FLOATING CITIES FROM CONCEPT TO CREATION

A discussion of the challenges that are pending the floating city through literature review

by

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Floating cities from concept to creation: a discussion of the challenges that are pending the floating city through literature review

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Abstract

Waterfront urban areas are home to a large portion of the global population. From the beginning, individuals have been living on the coast to meet their different needs. Throughout the most recent couple of decades, more individuals and infrastructure has moved to the coast than at any other time. Since reforming and globalization occurred, the internal reasons for quick urbanization caused the rebuilding of the Coastal city space. As the city develops, it reclaims part of its landmass for building infrastructure. This extension has altered the utilization of land and, in most cases, productive agricultural farmland around these urban areas has declined, which used to work as the food supply chain for metropolitan occupants before. Coastal land pressures due to population growth forced humans to come up with new innovative ideas to deal with this problem. The demand for developable land around the coastal cities is increasing and with that, the necessity for innovative solutions. The cumulation of these pressures gave birth to the idea of expanding urban access to nearby marine space.

The use of a floating house or an amphibious house can now be seen in various cities across the planet. These houses are attached to the shoreline and can easily adapt to the sea-level change. Although this idea is not entirely new, for some reason a floating city has not yet been successful. Various designs have been presented at different times but so far, no design has succeeded. However, shifting development towards water isn't a simple task. It needs to overcome some challenges. This paper focuses on exploring the challenges that a “Floating city” would face and proposes, why a “Floating City” has not yet been build?

Lay Summary

The primary purpose of driving this paper was to shed light on the discussion of the Challenges that are pending the “Floating City” through Literature Review. This was done by creating a multidisciplinary compilation of literate on the topic. This paper is a compilation of technical and socio-economic challenges regarding floating structures. What was concluded from this research is that there are several interconnected barriers that are hindering this technology, and they will need to be solved simultaneously if the dream of a floating city is to be realized.

Preface

This work is solely the product of the author's efforts, which gratefully builds on the extensive, and insightful, work documented in the publications of the many researchers cited in the various fields which it addresses.

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List of Abbreviations

EEZ - Exclusive Economic Zone

IAHR - International Association for Hydro-Environment Engineering and Research

MFS - Modular Floating Structures

ONR - Office of Naval Research Global

OTEC - Ocean Thermal Energy Conversion

UNCLOS - United Nations Convention on the Law of the Sea

VLFS - Very Large Floating Structures

Acknowledgments

I wish to acknowledge the contributions of Inge Roecker for her guidance throughout the course. I would have never been able to come up with an innovative idea without the countless support from my supervisor.

I must also recognize the assistance provided by all the people who helped me directly and indirectly to conduct this thesis project.

Finally, I want to thank my parents who directly supported me throughout the entire process.

1 Introduction

1.1 Background

Coastal zones have consistently attracted humans due to their numerous assets, particularly their rich supply of natural resources and access to water. Their unique setting, at the interface between land and sea, offers passages for marine exchange and transport, recreational and social opportunities, and a distinct sense of place. As a result, many of the world’s megacities are located in the coastal zone (Alex de Sherbinin, 2012). The world is currently undergoing the largest wave of urban growth in history (UNFPA, 2016). Today, 55% of the world’s population lives in urban areas, a proportion that is expected to increase to 68% by 2050 (UN, 2020). Urbanization poses significant challenges to the world's cities and megacities, as it becomes more difficult to manage them sustainably and control their spatial development. Urban areas consume land as their physical footprints expand, resulting in a complete landscape transformation (Burak Güneralp, 2020). This outward growth typically encroaches onto adjacent agricultural lands; urban sprawl is the leading cause of agricultural land loss globally (Burak Güneralp, 2020). The growing tension between urban and agricultural land uses is exacerbated when considering future global food requirements. To accommodate the projected 2050 global population, the land area devoted to farmland must increase to 22 million square kilometers or 8.5 million square miles, an area nearly equivalent in size of North America (Graaf R. D., Adaptive urban development . A symbiosis between cities on land and water, 2012).

If we are to meet this target, not only curbing the loss of agricultural land but also expanding our current agricultural land base, the sea suddenly becomes a viable option for expansion (Miguel Lamas-Pardo, 2015). This concept is fortified by the long-standing relationship humans have with living on the water. Our water homes span the fishing villages in Southeast Asia, Peru, and Bolivia to modern floating homes in Vancouver and Amsterdam. As our cities grapple with overcrowding and undesirable living situations, the ocean emerges as a potential frontier for sophisticated water-based communities (Wang, 2019).

The first step towards seaward urban expansion is the floating house. Floating houses, or amphibious houses, are now seen in various cities, such as in Vancouver and Holland. An amphibious house is a building that rests on the ground, but when a flood occurs, the entire building rises in its dock, where it floats, buoyed by the floodwater. Metro Vancouver has already adopted the idea of a floating house, which can be found in the areas of Granville Island and Ladner. With more than half of Holland's land surface below sea level, people from this country have proposed the concept of floating towns (Nitai Drimer, 2019). When exploring the concept of a coastal city the first step towards the water is crucial. Dutch architect Koen Olthuis plans to build Europe's first floating apartment building, the first step of many towards an entire floating city (Eaton, 2009).

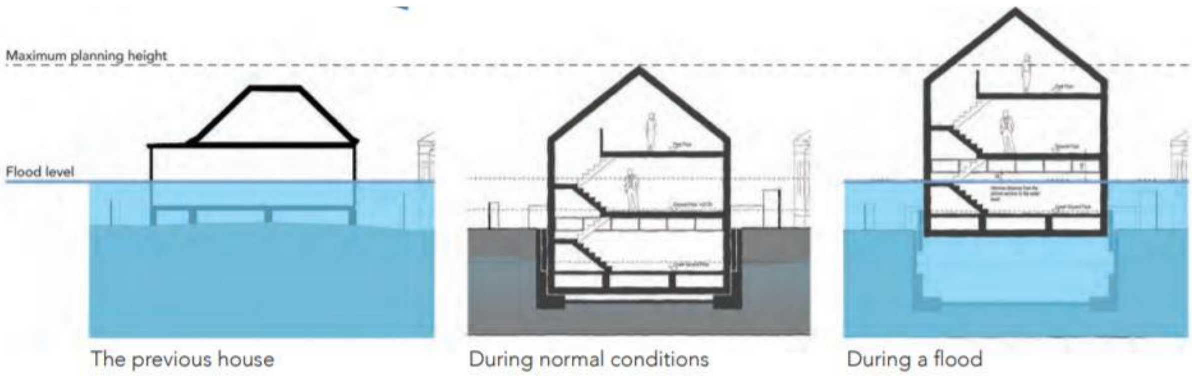


Figure 1: Fundamentals of a Floating house (Source: Baca Architects, 2014)

Figure 2: Floating house in the Netherlands (Source: webdesign stevenboot.nl, 2018)

Figure 3: Floating house in Granville Island (Source: Vancouversun.com, 2015)

While the number of floatable houses is increasing, this reality is far different for an entire floating city. The idea of a fully floatable city can be reached far back to the 'Tokyo Bay Plan' in 1960. Kenzō Tange was a Japanese architect, who first conceived the vision of building a floatable city on the bay near Tokyo. Tange saw the potential for technology and a benevolent kind of progress with which to build fantastical new cities straight from the pages of comic books (Beanland, 2016). But Tange was relentless and his ideas came from deep thought and scientific study. With his 1960 Tokyo Bay Plan, he envisioned Tokyo expanding into its bay (Beanland, 2016). Since then the idea has been practiced by many experts. The former tourism minister of French Polynesia, Marc Collins Chen, and architecture studio BIG advanced with the proposal. Chen is involved with the Seasteading Institute, which is seeking to develop autonomous city-states floating in the shallow waters (Wang, 2019). A speculative proposal, Oceanix City, was unveiled in April at the first Round Table on Sustainable Floating Cities, taking place at U.N. headquarters in New York (Wang, 2019). While this latest proposal has gained the attention of the U.N., it is a longstanding idea we have repeatedly returned to over the past 70 years with little success (Wang, 2019). For the last 70 years, this floating city idea has been polished repeatedly, yet has not fully materialized.

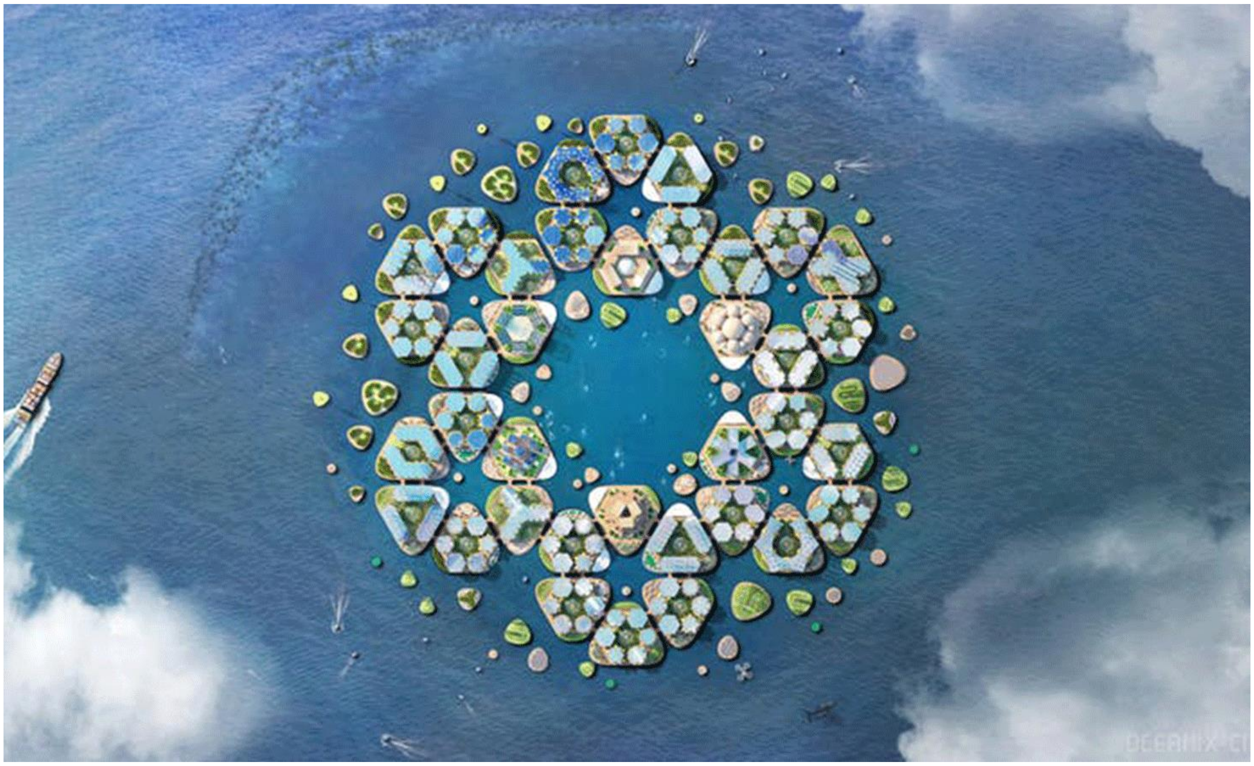


Figure 4: Oceanix City, Plan view (Source: BIG.dk, 2019)

Figure 5: Oceanix, a proposed floating city perspective view (Source: BIG.dk, 2019)

With global sea levels predicted to rise significantly over the next century due to climate change, many people living in low lying areas are expected to be displaced from their homes. Architect Vincent Callebaut has come up with a possible relocation destination for these climate change refugees in the form of the "Lilypad" concept – a completely self-sufficient floating city that would accommodate up to 50,000 (Quick, 2011). However, it's Callebaut's hope that this concept becomes a reality by 2100, a timeline that may not be ambitious enough for those most affected by rising sea levels (Quick, 2011).

Figure 6: The Lilypad floating city concept is designed to house climate change refugees (Source: Newatlas.com, 2011)

A collection of technology billionaires, architects, and dreamers hope to build neighborhoods and even city-states on the ocean, but they could face some serious barriers (Cosgrave, 2017). By 2030, 60% of the world's population will be living in cities. This will place a huge strain on the world's existing metropolises. The challenges associated with climate change are also important to consider, as about 90% of the world's largest cities are situated on the waterfront and are vulnerable to changing sea levels (Cosgrave, 2017). To cope with these changes, some engineers, researchers, and technologists say we should reconsider how we build cities; perhaps it's time to do something different. Rather than trying to resist the sea's advancement, some believe it is time to stop fighting the oceans and to work with them instead. "We have to start living with the water as a friend and not always as an enemy," says Koen Olthuis, founder of the Dutch architect firm WaterStudio. They are designing and building floating platforms that can act as the foundations to support buildings. Initially, they have focused on building single villas or offices, but Olthuis believes it may be possible to construct entire cities in this way (Cosgrave, 2017). "Imagine a city where you can plug and play floating houses and floating developments," Olthuis explains. "You could adjust the city for the season… to let the developments breathe." Imagining a city that can be adaptable to sea-level rise and a flood situation is quite fascinating. Developments are being made as researchers work on this topic to make it a reality. "We are convinced we can create better worlds on the ocean," says Joe Quirk, an author, and self-proclaimed "seavangelist". He is also the spokesman for The Seasteading Institute and hopes to create floating communities that can test innovative forms of governance.

This "Floating City" idea came first to light in 1960. Kenzo Tange's 1960 plan for Tokyo was proposed at a time when many cities in the industrial world were experiencing the height of urban sprawl. With a unique insight into the emerging characteristics of the contemporary city and an optimistic faith in the power of design, Tange attempted to impose a new physical order on Tokyo, which would accommodate the city's continued expansion and internal regeneration (A plan for Tokyo 1960, 2016). Although the plan did not become a reality, this was the starting point of a new era of floating cities.

Figure 7: Tokyo bay proposed floating city (source: A plan for Tokyo 1960, 2016)

Designers are proposing floating cities that could change with the seasons, tech entrepreneurs are looking to create settlements on the open ocean, and marine engineers are trying to solve structural issues, but no one has been able to build a successful prototype of an actual floating city. The question remains: is this idea feasible? How will these cities look in reality, and how would they work?

1.2 The purpose of this research

Currently, floating houses are becoming much more popular; they've been accepted by the general public as a strategy to adapt to sea-level rise and flood events. Sea levels could rise by more than a meter by 2100 if emission targets are not met (Nanyang Technological University, 2020). The reason floating houses are so popular is because of its adaptive nature. Floating and amphibious houses are built to be situated in a water body and are designed to adapt to rising and falling water levels (Climate Adapt, 2016).

On the other hand, the floating city is still a conceptual idea that hasn't become a reality. Although some experts believe that we can make this possible, several issues are stopping this idea from being realized. Humans by default are social beings and typically prefer to live in a community, with opportunities to visit other adjacent communities. When a community is situated within the middle of the sea, opportunities for social interaction will be disrupted. The amphibious houses that are built attached to the shoreline make their inhabitants less isolated and therefore more palatable to the general public. The idea of a floating city has the potential to solve problems like housing shortages and sea-level rise but needs to address social accessibility.

This research aims to understand the question: why haven't "Floating Cities" been built yet? What are the challenges and the barriers that must be overcome before this concept finally becomes a reality? Will technological advancement be enough to support this idea? What are the environmental impacts of this floating structure on the ecosystem will be?

Floating homes at Ijburg, Amsterdam (source: Bowcrest.com)

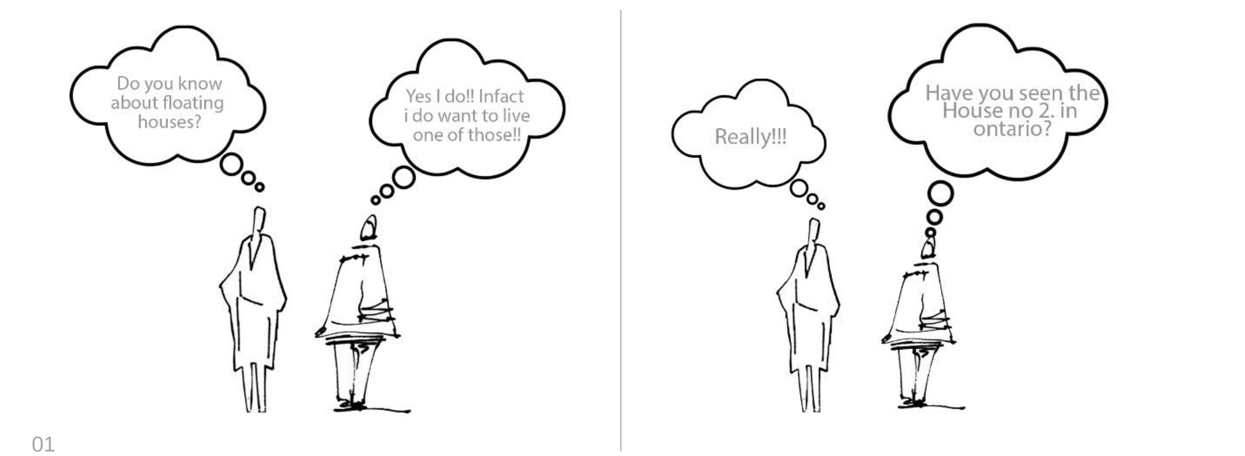
Proposed Ocenix Floating City by BIG (source: BIG.dk)

Figure 8: The missing link between the community close to the shoreline with the community in the middle of the ocean

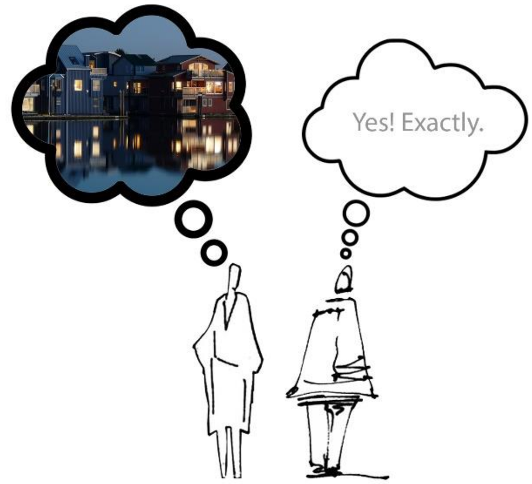
1.3 Significance of this paper

This research will be a resource and a discussion point for the designers, engineers, city planners, and real estate developers who are willing to explore potential opportunities associated with a floating city. It will give an overview of the challenges that a floating city might face and will look for answers on how to make it a reality.

The argument in this research paper is trying to understand how we can slowly extend the coastal city to adjacent waters by understanding why it is so challenging to build a self-sufficient floating city. This paper will help to understand how to gradually move forward from a floating house to an entirely floatable community on open waters. The connection between a floating community and the land needs to be understood properly. Although research has been done on floating cities and working modules exist for floating houses. However, there is a research gap on how to connect these two concepts. A floating city and a floating house vary in scale, but the uniting concept is a desire to live on open waters. This paper will assist in understanding how the concept of a floating house will expand to a floating city.




Yes this one. Have you seen the palces in ladner as well??

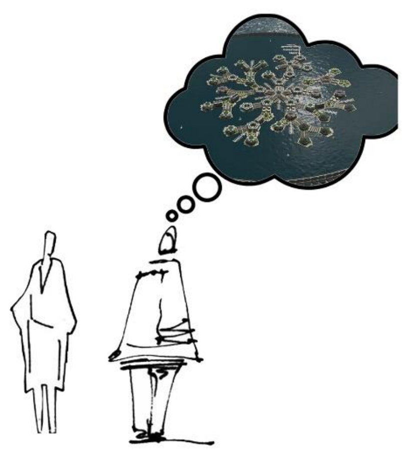

Yes! Exactly.

02


Why do you want to live there?


Because i have access to every where from this place. It is attached to the land. I can connect to my work place, i can have the same social life and get to use the land transportation as well even if i am livivng on water!!


Have you heard about a floating city?



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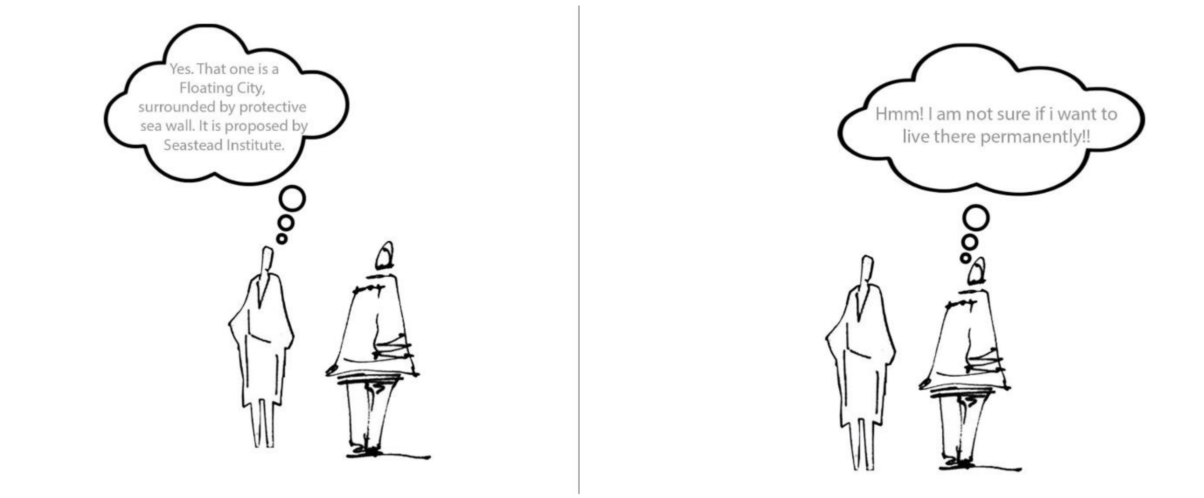

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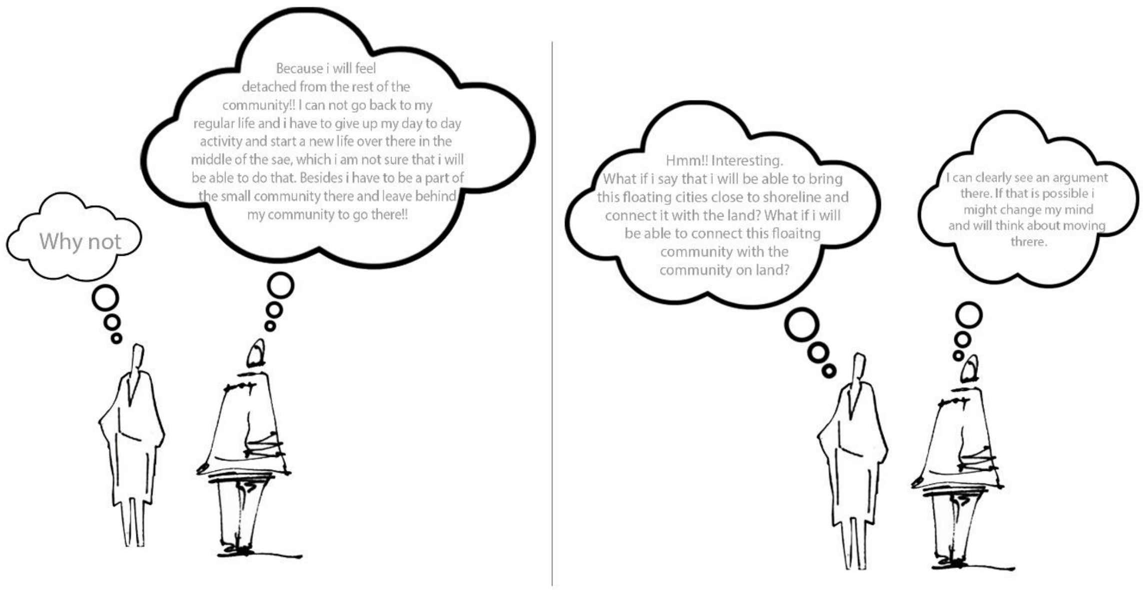

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1.4 Structure of the report

The impacts of climate change and the growing need for new housing is challenging coastal cities; cities near the coastline are trying to brainstorm new ideas. A growing number of cities are exploring creative solutions to mitigate the effects of sea-level rise (Muggah, World Economic Forum, 2019). The good news is that coastal cities are not starting from scratch – most of them have deep stores of knowledge and expertise (Muggah, World Economic Forum, 2019). This paper will contribute to a body of knowledge that seeks to understand how to successfully establish a coastal city. The research methodology section of this paper expands on the process used to work through the research question.

The Literature review section describes the basic concept of a floating structure. The precedents examined in this section prove that a floating house could be the solution to sea-level rise as highly adaptable structures. The literature review brings forward existing projects and future project ideas which helps to understand where we at the current time are, where do we want to go in the near future, and what will be the process. This section also focuses on why is this thesis is important and how does it will add to the existing body of knowledge. It helps to show the bridging concept between a floating house and a floating city.

The fourth section focuses on the importance of a floating structure. This kind of structure is already in use and people have already started to accept this process. This form of development is becoming more widely accepted because of its ability to adapt to challenges caused by climate change while maintaining a connection to communities on land.

The fifth section speaks to the concept of a floating city situated within the context of both Maldives and Port Moody. It is important to question if these places are suitable for a floating community and if so, then what is the realistic approach for implementation. This section will also examine how to connect a floating community with the people on land, and which site would be practical for a floating community.

The final portion is proof of concept. This section explains a design approach that will enable a floating house to graduate to a floating city. Additionally, It will examine how to create connections with the people on land.

2 Research Methodology

2.1 Methodology

This research was conducted in five stages, shown in figure 9, and is based on a literature review, related case studies, and information gathering. This helped to understand existing applications of floating homes within the context of Vancouver and inform proposed design development.

Literature review: This portion will help to understand the basic research question this paper is seeking to answer and the direction of this paper. It will help to provide supporting evidence on this topic as well.

Related case studies: The study of existing successful projects will help to realize the basic functions of a floating structure. Although all the examples regarding floating cities are still in the test phase, this will help to understand the missing connection between a floating house and a floating city. It is the essential gap that needs to be filled to make a floating city a possibility.

Information gathering: Information will be gathered from the literature review and related case studies which will be used to assess the situation. All the examples that are used in this paper will help to work through the research question and arrive at a resolution. It will also help to expand the idea to the next level and that is the proof of concept.

Application in the Port Moody Context: Information from the previous sections will be analyzed to understand the application of the concept within the context of the city of Port Moody. Similar to many other coastal cities, the Maldives and Port Moody are facing serious challenges regarding climate change, sea-level rise, and population growth. Part of the methodology is to understand the feasibility of a floating community in those areas.

Proof of concept: The final stage of this research will explore design development in the context of the Maldives and Port Moody. If a floating community needs to grow in Greater Vancouver, what will be the best place to test the idea?

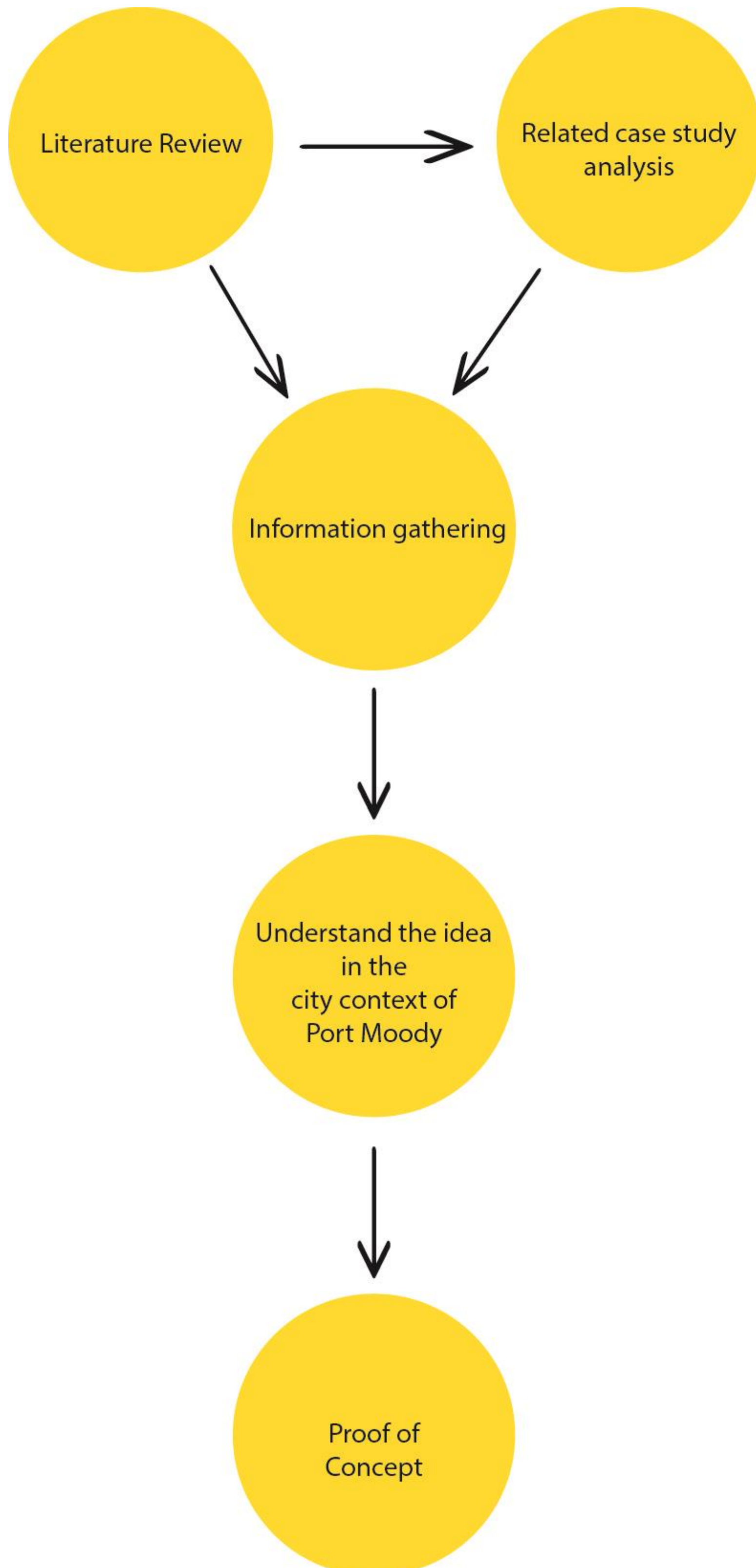


Figure 9: Structure of the research methodology

2.2 Scope of research

This paper aims to understand the connection between a floating community and the people inland, which involves a wide knowledge base around floating houses (amphibious houses), sea-level rise, social issues regarding a floating community, managed retreat, and the floating city itself.

