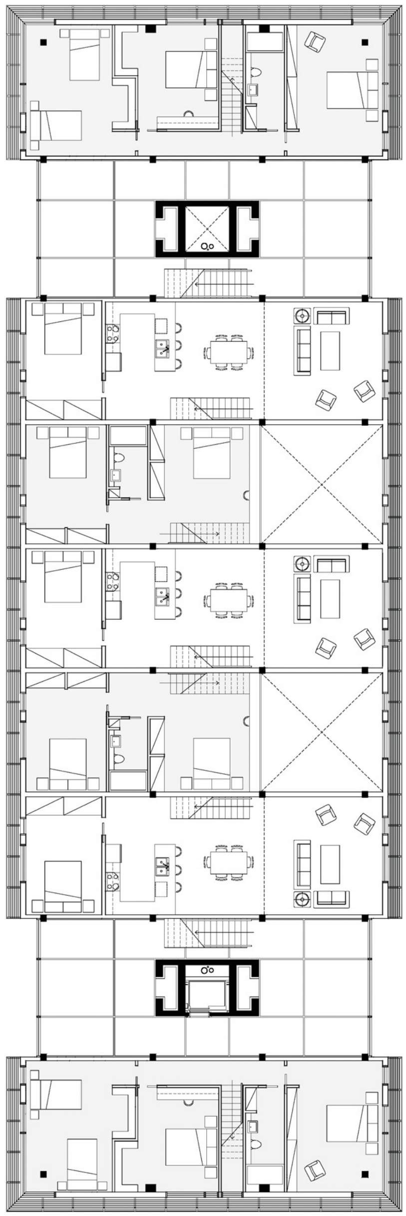
Longitudinal section illustrating land independent services after flooding



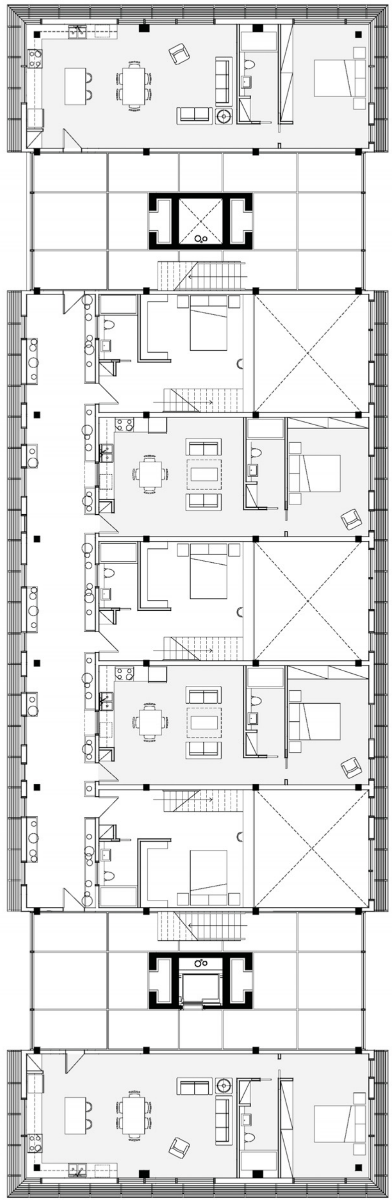
Underwater plan of an amphibious housing block



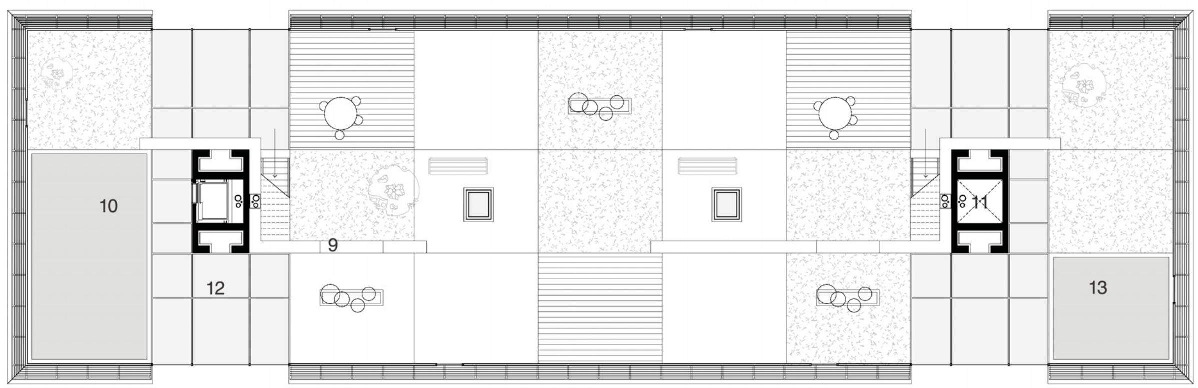
Ground floor plan of an amphibious housing block, illustrating its relation to the pedestrian piers



