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Floating utopia : a modular approach against sea level rise using recycled marine structures

Muhammad Djamil Suffee

► **To cite this version:**

Muhammad Djamil Suffee. Floating utopia : a modular approach against sea level rise using recycled marine structures. Architecture, space management. 2022. dumas-03677960

HAL Id: dumas-03677960

<https://dumas.ccsd.cnrs.fr/dumas-03677960>

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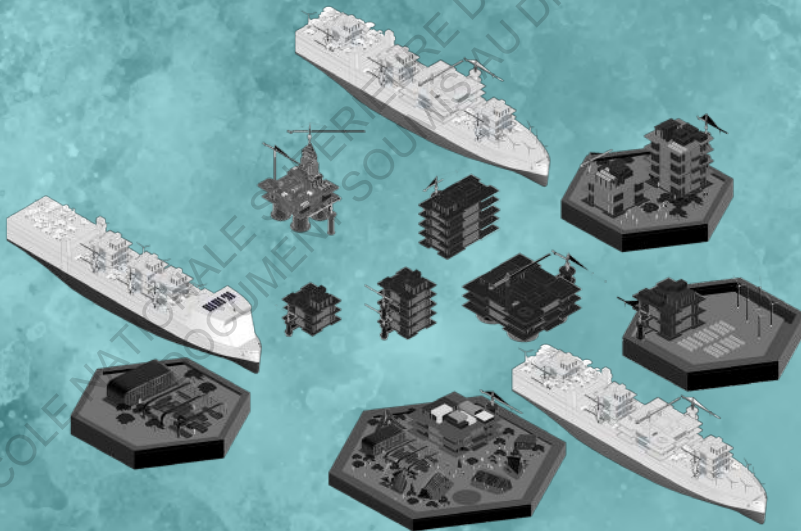
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FLOATING UTOPIA

**A MODULAR APPROACH AGAINST SEA LEVEL RISE
USING RECYCLED MARINE STRUCTURES**



Thesis Master - Suffee Muhammad Djamiil - ENSA Nantes 2022

FLOATING UTOPIA

A MODULAR APPROACH AGAINST SEA LEVEL RISE USING RECYCLED MARINE STRUCTURES

SUFFEE MUHAMMAD DJAMIIL
January 2022



Ecole Nationale Supérieure d'Architecture de Nantes

MASTER'S THESIS 2022

Seminar 'RECIT DIGITAUX'
Under the supervision of Dr . Laurent Lescop

ACKNOWLEDGEMENTS

I am very thankful to my tutor, Dr. Laurent Lescop for his advice and continuous support during the development of this thesis.

I would like to thank all my lecturers and my friends at ENSA for their precious suggestions, support and for having motivated me throughout the pursuit of this thesis.

I would also like to extend my gratitude to my friends of the 'DPEA architecture navale' of ENSA Nantes for their advice providing me with an introductory insight and knowledge towards the various topics of my research.

Last but not least, I want to thank my family for their continuous support, especially my sister for her help in proofreading.

PREFACE

The subject covered in this thesis is a conceptual floating utopia against sea level rise. The interest for this subject is defined by urban sprawl; we are currently in an era where we can see urban growth all around the globe. Villages are turning into cities, cities into metropolises and metropolises into megalopolises in order to accommodate the demographic growth, which predicts that we will exceed the bar of 9.9 billion people worldwide by 2050. At that time, when man will most probably have depleted all terrestrial resources, we will turn our attention back to the ocean with the primary intention of marine territorial conquest.

KEYWORDS

SEA LEVEL RISE - FLOAT - SHIP - MODULAR - UTOPIA - SELF-SUSTAINING ECOSYSTEM - RENEWABLE RESSOURCES

ABSTRACT

The aim of this thesis is to explore the possibility of creating a floating city based on the recycling of old cargo ships and decommissioned oil rigs. The goal is to provide a second life to those massive structures by incorporating a sustainable project.

The undeniable effects of climate change are already affecting several countries around the globe and emerging pandemics such as the coronavirus are calling for novel forms of architecture to answer those arising problems.

The thesis focuses on the proposal of a floating city based on the principles of ancient utopias alongside an ecological approach with respect to the recycling and reuse of decommissioned ships and oil rigs. The resulting project can be re-contextualised on a global aspect via the modular aspect to promote growth and sustainability of threatened cities and communities.



Fig 1: Anthony Lau - Vision for London , OFFSHORE LIVING - Floating city 2030.