The following topics are included in the scope of this research:

- Reviewing the literature and understanding the basic concepts about floating structures.
- Related case studies that provide a wide range of knowledge about the topic.
- Understand the importance of a floating structure and the impact of floating houses on the community.
- Research on social accessibility issues regarding floating houses.
- Gather knowledge about the sea level rise and managed retreat and how this improved understanding informs the development of a floating city concept.

The following points are excluded from this research and may be considered as a future research topic which will complement this paper

- The cost calculation of the entire project and finding the source of funding.
- Proving the fact that a 'Floating city is the idea of the Future' or establishing a need for a 'Floating city'.
- In-depth technical analysis or research about the mechanical system of a floating structure.
- Stabilization methods involved in the analysis of a high-tech engineering system.
- Analysis of the building code regarding a floating structure as this research paper focuses on addressing issues that go beyond the existing building codes.

3 Literature Review

3.1 Specific research area

Coastal cities have attracted residence for hundreds of years and this will unlikely change soon. However coastal areas face challenges. Coastal regions are home to a large and growing proportion of the world's population and undergoing environmental decline (CREEL, 2003). Today, approximately 3 billion people about half of the world's population live within 200 kilometers of a coastline. By 2025, that figure is likely to double (CREEL, 2003). In 2050, the ignominiously growing population will require one more of North America i.e. we may fall short of 22 million sq. meter land which is equal to the area of the North American continent (Jain, 2020). The high concentration of the general public in coastal areas has generated numerous financial advantages, including improved transportation links, easy access to water, industrial and urban turn of events, income from the travel industry, and food production. Yet, the consolidated impacts of a growing population and financial and innovative advancement are undermining the environments that give these advantages. Not to mention the sea-level rise, which exacerbates these challenges. Sea-level rise is occurring at a rate faster than previously believed and could exceed 1 meter by the end of the century unless global emissions are reduced, according to a survey of more than 100 specialists (Watts, 2020). Even if we collectively manage to keep global temperatures from rising to 2°C, by 2050 at least 570 cities and some 800 million people will be exposed to rising seas and storm surges (Muggah, The world's coastal cities are going under. Here's how some are fighting back, 2019).

While cities are preparing to build dikes and focusing on how to prepare a flood protection strategy, one group of experts believe we have another option at hand to deal with all of these growing challenges. Rather than trying to physically resist the ocean overtaking urban areas, there is growing evidence that we must redefine our relationship with coastal waters. "We have to start living with the water as a friend and not always as an enemy," says Koen Olthuis, founder of the Dutch architect firm WaterStudio (Cosgrave, 2017). Floating structures will help the coastal cities with expansion.

With all the possibilities and all the theoretical assumptions made by the experts around the globe, the question remains the same: how can a coastal city expand? What will future expansion look like? To answer this question and we need to get back to the original question that this research paper raised: Why has a "Floating city" not been built yet. The first question that comes to mind is evaluating if the technology is sufficient enough to support this idea and if we are capable of financing the costs for this project? The word "Floating city" means a city that is floatable and is flexible on water. It should be fluid when it comes to mobility. It sounds simple, but the main problem lies within a seemingly simple concept. This free movement characteristic makes this idea challenging. Suppose a floating city is been designed, financed, and owned by the Canadian government. For some reason, it needs to move close to the US coastline for some time. Which nation it will belong to then? It will be a nation within a nation. The jurisdictions and rules will be far more complicated as a result. Which government will provide facilities to the citizens of that floating platform? To be clearer on this point see Figures 10 & 11.

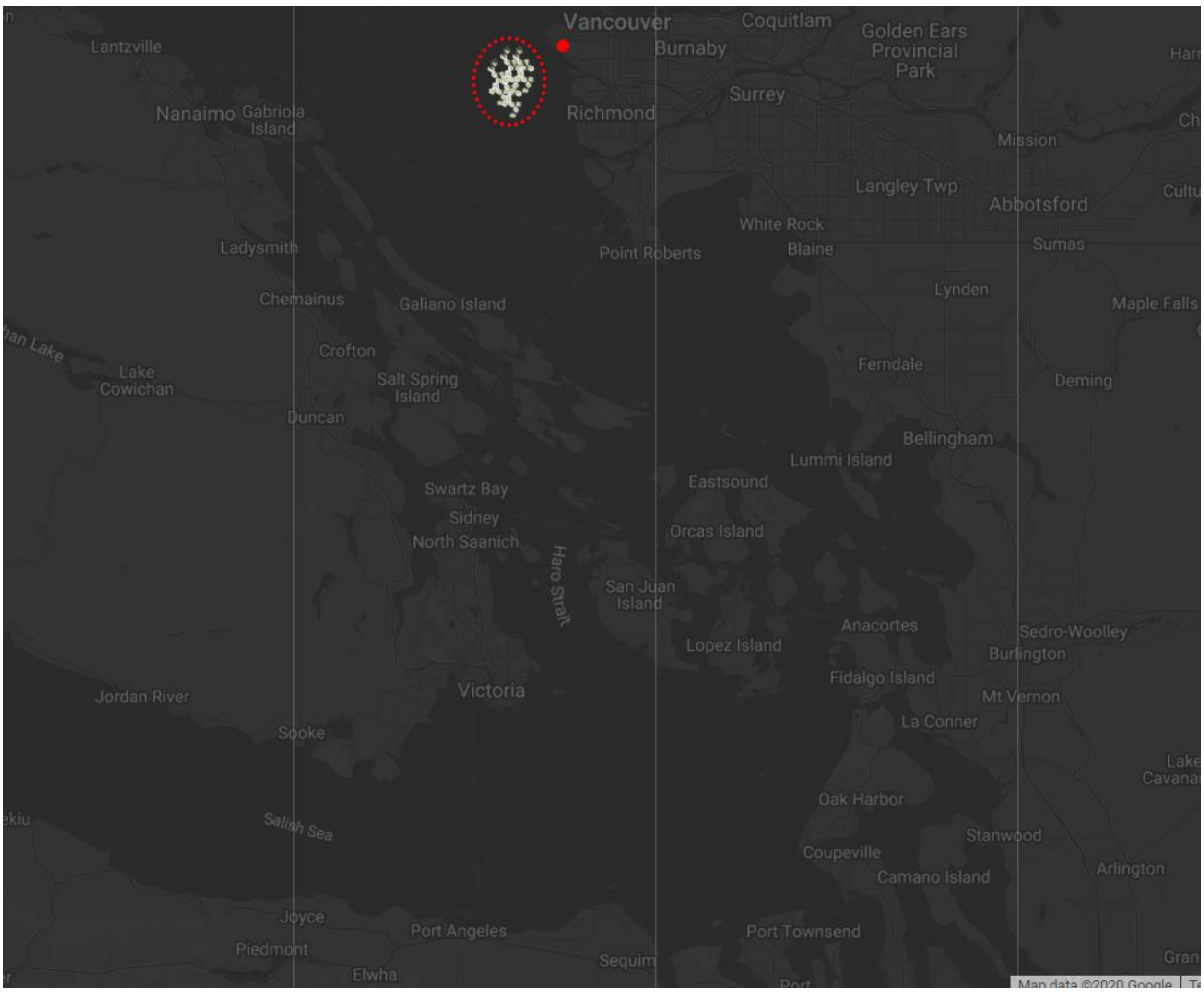


Figure 10: Floating city close to Canadian coastline (source: google map)

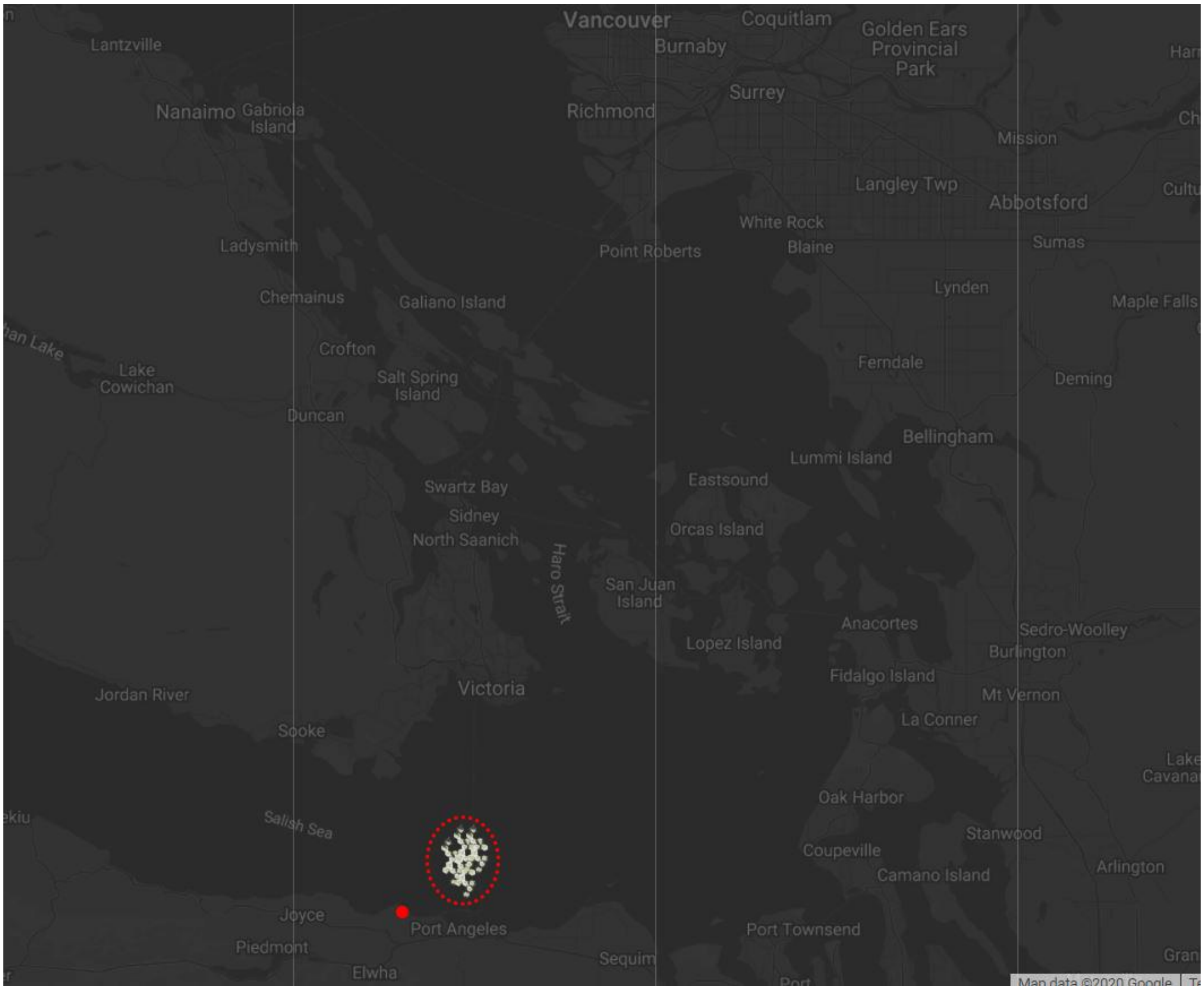


Figure 11: Floating city close to US coastline (source: google map)

It seems like it is far more challenging to solve political issues rather than technological issues. Technology is not a barrier to floating cities in international waters. Advances in technology enable us to create structures for habitation in deep-sea waters. These schemes have never really taken off because of political and commercial barriers (Wang, 2019). In 1983, President Ronald Reagan claimed the EEZ (Exclusive Economic Zone) in the name of the United States. In 1994, all countries were granted an EEZ of 200 miles from their coastlines under the International Law of the Sea (EIA, 2019). Several federal government agencies manage the natural resources in the EEZ. The U.S. Department of the Interior's Bureau of Ocean Energy Management and Bureau of Safety and Environmental Enforcement manages the development of offshore energy resources by private companies that lease areas for energy development from the federal government (EIA, 2019). Any natural resource that is found in this zone, comes under the ownership of the coastal nation. UNCLOS (United Nations Convention on the Law of the Sea) is an international treaty that sets out the legal framework for ocean activities. It defines the maritime zones along a country's coastline and the rights and duties of a country regarding these zones. UNCLOS also recognizes that coastal states have sovereign rights over the natural resources of the seabed and subsoil of the continental shelf, as well as jurisdiction over certain activities like marine scientific research (Fisheries and Oceans Canada, 2019). UNCLOS defines the limits of nations jurisdictions at sea in three zones of decreasing sovereignty. The first 12 nautical miles are a nation's "territorial waters", where land-based governments have the same power they have on land. The area 12 to 24 nautical miles from the coast is a sort of buffer called the "contiguous zone", where a state may pursue vessels that break certain laws or pose a threat to the coastal nation. Beyond that, each nation is enrolled in EEZ (Exclusive Economic Zone) that extends 200 nautical miles, where nations reserve the right to exploit natural resources such as oil and minerals below the surface of the sea. This means that states won't regulate vessels within the EEZ, they reserve the right to regulate "artificial islands, installations, and structures" (Joe Quirk, 2017). Beyond 200 nautical miles are the high seas, where ocean industries in cooperation with the international governing bodies have deployed a polycentric system of rules managing 45 percent of the planet's surface that is unclaimed by countries (Joe Quirk, 2017).

Vessels traverse internationals waters under the jurisdictions of the country whose flag they purchase permission to fly. That means little islands of sovereignty from one nation sails through the 200- miles EEZs claimed by two other nations (Joe Quirk, 2017). Almost 90% of all commercial marine vessels calling on US ports are under foreign flags (Cruise Ship Registry, Flag State Control, Flag of Convenience, 2020). Cruise ships dock in one nation, incorporate in another, and hire from anywhere. They pick and choose the national laws best suited to their industry, and through a sophisticated practice of "jurisdictions arbitrage," flourish as semi-independent pioneer entities while maintaining friendly alliances with all nations (Joe Quirk, 2017).

For example, if a Dutch-owned cruise ship enters Canadian "territorial waters" the ship will have to follow the jurisdictions imposed by the Canadian government while maintaining the laws of Dutch governments as well. If we consider a cruise ship with a floating city, it becomes even more complicated. Cruise ship law is so complex due to the fact prosecuting crime at sea can be more challenging than prosecuting crime on land. Marine law is known for being one of the least updated and most intricate of the legal sectors. In many cases, laws that govern sea-based operations are decades–or in some cases hundreds of years old (LMAW, 2019). Once a cruise ship sails more than 24 miles off the coast of any country, it is considered to be in international waters. This means that the laws governing crimes on the ship are determined by the flag that the ship is sailing under. It is not uncommon for a ship to be flagged in a different country than the one from which it departed. Cruise lines often flag their ships in countries where the laws are less stringent, to avoid greater oversight (LMAW, 2019). Although a cruise liner has to deal with complex rules and regulations, it did not happen overnight. The earliest ocean-going vessels were not primarily concerned with passengers, but rather with the cargo that they could carry. Black Ball Line in New York, Advertisement in 1818, was the first shipping company to offer regularly scheduled service from the United States to England and to be concerned with the comfort of their passengers (Brief History of the Passenger Ship Industry, 1999). It took almost 200 years to write laws that vessels follow while traveling international waters, yet it is not perfect.

Imagine a floating city, which is still a concept on paper, and how hard it will be to pass through bureaucrats and government rulers. Due to this reason the "Oceanix City", a floating city designed by BIG has not yet been successful in solidifying an agreement with any government. The laws that govern floating cities extend beyond the laws of the nearest coastal nation; a floating city must abide by the laws of international governing bodies who manage the 45% surface on the ocean which is unclaimed by any country. This challenge might take decades to resolve. When discussing the viability of a floating city, no one talks about the bureaucracy or the political issues associated with claiming the ownership of a "Floating City". However, the answer to why a floating city has not yet been built may lie here.

The second and obvious reason that comes after this is the cost surrounding a floating city. Can we bear the cost of making a self-sufficient floating community? Before further examining this point, let's consider space exploration and its high price tag. Despite the seemingly insurmountable costs associated with space exploration, billionaires Elon Musk, Jeff Bezos, and Sir Richard Branson, who all made their fortunes in other industries, offer billions of dollars for space exploration funding(Cheetham, 2018). Fuelled by intense rivalries, their ambitions include the development of space tourism and developing permanent human settlement on the Moon and even Mars (Cheetham, 2018). If we can raise funding for space exploration why not for the habitation of the sea? An article named "Why Does Mankind Explore Outer Space More than the Ocean?" written by D. L. Shultz tried to answer that question. He thinks there are several reasons why mankind explores outer space more than the ocean? He thinks, exploring and learning about outer space is fascinating, important, and worthwhile. It seems like the human species would benefit more from having fuller awareness about the earth than outer space because earth is our immediate environment and we are literally surrounded by the ocean, and yet mankind seems to care much more about outer space than the ocean. Only 5% of the ocean floor has been charted, while “NASA has thoroughly mapped Mercury, the dwarf planet Ceres, almost all of Venus, Mars, and the Moon’s every nook and cranny” (Shultz, 2019).

But fascination could not be the only reason for spending billions of dollars. Schlutz goes on to say “whatever he finds in space he can name after himself, whereas whatever he finds in the ocean might force him to re-classify what he has already found” (Shultz, 2019). It’s a race against time. Whoever gets there first, whether it's Mars or making a colony on the Moon, can name their discovery after themselves; the vast majority of outer space is still unclaimed by any government or any species. In contrast, whatever we find inside of planet earth is one way or the other under the jurisdiction of a governing body.

Joe Quirk along with Patri Friedman tried to find this answer. They are the author of the book called “Seasteading”. In this book, they discussed the challenges a floating city faces regarding its cost. Building an entire self-sufficient city which in the middle of the sea does not come cheap. To answer this question a wide range of points needs to be touched. In that book Joe Quirk thinks, thinking as from a real estate business module a floating city will never be able to attract investors. It needs to focus on the broader picture such as the environmental issue, transportation, trade, and its capability to produce food. In his book, he shifts his focus to building a “Self-sufficient floating city”, not only a floating city. Quirk states that a floating city needs to compete with the existing cities on land to mark its ground on the global map. Presently, all major cities need to source food, infrastructure, and other facilities from elsewhere so that they can meet the needs of their citizens. Joe Quirk thinks differently. He thinks a floating city needs to be built in a way that it can produce certain valuable goods which it can trade with the other coastal cities and become an economic partner in the global market. No nations produce their entire food demand (Joe Quirk, 2017). Every nation is dependent on other nations through the global trade market.

The ocean is one of Earth's most valuable natural resources. It provides food in the form of fish and shellfish—about 200 billion pounds are caught each year (Ocean Resources, 2019). Fisheries of today provide about 16% of the total world’s protein with higher percentages occurring in developing nations. Fisheries are still enormously important to the economy and well-being of communities (Ocean Resources, 2019). Besides fish cultivation, he believes there are many more resources available on the ocean that needs research. Almost 50% of the air we breathe comes from oceans (Dietz, 2017).

Scientists believe that marine phytoplankton is responsible for more than half of the oxygen in Earth's atmosphere (Dietz, 2017). Researchers from the University of Manchester are using synthetic biology to explore a more efficient way to produce the next generation of biobased jet fuels—partly made from seawater (University of Manchester, 2017). The Manchester research group, led by Professor Nigel Scrutton, Director of the Manchester Institute of Biotechnology (MIB) and supported by the prestigious US-based international maritime research agency Office of Naval Research Global (ONR), is using synthetic biology to help identify a more efficient and sustainable method to make biofuel than the one currently used (University of Manchester, 2017). Scientists have discovered that the bacteria species called Halomonas, which grows in seawater, provides a viable "microbial chassis" that can be engineered to make high-value compounds. This in turn means products like biobased jet fuel could be made economically using production methods similar to those in the brewery industry and using renewable resources such as seawater and sugar. The breakthrough behind this approach is the ability to re-engineer the microbe's genome to change its metabolism and create different types of high-value chemical compounds which could be renewable alternatives to crude oil. Dr. Benjamin Harvey and his team of researchers at the world-leading Naval research facilities in China Lake, California, U.S., have pioneered this exciting work on converting biological precursors to relevant jet fuels (University of Manchester, 2017).

In the book "Seasteading" Joe Quirk also investigated producing biofuel from ocean resources. The oldest photosynthesizers, cyanobacteria or blue-green algae, have been attributed as the evolutionary bridge between bacteria and plants. Algae are crucial to the earth's self-regulating system and they represent two-thirds of the world's biomass (Joe Quirk, 2017). Algae and phytoplankton absorb nutrients from the water and manufacture their food by using energy from the sun (Joe Quirk, 2017). If we could develop an advanced technology that could potentially harvest food using seawater and solar energy a biofuel industry could be sustained. A floating city could sell this fuel to the coastal cities, just as nations such as Saudi Arabia and Qatar market their fossil fuel resources to other nations.

Research is ongoing in this sector. Ricardo Radulovich is a professor of water science at the University of Costa Rica, with a Ph.D. in soil-plant-water relations from the University of California. He states, "we depend on photosynthesis, yet nobody knows how to do it. Nobody has invented the machine that can take CO2 from the air and, with added water and energy, churn out sugar. Not with any amount of energy" (Joe Quirk, 2017). Human knowledge of photosynthesis has not yet reached the intelligence of kelp, a brown seaweed chock-full of nutrients, which performs this trick effortlessly (Joe Quirk, 2017).

“Photosynthesis has only been mastered by plants and bacteria,” says Ricardo. “All food and fuel energy created by photosynthesis. Why not use the best and most plentiful photosynthesizes to power everything: food, energy, you name it?” (Joe Quirk, 2017). Exactly 97.5 percent of the free liquid water is in the sea, which is filled with seaweed, the most nutritious plant in the world, a healthy protein source, and the greatest carbon collector on the planet. All seaweed needs to grow are water and sunlight, two of the most common resources on the planet, both plentiful at sea (Joe Quirk, 2017).

Recently China has invented the world’s largest floating fish farm. The “Hua Hai Long” carried the giant rig from the yard in China to Norway. China believes it will be a sustainable and environmentally friendly way of cultivation fish (Bjorn Ronningen, 2017).

Figure 12: Worlds largest floating fish firm (source: Bjorn Ronningen, 2017)

A floating dairy farm has opened in Rotterdam, showing how food production can become less vulnerable to climate change (Frearson, Dezeen, 2019). Thirty-two animals recently arrived at the farm (Mccullough, 2019). Although the farm is a working business that will sell milk to consumers via a vending machine, it has also been designed to be an educational tool to highlight the production path of milk (Mccullough, 2019). The fresh milk will be sold, while the manure will be separated and reused as an organic nutrient for Rotterdam's plants, gardens, and parks. The designers of the floating farm have included floating solar panels to supply all of its energy needs. Rainwater is captured on the roof and then purified for drinking (Mccullough, 2019). The dairy products are for sale at the floating farm and will soon be stocked in certain stores around Rotterdam (Mccullough, 2019). This aligns with Quirk's self-sustaining city concept mentioned in the book "Seasteading", in which floating cities that produce products which could be exchanged with the coastal nations to earn currency.

Figure 13: Floating dairy firm in Rotterdam, Front view (source: Mccullough, 2019)

Figure 14: Floating dairy firm in Rotterdam, Perspective view (source: Mccullough, 2019)

“The ocean is the largest solar conductor in the world”, says Bob Nicholson, former president, and director of global market development of OTEC International. Four-fifths of all solar energy that reaches the earth is stored thermally in the oceans (Nicholson, The Foundation of Life, 2017). “We have three hundred times the amount of energy in the oceans of the tropics than the world currently consumes, and it's replaced every day,” Nicholson claimed at the Seasteading Conference in 2012. Incredibly, the ocean's stored energy can be trapped by ocean thermal energy conversion (OTEC), or ocean thermal energy conversion. “Our challenge is to design a system that can harvest or convert that solar energy into electricity” (Nicholson, The Foundation of Life, 2017). The ever-hard-headed Lockheed Martin scientists are much more conservative in their estimates, claiming that each day the tropical oceans absorb the energy equivalent of 250 million barrels of oil. That’s only triple the world’s daily oil consumption (Nicholson, The Foundation of Life, 2017).

OTEC is a process that can produce electricity by using the temperature difference between deep cold ocean water and warm tropical surface waters. OTEC plants pump large quantities of cold, deep seawater and surface seawater to run a power cycle and produce electricity. OTEC is firm power (24/7), a clean energy source, environmentally sustainable, and capable of providing massive levels of energy (Ocean Thermal Energy Conversion, 2015). OTEC produces no greenhouse gases, blights no land, is not visible from shore, requires minimal maintenance, and runs twenty-four hours a day, 365 days a year. So why hasn't humanity-built thousands of OTEC plants over the last few decades? (Nicholson, The Foundation of Life, 2017).

Once up and running, OTEC can be maintained with relatively low running costs. Unfortunately, the initial start-up costs are very high. The start-up costs to build a pilot plant generating 10 megawatts, and then scale up to 100 megawatts, and so on, has always made the immediate profits of fossil fuels a more attractive option. Put simply, a global market for fossil fuel extraction and transportation is already in place. The infrastructure of OTEC is just getting started (Nicholson, The Foundation of Life, 2017).

But Lockheed Martin reports that the cost of OTEC construction is getting cheaper every year. Improvements in composite materials, fabrications, and modeling, along with related technology advances in the offshore oil industry, are facilitating OTEC's developers. So far, Lockheed Martin has invested $15 million in developing the first, prototype OTEC plant. As the OTEC technology matures and more plants are built, the cost for the energy they generate will decrease. Labor efficiencies, improved technology, quantity, capacity, size, and incentives would reduce the cost of future plants (Joe Quirk, 2017). Despite these obstacles, Lockheed Martin has partnered with the Hong-Kong-based Reignwood Group to build an OTEC plant off the coast of China which is expected to support all the power needs of a green resort (Nicholson, The Foundation of Life, 2017). "When companies like Lockheed Martin are funding OTEC research, you know the blue-green economy is on its way to becoming profitable" (Nicholson, The Foundation of Life, 2017).

"So, the question is how many megawatts can you generate ultimately?" asks Takahashi. Patrick Kenji Takahashi is a Hawaiian biochemical engineer and popular science writer who has published more than a hundred scientific papers and several books. "The answer is, we don't know", he replied. (Joe Quirk, 2017). He also added, "One of the engineers from the University of Hawaii, whom I hired a long time ago, came up with a figure of twenty-five terawatts (25 million watts) that you can sustainably draw from the ocean. That's much higher than all the energy humans use today" (Nicholson, The Foundation of Life, 2017).

The technology is not as futuristic as it might sound. A working OTEC plant was introduced the same year as the Sony Walkman. In 1979, Takahashi spearheaded the passing of the original OTEC research and development bill while working as a special assistant for Senator Soark Matsunga of Hawaii. That same year Lockheed Martin led a consortium to push forward the world's first floating "Mini-OTEC", which was to produce 50 kilowatts of clean, emission-free electricity (Nicholson, The Foundation of Life, 2017). Soon after Patrick Takahashi addressed Congress on the potential of OTEC, fossil fuel prices dropped, and interest in OTEC dropped with it. After extensive consultation with energy industry lobbyists, OTEC was put on the back burner and forgotten. Mankind has since realized the inherent flaws of a global economy rooted in the consumption and production of fossil fuels. Based on BP's Statistical Review of World Energy 2016, we'd have about 115 years of coal production, and roughly 50 years of both oil and natural gas remaining (Ritchie, 2017). But then again it comes down to cost. Takahashi's needs $1.5 billion to make this project up and running. "It's a fraction of $150 billion the cost of International Space Station", says Takahashi (Joe Quirk, 2017). Bob Nicholson also says, "I think the two concepts of OTEC and seasteading are just the perfect combination" (Takahashi P. K., 2017).