Second floor plan of an amphibious housing block

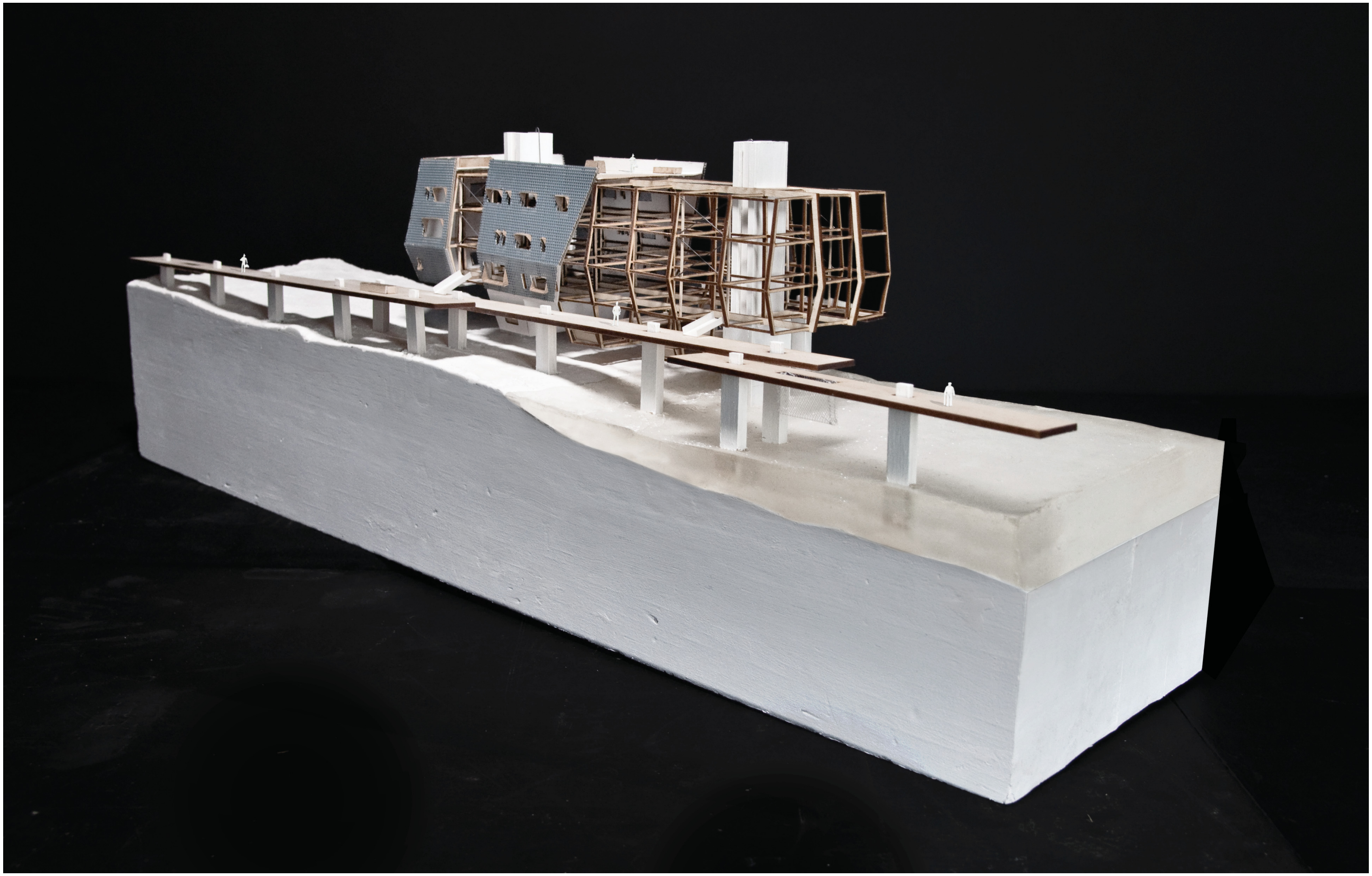


Third floor plan of an amphibious housing block

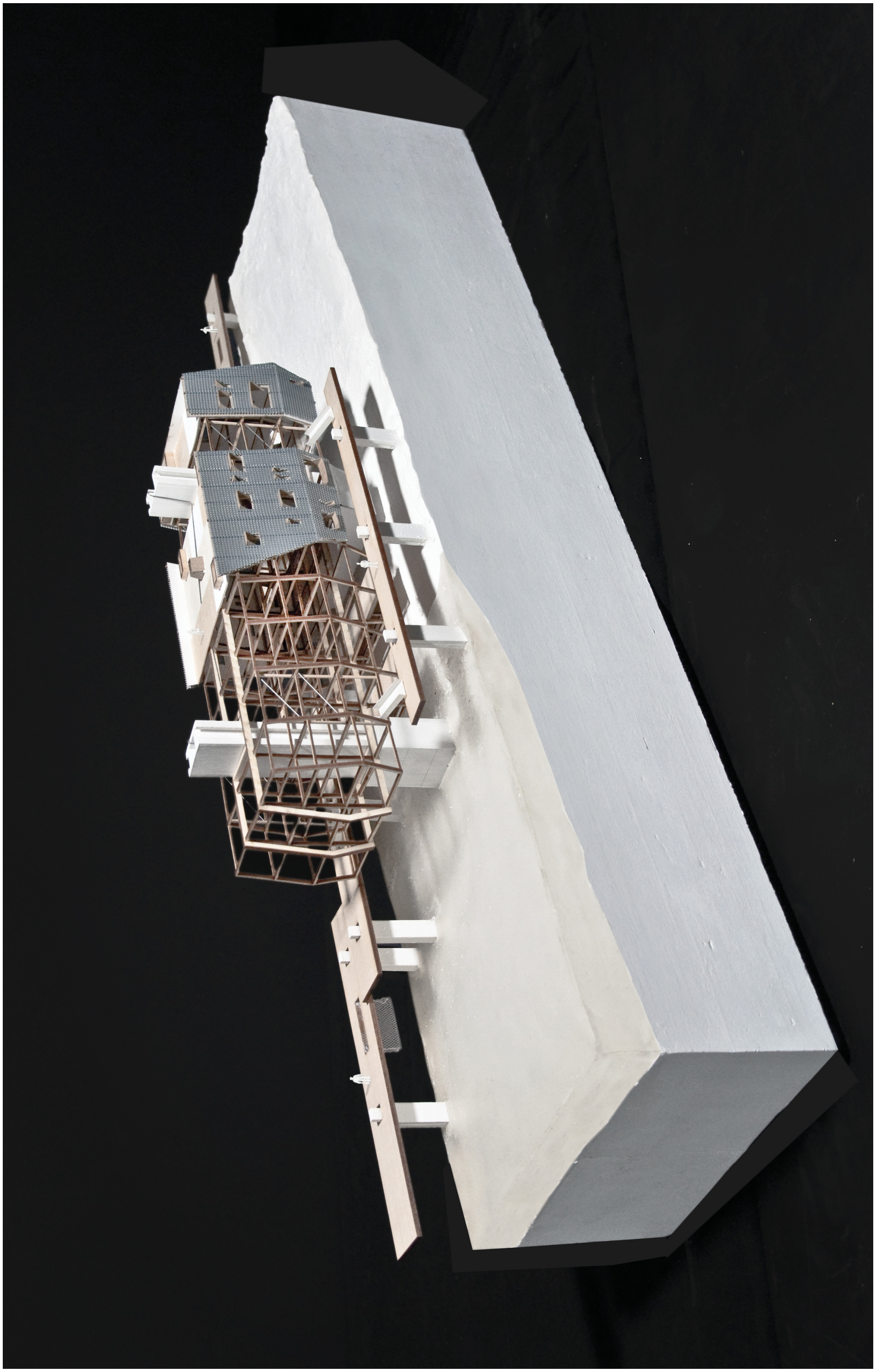


9. service lines
10. pool
11. structural core
12. glass floor
13. hot tub

Roof plan of an amphibious housing block, illustrating the shared community space