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Introduction

The rise of Sea level is an ongoing phenomenon caused by climate change. This adverse effect, unfortunately, forms part of our reality. Curbing its effect remains no longer a reasonable option even if we apprehend a rise of 2 degrees Celsius for global warming. Research shows that about 20% of the population around the globe, particularly those in coastal cities will have to migrate away as the sea level rises. (NASA, 2018)

Coastal islands such as the Maldives and Kiribati are expected to be covered completely by the ocean. Countries like the Netherlands and cities including London, New York, Shanghai, Calcutta, and Jakarta would most likely be submerged because of melting polar ice icebergs.

As a matter of fact, on 23 September 2019, the UN convened a Climate Summit to bring together world leaders, the private sector, and civil society into a multilateral process to promote and accelerate climate actions in an attempt to save the planet from future chaos. The Summit focused on key sectors whereby actions may demonstrate effective endeavours such as nature-based solutions, cities, energy, resilience,

and climate finance.(United Nations, 2019) In November 2021, The Busan Metropolitan City of the Republic of Korea, UN-Habitat and OCEANIX signed a historic agreement to build the world's first prototype sustainable floating city. The goal is to seek breakthrough solutions and innovations for coastal cities and territories threatened by sea level rise.

Indeed, Coastal cities today are facing unique demographic, economic, environmental, spatial and social challenges. Therefore the expansion of the existing cities are becoming more restricted and with nowhere else to expand the rapid urban population growth is leading people closer to water. Housing costs are being driven to prohibitive rates and poor families are being squeezed out. (unhabitat.org, 2021)

"Sustainable floating cities are a part of the arsenal of climate adaptation strategies available to us. Instead of fighting with water, let us learn to live in harmony with it."

- Executive Director of UN-Habitat,
Maimunah Mohd Sharif



Fig 2 : One prediction of where rising sea levels will end up at Cottesloe Beach, Perth Western Australia.

Problem Statement

In response to the arising concerns of the effects of rising sea level on cities and coastal villages, this research presents an architectural solution based on the theoretical approach of floating utopias and inspired by a modular approach of existing floating structures. The thesis also puts forward the reuse of marine structures and ships which have been decommissioned either after fulfilling their operations or by other causes such as the pandemic.

As such the concept of a modular approach using recycled marine structures against sea level rise is explored based upon the theoretical approaches of ancient utopian projects and city movements.

Structure and Methodology

Chapter 1 (problem & arguments)

The first part of this thesis is an inspiration of the fable of the Syracusia designed by Archimedes. The focus is laid upon the evolution of the sizes of the ships and consequently the evolution of harbours accommodating those kinds of ships. Today, it is becoming more inconvenient as methods such as land reclamation uses more resources and hinder the evolution of the marine environment. The thesis also underlines the rise in the decommissioning of ships due to the pandemic crisis whereby they are dismantled by locals in inappropriate conditions.

Chapter 2-5 (hypothesis & case study)

The second part of the thesis suggests a hypothesis of a floating city followed by a state of art around the subject. The numerous aspects of floating technology such as buoyancy and metacenter are explored

alongside other essential factors for the implementation of a project in the marine context. These include floating structures other than ships, flood control structures, breakwater, floating materials, and unconventional materials such as biorocks which promote coral reef regeneration.

Chapter 6-8 (key principles & project)

The third part of the thesis explores numerous unachieved city projects and movements such as the spatial city and garden city which takes an unconventional approach to city design. These aims at defining key principles which define the characteristics of a proposed project against sea rise. The proposed project adopts modular concepts by incorporating three types of components; new floating modules, decommissioned platforms such as oil rigs, and the reuse of cargo ships so as to create a harmonious floating city.

Aim

- This thesis aims to propose an architectural solution in regards to climate change, global warming, and the threat of the rise of the sea level as well as worldwide population growth.
- The goal is to define a new purpose for decommissioned ships and marine structures; attributing them with a second life by incorporating them into a sustainable floating project.

Objectives

- To aid cities and coastal villages affected by the threat of the rise of sea level.
- To provide an alternative to land reclamation methods that hinders the landscape of lagoons and marine ecosystems.
- To offer a new purpose for decommissioned marine structures and ships by incorporating them into the proposed project.
- To create autonomous areas able to accommodate populations facing a crisis such as pandemics or wars.

Limitations

- This thesis focuses on the conceptual part of designing a floating city on the sea as per the norms of urban theories and as such does not focus on existing floating villages that are laid upon some kind of structural foundation such as piers rooted under seawater or rivers.
- The technical aspects of the proposed project are based upon the existing research work of others and as such the feasibility of realisation of the proposed project is not the focus of this research.

The thesis serves as mostly a guideline of a proposed concept that can be built upon and further improved so as to initiate novel types of architectures to answer the problem of the sea level rise.

CHAPTER 1

PROBLEMS & ARGUMENTS

The problem.

A. SEA RISE IN THE NEXT CENTURY

Inspiration behind the thesis.

B. ARCHIMEDES AND THE SYRACUSIA

Arguments leading to the hypothesis.