"Water will not be the next fuel", said Dr. Ted Johnson. Under his leadership, the Oceans Systems Group at Lockheed Martin created the world's first floating OTEC plant, "Mini OTEC", in 1979. Claiming, "Clean energy and clean water equals peace", Ted Johnson has pushed the advancement of the nonpolluting carbon-free OTEC technology with lifelong single-mindedness. In an interview with colleague Mike Straub he said: "Logically, OTEC is the ultimate answer. It's clean because you are not burning anything. The world is still stuck in an age of fire, but when you burn, you release carbon. OTEC simply uses the ocean's temperature difference- nothing is burned" (Johnson, 2017).

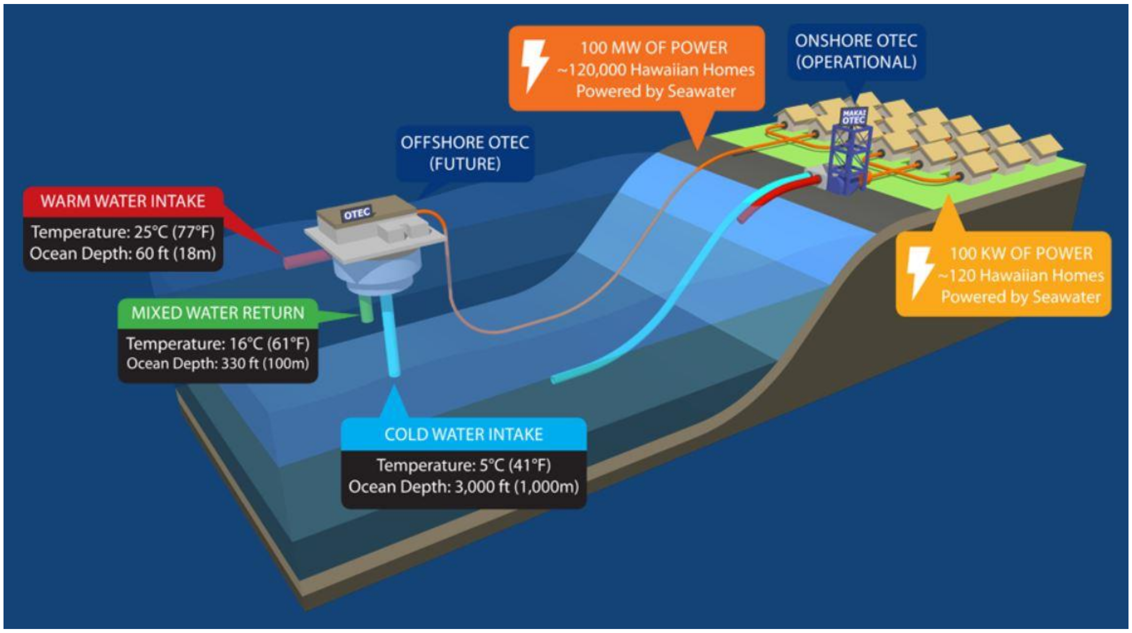


Figure 15: Basic concept of an OTEC plant (source: Ocean Thermal Energy Conversion, 2015)

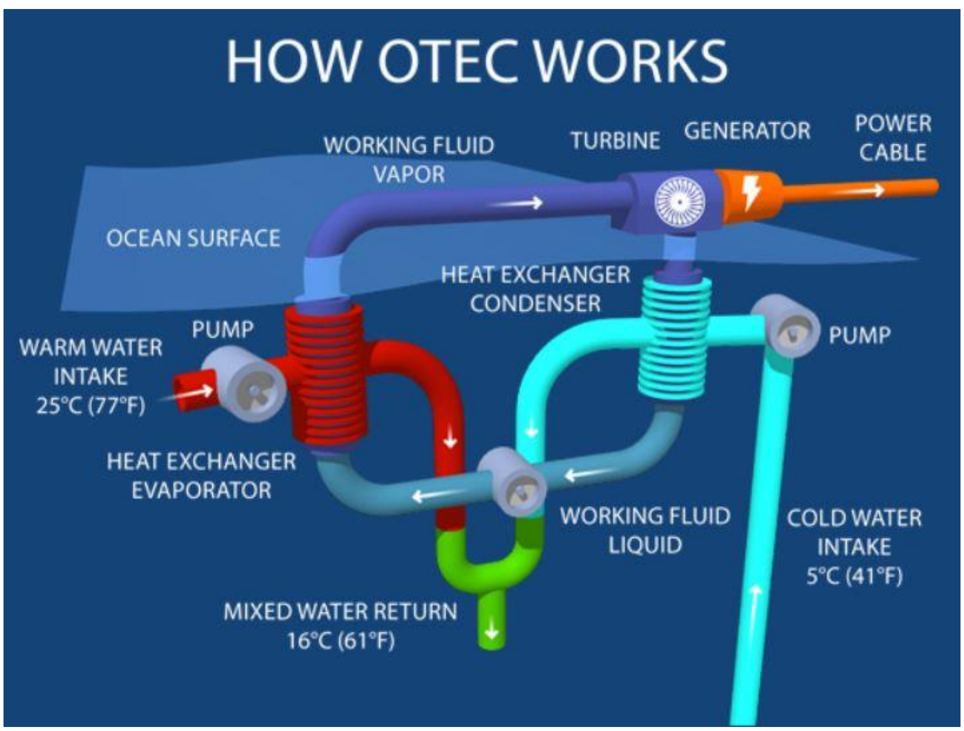


Figure 16: Basics of an OTEC plant (source: Ocean Thermal Energy Conversion, 2015)

Figure 17: The Ocean Energy Research Center in Kailua-Kona, Hawaii (source: Ocean Thermal Energy Conversion, 2015)

Scientists have also designed a Fischer-Tropsch reactor (a technology that normally converts carbon monoxide into fuel) that can combine carbon dioxide with hydrogen in a 100-megawatt power plant and produce a hundred thousand gallons of jet fuel per day using seawater as the feedstock and solar energy as the energizer. So, it's a cleaner-burning jet fuel (Nicholson, The Gold rush Ain't got nothing on the blue rush, 2017).

OTEC technology will also be able to stop hurricanes. While there's speculation around the ability of a floating city to survive a category five hurricane, experts believe that a floating city merged with OTEC will stop the hurricanes before even they start. Floating cities may be expensive, but platforms in the equatorial waters are cheap (Takahashi, 2017). "You can put some of these platforms in the path of potential hurricanes. They won't be able to gather energy to get started". OTEC draws cold water up, cooling the surface water near the seastead. This will significantly stabilize the coastal economies, which won't be wracked with hurricanes. In Takahashi's view, hurricanes are not a threat to seasteads, seasteads are a threat to hurricanes (Takahashi, 2017). "You cool temperature one or two degrees on the ocean surface, hurricanes won't form. It's as simple as that (Takahashi P. K., 2017). Kelvin Ko who is an intern in ‘Blue21’ and just completed his Civil Engineering Masters thesis at TU Delft. He published research on floating structures, where he said, “I researched whether it’s technically feasible to build a floating city in the open sea with huge waves and frequent storms. The answer is yes. And what surprised me is that you can realize high-rise buildings up to 50 meters high and still being hurricane-proof, assumed that the building and floating platform are very rigid connected. Which means waves of 4 meters high and the wind blowing at 200 kilometers an hour” (BLUE21, 2015). This gives a brief idea that natural disasters won’t a problem for a floating platform.

Floating solar panels could be another source of producing energy for ocean cities. Floating PV panels could be a potential energy source amid growing interest in offshore solar. A Belgian consortium including Dredging, Environmental and Marine Engineering (DEME), Tractebel, Jan De Nul Group, Soltech, and Ghent University announced plans to build a solar farm in the North Sea, in combination with offshore wind or aquaculture (Design, 2019). “We are confident that high-wave offshore solar technology can play a key role in realizing a sustainable energy transition,” said DEME’s CEO, Luc Vandenbulcke, in a press statement. “We look forward to working to develop and install the world’s first high-wave offshore solar farm” (Design, 2019). More than 70 percent of our planet's surface is covered by water, hence researchers are attempting to utilize this vast amount of space for the generation of renewable energy (Nield, 2016).

It seems strange that water should be such a scarce resource when our planet is drenched in 326 million trillion gallons of the stuff (Geris, 2020). The ocean holds 97.5 percent of the world’s water, with another 2 percent frozen in polar ice caps. Most of the remaining 0.5 percent are mixed in the soil or lies deep underground in inaccessible aquifers. That leaves roughly 0.007 percent of the world’s water available for human use (Quirk, Ricardo's Oceanic Epiphany, 2017).

A floating city would require quite a large amount of fresh water supply for its residents. This water source should be placed on site. Getting it shipped from somewhere else is not an economical option. Converting seawater to freshwater is a practice relied on heavily by cruise liners that use this technology to meet onboard water supply requirements. A freshwater generator, one of the important types of machinery onboard a ship, is something that cannot be done without. Freshwater produced from the freshwater generator is used for drinking, cooking, washing, and even running other important machinery which uses freshwater as a cooling medium (Chopra, 2019). Freshwater is generally produced onboard using the evaporation method. Two things are available in plenty on the ship to produce freshwater –Seawater and heat. Thus, fresh water is produced by evaporating seawater using heat from any heat sources. The evaporated seawater is then cooled by the seawater and the cycle repeats (Chopra, 2019). Generally, the heat source available is taken from the main engine jacket water, which is used for cooling the main engine components such as cylinder head, liner, etc. The temperature available from this jacket water is about 70 deg. centigrade. But at this temperature, the evaporation of water is not possible, as the evaporation of water takes place at 100 deg centigrade under atmospheric pressure. Thus, to produce freshwater at 70 degrees the atmospheric pressure is reduced, which is done by creating a vacuum inside the chamber where the evaporation is taking place. Also, as a result of the vacuum, the cooling of the evaporated seawater will take place at a lower temperature. This cooled water is collected and transferred to the tank (Chopra, 2019). Nowadays, reverse osmosis is one of the methods which are used on board for generating fresh water. Generally, this is used exclusively on passenger vessels where there is a large requirement of freshwater production. However, in merchant ships, the evaporation method is used as reverse osmosis is costly and includes large maintenance costs for the membrane (Chopra, 2019).

If the technology for these processes is readily available why can't we just make fresh water from seawater on an industrial scale? It is not as easy as it sounds. Everything comes with a price. Desalination practices date as far back as the ancient Greeks, but when taken to the scale of cities, states, and nations, purifying seawater has historically proven prohibitively expensive, especially when compared to tapping regional and local sources of fresh water. However, as advancing technology continues to drive costs down and freshwater continues to grow scarcer and more expensive, more cities are looking to seawater conversion as a way to meet this vital demand (Geris, 2020). The largest users of desalination globally in terms of volume capacity are (in descending order) Saudi Arabia, United Arab Emirates, United States, Spain, Kuwait, and Japan. Desalination provides 70 percent of drinking water in Saudi Arabia (Geris, 2020). Within the United States, Florida, California, Texas, and Virginia are the largest users, and the country as a whole can desalinate more than 1.4 billion gallons (5.6 million cubic meters) of water per day. To put that in perspective, that equates to less than 0.01 percent of municipal and industrial water use nationwide (Geris, 2020). There's little doubt that the world needs more drinking water. It's also abundantly clear that the need will keep pace with mounting population growth and the pressures brought about by climate change. Within 15 years, almost 2 billion people globally will live in areas confronting water scarcity, and, according to most model scenarios, such shortfalls will only worsen under projected climate change conditions (IPCC, 2010). Until recently, purifying seawater cost roughly five to ten times as much as drawing freshwater from more traditional sources (Geris, 2020). RO filters have come a long way, however, and desalination today costs only half of what it did 10 to 15 years ago. Consequently, transportation, energy, and environmental costs have now replaced technology as the primary impediment to large-scale desalination (Geris, 2020). Ultimately, costs are the largest deterrent to desalination practices on an industrial scale.

Offshore waste management will also be a huge task for a floating city. The logistics related to waste handling differ from region to region, but typically involves owners or operators, or both (USON, 2020). There are more than 4,000 offshore oil rigs in the Gulf of Mexico (How to Manage Waste on Offshore Oil Rigs, 2020). A huge variety of solid and liquid waste streams are generated, including waste oil from engine rooms, black water, grey water, bilge water, sewage, dry waste, food and galley waste, and others. All the waste needs to be handled – initially onboard the rig or ship and later onshore (USON, 2020). This kind of transportation adds logistic costs. Waste handling from the vessel to the port and from the port to a waste station is costly. In house food waste management could be installed on a vessel or an Oil rig. On fixed platforms, efficient food and galley waste handling systems eliminate the need to transport some food waste and enables controlled, hygienic, and easy handling. Food waste is collected and ground where it is produced. Thus, the work for the crew is minimized and proper hygiene is maintained in the galley. If the rig is more than 12 nautical miles from land and the food waste is ground to <25 mm, discharge is permitted in many areas. Food waste that cannot be ground must be transported to land (USON, 2020). This kind of offshore waste management technology is already in use. A floating city can easily use this technology.

It's evident that cost is a significant issue when considering the feasibility of building a “Floating city”. According to Joe Quirk building, a floating city is easy. The true challenge becomes apparent when attempting to build a self-sufficient floating city. Without a means of self-sufficiency, a floating city is no different than a cruise liner. Both carry thousands of passengers which are heavily dependent on land-based resources for its existence. Floating cities could offer their services to coastal cities all over the world (Graff, 2017). In essence, pioneers interested in founding floating cities could approach any coastal city and say, “You give us your pollution, we’ll give you food, fuel, and flood protection” (Graff, 2017). Investors must see a return on investment. To attract the capital needed for a project of this scale, a complete, self-sustaining system must be developed which would market its products.

Is existing technology capable of developing a floating city? The answer is “Yes” and “No”. We are capable of creating a floating residence and we have been doing this for decades. Rutger says, “We already know how to build floating platforms” (Graaf R. d., 2017). “We know how to make floating buildings. It's not science fiction, as you can see from (sixty thousand) floating houses in Amsterdam. We just need to bring together the modules that are already in use” (Graaf R. d., 2017). Then why has the concept of a floating city not been fully realized? A floating city must be capable of sustaining food production, harvesting energy from seawater, producing biofuel from seawater using sunlight, and harvesting minerals from the ocean surface. Each of these processes requires a huge among of resources, further research, capital, and government intervention.

A Dutch architectural firm call Blue21 brings the floating city concept one step closer to reality. Blue 21 proposes a similar but more pragmatic idea. it’s a pragmatic approach as they have attempted to address all the points that we have examined in this paper. They have attempted to design a self-sufficient city. Designed by Delta Sync, the Blue21 proposes the idea of, not just a city, but an entire floating ecosystem. The team claims, “Blue 21 will have a positive impact on the planet by creating productive, rather than consumptive communities”. It’s a step ahead of the concept of sustainable architecture, which seeks to exclusively minimize the use of resources. The project utilizes ‘productive architecture’ where resource use is not only minimized, encourages the production of resources (Jain, 2020). This calls into question what sets apart their idea is different than others. Blue21 believes that they are employing creative solutions that will reduce their environmental footprint in comparison to other systems. Infusion of sustainable features like hydroponic growing systems, bio-fuel production through floating algae, and protected fish and seafood habitats will result in “cyclical metabolism”, reinforcing the viability of a self-sufficient system. Furthermore, this could be “plugged in” at various existing city deltas, acting as the treatment plant for the local waste materials and CO_2 emissions (Jain, 2020).

Figure 18: Why it is called a Blue Revolution? (source: Deltasync, 2012)

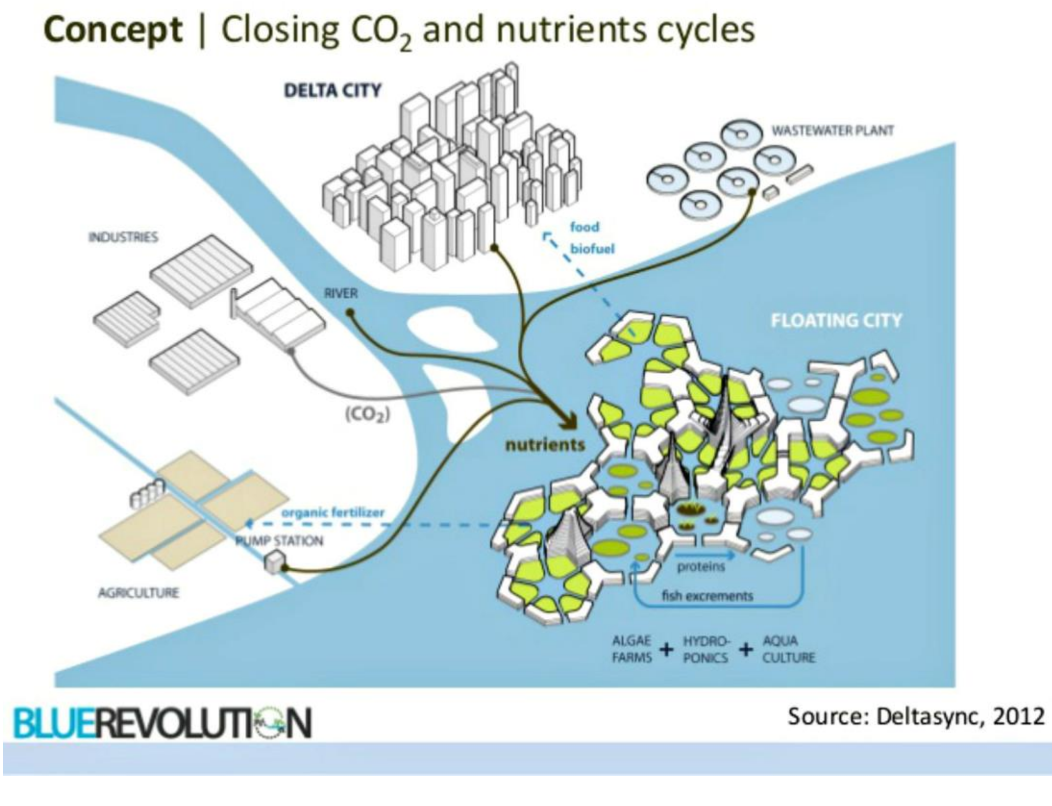


Figure 19: Closing CO2 and nutrients cycles (source: Deltasync, 2012)

Figure 20: Floating cities concept by Dutch floating architecture firm Blue21 (Source: Blue21.com)

Figure 21: Floating cities concept with a phase-wise development strategy (source: blue21.com)

Bjarke Ingels, Danish architect, and the founder of BIG tried to overcome those challenges while designing the “Oceanix City”. Although this is a conceptual idea, his works reflect the future visions for a floating city. Marc Collins Chen, the co-Founder, and CEO of OCEANIX said “humans can live on floating cities in harmony with life below water” (Bjarke Ingels Group, 2019). Waste management, food production, water management, and an energy source, are all challenges that need to be addressed. With the current technology, we may be able to address those points. The impacts of urban areas on the environment may also be reduced. Water management and waster management plants also need to be solved accordingly. The following diagrams will show the future vision of “Oceanix city” design by BIG and their ways of adapting to the problems.

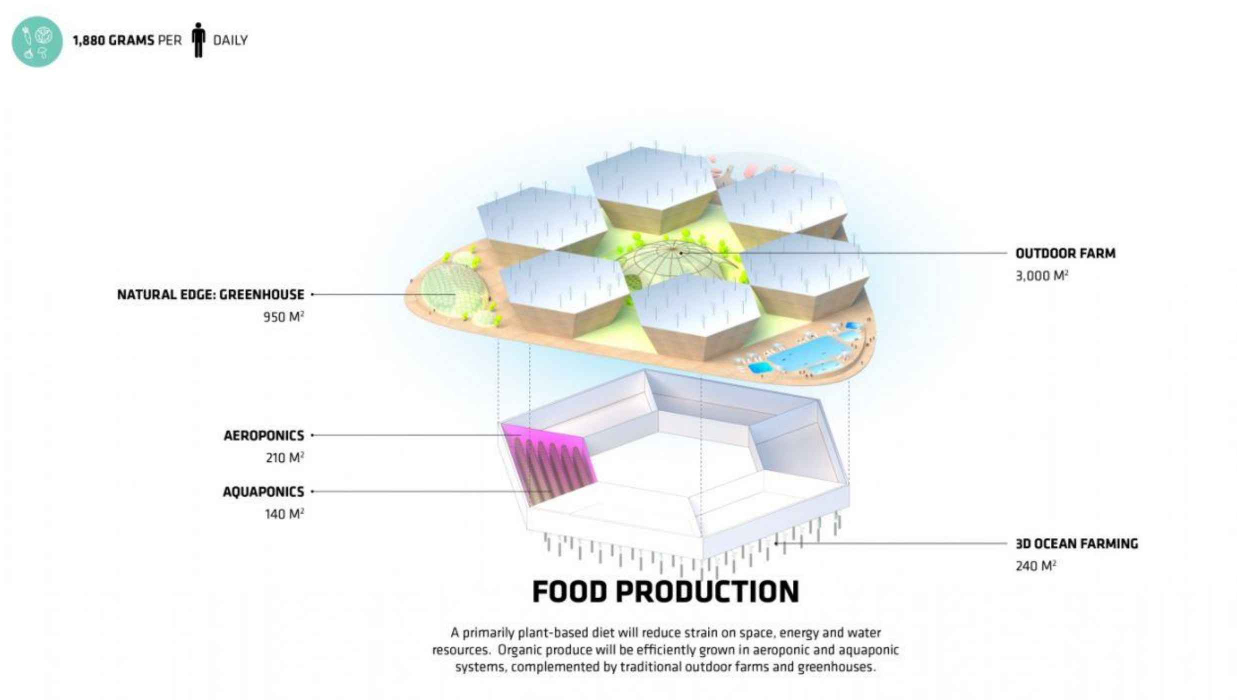


Figure 22: Food Production (source: BIG)

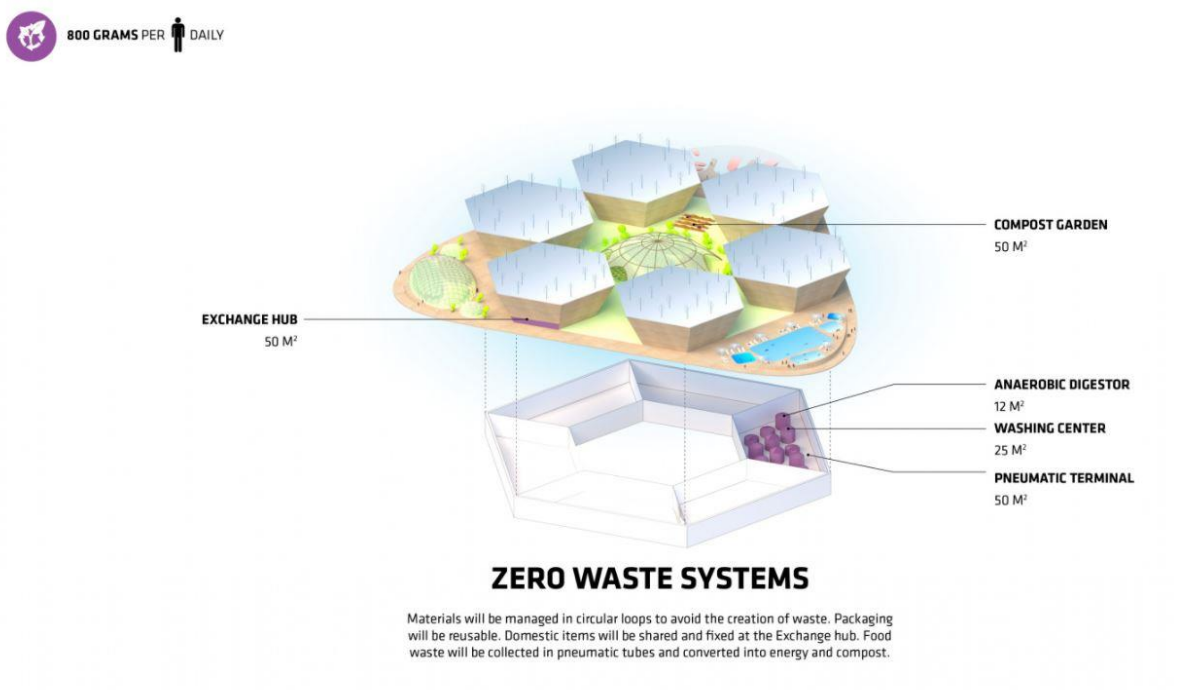


Figure 23: Zero waste (source: BIG)

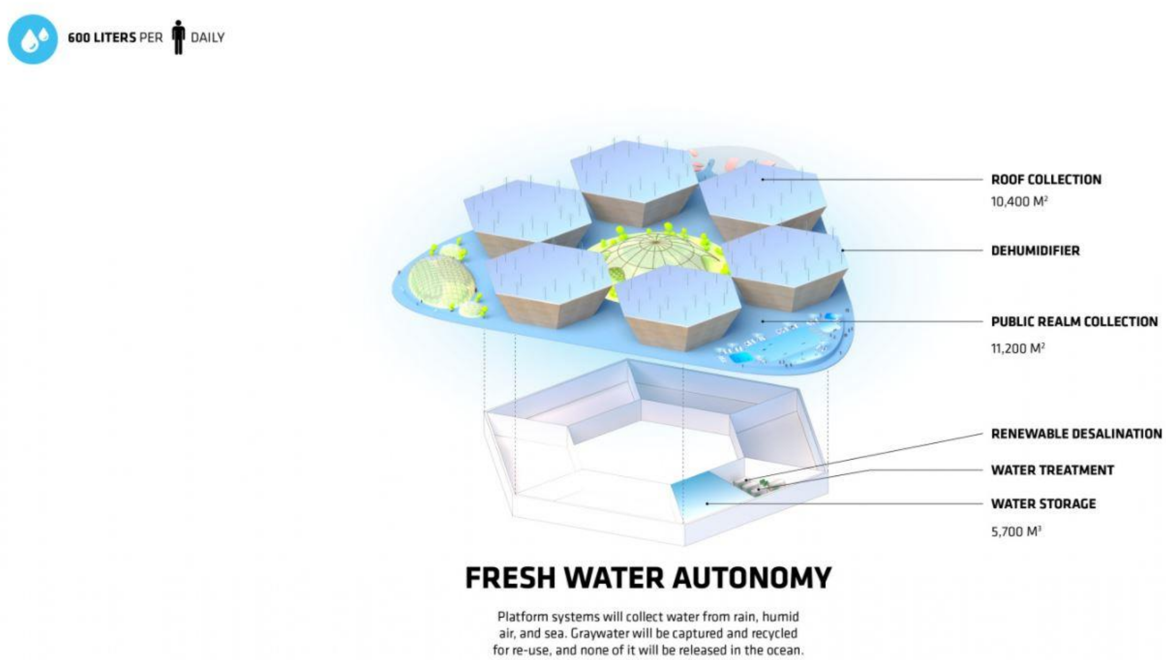


Figure 24: Freshwater autonomy (source: BIG)

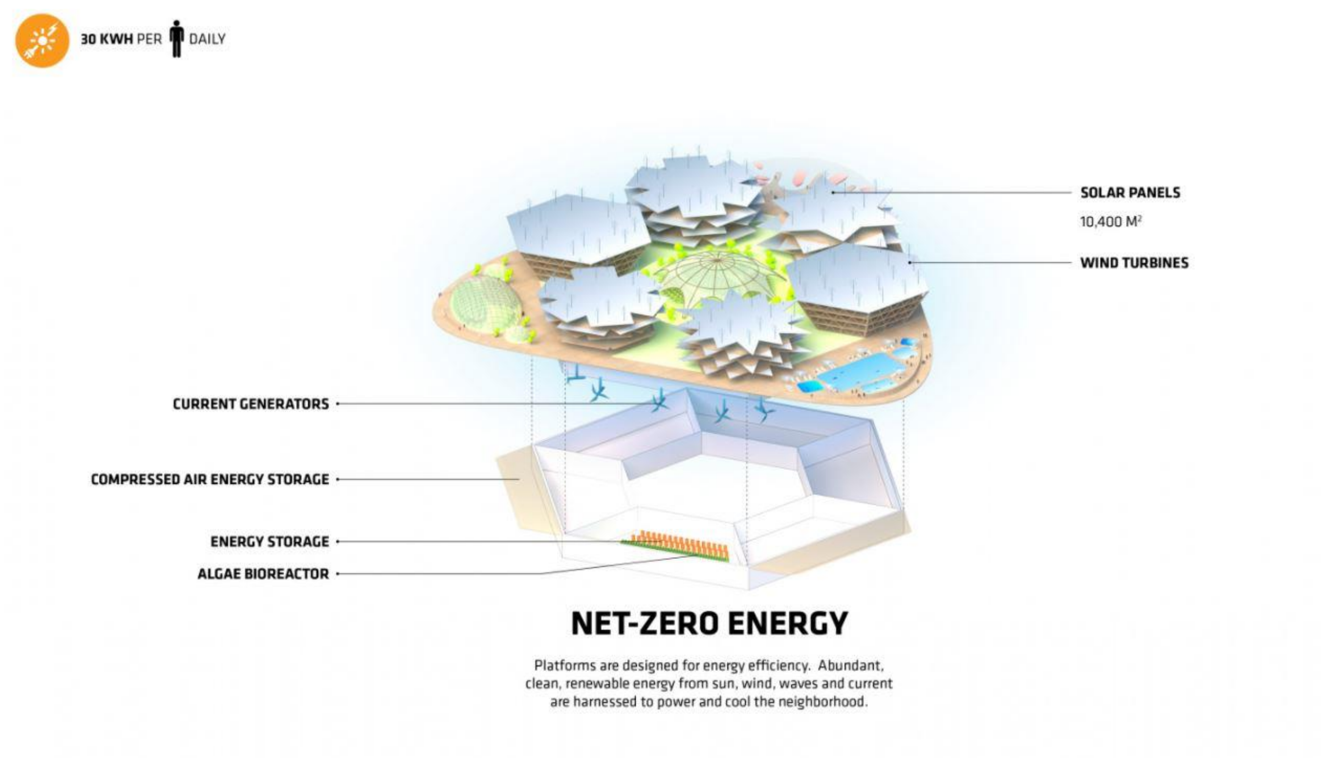


Figure 25: Net-zero energy (source: BIG)