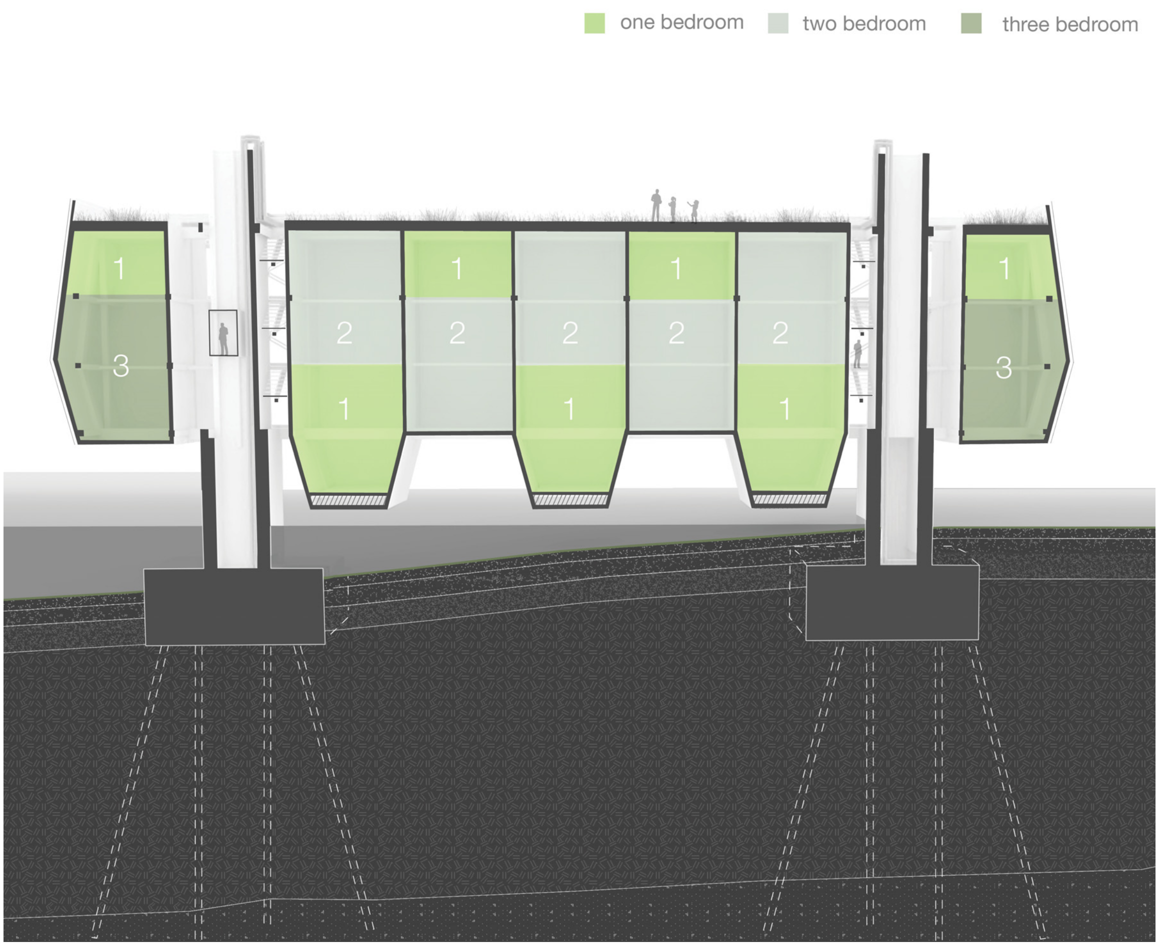
Structural model of an amphibious housing block, illustrating the front yard space



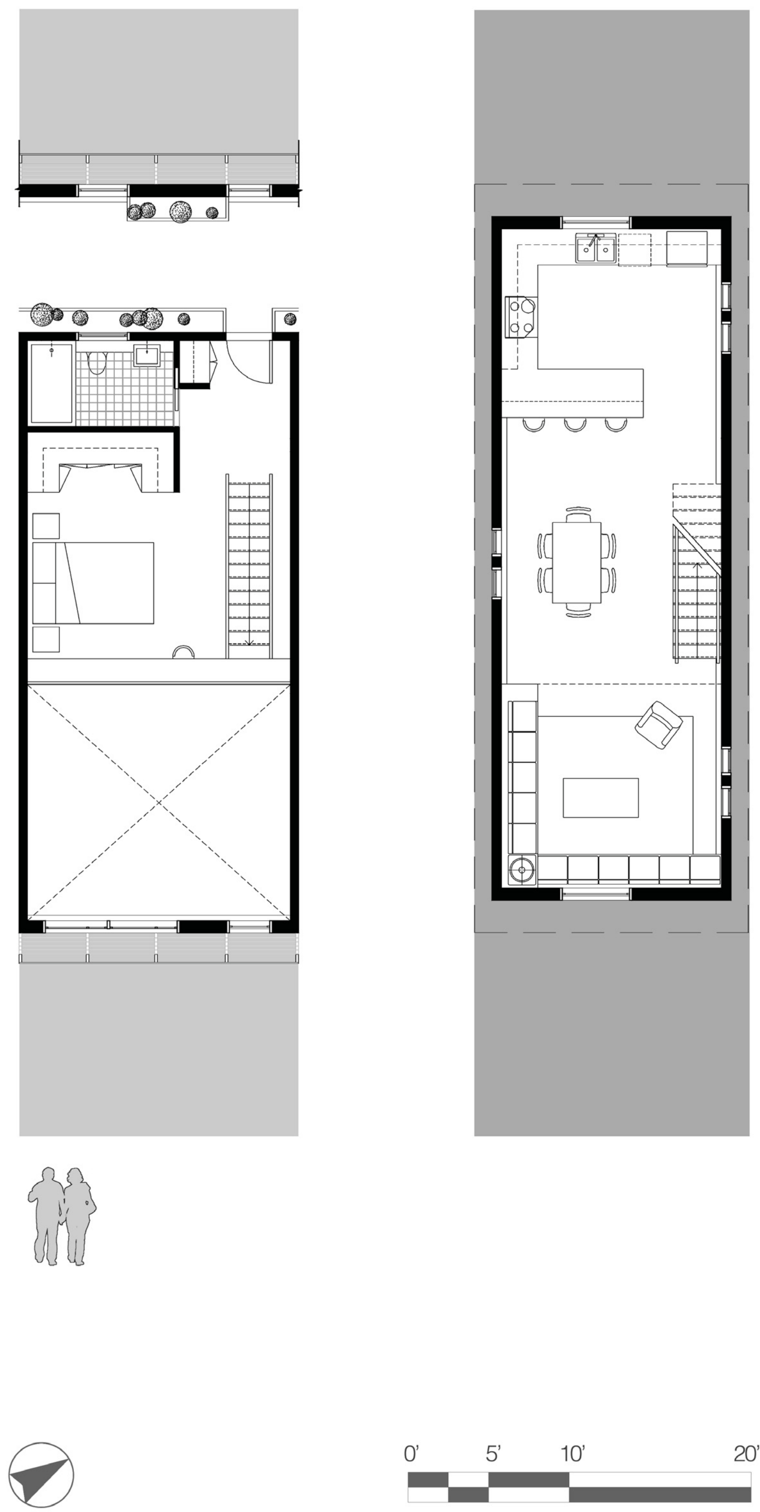
Structural model of an amphibious housing block, illustrating the backyard space and the community rooftop