Figure 26: Village (source: BIG)

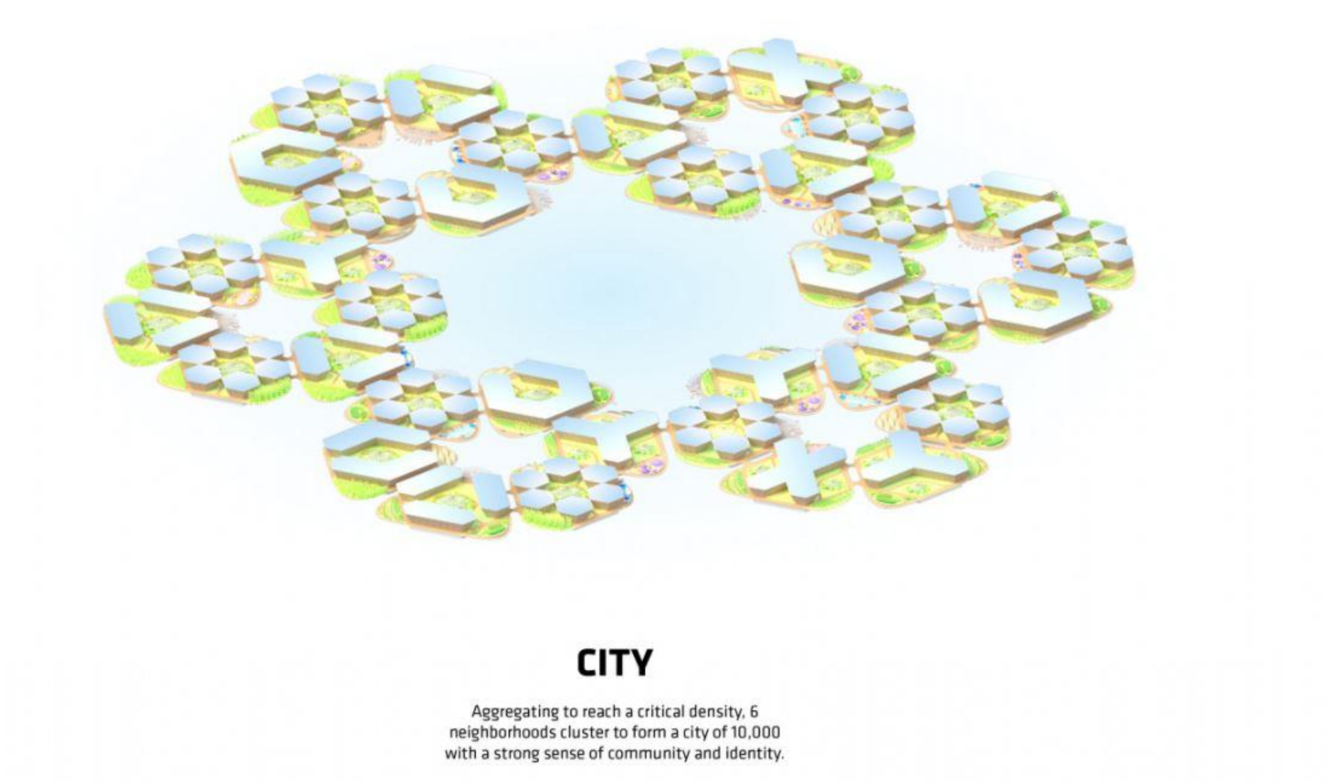


Figure 27: Creating a city (source: BIG)

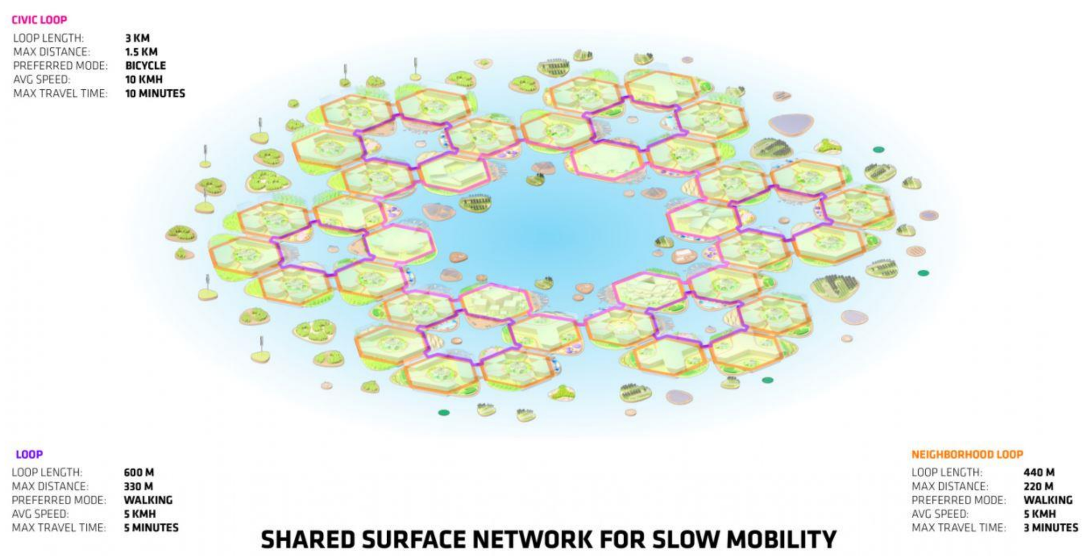


Figure 28: Floating city network (source: BIG)

3.2 Direction of this research

The main interest of this research paper is to examine why mankind has not been able to build a "Floating City", which has been discussed in the literature review. After defining the challenges associated with this concept, the next step is to explore how we can overcome these challenges and what would be the steps that are needed to make it a reality.

The realization of self-sustaining, floating cities may seem far-fetched; however, it is essential to consider the current global issues that floating cities may address. The first rebuttal that a designer will face is 'why we don't increase the density of our existing urban land areas?' The most obvious option may be to do just that. However, how long can you continue to densify? Will you be able to solve all the problems without creating a new land area? The world population increased from 1 billion in 1800 to 7.7 billion today (Max Roser, 2019). The UN projects that the global population increases from a population of 7.7 billion in 2019 to 11.2 billion by the end of the century (Roser, 2019). As the population growth continues the world will need more land to support the projected population. In 2015 the United Nations Food and Agriculture Organization completed a landmark study estimating that 25 percent of the world's land is now "highly degraded", yet the world's farmers must produce 70 percent more food by 2050 to feed the 9 billion people (Quirk, From the Green Revolution to the Bule Revolution, 2017). With 83 million more people appearing on the planet every year, rising populations are placing increasing pressure on the land (Gray, 2017). This triggers the thought of looking for a way to create new lands for future generations. "When people think of the Maldives, it is usually of a beautiful paradise with crystal clear lagoons and white sand beaches," says Shamau Shareef, the city's recently elected deputy mayor. "Malé is very different. We have very limited space and life is tough." (Gray, 2017). This paper never said that a "floating city" is the only option rather it is trying to say that it is amongst one of many options. With rising sea-level, climate change poses a great threat to the coastal cities and a new development plan needs to take place. "Now this is one of the many possible ideas" explained Anne Lise Kjae (a London-based futurist and keynote speaker) when she was asked, "Is this the future" (Foster, 2020). A coastal city can be developed in many ways, but the expansion of a coastal city to its marine environment could be one of the options that could be explored.

When examining the possibility of a coastal city expanding to its marine environment, understanding the environmental impact must be prioritized. Research done by the International Association for Hydro-Environment Engineering and Research (IAHR) will prove that a floating Structure does not pose any threat to the environment if it is designed in the right way. IAHR has done research that monitors the impact caused by the “Rotterdam Floating Pavilion”, an exhibition pavilion that showcases floating building construction, energy efficiency, and climate management. The underwater quality and ecology were examined using an underwater drone.

Monitoring water quality under floating structures has been difficult until recently due to the poor accessibility of the water body underneath the structures (R.L.P. DE LIMA, 2015). In that research, a remote-controlled underwater drone (Thunder Tiger Neptune SB-1) equipped with water quality sensors and a video camera (Figure 29), was used to perform dissolved oxygen measurements under and around floating buildings/platforms. The drone monitored several water quality parameters, such as pressure (depth), temperature, conductivity, nitrate, ammonium, dissolved oxygen, and turbidity. In addition to the data from the sensors, the underwater drone also collected footage of aquatic life, which was used to assess the ecology and habitat under the vicinity of the floating structures (R.L.P. DE LIMA, 2015). Data were collected from several different locations throughout The Netherlands, from July until October 2014 (R.L.P. DE LIMA, 2015).

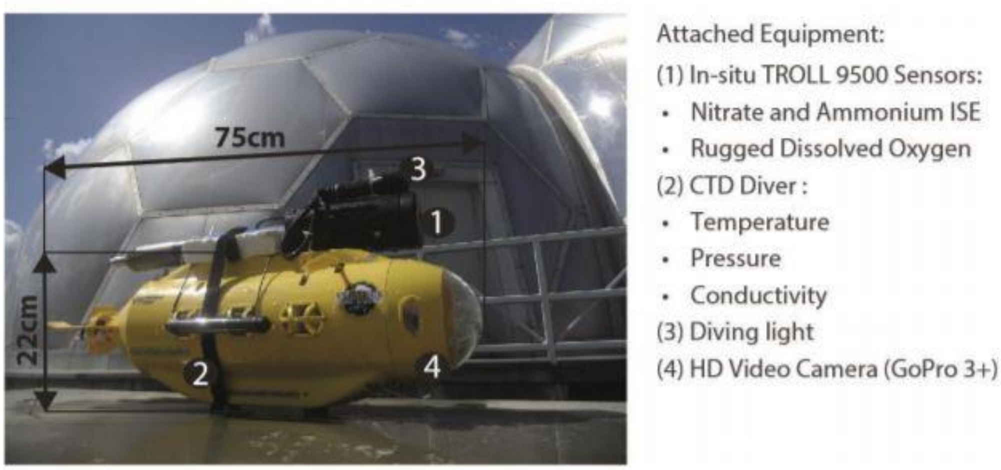


Figure 29: The underwater drone with the attached equipment (source: R.L.P. DE LIMA, 2015)

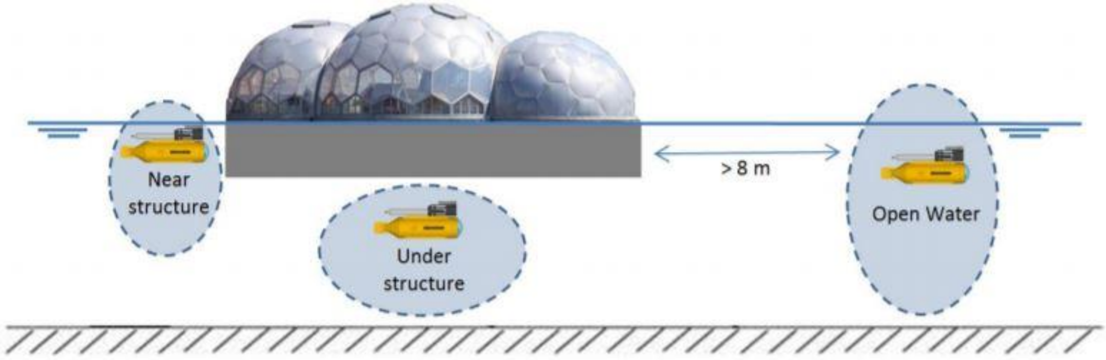


Figure 30: Schematization of the zones of collection of data (source: R.L.P. DE LIMA, 2015)

The results from that paper focus on the analysis of dissolved oxygen. It is one of the most affected parameters by the presence of floating structures, due to the coverage of the water surface, and consequent influence on the air-water interactions (R.L.P. DE LIMA, 2015). Water quality assessment is a subject of high complexity, as the parameters vary not only temporally (e.g. daily, seasonal) and spatially, but also with water depth and temperature (R.L.P. DE LIMA, 2015). To analyze how the water quality parameters vary under floating structures, the measured data was divided into depth ranges and then the averages for each depth were computed (Figure 31). This allowed evaluation and comparison of results from different depths and zones, and to quantify the effects that the floating body may cause. Figure 31 shows that the dissolved oxygen is always slightly lower under the floating structure than in open water at the same depth (R.L.P. DE LIMA, 2015).

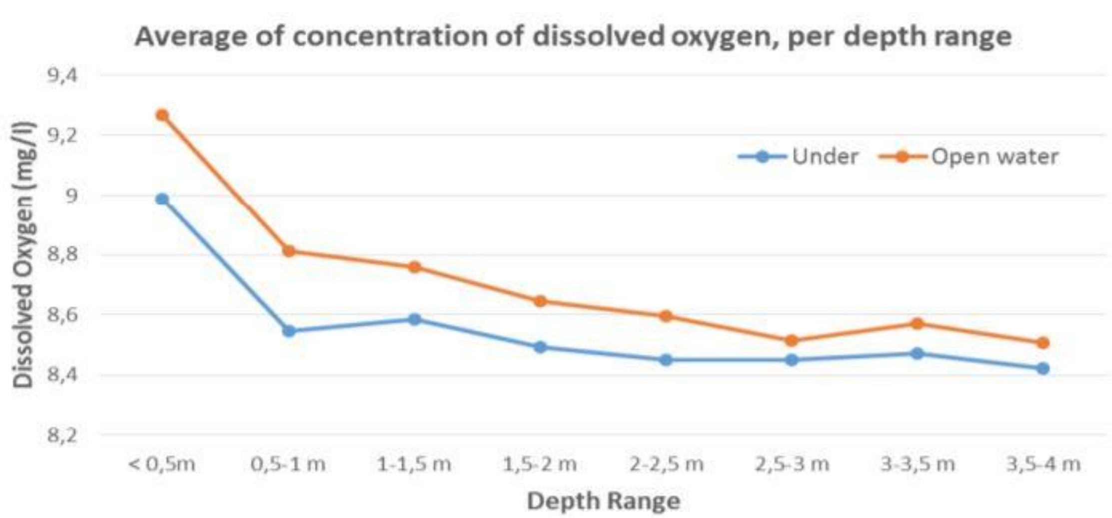


Figure 31: Comparison between the averages of the concentration of dissolved oxygen under/near floating structures and in open water, per depth range (source: R.L.P. DE LIMA, 2015)

The analysis of the oxygen concentrations detected under floating constructions is also of great interest because it allows us to see if acceptable oxygen levels for aquatic life are maintained at all times. Figure 32 represents these minimum values of dissolved oxygen, which was collected from that research paper, both in open water and under the floating structures at different locations.

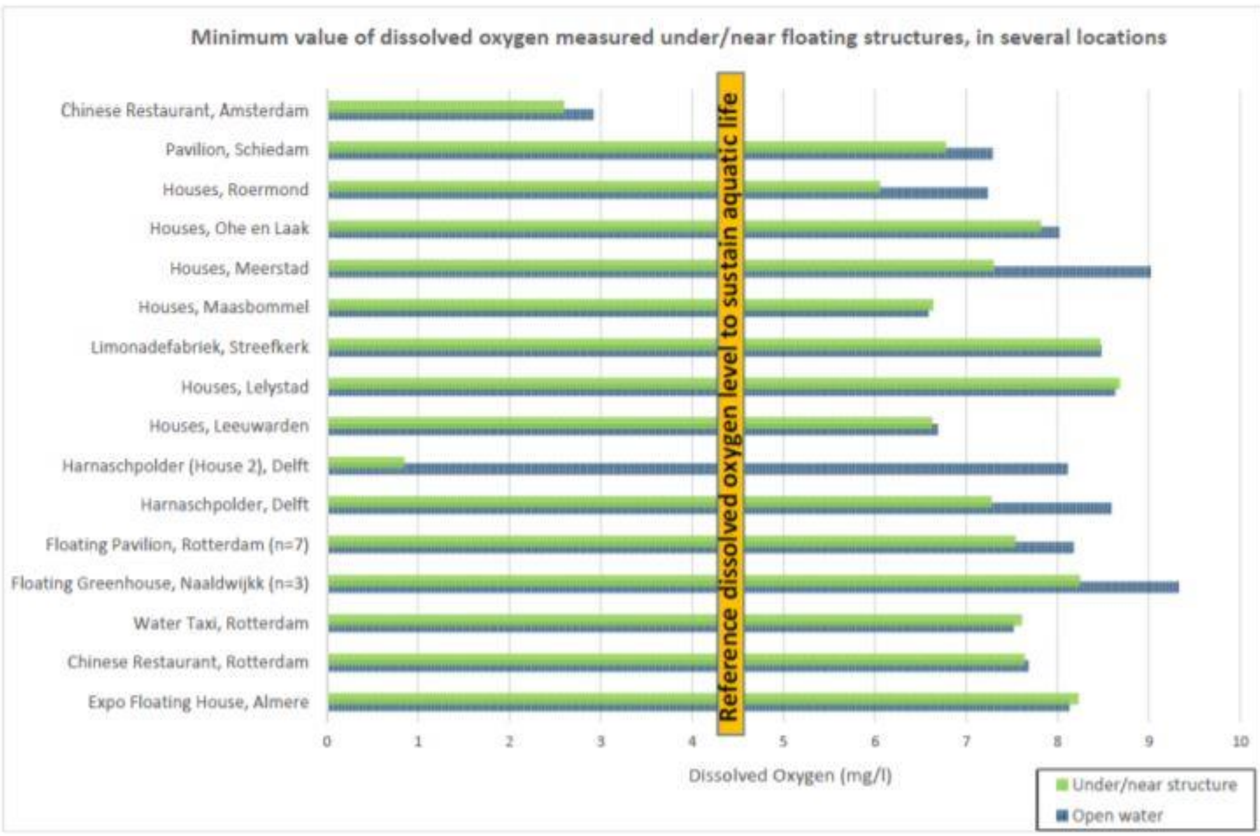


Figure 32: Comparison between the minimum concentrations of dissolved oxygen detected under/near floating structures and in open water (source: R.L.P. DE LIMA, 2015)

In addition to the dissolved oxygen data from the sensor, a high definition video camera was used to collect underwater footage (Figure 33). However, in some locations, the water was turbid, which resulted in poor video quality observations or even made it impossible to see more than a few centimeters ahead of the camera (R.L.P. DE LIMA, 2015). When the water was clear enough, it was possible to identify several fish species swimming under and near these floating structures, along with many other organisms attached to the structures (e.g. dreissenid mussels). The floating structures seem also to be attractive for zooplankton and Mysidae (Neomyses spp). The presence of these species of fish and other aquatic life forms interacting with these structures may also be regarded as good water quality indicators. The underwater footage gave some insight into what happens under floating structures. It was observed that a whole new habitat is created, which was previously not present (R.L.P. DE LIMA, 2015).

Figure 33: Examples of underwater footage with aquatic life under floating houses in Maasbommel and Lelystad (source: R.L.P. DE LIMA, 2015)

Based on the results from that study, the existing current small-scale floating structures do not have a significant influence on water quality. The detected differences in the concentration of the measured water quality parameters (e.g. dissolved oxygen) between open water and under/near the structure's parameters are low, and most parameters remain at acceptable levels (R.L.P. DE LIMA, 2015). Regarding the ecology, underwater footage from the video camera revealed a multitude of aquatic organisms attached to these structures and fish swimming underneath them. This shows that, if designed correctly, floating constructions can stimulate aquatic life and biodiversity in the area surrounding these structures by creating new habitats and by providing shelter for smaller and juvenile fish (R.L.P. DE LIMA, 2015).

While designing the "Oceanix City", underwater marine life was prioritized. The village (individual platforms of Oceanix city) would also focus their efforts on farming below and above land with floating reefs, seaweed, oysters, mussel, and clam farming (King, 2019). It is not a question of one versus the other. The technology exists for us to live on water, without killing marine ecosystems," Bjark Ingles said (Bjarke Ingels Group, 2019). Figure 34 shows a rendered image of how underwater habitat has been respected and a lot of thought process is going on while designing these floating structures.

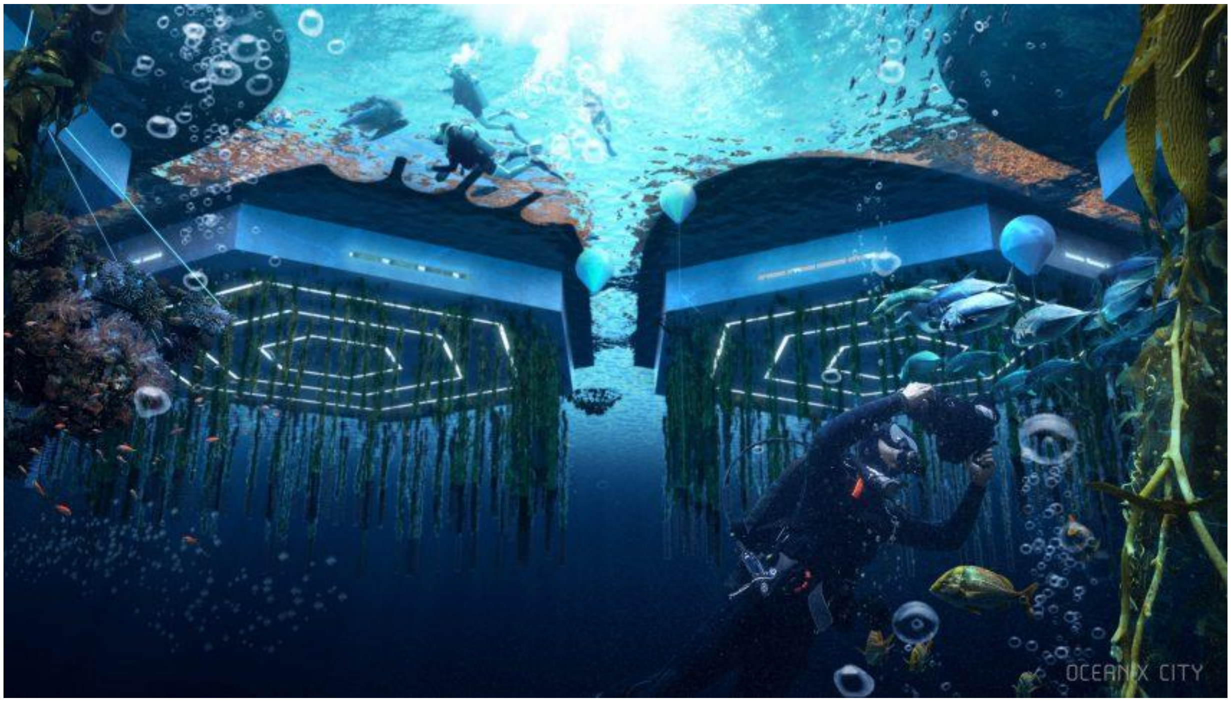


Figure 34: New underwater Habitat, Oceanix City proposed by BIG (source: BIG)

Newly available materials are also helping to achieve the goal of building a sustainable structure. Concrete a potential element when it comes to building a floating structure plays a crucial role. Fiber-reinforced concrete is referred to as a material that contributes to sustainable construction, as the utilization of fiber-reinforced composites enhances the durability and resiliency of structures and structural elements (Broukalova, 2018). The advances in concrete mix design, production technology, inventions in advanced materials, new use of traditional materials, new perspectives in the designing concrete structures should lead to a change of understanding concrete as a material hostile to the environment (Broukalova, 2018).

Any form of urban coastal expansion is challenging. One of the traditional ways of doing so is, land-reclamation. Such kind of work is easily seen in Dubai or Singapore. Man-made developments and tourist projects have seen Dubai's coastline grown by 6 percent over the past six years (Land expansion sees Dubai's coastline grow by 6%, 2017). Using satellite imagery, Mohammed bin Rashid Space Centre (MBRSC) has said projects like the Al Mamzar Corniche Beach, Jumeirah Bay Island, Jumeirah One Beach, Pearl Jumeirah, Umm Suqeim 1 and 2 Beach, and the Dubai Water Canal have led to the expansion of

Dubai’s coastline between 2009 and 2015. The study also showed the construction of several breakwaters and sand barriers aimed at protecting the coast from medium-high waves, coastal erosion, and sediment transport (Land expansion sees Dubai's coastline grow by 6%, 2017).

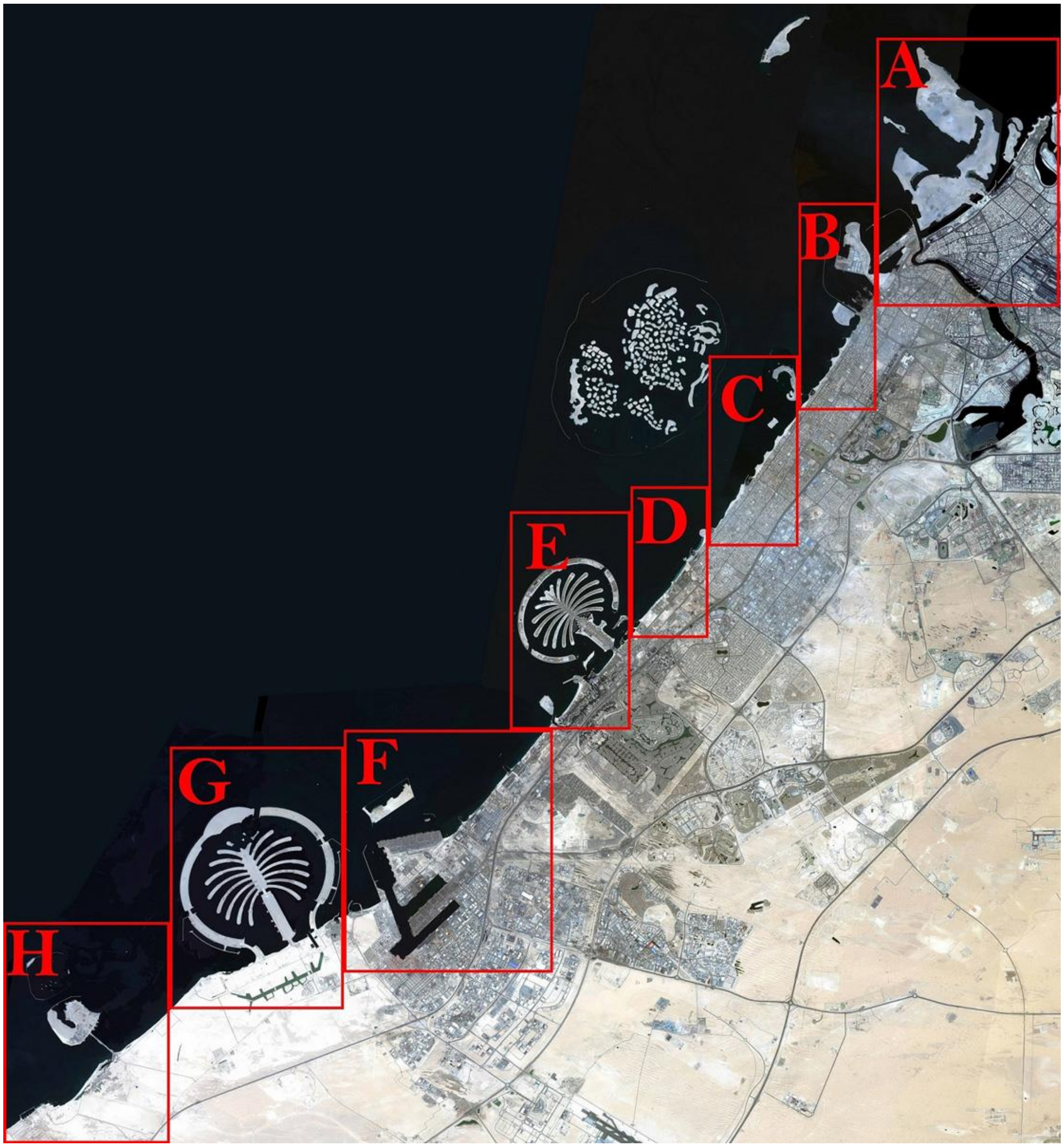


Figure 35: Dubai land expansion (source: Arabic Business News)

Over the past two centuries, Singapore’s land area has expanded by 25% – from 58,150 to 71,910 hectares (or 578 to 719 sq km). This gradual increase in the land surface is not because of tectonic movements or divine intervention, but rather the miracle of a man-made engineering feat known as land reclamation (Land From Sand: Singapore’s Reclamation Story, 2020). Land-scarce Singapore, however, has elected to create new land by reclaiming it from the rivers and the seas (Land From Sand: Singapore's Reclamation Story, 2020). Land reclamation has been increasingly seen as a solution to this. However, it's highly controversial because of the impact it would have on the surrounding environment (Duong, 2017).

On one hand, land reclamation is seen as a potential response to Hong Kong's growing population, as well as a way of boosting economic development. Major reclamation projects include the construction of Hong Kong International Airport, which aided infrastructural development and has proved indispensable for Hong Kong's quest in becoming a global financial hub. Hong Kong Disneyland is built on reclaimed land and is seen as a major tourist attraction (Duong, 2017). On the other hand, land reclamation has a serious impact on the environment (Duong, 2017). A government review in 1996 stated that land reclamation would result in the "large displacement of the marine sediments and the development of mud-waves beneath the reclamation fill" (Duong, 2017). This would disrupt the ocean's ecosystem, lead to soil liquefaction, and pollute the water (Duong, 2017).

"Floating is a lot better than land reclamation because it protects the marine environment. It can be easily be removed or expanded, whereas land reclamation usually takes a bunch of sand and dumps it over a place, killing everything that lives there," Mezza-Garcia, a complexity scientist who once worked with the Seasteading Institute, explained (Shepard, Floating Cities: The Next Big Real Estate Boom, 2019). "I think the first steps in living on the ocean will be a coastal expansion of existing cities", Rutger explained (Graaf R. d., 2017). "The most logical way is that we see urban densification in all port areas like we are seeing now in Rotterdam. Then the next step would be probably coastal expansions on the water. Then the step after that will be perhaps first floating cities in territorial waters and then floating city-nations" (Graaf R. d., 2017). Which is exactly the coastal expansion process followed by Deltasync while proposing their "Floating City" module (Figure 20 &21).

Floating houses are becoming more and more popular in coastal cities and marine expansion of coastal cities appears to be promising. No doubt that floating houses are the most palatable first step for the general public. The development of a floating city depends on the gradual expansion of floating homes near the coastline.

Floating Houses in IJburg (Figure 36 & 37), designed by Marlies Rohmer Architects & Urbanists, is a floating community that includes seventy-five floating homes and waterside dike houses in the private (rental and owner-occupied) sector. In recent years, there has been an increase in the number of water-based housing developments that share more characteristics with land-based housing. They are financially classified as immovable properties and compete with land-based accommodation in their interior volume and comfort level. The new water-based developments can incorporate several forms of living with the water.

Figure 36: The Floating Houses of IJburg, Amsterdam (source: Marlies Rohmer Architects & Urbanists, Photo credit: George Steinmetz)

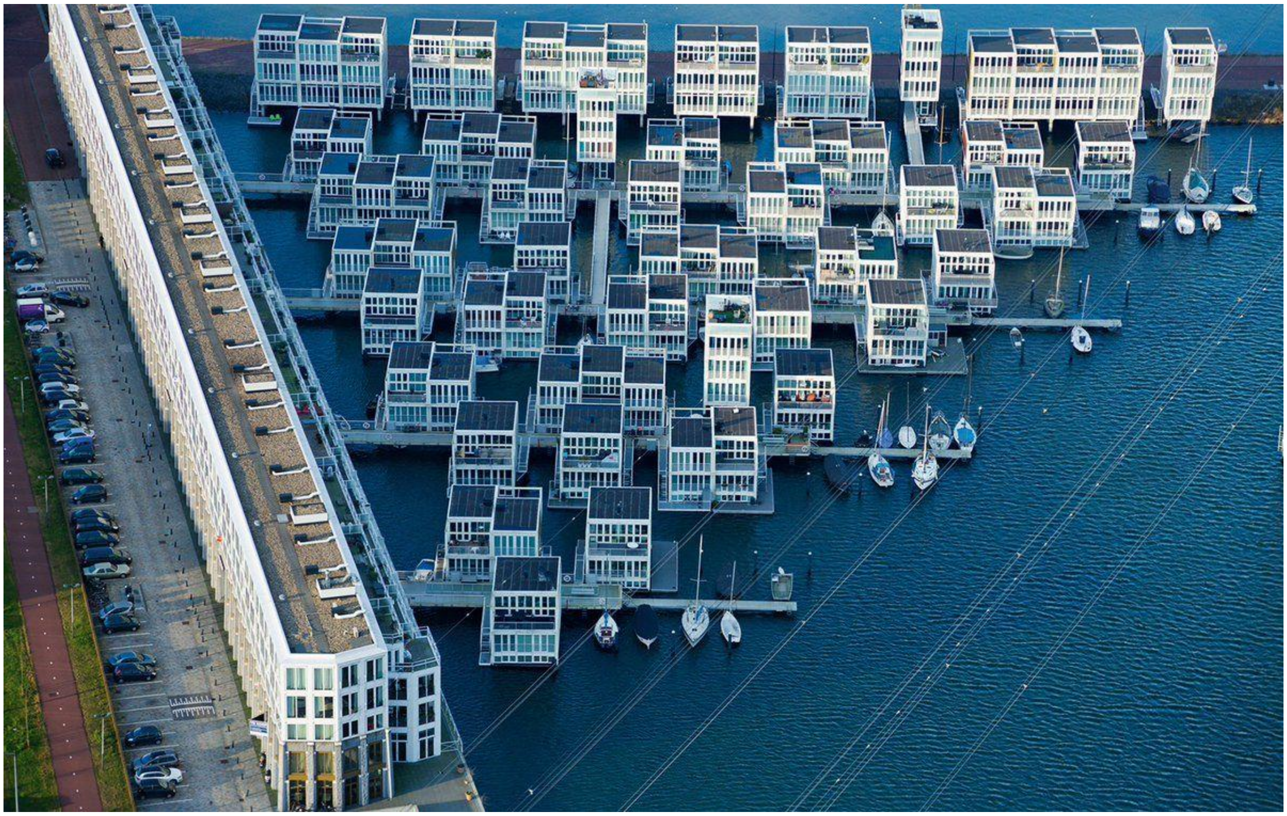


Figure 37: The Floating Houses of IJburg, Amsterdam, Arial view (source: Marlies Rohmer Architects & Urbanists)

Another example is The Schoonschip (Figure 38,39 &40). A floating neighborhood in the Buiksloterham district of Amsterdam has been a massive success thus far (Roberts, 2015). The first four of the floating neighborhood's 46 households have already been set up in the Johan van Hasselt canal. Since the idea for Schoonschip first gained attention back in 2009, other cities have weighed the option of developing similar communities (Roberts, 2015). This project seamlessly integrates with the urban fabric of the city, although these houses are built on water.

Figure 38: Schoonschip, a floating neighborhood- Model view (source: spaceandmatter.nl/schoonschip)

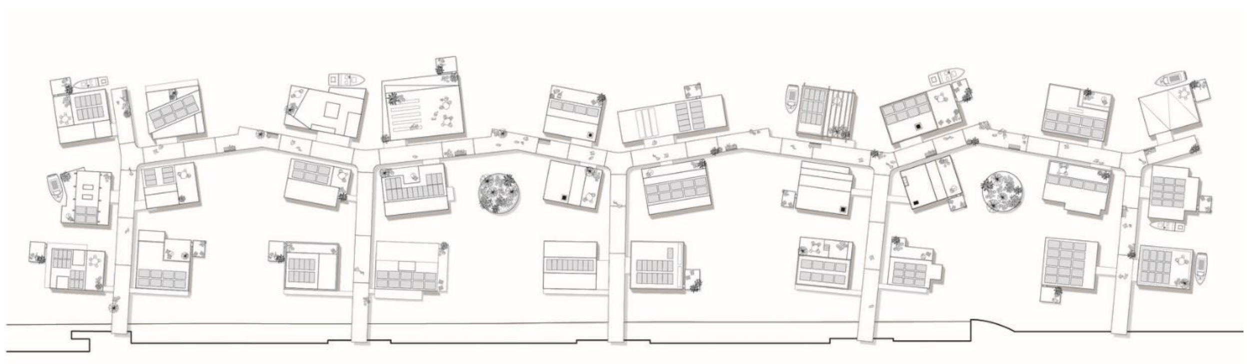


Figure 39: Schoonschip, a floating neighborhood- Plan view (source: spaceandmatter.nl/schoonschip)

Figure 40: Schoonschip, a floating neighborhood (source: spaceandmatter.nl/schoonschip)

Each separate house is insulated and equipped with solar panels. Water pumps extract heat from the water in the canal to heat the homes. There is only one connection to the national energy grid, through which residents of Schoonschip trade their generated solar power (Space&Matter.NL, 2020). Each home has a battery that stores the energy surplus. Wastewater from toilets and showers is treated separately and converted back into energy (Space&Matter.NL, 2020). Many homes also have a green roof, where residents can grow their food (Space&Matter.NL, 2020). Schoonschip is not only sustainable in an ecological sense, but also socially: the residents work closely together to realize their residential area and coordinate their plans (Space&Matter.NL, 2020). They have agreed to renounce their personal cars and instead share electric cars. The group also made a conscious search for diversity in the composition of residents. On that note, there are two ‘kangaroo houses’ in Schoonschip, where two households live together on one boat (Space&Matter.NL, 2020). Meanwhile, the houses are connected by a 'smart jetty' that serves as a pavement and meeting place (Space&Matter.NL, 2020).

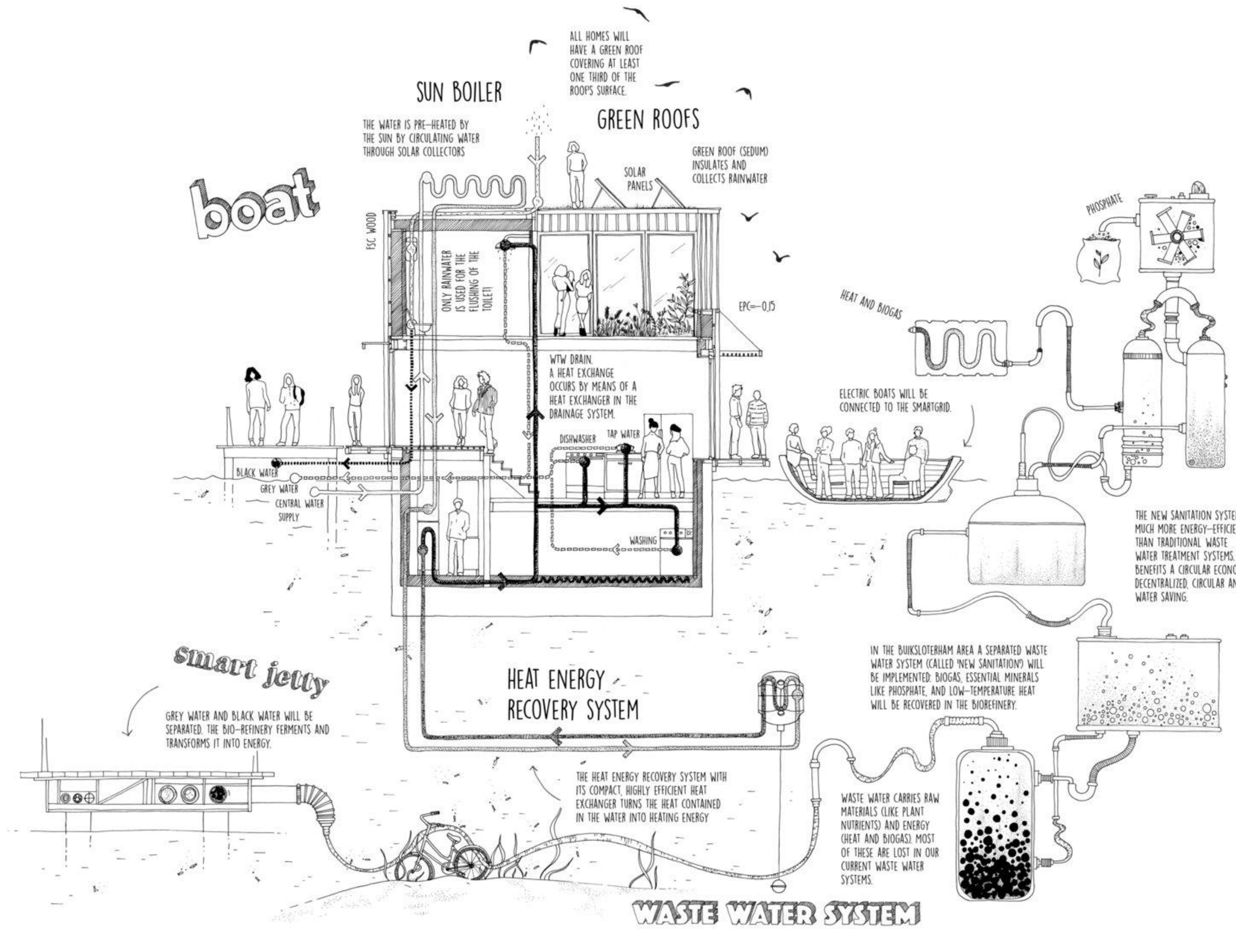


Figure 41: A self-sufficient system designed for Schoonschip (source: spaceandmatter.nl/schoonschip)

The floating pavilion in Rotterdam is another example of a successful floating structure. Initiated by DeltaSync, the Floating Pavilion is intended as a pilot for building on water and a first step towards floating urbanization (MILATESIC, 2020). The Floating Pavilion is a unique floating venue in the center of Rotterdam. It can be rented partly or entirely for conferences, exhibitions, presentations, receptions, and dinners. Three transparent domes are currently floating in the Rotterdam City Harbour 'Rijnhaven'. It is an exhibition pavilion that showcases floating building construction, energy efficiency, and climate management technologies (GUPTA, 2010). Not only does this pavilion illustrate the capabilities of a successful floating structure, further, it also exhibits the importance of a sustainable floating building. Important objectives of the new pavilion are to showcase ways to reduce energy consumption and CO_2 emissions, which align with the Rotterdam Municipality objective of reducing CO_2 emission by 50%

before 2020 (GUPTA, 2010). This project proves the importance of innovative design solutions to pioneer the expansion of coastal cities to adjacent waters; these are only the first steps toward a marine city.

Figure 42: Floating pavilion in Rotterdam (source: insideflows.org)

Figure 43: Floating pavilion in Rotterdam, front view (source: insideflows.org)

Vancouver’s Canoe Pass Village is a perfect example of Life on a tidal river. This floating community occupies a portion of the Fraser River on the southwest coast of British Columbia. “Powell lives in Canoe Pass Village, a float home community in the Fraser River just on the edge of Ladner. We meet ashore, go through the locked gate, and head down the sloping ramp. It’s low tide”, she said (BRAMHAM, 2011). It’s called a village for good reasons. There are only 43 homes in the strata-titled village where homes are secured to docks (BRAMHAM, 2011). Another floating community exists in the heart of Granville Island. A resident of that community leads a similar to their neighbors living in a townhouse in nearby Kitsilano. They shop from the Granville market. Their kids go to a school near Granville and most of the residents work and travel and use land-based public transport like others. The only difference is that they live in a floating house and their rest of the lifestyle is the same as others inland.

Figure 44: Canon pass village floating house (source: floatingstructures.com)

Figure 45: Floating houses in Granville island (source: Vancouversun.com)

These case studies provide evidence that the success of a floating community is dependent on its connection to the shoreline. Although experts believe we can start building on open oceans now, it seems the future of floating cities may lie somewhat closer to the land (Cosgrave, 2017).

3.3 Debates related to a floating structure

This paper began by questioning the technological advances needed to develop a floating. Is the technology advanced enough to support this idea? According to research, it seems like technology is not the barrier. With the current scientific advancement, it is quite possible to build a floating structure on the open waters. Advances in technology enable us to create structures for habitation in deep-sea waters. Ultimately, these schemes have never really taken off because of political and commercial barriers (Wang, 2019).

Cost is another barrier. The cost of building a floating city brings many challenges. Marc Collins Founder and CEO of ‘OCEANIX’ attended ‘Roundtable’, a discussion program broadcasted out of London and presented by David Foster. He was asked about the costs associated with his project and whether it was insurmountable. He responded that cost is not a barrier; he has been able to gather a lot of interest from different sources in the real estate market who are willing to invest in his project (Foster, 2020). When asked about the political issues, he mentioned that OCEANIX has not selected a government to work with or whether their proposal has been accepted by a political body. Their floating city ‘OCEANIX’ is designed for open waters and not designed for a specific country or continent. He also mentioned that later this year (2020) he is confident that their team will be able to sign a contract with one government amongst the many who they are currently negotiating with (Foster, 2020). So far it seems like getting over the political and social accessibility issues is more of a barrier than the financial costs and technological capabilities. A floating city has major implications for land-based real estate as the project would inevitably flood the housing supply, dropping land valuation. Another potential issue is the high cost of food and energy production inherent in ocean-based development. Navigating both of these issues in a legislative environment would be a challenge as there are vested interests that could be opposed to the negative effects of these issues.

In the Roundtable interview, David Foster took issue with the point, “If you think from a social perspective and you put people offshore, you somehow need to connect them to the people on land otherwise it will turn into an empty community” (Foster, 2020). Although no clear answer was received from Marc Collins, he did mention that they are planning to build this project close to the land. Connecting ocean-based cities with land-based cities is crucial for the success of these developments. This connection could be achieved by starting as close as possible to the shoreline. We won’t be able to build a floating city that is fully self-sufficient at the beginning, though that will be the final goal. By starting close to the shore, the floating city will naturally develop close connections with its land-based counterpart through supply chains, transportation networks, and social interaction. Over time, the ocean-based city will develop a more self-sustaining economy while ideally, the social networks that exist between sea and land persist. Any kind of change takes time, it can not be achieved overnight.

With the increasing tension caused by global warming and rising sea-levels, we are starting to recognize the need for a more innovative solution. Development concepts that once may have seemed drastic or unfeasible are now becoming realistic solutions for mass displacement caused by a rapidly changing climate. Just as Joe Quirk stated in his book Seasteading, “Give me your pollution and I will give you food” (Joe Quirk, 2017). What he means by this is that humans are responsible for global climate change and temperature rise and there is no doubt about that. A self-sufficient floating city planned around renewable energy sources would go a long way to curbing human environmental impact. To make this possible a ton of research needs to be done. We can make a city float but making it a completely climate-proof and self-sufficient ecosystem should be a top priority.

4 Importance of a Floating Structure

4.1 Background

Sea level rise is a potential threat that will affect most of the world's coastal cities. If the rate of ocean rise continues to change at this pace, the sea level will rise 26 inches (65 centimeters) by 2100 (Weeman, 2018). To say we have a problem is an understatement. By the middle of the next century, many of the world's major cities will be flooded, and in some cases, entire island nations will be underwater (Oberhaus, 2019). Expansion of a coastal city to their adjacent waters has only been looked at on paper, though should be considered as an exciting solution. Floating structures are highly resilient to sea-level change, for obvious reasons.

Land shortage in and around coastal cities is a growing issue in both industrialized and developing countries. The lack of development areas increases the pressure on infrastructure and impacts both growth and quality of life. This stimulates discourse concerning the creation of new land on water and the expansion of cities towards adjacent waters.

Floating structures can be touted as cheaper and faster to construct compared to land reclamation. Generally, it takes multiple years for the sand to stabilize when developers reclaim the land. Floating cities have no such requirements, work can start the day the platform is anchored. It also does not scar the development site in the same way as land-based development, after the work is finished it simply gets dismantled and removed from the surface of the water.

Ahmed A. El-Shihy wrote a Journal named "Architectural design concept and guidelines". The journal said, the floating building method may not be the best solution for every scenario. However, such an approach has more benefits over the old and traditional land reclamation solution in terms of space created in the following aspects:

- They're cost-effective where the water depth is considerable.
- Sensitive to the conservation of fragile ecosystems where they do not harm the marine eco-system, silt-up deep ports, or disturb the tides and sea waves.
- They are uncomplicated and fast to assemble. Different elements and components could be manufactured at different dockyards and then transported to the location to be assembled.
- They could be easily disassembled or withdrawn if the sea space is required in the future, or expand as modular units.

- The facilities and the structure are protected to avoid harmful seismic shocks where their bases are fundamentally isolated.
- Their position in seaside waters offers an attractive form in the water, making them an appropriate fit for future developments related to leisure, activities, and water sports events.

4.2 Types of floating structures

4.2.1 Very large floating structures (VLFS)

Various types of floating structures exist currently. Very Large Floating Structures (VLFS) have sparked tremendous interest and been the focal point of several articles. Very Large Floating Structures (VLFS) are artificially man-made floating land parcels on the sea. They appear like giant plates resting on the sea surface. The Mega float is particularly well known for coastal use (Miguel Lamas-Pardo, 2015). This type of structure is used to make large scale projects such as Airports, bridges, and ports. What makes this structure popular is the flexibility for deployment? The modular nature of floating structures also affords the superior advantages of mobility and flexibility that are not inherent in their reclaimed counterparts. Where necessary, floating facilities can be removed if they become obsolete, towed, and sunk as artificial reefs, or expanded and grouped with other floating structures as needed (C.M. Wang, 2015). Japan has been a clear leader in demonstrating the effectiveness of this technology in the various iterations of floating dormitories and plant barges that have been built in Japan and subsequently towed and installed in different jurisdictions (C.M. Wang, 2015).

Figure 46: Floating Airport in Japan (source: C.M. Wang, 2015)

Figure 47: A semi-submersible type floating offshore wind turbine in Fukushima, Japan (Photo courtesy Takeshi Ishihara—Professor in the Department of Civil Engineering at the University of Tokyo's Graduate School of Engineering

(source www.japantimes.co.jp)

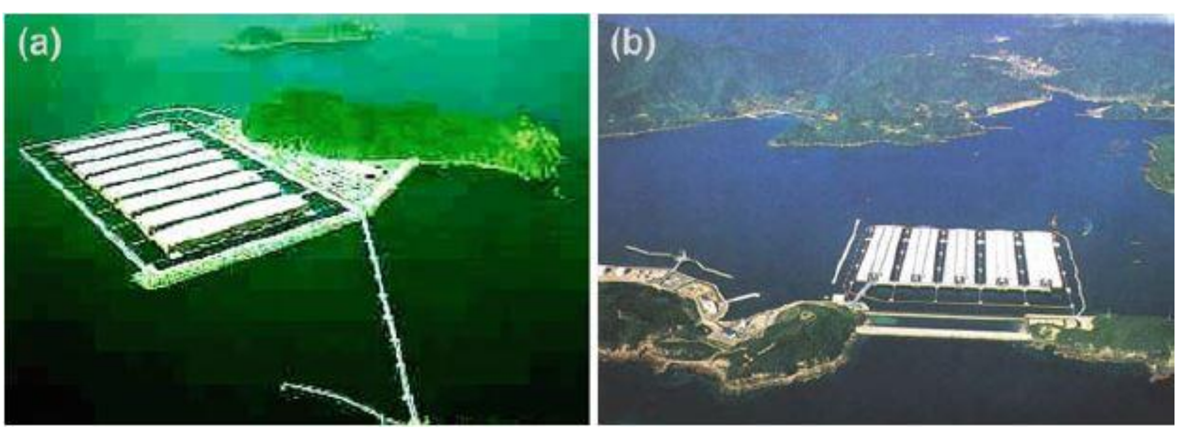


Figure 48: a Shirashima floating oil storage base, Japan (Photo courtesy of Shirashima oil storage Co Ltd) and b Kamigoto floating oil storage base, Nagasaki Prefecture, Japan

(source: C.M. Wang, 2015)

Figure 49: a Jumbo restaurant in Hong Kong and b floating restaurant in Yokohoma (source: C.M. Wang, 2015)

Another example of this type of structure is The Hotel Haegumgang and King Pacific lodge Princess royal Island. Hotel Haegumgang is a floating hotel that began operations in Queensland, Australia, was moved to Vietnam, and is currently docked at Mount Kumgang on the east coast of North Korea.

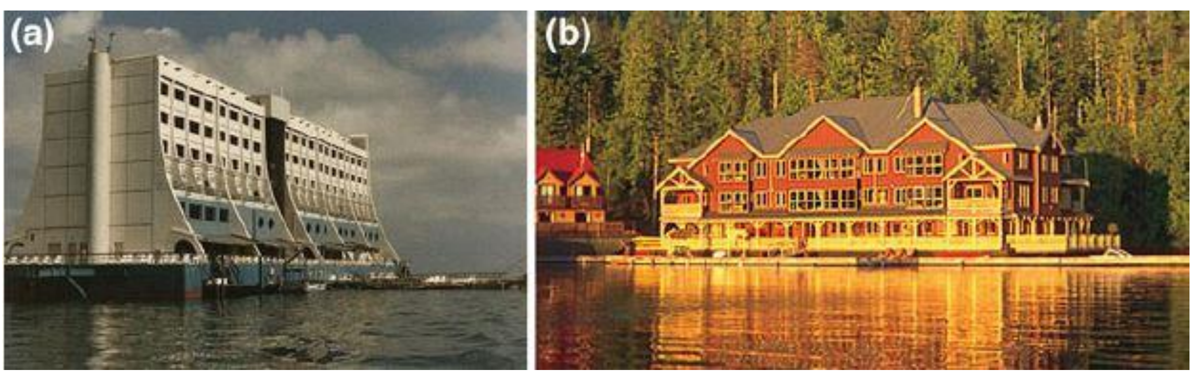


Figure 50: A Four seasons hotel and b King Pacific lodge Princess royal Island (source: C.M. Wang, 2015)

The mobility of a floating structure also makes it useful for utility plants. It has been exploited for industrial purposes since the latter half of the 20th Century. These facilities can be constructed in one location and towed to the site and installed as a permanent facility or moored and towed again to a subsequent site where the need arises.

Figure 51: Floating solar power station in Kagoshima Prefecture (source: http://cleantechnica.com/2013/11/ 07/kyocera-opens-70-mw-solar-power-station-japan)

Figure 52: Floating rescue emergency base at Tokyo Bay (Photo courtesy look at the sea. The floating structures Association of Japan)

(source: source: C.M. Wang, 2015)

4.2.2 Modular floating structures (MFS)

Modular Floating Structures (MFS), which is a type of system of multiple floating structures assembled to make a large group. The MFS can be described as an array of relatively small floating elements. MFS is not designed for a single task such as floating airports, storage facilities, or bridges, and its modular layout permits dynamic spatial growth, compatible with urban use (Nitai Drimer, 2019). Modular construction gives it the flexibility to add or subtract a portion with or from the entire structure. A leading research institute called 'The Seasteading Institution' and 'DeltaSync' worked jointly to make a contemporary concept design and a rough cost calculation of a floating city. The entire research was based on how to build and stabilize a floating city.

The most important ambition of The Seasteading Institute is to guarantee political freedom. This aspect is directly linked to the ability to move a floating community when a specific location is no longer suitable because of political interference. The most important design qualities in terms of mobility are the speed, safety, and convenience of the movement. The different possibilities to move a floating structure are directly linked to the size. A large structure has a relatively simple mooring system and can be moved quickly. Smaller-scale floating structures have more connections between the city elements and with the ocean floor. The expected frequency of movements is infrequent, if at all. However, in some regions, it would be a large benefit to be able to move away from hurricanes or cyclones (Ir. Karina Czapiewska, 2013). In that report, they included multiple ways to make a floating structure movable. Figure 53 shows the different styles proposed by Deltasync.

TYPE	DESCRIPTION	PROS	CONS
 SELF-PROPELLED	Ultimate movability is gained by integrating a seastead with or building it on a ship – the most suitable option if city is often relocated.	– Easy to move – Can be moved quickly – With large structures, a simple mooring system	– Large propulsion system – needed for occasional transport – High maintenance costs.
 TOWED	Seastead platform(s) are designed in such a way that they are easy to move using a tugboat or other external device that can generate propulsion.	– Easy to move – Can be moved quickly	– External device needed for transport. – Design should be suitable for towing. – For travelling high seas, only large structures possible.
 SEMI-SUBMERSIBLE SHIP	Seastead is transported by a semi–submersible ship.	– Can be moved quickly – Least design restrictions. – Freeboard can be lower, allowing better water experience – A large variety of platform sizes can be transported. – Allows smaller scale structures to be transported over high seas. – The total structure stays intact.	– External device needed for transport – Large number of ships needed when there is a large number of small platforms. – Mainly suitable for large structures. – Size of floating platforms is restricted to the size of the ship (but ship size is very large) –Structure must be strong enough to be lifted out of the water.
 DISASSEMBLED	Seastead is designed in such a way that it can be disassembled and transported using containers.	– Transport can be fast. – Transport can be to any given location.	– Preparation for transport takes a long time. – Inhabitants must be transported separately.

Figure 53: Option for movability proposed by 'DeltaSync' (source: Ir. Karina Czapiewska, 2013)

Although all the floating cities are now being designed for open seawater, it appears they will be situated on protected waters primarily. This mobility also gives an advantage to a floating city. Whenever needed it can be transferred from a bay to another, which will help improve their resilience to extreme weather events such as hurricanes. While future floating communities are envisioned to withstand the high seas, the first communities in The Floating City Project will start in more protected waters, and will only be in higher seas occasionally and for short periods, such as when moving or fleeing hurricanes (Ir. Karina Czapiewska, 2013).