Dwelling Scale

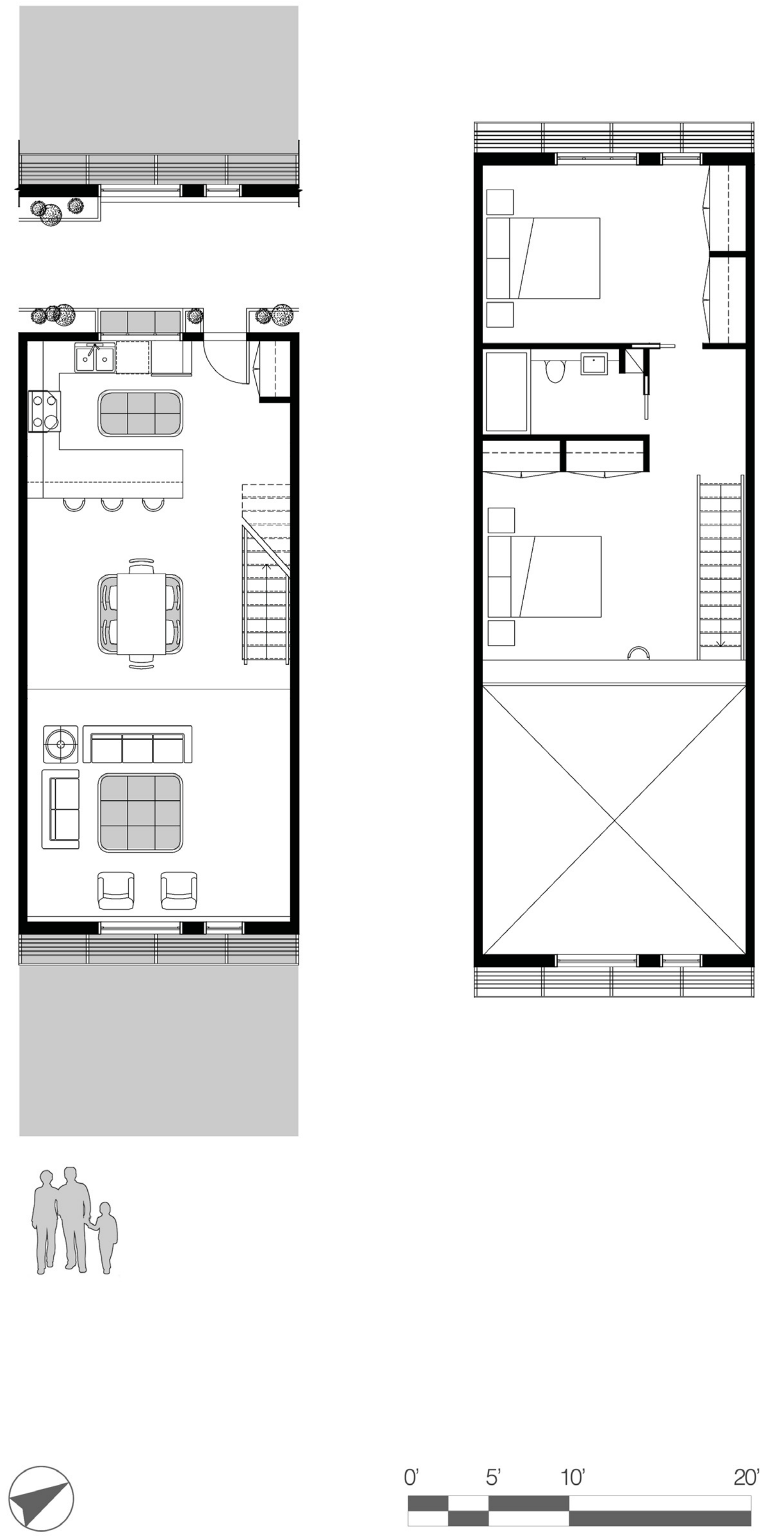
Within the amphibious housing blocks a transparent lobby space surrounding the cores serves to receive residents, but also display the mechanics and functioning of the building. From the lobby space a stacked single loaded neighbourhood corridor provides a route to individual housing units. Various unit types have been developed (1-3 bedroom) to accommodate a range of dwelling possibilities for singles, couples, and families. The housing units are also stacked, with most above and some partially below the waterline to provide a variety of living conditions. The units are arranged longitudinally with a double orientation to enhance natural ventilation, light and views. Haptic qualities are further enhanced through the interior of each unit, with an amphibious material palette of both land and water based elements.