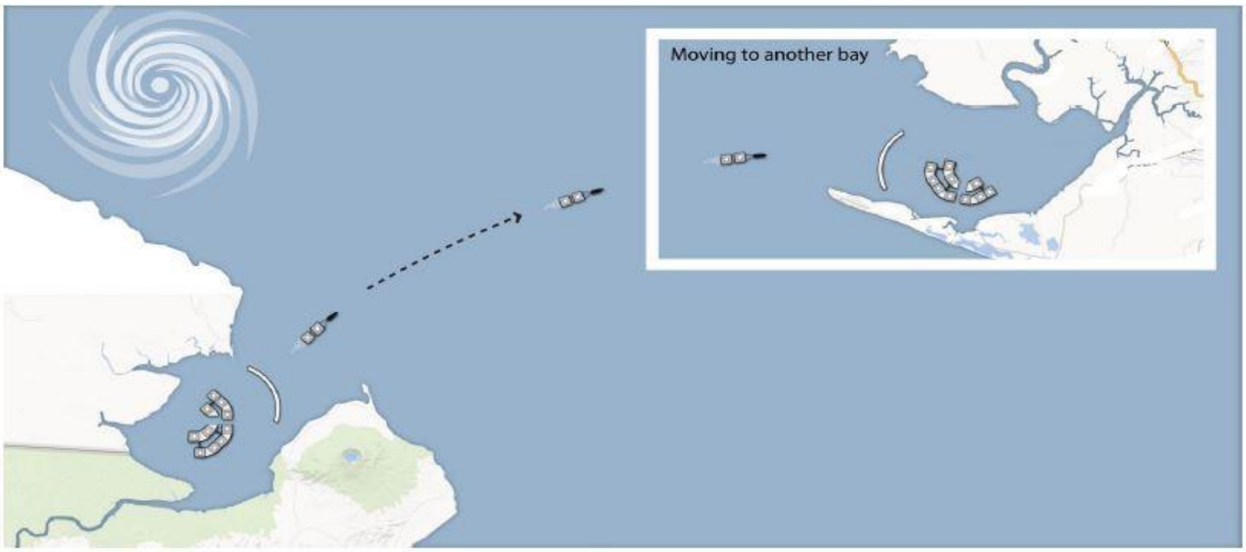


Figure 54: Moving from one bay to another (source: Ir. Karina Czapiewska, 2013)

In addition to mobility, the most important factor is the modular design. Delta sync called this the 'dynamic geography'. Preferably, this would be enabled on as fine-grained a scale as possible, allowing movability down to the size of a single autonomous house (Ir. Karina Czapiewska, 2013). Figure 55 shows different spatial configurations of floating cities that are evaluated for their ability to achieve dynamic geography. The two most suitable options are the islands and the branch. Both structures consist of a small number of houses. Where the islands are connected by bridges or jetties, the branches are connected using a hinged connection. Because of this, both structures can be disconnected easily. The islands can be used by only one person, a family, and in the case of the branched structure, a small number of families. This gives people the ability to move to another location (Ir. Karina Czapiewska, 2013).

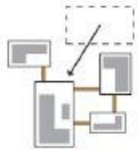
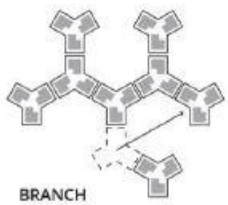
TYPE	DESCRIPTION	PROS	CONS
 ISLANDS	Every building is located on its own platform (or hull). This enables maximum freedom of movement. Structures are connected with hinged joints.	- Optimal dynamic geography.	- Large number of connections. - Large number of moorings is needed. - Large swell.
 BRANCH	The floating structures consist of several houses or other buildings. The structures can be connected with hinged or rigid joints.	- Easy to move away. - Less swell than 'islands'.	- No possibility to move a single house - Structures need to be uniform to be able to fit together. - Large number of mooring constructions are needed
 COMPOSITE STRUCTURE	Semi large structures are connected to each other until they form one larger structure. Connections are rigid.	- Fewer moorings needed. - Little swell.	- Not easy to disconnect - When rearranging, adjacent structures also need to be moved.
 SINGLE LARGE STRUCTURE	Using a large structure such as a (cruise)ship or oil platform as one unit.	- Fewer moorings needed. - Little swell.	- Rearrangement not possible.

Figure 55: Options for Dynamic Geography proposed by the Deltasync (source: Ir. Karina Czapiewska, 2013)

While it is evident that the modular floating structures are far more flexible, it exhibits its relevance to another research as well. Research conducted by Ahmed A. El-Shihy and Jose´ M. Ezquiaga on the floating structures on Abu-Qir Bay, came up with multiple options for expanding a floating city. Pentagonal and squared modules (Figure 56) and have provided more freedom for platform configurations. The hexagonal and square design platform designs have proven to be the ideal configuration. They offer the ability to implement a straight-road system. The hexagonal platforms allow for an organic growth pattern, while the squared modules can only expand linearly (Ahmed A. El-Shihy, 2019).

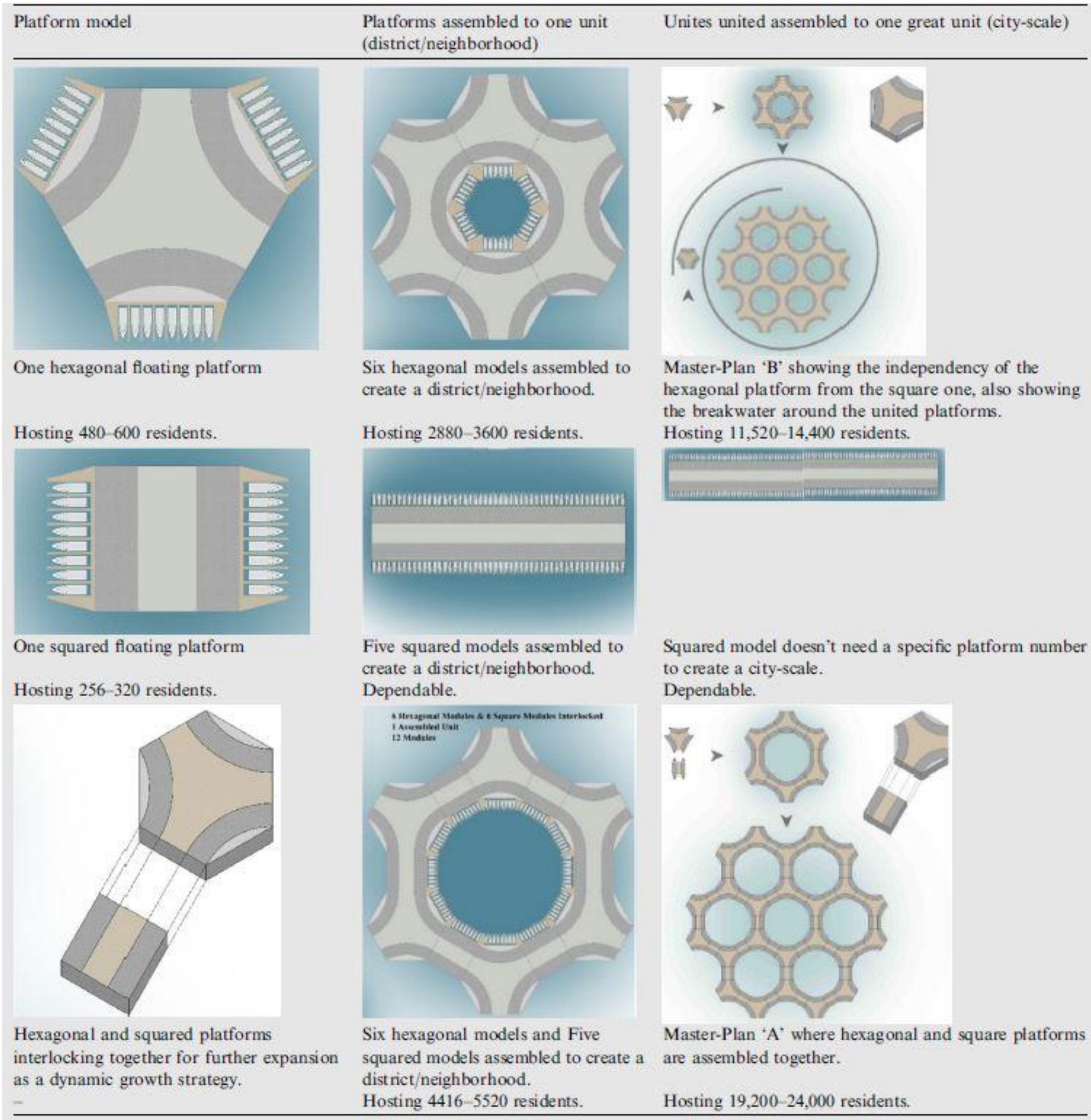


Figure 56: Proposed modular master plan for expanding a floating city (source: Ahmed A. El-Shihy, 2019)

In another report published by Natasha Lister and Ema Muk-Pavic, focused on Modular structures which are proposed for the Republic of Kiribati. Kiribati (Figure 57) consists of 33 islands, of which 21 are inhabited. The islands are in the central Pacific Ocean approximately 2100 nautical miles South West of

Hawaii and 2000 nautical miles North East of Australia. The Kiribati population is just over 100,000 with 50,000 living on the capital island of South Tarawa (Natasha Lister, 2015).

The nation of Kiribati is in desperate need of a long-term solution to its current crisis, and the construction of an artificial island could be an option. The artificial island described in that paper is intended to facilitate the gradual relocation of inhabitants of South Tarawa, whilst minimizing the disruption of the's population lifestyle. The approach used in this study (Figure 58) was a modular floating structure. The module that was proposed was a Hexagonal community layout consisting of six triangular modules which are then connected to make an entire floating city (Natasha Lister, 2015).

(a) (B)

Figure 57: a Republic of Kiribati (Natasha Lister, 2015), b Photo of Tarawa Atoll (GovernmentofKiribati,2005).

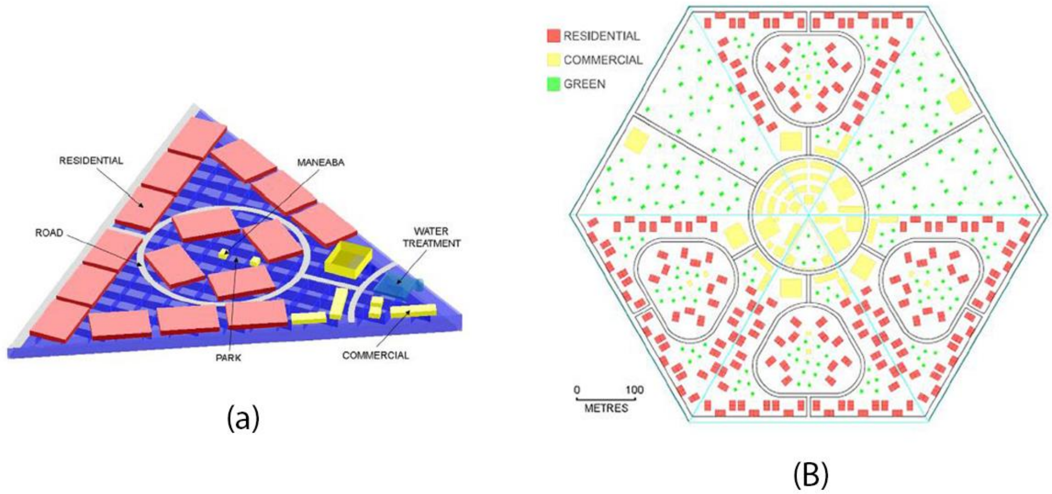


Figure 58: A Triangular Modular design, B Hexagonal community layout consisting of six triangular modules (source: Natasha Lister, 2015)

Fig. 59 shows the proposed artificial island location. The new structure is placed within the lagoon so that the existing island protects it from the ocean by acting as a natural breakwater. The site is close to land, connected by two bridges, to allow a gradual transition from the old island to a new island. The lagoon depth at the proposed site is currently approximately 20 m, allowing either fixed or floating structural options (Natasha Lister, 2015).

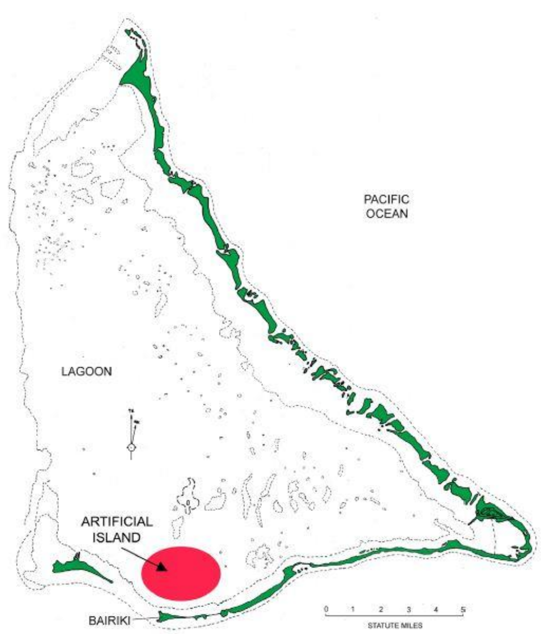


Figure 59: Artificial island location (source: Natasha Lister, 2015)

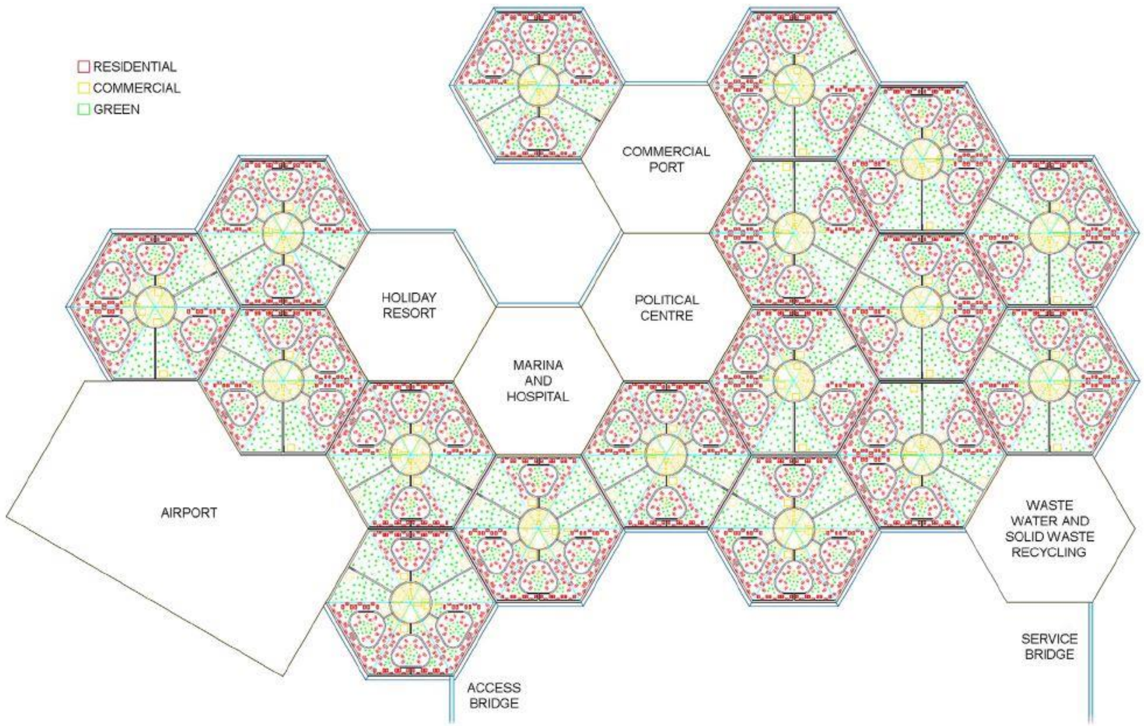


Figure 60: Island layout (source: Natasha Lister, 2015)

Modular floating structures are now being used in many floating city proposals by different architectural firms and research institutes. The Seasteading Institution proposed a real water world (Fig 61 & 62). Floating City Project is touted by its creators as a viable option for those electing to live life on the open seas, completely off-grid, and as part of a close-knit community with shared values and vision for the future (Gamble, 2016). Architecture studio AT Design Office has developed a concept (Fig 63 & 64) for an ocean metropolis (Frearson, Floating City concept by AT Design Office features underwater roads and submarines, 2014). AT Design Office, who has offices in England and China, was commissioned by Chinese construction firm CCCC-FHDI to design a floating island with an area of four square miles – utilizing the same technologies that CCCC-FHDI is using to build a 31-mile bridge between the cities of Hong Kong, Macau and Zhuhai (Frearson, Floating City concept by AT Design Office features underwater roads and submarines, 2014). The concept proposed by Bjarke Ingels used modular structures to create a floating city called the 'OCEANIX' (Fig 42) which has been discussed earlier in this paper.

Figure 61: Floating City, surrounded by a protective sea wall (source: seasteading.org)

Figure 62: Floating City, modular construction, panel by panel (source: seasteading.org)

Figure 63: The proposed concept of a floating city by AT Design office (Frearson, Floating City concept by AT Design Office features underwater roads and submarines, 2014)

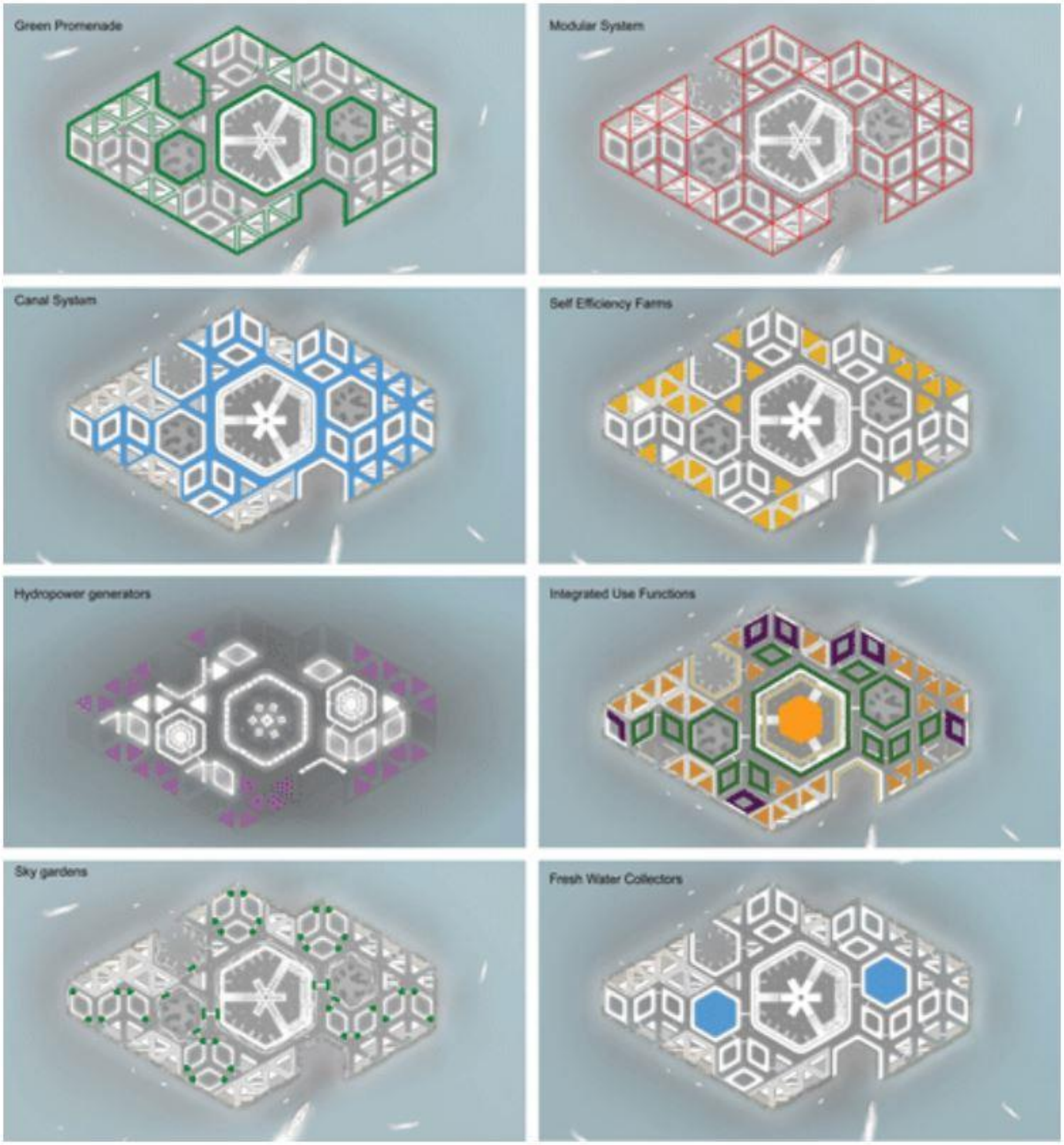


Figure 64: Diagrams showing masterplan concept (Frearson, Floating City concept by AT Design Office features underwater roads and submarines, 2014)

Figure 65: Oceanix city Perspective view (source: BIG.dk)

Figure 66: OCEANIX city modular design concept proposed by BIG (source: BIG.dk)

“Next Tokyo” is also another example of a modular floating community that connects the floating community with both sides of the bay. In the 2015 – 2025 Lloyd’s City Risk Index, Tokyo was identified as the 2nd most at-risk city only behind Taipei. Hurricanes, earthquakes, and flooding were the primary issues raised that put the metropolis at risk. And in alignment with those waterborne risks, global architecture firm KPF has proposed “Next Tokyo,” a vision for Tokyo in the year 2045 when a mile-high tower and eco-city floats on Tokyo Bay providing a home for half a million citizens and simultaneously addressing city-wide vulnerability by providing coastal defense infrastructure (Jonhhy, 2016).

Figure 67: Next Tokyo: a vision for a floating eco-city built in the middle of Tokyo Bay (source: Jonhhy, 2016)

Figure 68: Land use diagram of the proposed Next Tokyo district (source: Jonhhy, 2016)

Figure 69: 'Next Tokyo', render view (source: Jonhhy, 2016)

5 Maldives and The City of Port Moody in Context

5.1 Site selection

Architects and city planners across the world are starting to look beyond the traditional confines of the city, towards building on the water as one of the answers to reducing inner-city population density and also developing flood-resilient designs (Paddison, 2016). At first hearing, the concept of floating cities has the feel of magical thinking. But coastal cities around the world face the ultimate space crunch, and it's worsening fast. (Revkin, 2019).

Before even finding out the right site for this project the first thing that needs to be considered is, do we have a reason for starting a floating community? Why we need this? To answer this, we need to understand that a floating community has a flued character. It is not static. It is designed to float freely on open waters. It is a generalized concept that can be applied anywhere. We may not have a land crisis here in greater Vancouver, but the situation could change in the future. What will happen after 100 or maybe 200 years, no one knows? Sea level rise will also add another level of pressure on top of this problem. This is a problem for most of the coastal cities around the globe. The Maldives is the biggest example who are facing this problem now. Over 80 percent of their 1,190 islands are no more than a meter above sea level (Deulgaonkar, 2011). The temperature in the atmosphere is also accelerating the polar ice melt. Thwaites Glacier and Pine Island Glacier, both in the frigid continent's west—could increase global sea levels by more than three feet by 2100 (Meyer, 2019). Building a "floating city" of 20,000 houses next to Male, capital of the Maldives, maybe the answer for the tiny nation's agony of finding a new homeland for its populace as some of its coral reef islands face an imminent threat from the rising sea level (Deulgaonkar, 2011). The company (Waterstudio) will soon unveil the first floating island with six to eight affordable houses that people can see, feel, and walk. "We are working on the master plan, which we have already partly presented to the government and the President of the Maldives, in which we make affordable floating islands. We can provide them with a whole 'floating city' of 20,000 houses next to Male, where the locals can live in floating houses" (Deulgaonkar, 2011).

The Maldives is a great example to answer one more question that people are living on Islands. So, what is the difference between living on an "Island" than a "Floating City". An Island is static it does not have the flexibility that a floating structure has. It can not adapt to climate change nor with the sea level rise. If the sea level would rise to a certain level in the future it might go underwater. Now if we want to start a floating city close to the Maldives or close to Vancouver the basics will the same. It needs to start close to the shoreline as experts like Bjark Ingles, Joe Quirk, and Koen Koen Olthuis suggested. Although in the proof of concept section options for both the Maldives and the city of Port Moody is been explored, as this research project is being conducted in Vancouver (Canada), a local site is also been selected and tested for the proof of concept.

Richmond is right now a meter above the current sea level (The city of Richmond, 2020) and with the increasing sea-level rise even if the water rises by a meter, it could go underwater. Delta and Richmond could be wiped out by rising sea levels, even if we succeed in limiting global warming (Staff, 2017). The city of Richmond is on its way to establish a hard protection dike system that will keep the seawater out. It has 49 kilometers of dikes and 39 drainage pump stations that provide the City with flood protection from ocean storm surges, freshet, and sea-level rise (The city of Richmond, 2020). Recently a major new master plan is underway to update all the existing dikes. The city of Richmond is poised to start the next phase of construction and upgrades to its dike network and flood protection system (DCN-JOC News, 2020).

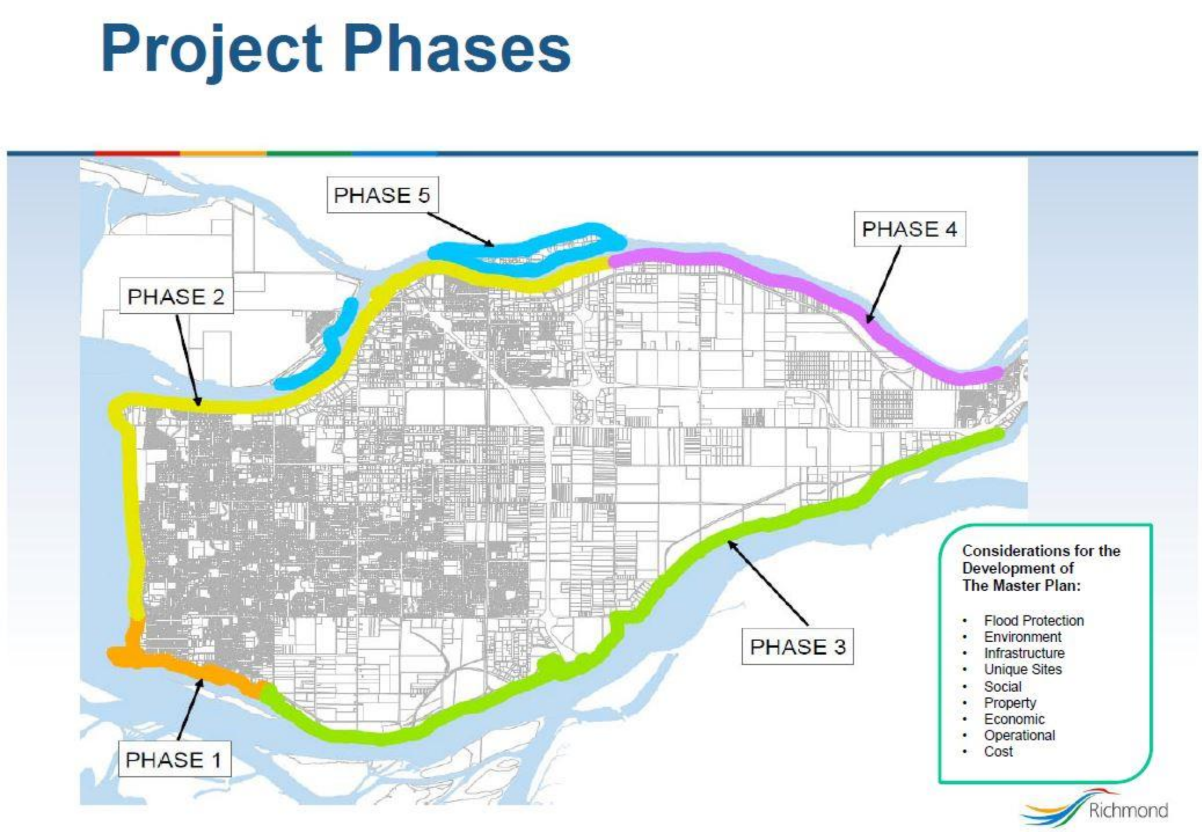


Figure 70:New dike system up-gradation plan (source: Richmond.ca)

A floating city concept must have to compete directly against the future master plan that the city of Richmond has already in place. Which is more of a political issue rather than a technical issue. Also, the adjacent water is mostly marine wetland and by expert advice, it is certain now that it would be wise to start a floating city on sallow or calm waters first. Part of it is also an estuary. Where freshwater from the Fraser river meets with the saltwater at the sea and there is a downstream force generated in that spot. Any kind of floating structure will face some challenges to overcome the issues, but it would not be impossible. It needs to be stabilized and a huge amount of money and effort must be made to ensure the stabilization of that floating structure. So far by research, we came to know that technology is never the barrier rather it is politics that poses the biggest threat. That is why coastal waters near Richmond city has been rejected for only these reasons.

The second option would be thinking about 'False Creek'. The shallow water and calm nature of the water make it suitable for a floating structure and an existing floating community already exists there. Then again, the heavy traffic that passes through False creek makes it difficult to place any floating structure there. It will certainly disrupt the traffic flow.

The next option is Port Moody. Port Moody is a city in Metro Vancouver, enveloping the east end of Burrard Inlet in British Columbia, Canada. Port Moody is the smallest of the Tri-Cities, bordered by Coquitlam on the east and south, and Burnaby on the west. Tide differences make this place an interesting option for testing a floating structure. The water is relatively calm and as the site is situated so farther inland, it does not need breakwater. The downstream (Fig 71) from the Indian Arm goes directly towards open water leaving port Moody out of the way. Although each arm is similarly part of ocean tidewater. The red marked zone is affected by the tidal change but the downstream which coming from the mountains barely affect this part. This calm water is suitable for floating structures and no traffic pass through this site and this water does not need to be stabilized as it is naturally stabilized.

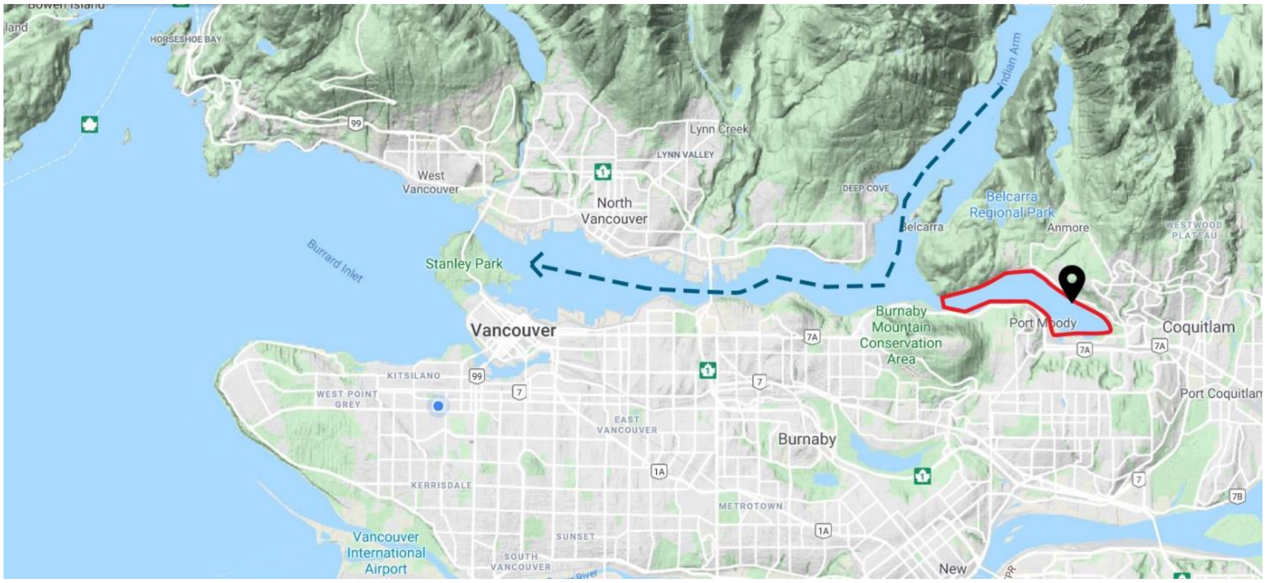


Figure 71: Map showing the water flow towards open waters (source: google maps)

According to the tide chart normally the water level changes between 0.7 meter to 4.6 meters regularly (Tide Times for Port Moody, 2020). With the expected sea level, it could add from a meter up to 5 meters on top of this incoming century (Nanyang Technological University, 2020). If this is so, then proper managed retreat plans should be taken into count. One of the many solutions to how to tackle this sea rise is to plan for the future. Building floatable cities could help this process.

Managed retreat or managed realignment is a coastal management strategy that allows the shoreline to move inland, instead of attempting to hold the line with structural engineering. At the same time, natural coastal habitat is enhanced seaward of a new line of defense. This approach is relatively new but is gaining traction among coastal policymakers and managers in the face of increased coastal hazard risks (Coastal Processes, Hazards, and Society, 2020). There is a growing recognition that attempting to “hold the line” in many places is a losing battle. In response to sea-level rise, intertidal habitats migrate landward. Human flood defenses such as sea walls prevent this migration. This leads to the narrowing of the intertidal area. This is sometimes referred to as "Coastal squeeze (Coastal Processes, Hazards, and Society, 2020).

In many cases of manage retreat, man-made development moves out of harm's way and flooding is allowed. In this way, nature gets a chance to adapt to the new ecosystem. This process could be combined with the amphibious house concept. Instead of trying to control or prevent flooding, residents should adapt their homes to withstand it, says an architect Elizabeth English, who develops amphibious homes. "We need to let Mother Nature do more of what Mother Nature wants to do rather than humankind trying to control the water," Elizabeth English, an associate professor at the University of Waterloo School of Architecture, told The Current guest host David Common (CBC Radio, 2019). Amphibious homes are retrofitted with "a hidden floating dock underneath" and vertical posts that guide the house up and down, allowing it to float on water, she said. "It lets the water go wherever the water wants to go and the house gets out of the way. So, it doesn't try to compete," she said. "Humankind does the accommodation rather than trying to push the water around" (CBC Radio, 2019).

In a recreation area located outside the dikes near Maasbommel in Gelderland Province, 32 amphibious and 14 floating homes have been realized. The amphibious homes are fastened to flexible mooring posts and rest on concrete foundations. If the river level rises (Fig 72), they can move upwards and float. The fastenings to the mooring posts limit the motion caused by the water. The floating homes are lowered when the water level drops and comes to rest on concrete foundations (Vermeer, 2009).

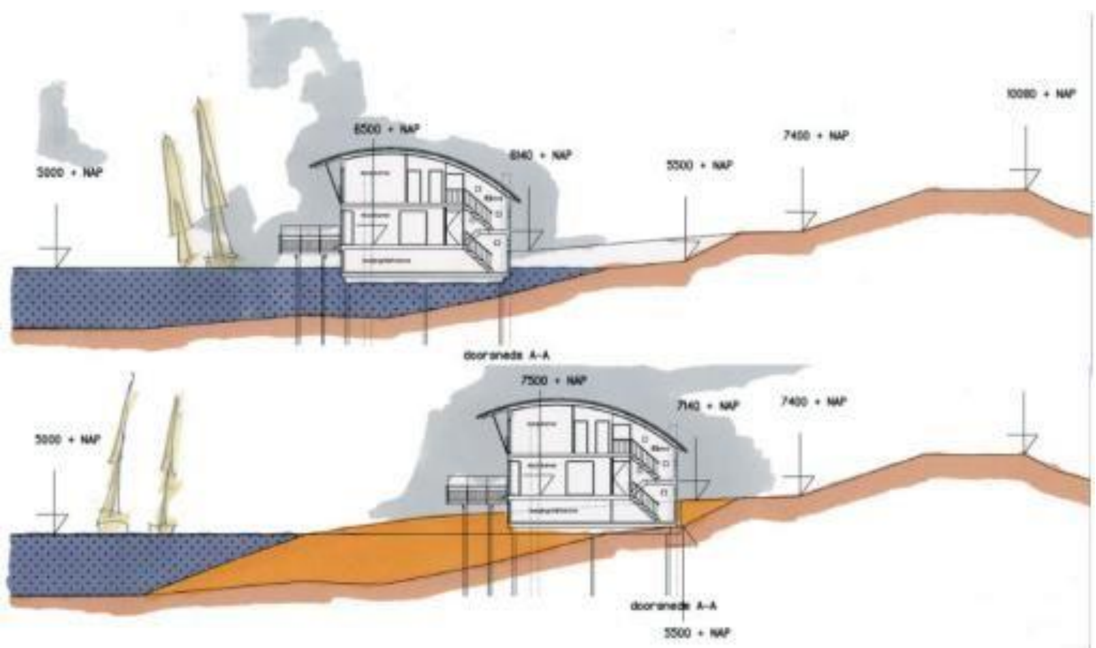


Figure 72: Amphibious house (source: Vermeer, 2009)

Figure 73: The mooring posts in which the houses can move up and down according to the water level (source: Vermeer, 2009)

Work also has been done on the Amphibious House (Fig 74) by Baca Architects – a family residence on an island in the middle of the River Thames that can float on rising floodwater like a boat in its harbor. The house by London studio Baca Architects was designed for a couple who had been looking for a site to build a home on the flood-prone river island near Marlow in Buckinghamshire for seven years. "During the flood event the whole house will raise gently like a boat and will keep all of the habitable spaces safe above the flood level," Baca co-founder Richard Coutts told Dezeen (Winston, 2014). "Rather than building flood defenses, the project considers a different approach, to acknowledge man cannot beat nature and to make space for water," said Coutts (Winston, 2014). Baca considered various ways to deal with managing the rising water levels on the site, including a completely floating structure – an alternative option proposed by authorities from the administration's Environment Agency – and raising the house on stilts.

Figure 74: UK's first amphibious house (source: Baca Architects)

"If we'd have gone for an elevated house the ground floor would have been so high, almost two meters off the ground, the house would have looked out of keeping with its neighbors," explained Coutts. "The benefit of an 'amphibious house' is that it looks in all intents and purposes like a normal house. Rather than having a house that's up in the air, you get proper engagement with the garden" (Winston, 2014). On the riverside (Fig 75), the garden is terraced to act as an "early warning system" for rising waters – when the first two terraces fill with water the house should begin to rise (Winston, 2014). The house is currently designed to travel up to two and a half meters, based on worst-case scenario flood predictions from the Environmental Agency and some additional tolerance for climate change.

Figure 75: Amphibious house by Baca Architect, after completion (source: Baca Architects)

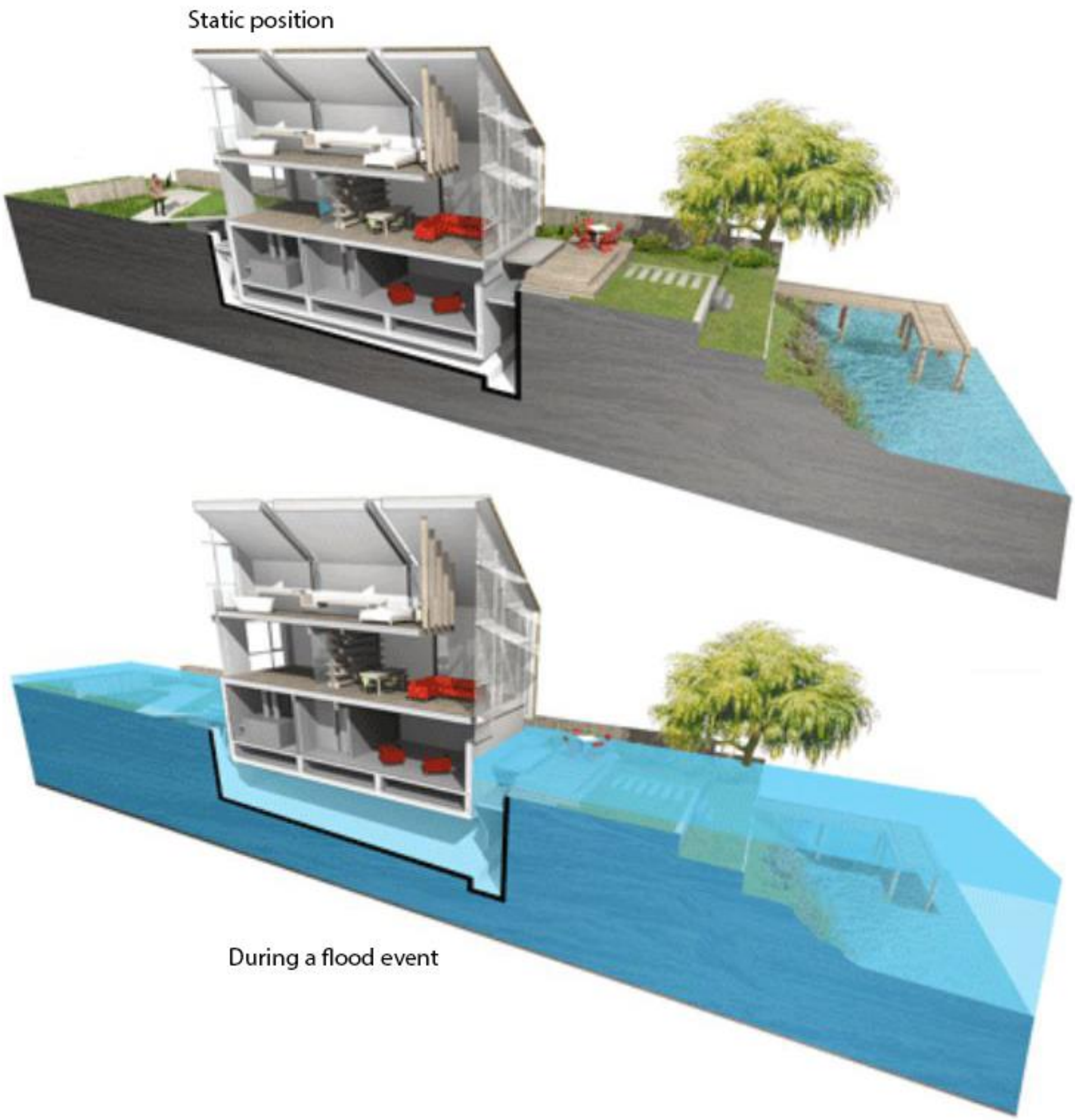


Figure 76: Diagram showing house adapting to the water level change (source: Baca Architects)

6 Proof of Concept

The knowledge that has been gathered from the literature review will be used to test this idea. This paper suggests that this floating city is not designed for a particular coastal city or a specific country rather it will be a generalized concept. This could be used anywhere where there will be a requirement. The question might come that is a floating city is a necessity right now? The correct way of answering this question will be that it will be depending on the context. Maldives is a country that comprises almost 1200 islands (Britannica, 2020). In 2004, a tsunami swallowed two-thirds of the country (Chang, 2015). As a result, over 20 islands were permanently erased from the map. The Earth is currently undergoing a climate change of historic proportion, with sea levels rising noticeably from the melting of glaciers and icebergs (Chang, 2015). If the trend continues, the Maldives will be completely submerged in 30 years (Chang, 2015). For the people of Maldives, a Floating city is an urgent necessity. Within the next few years, there will be no Maldives and because of these reasons, this is the most suitable site for testing this idea.

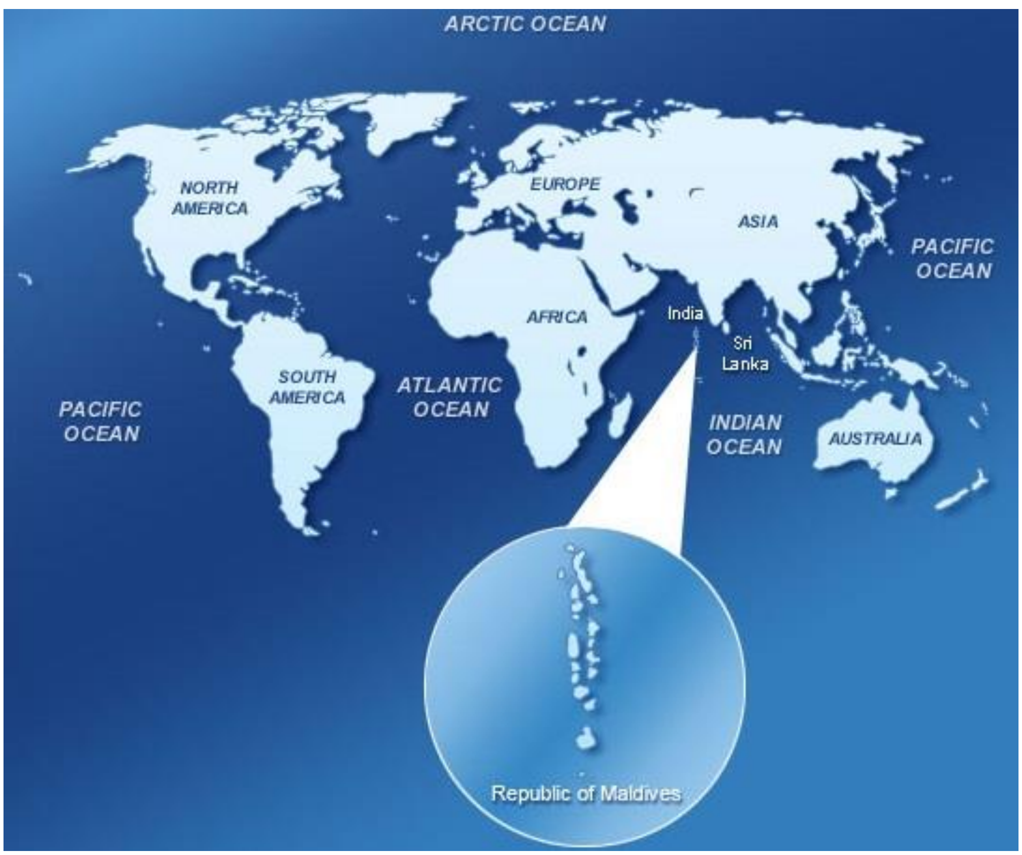


Figure 77: Map of Maldives (source: Cities and places)

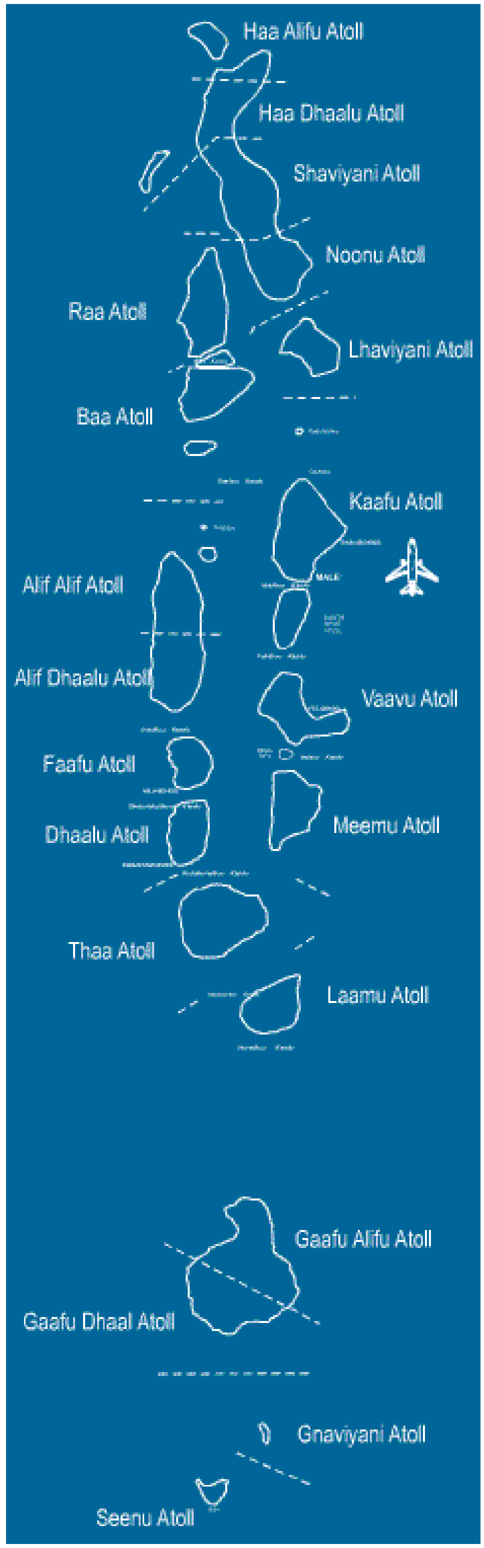


Figure 78:Maldives (source: Wordpress.com)

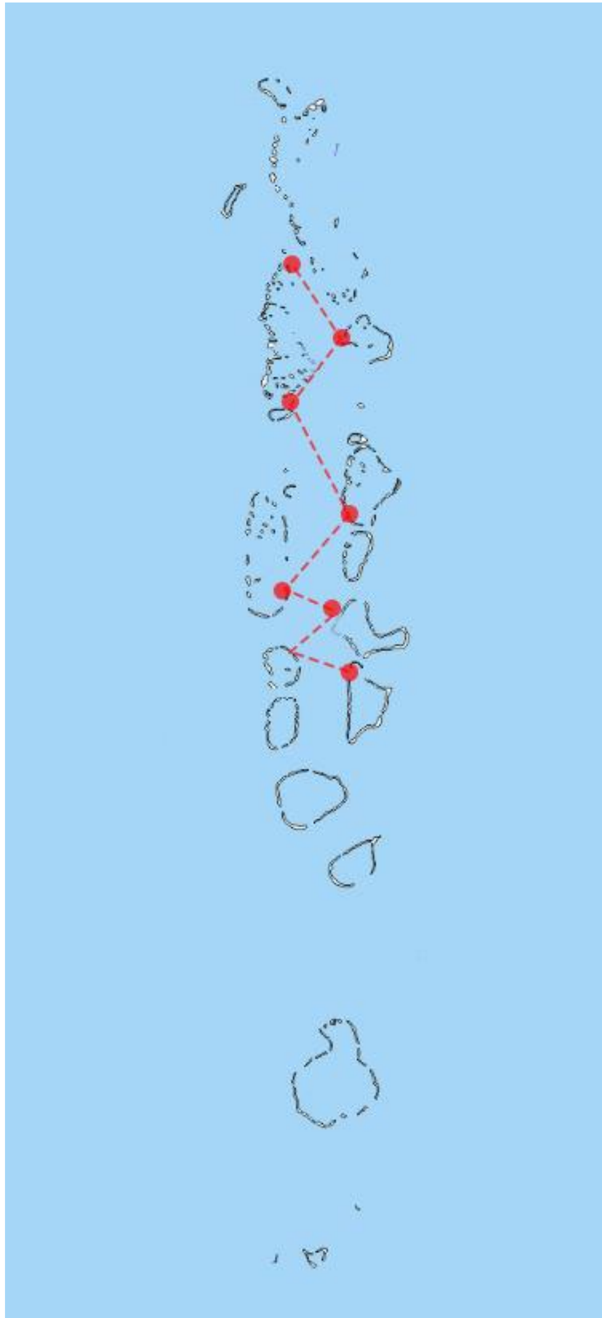


Figure 79: Conceptual connection by floating platforms

While the entire existence is on a threat for the Maldives, Floating structures could make a new connection. The existing islands will be connected by a series of newly developed floating platforms, eventually transforming the entire nation into a new floating community.

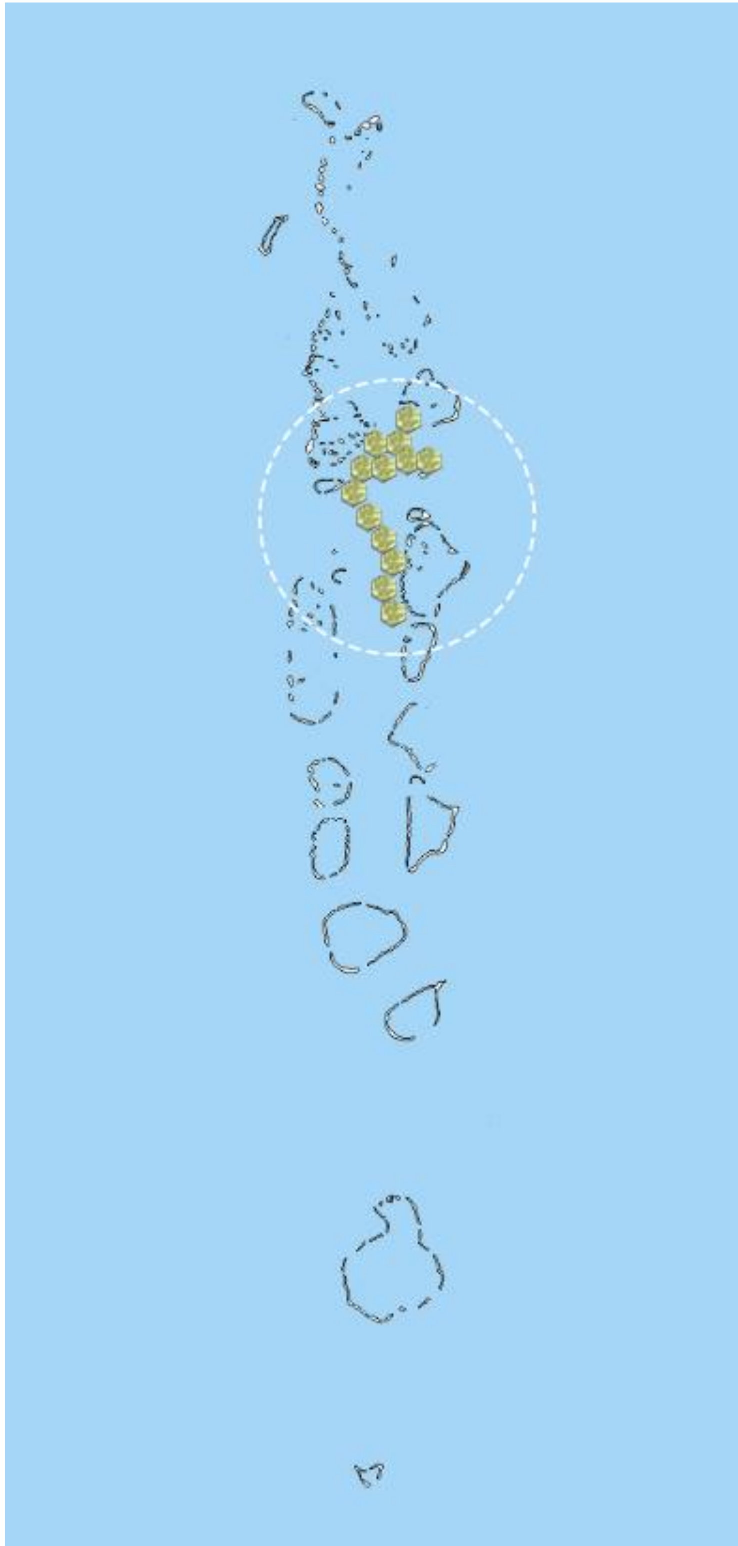


Figure 80: Conceptual growth of the floating community

While other parts of the globe like Canada do not show signs of a necessity for a floating city yet rising sea level and global warming are changing things rapidly. If this is the case, then some of the parts of the west coast will be submerged underwater and we might consider this idea then. So, in a nutshell, if that is the case and we need to find a site to test this idea then Port Moody has a very interesting character with the water level. Here the tide difference is noticeable, which makes it a realistic and practical site for testing the idea of a floating community. On a given day it varies between 0.5 meters to 4.5 meters on average (Tide Times for Port Moody, 2020). On a given week, between June the 26th to July 4th the tidal difference is 4.88 meters (Fig 81).

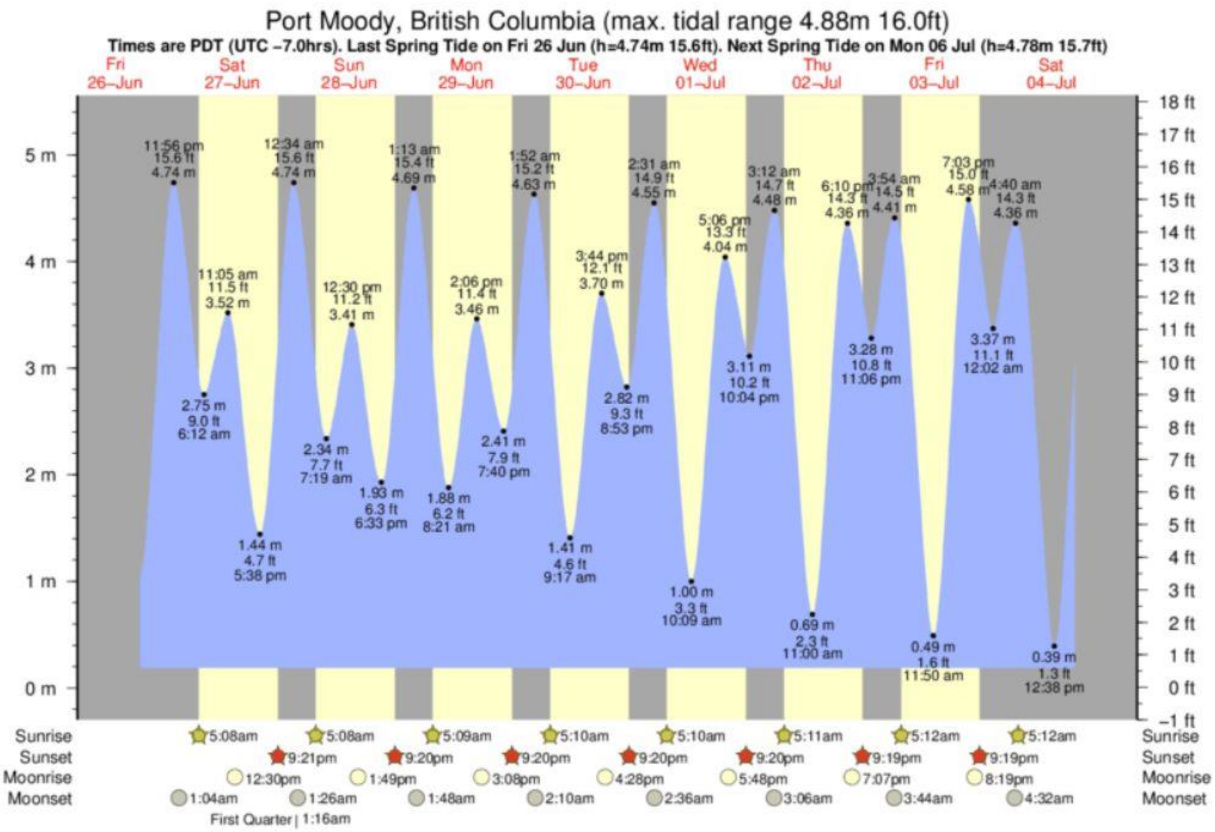


Figure 81: port moody tide chart (source: Tide Times for Port Moody, 2020)

Sea level rise will add more height on top of this water level. The beachside houses will be affected by this change. Although the Alderside road is on high ground and will not be affected but the first row of beach houses on the beach beside Old Orchard Park is in danger of flooding if the sea level continues to rise. Among many options, one option is a plan a solution in advance. This process could be combined with the amphibious house concept which will allow it to adapt to nature instead of fighting with nature. Nature could take its portion and the natural habitat will get a chance to adapt to the new ecosystem. This will also allow a certain time for the residence of the community to understand more about the floating house concept and accept this as a part of their regular life. This first step will play a crucial role in social accessibility.