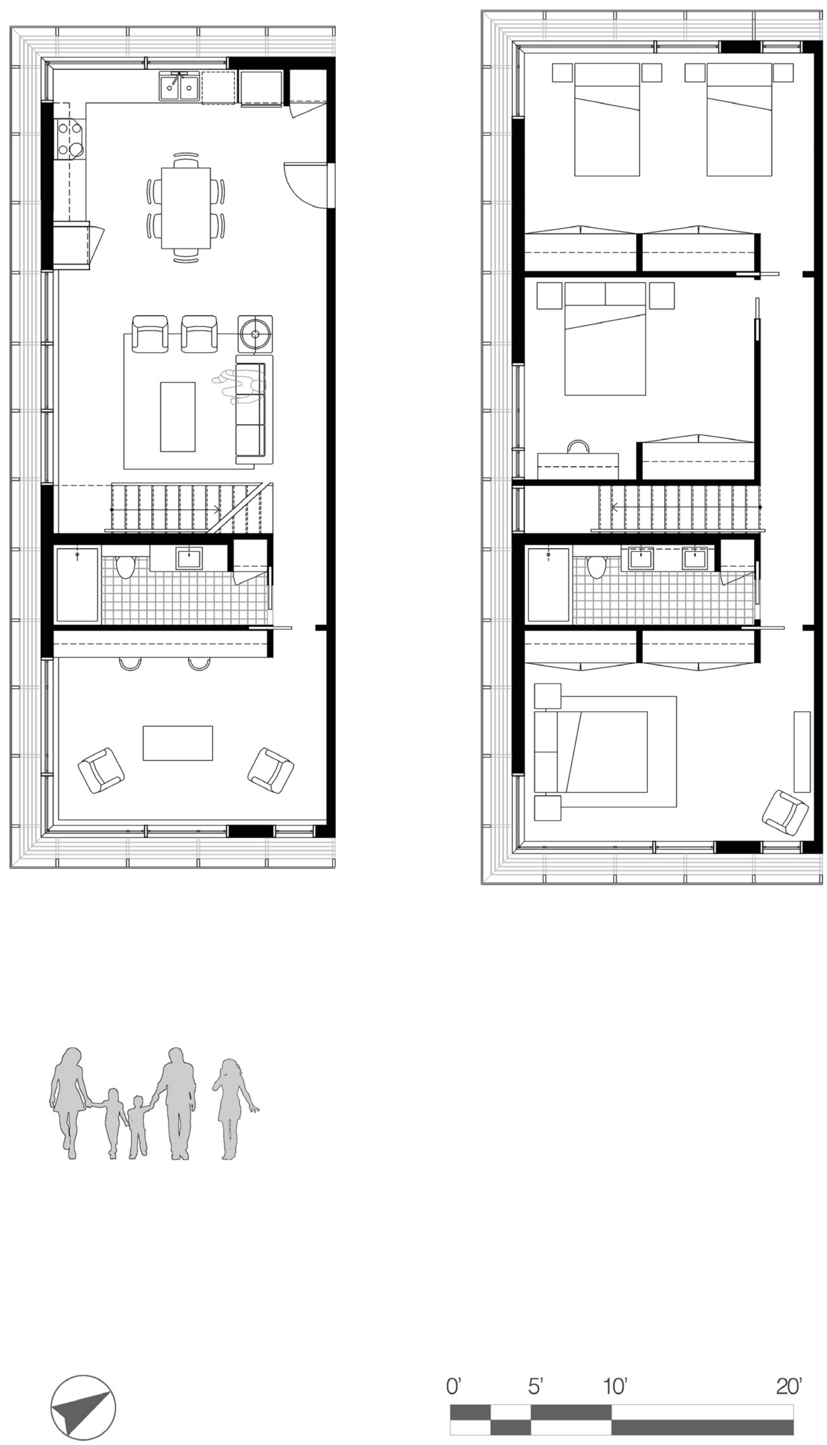
Program diagram of the interlocking units within an amphibious housing block



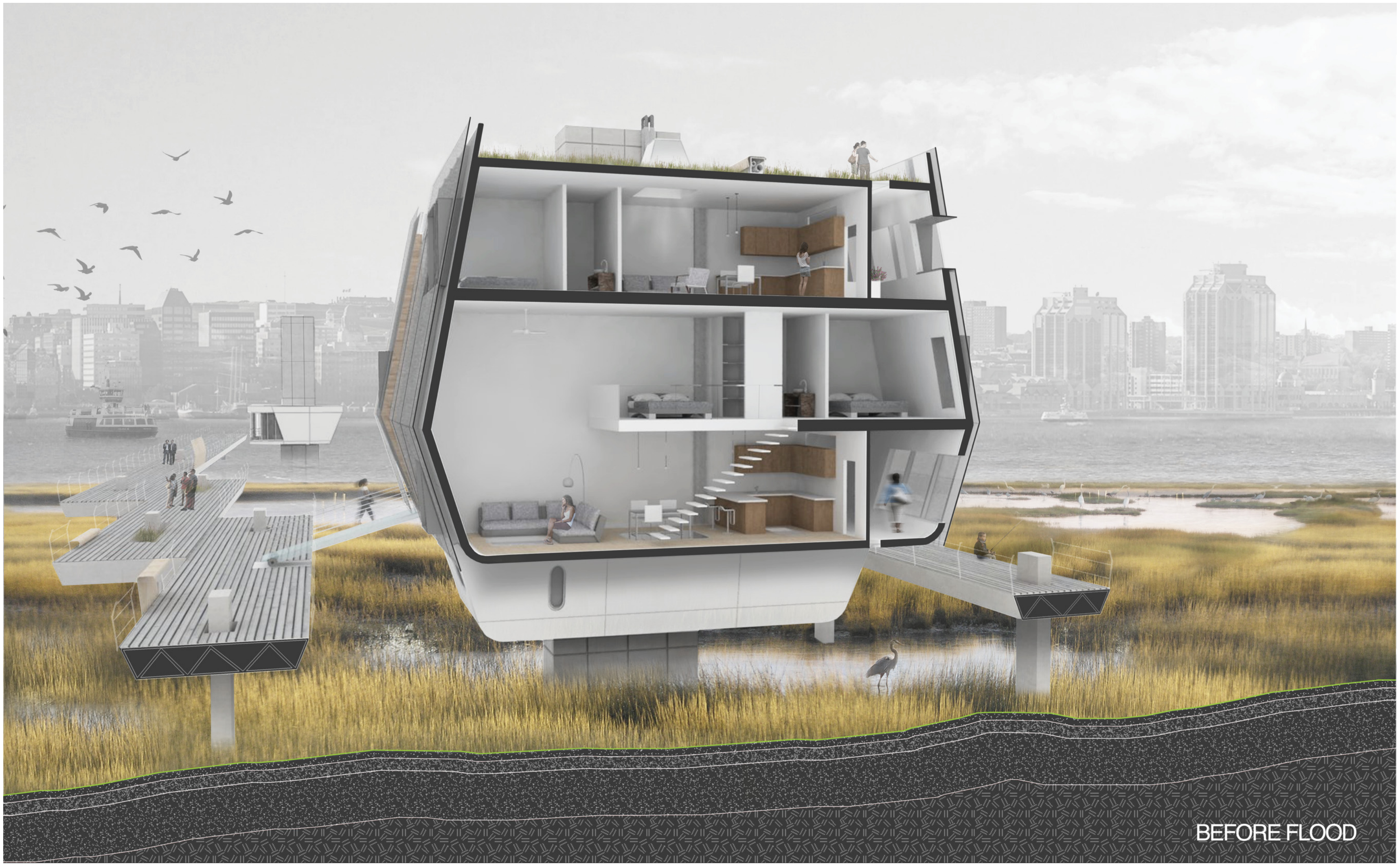
One bedroom unit type



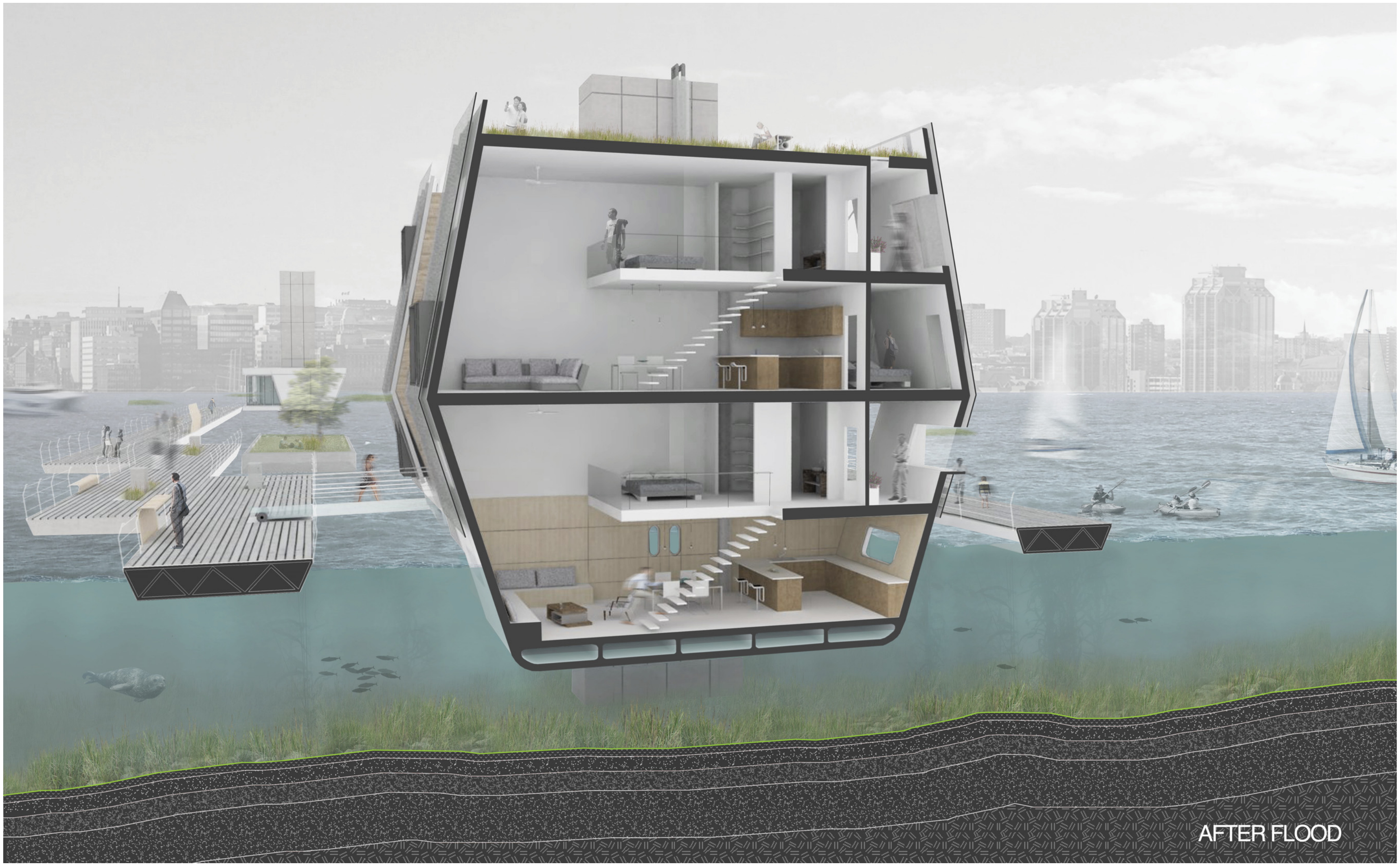
Two bedroom unit type



Three bedroom unit type



Sectional perspective illustrating units as they relate to their surroundings before flooding



Sectional perspective illustrating units as they relate to their surroundings after flooding

Neighbourhood Scale

At the neighbourhood scale, a network of shared community green spaces line the rooftops of the amphibious housing blocks. These spaces are programmed in a number of different ways (pools, gardens, recreational, etc.), allowing each housing block to acquire its own distinct character within the community. The housing blocks are located on either side of the pedestrian piers defining the streets for the neighbourhood. The streets support a number of docking points for mobile programmed barges (coffee shops, markets, restaurants, etc.), emphasizing the idea of a mixed use community. The backyard is characterized by a water courtyard, which supports a boat community and recreational space. The intersection between the existing suburban fabric and the amphibious community is marked by a number of public squares, which are connected by a boardwalk that consists of several recreational and public amenities and provides access to the water after sea level has risen.

Perspective of the shared community green spaces along the rooftops

Perspective of a street within the amphibious community

Perspective of a backyard space within the amphibious community

Perspective of the public squares at the intersection of the existing suburban fabric and the proposed amphibious community

CHAPTER 5: CONCLUSION

This thesis focused on an architectural response for low lying coastal communities vulnerable to sea level rise. Amphibious architecture provides an adaptation strategy which is both sensitive to the future of our coastal environments and accommodating to the rising sea. The strategy suggests that climate change is an opportunity to initiate the transition from land based to water based living, inverting the typical direction of evolution. The resulting amphibious lifestyle embraces the uncertainties of our future and imagines a flooded future rather than an abandoned coastline. Dartmouth Cove was central to the investigation; however, one can imagine the strategy being applied to other flood prone locations around Halifax harbour. In developing amphibious communities in these low lying areas the harbour could be transformed from a predominantly industrial zone to a new urban ground for living and recreation. Because this project focused strictly on the development of flood sensitive communities, potential for further study exists. How could more urbanized coastal cities such as New York, San Francisco or Venice adopt these amphibious qualities? What are the limits to growth and expansion for amphibious living and how do we complete the transition from land to living solely on water? Although many important questions remain, it is clear that we need to devise strategies to cope with the effects of a rising sea level and the development of amphibious architecture offers one effective solution to this dilemma.

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