To test and confirm the idea the entire process needs to be divided into multiple phases. It must be a phase-wise development process. So far what the precedence has proved that the key to a successful floating community is to build it as close as possible to the shoreline and it needs to be connected with the existing city. The yellow highlighted area is the most vulnerable area due to sea-level rise. When the water level will rise these houses will go partially underwater. That is why the first step of transformation work needs to be done for these houses.

Figure 82: Port moody beachside houses (source: Google map)

Figure 83: Site selection

Figure 84: Water level, picture taken by google satellite in 2003 (source: Google maps)

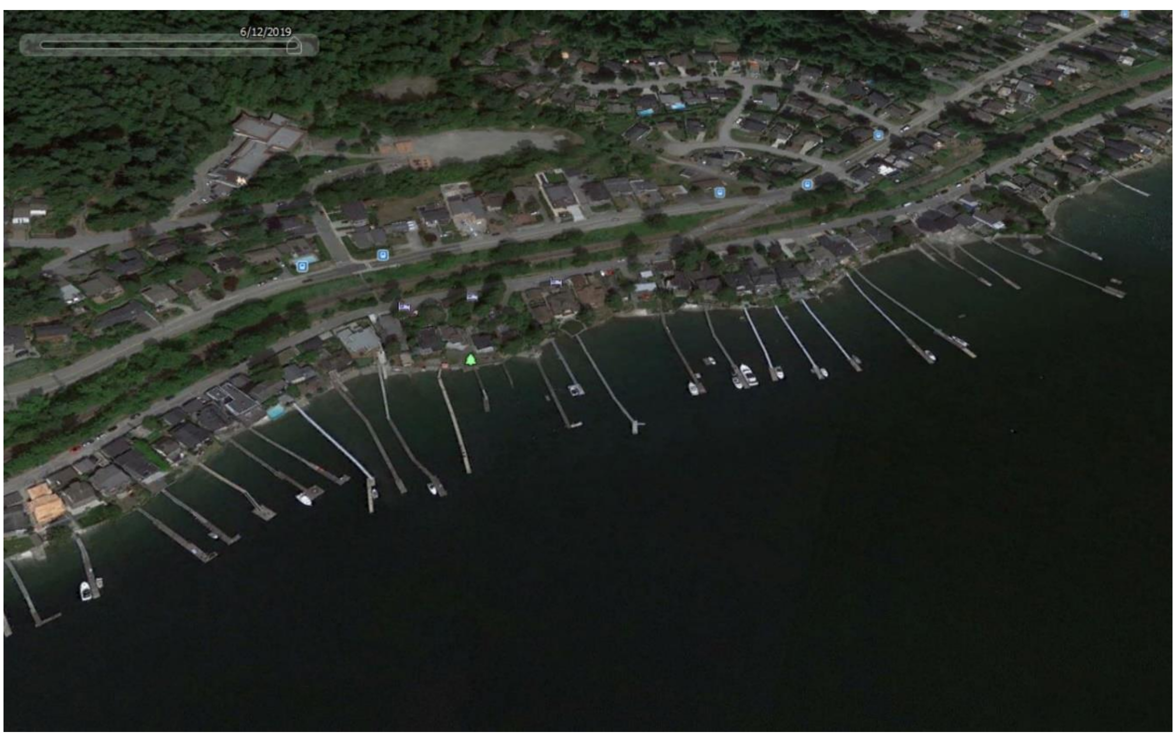


Figure 85: Water level, picture taken by google satellite in 2019 (source: Google maps)

Figure 86: Low tide at port moody (Photo credit: Author)

Figure 87: Wetland in low tide (Photo credit: Author)

The first step would be transforming all the houses that are close to the water into floating houses. Those houses do not have a basement so, it needs to be placed on a floatable slab which will allow them to move up and down with the water level rise and maintain its original position.

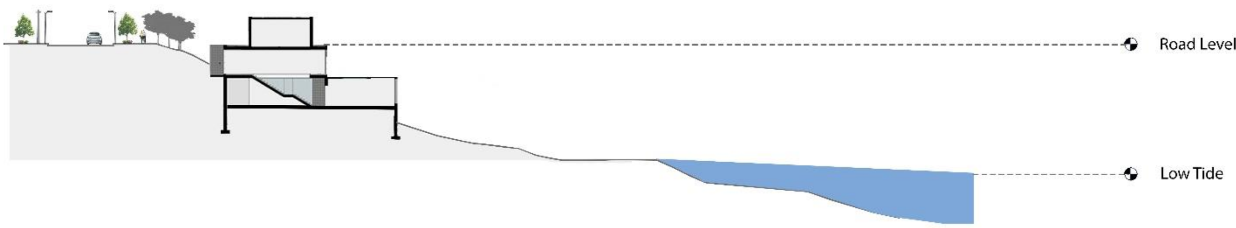


Figure 88: Cross Section of port Moody beach houses showing low tide situation (Drawing: Author)

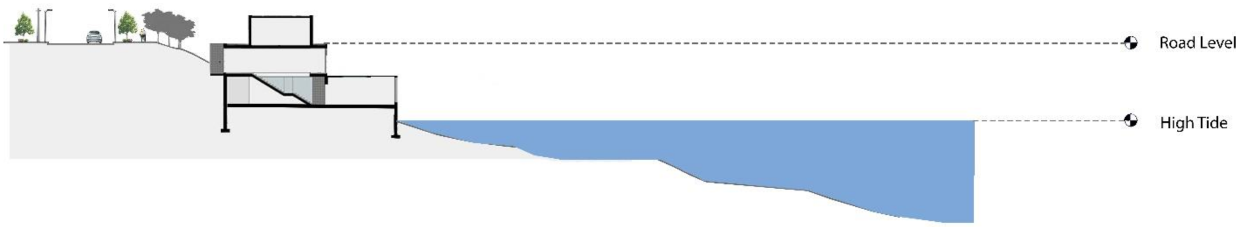


Figure 89: Cross Section of port Moody beach houses showing high tide situation (Drawing: Author)

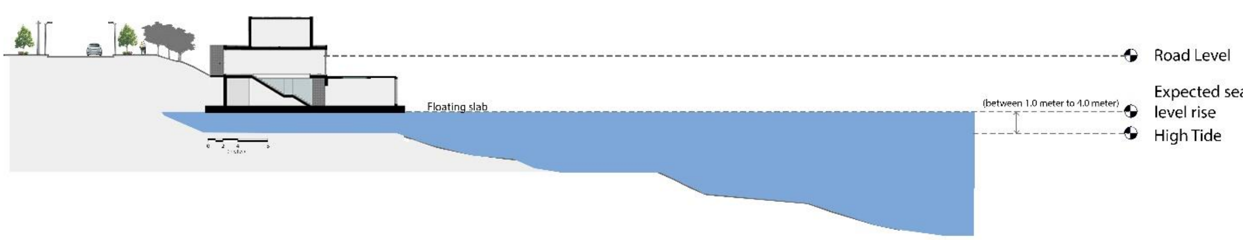


Figure 90: Cross Section of port Moody beach houses showing predicted future sea-level rise situation (Drawing: Author)

Managed or planned retreat (also known as managed realignment, resilient relocation, and transformational adaptation) allows the shoreline to advance inward unimpeded. This process could be altered and instead of inward motion and outward motion could be implemented. That is what exactly the idea of a floating city concept was designed for. This must be slowly implemented, and the process will take years to establish. At the very first step, (Fig 86) the houses close to the beach must be transformed into floating houses and this will lead ultimately to a future floating city.

The only way to understand if the design and the process are successful is to wait and understand how people will adapt to the first phase and if the floating houses are becoming a part of their regular life. If this first phase is successful and after a few years people did accept this floating house and start living there the next phase could be started, which is building an offshore floating community. Now this will require a series of the floatable platform which could be connected and needs to be modular in shape so that it could be dismantled if needed. A single platform could house multiple single-family residences or could house other functions such as schools, community centers, medical centers. This community needs the same infrastructures as any other community would need on land and it needs to hold the same culture and social life. The only physical difference would be that this community will be a floating community.

The water body divides the entire Port Moody into two different main parts (Fig 91). One is the residential zone and the other is the commercial zone. One of the possible ways would be connecting the two sites and building a connection point that will connect all the northern residential areas with the southern city center (Fig 92). This floating community could become the connecting hub of port moody and could act as a floating bridge as well. The only way to come to the city center is around the Burrard Inlet and this new connection could ease the connectivity and could work as a passage for both sides. If people start to use this floating community as a passage by default people will start to accept it as a part of their daily life and it will get connected with the existing land community. The most important part of building a floating community is to make sure that it connects with the rest of the city and does not become dethatched from the rest of the city. For that reason, it is important to connect a floating community with the people on land.

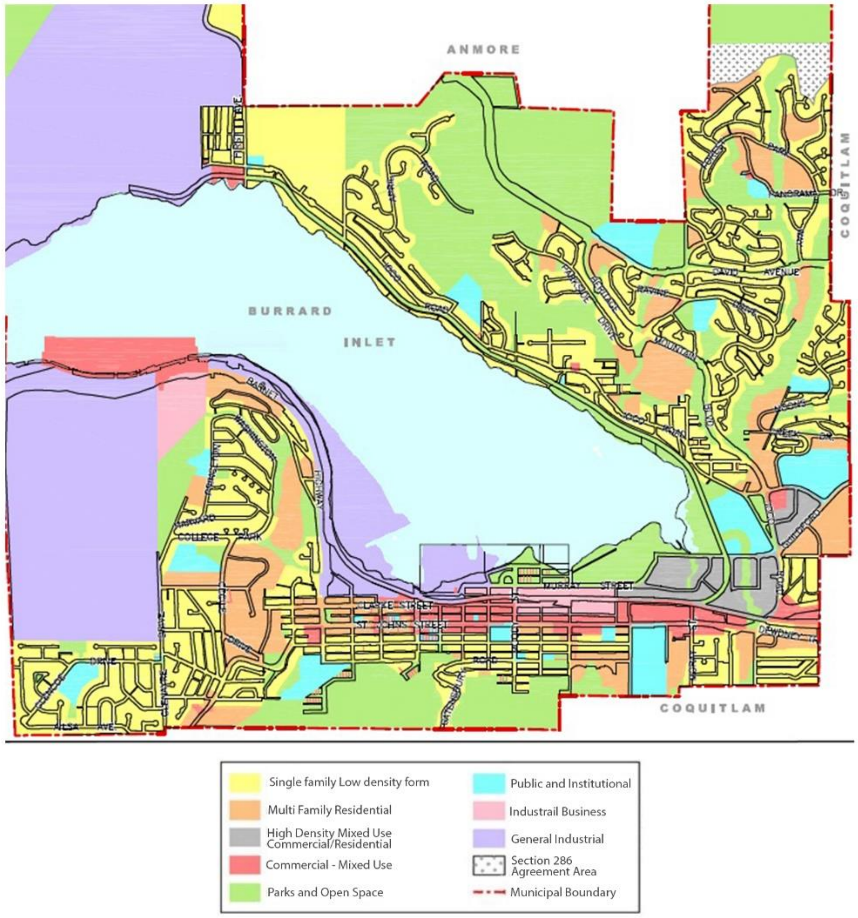


Figure 91: Zoning of Port Moody (source: 2013-08: OCP Bulletin — OCP affects everyone in Port Moody, 2020)

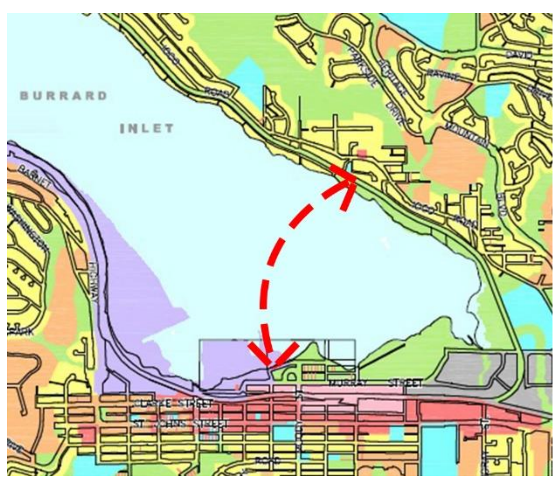


Figure 92: Connecting the Northern part with the southern part (source: 2013-08: OCP Bulletin — OCP affects everyone in Port Moody, 2020)

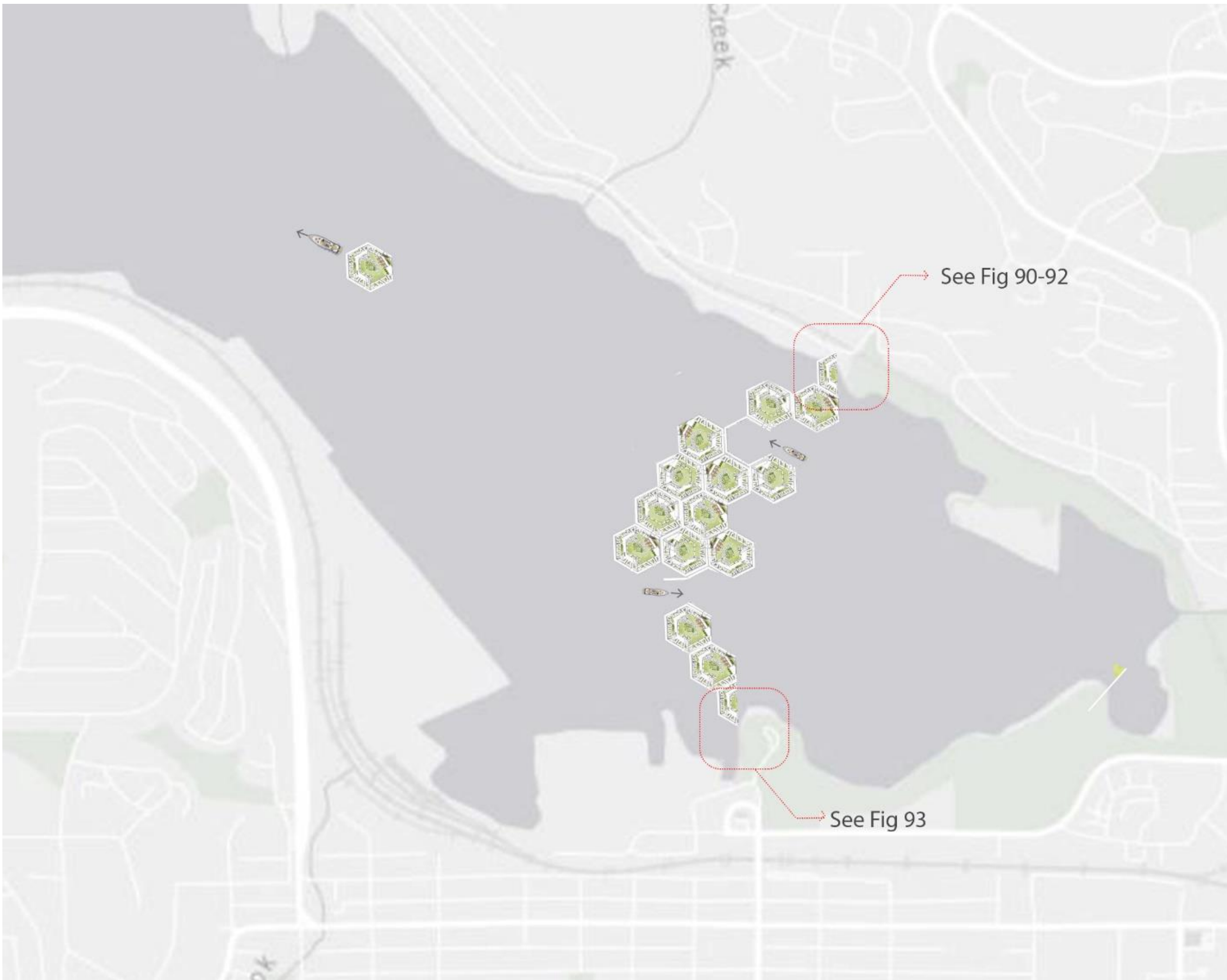


Figure 93: Floating structure connecting the two parts of the town (Drawing: Author)

The connection bridge on the north side will land beside the old Orchard Park and the connection on the south side will land on the Royal Point Park. The reason behind this is this floating platform will work as a bridge connection which will connect the north and south part of Port Moody. On both sides, it will be connected with the park. The Royal point park already has a floating bridge that extends towards the open water and it adapts to the tide change. The southern connection will be connected with this bridge.

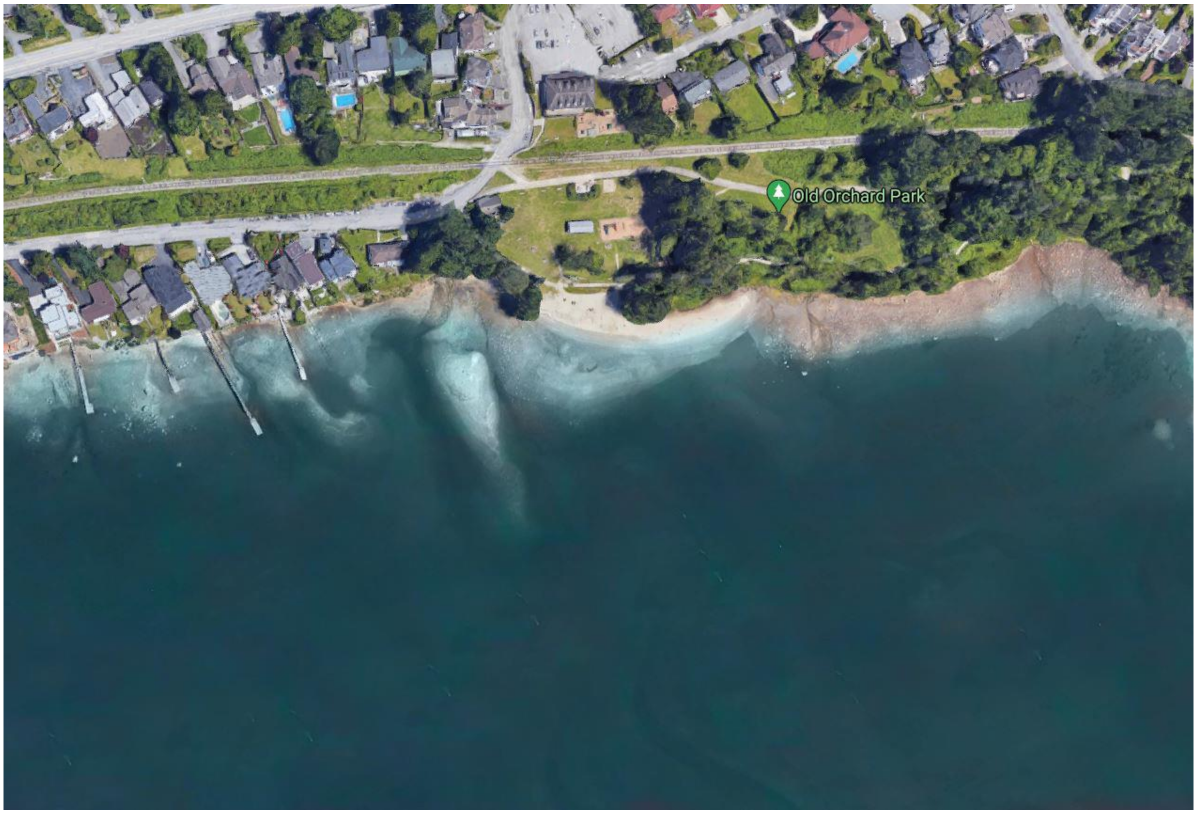


Figure 94: Present condition (source: google maps)

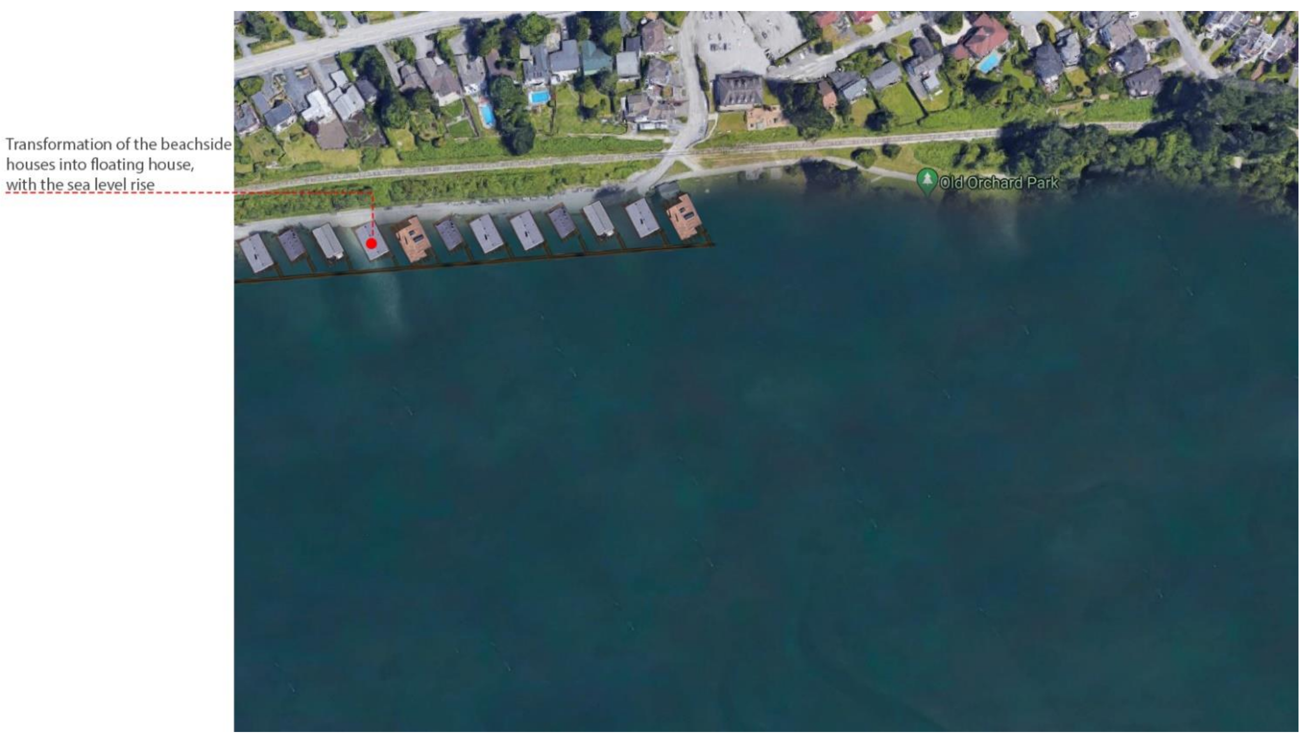


Figure 95: Predicted condition with sea-level rise

Figure 96: Proposed Floating platform connecting with the land (Northern side)

Figure 97: Connection to the south part

The reason for choosing a hexagon modular shape is simply because of its high floor space usage. A hexagon is a shape that best fills a plane with equal size units and leaves no wasted space. Hexagonal packing also minimizes the perimeter for a given area because of its 120-degree angles. With this structure, the pull of surface tension in each direction is most mechanically stable (Sullivan, 2017). In easy words, a hexagon is a simple shape with six sides (Vyas, 2018). This shape can be easily added with the rest of the floating structures and can be dismantled from the rest of the structure. It could easily be transported from one bay to another. After the successful experimentation of this phase, the final stage of the process could begin and that is to start building the entire floating city offshore. This offshore modular floating structure will be the outcome of this entire project which started with transforming a beach house into a floating house.

The plan that has been shown (Fig 96 & 97) is a conceptual representation only. Extensive research needs to be done to determine the size and volume of the hexagonal floating structure. Also, research needs to be done to finalize the exact area of building footprint and how much load they can carry which will come from the feasibility test report. Research is also required concerning how the platform would interlock and what masterplan would best fit to accommodate all the housing. To support this idea and a team of professional Architects, Marine Architects, Structural Engineers, Environmental Scientists, technicians, and more would be needed to develop a successful design. This realization of a floating city requires an interdisciplinary team. This future research will complete the future predictions of this paper. The outcome of all this research will be a generalized solution that can float close to any shoreline. It will not be only designed for a single location rather it should serve as an independent floating structure.

Figure 98: Adding more units to the future "Floating City" (Drawing: Author)

7 Conclusion and Way Forward

The primary purpose of driving this paper was to shed light on the discussion of the Challenges that are pending the "Floating City" through Literature Review. This was done by creating a multidisciplinary compilation of literate on the topic. This paper is a compilation of technical and socio-economic challenges regarding floating structures. What was concluded from this research is that there are several interconnected barriers that are hindering this technology, and they will need to be solved simultaneously if the dream of a floating city is to be realized. The secondary purpose of this paper was to evaluate locations that could benefit from this technology and propose floating city concepts that could address their geological issues.

The primary challenges the field is facing is an apparent "Lack of Reason", in other words, the threat of climate change and rising sea levels is not great enough yet to warrant serious consideration of a floating city given that there is no financial model yet developed proving that such an endeavor can be economically successful. Floating cities can essentially ignore the challenges imposed by rising sea levels as they are already floating atop the ocean, and they have the ability to maneuver away from tropical storms as these will also occur more frequently due to climate change increasing the amount of energy in the atmosphere. Despite these advantages, the fact that floating cities are not the only option being prosed to address global warming and sea-level rise means that there is still no sufficient "reason" to pursue this technology. However, this paper concludes that vulnerable island nations, such as the Maldives, have far fewer options available to address their current seas level crises, and deploying a floating city in this location is likely the most realistic method of aiding this country and will provide an invaluable opportunity to study a floating city in real life.

This paper also highlights the fact that development and deployment of this technology will take time, and faster progress in research is important because no one knows for certain when drastic action to address climate change/sea level rise will be required. On one hand, Maldives is in critical need of a solution as the majority of its land will be submerged underwater. Additionally, almost every piece of land is directly or indirectly claimed by some nations, so for the Maldives, a floating city is likely a necessity. On the other hand, Vancouver is also at risk of rising sea levels, and as proposed in this paper, the smooth implementation of a floating ecosystem will take many years. We don't know what the optimal solution to this problem will be or when exactly it will be needed but seeing as we want to be ready to address these challenges ahead of time meaning the research and development should become more of a priority.

7.1 Limitations

Some of the limitations of this research project are as follows:

The study does not show a detailed design solution for either the Maldives or the Port Moody side. The design that is been presented in the paper is a conceptual representation only. This project is complex and does need an interdisciplinary team to produce a real scale master plan.

The study does not show a physical feasibility test of the chosen site for testing the idea. The sites were chosen from the knowledge gathered from the literature review. While in real-life scenario sites are been selected by the feasibility test. All the recommendations and proposals that are made are based on desktop research and based on a sample of case studies across the globe.

The study does exclude issues of building code analysis or rules regarding building on open waters as this project surpasses the traditional guidelines and laws, which would regulate the layouts and plans for the floating structures.

7.2 Future research area

Future research on these areas might be needed to move this project forward:

- Research needs to be done on how to make a floating community self-sufficient, which needs the support of modern-day technology. Most of this research needs to be accelerated so that it can support all the requirements like food production, generating electricity, managing waste, etc.
- Building codes need to be analyzed and studies. If the codes are not sufficient enough, then the law should be modified so that it can support the development process of an entire floating city. This kind of new settlement will not only require building codes but also a wide range of other regulations that will guide the process.
- Political implications are the most important point that is working as a barrier for a floating city. Law needs to be modified so that it can support and make a floating city sustained.
- Financial models need to be studied with more precision. Unless we can make a profitable module, it is going to be hard to gather financial backup.

- Research needs to be done on the marine environment and how they will adapt to the floating structures and in case of adapting with the new development of how they are going to survive.
- Detailed research is also needed on the materials that are going to be used to make the floating platforms. Although some of the materials are already in use, in-depth research on materials will ensure how sustainable they are to the environment.
- Finally, human perception needs careful attention. Living on the water involves a very different mental state. How humans react while they are living on water needs to be understood which will help to design a solution while will be more accurate.

There are immediate and long-term incentives to further the development of this technology. It might take time before technology has advanced and is affordable to support a floating community like this. Floating cities may not be the answer to all our problems, but the ocean's surface and a massive and mostly untapped resource that shows the potential to address the problems of climate change and the growing world population. This paper shows the problems that floating cities are facing are solvable and benefits may be great, and as such deserve more attention.

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