C. EVOLUTION OF SHIPS

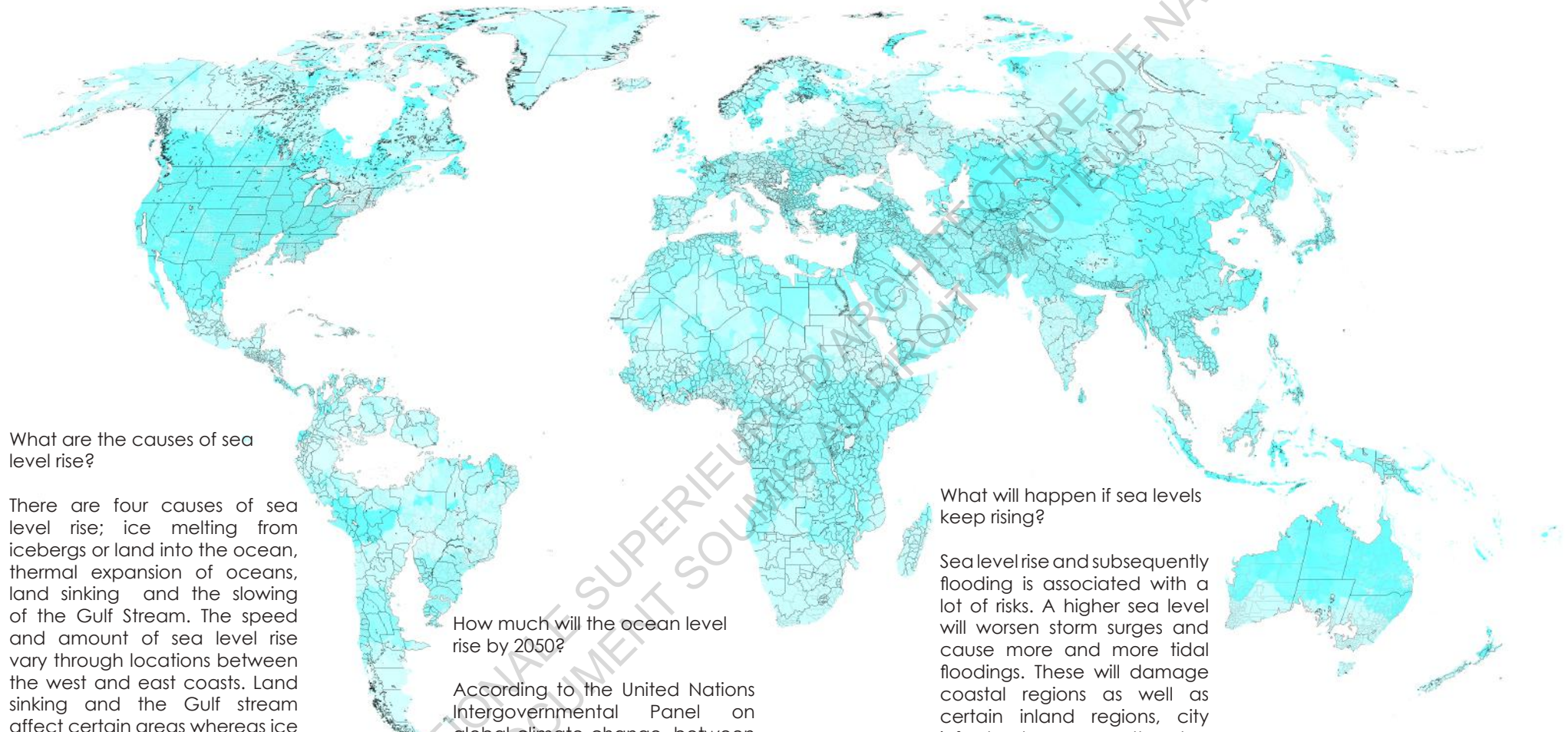
EVOLUTION OF HARBOURS

EXPANSION OF HARBOURS

LAND RECLAMATION

LIFE CYCLE OF SHIPS

SEA RISE IN THE NEXT CENTURY



What are the causes of sea level rise?

There are four causes of sea level rise; ice melting from icebergs or land into the ocean, thermal expansion of oceans, land sinking and the slowing of the Gulf Stream. The speed and amount of sea level rise vary through locations between the west and east coasts. Land sinking and the Gulf stream affect certain areas whereas ice melting and thermal expansion are considered as global phenomena contributing to sea rise everywhere. (SeaLevelRise.org, 2017)

How much will the ocean level rise by 2050?

According to the United Nations Intergovernmental Panel on global climate change, between 1901 and 2018, the ocean level has risen by 20 cm. In fact, it rose faster because of the increase in greenhouse emission emissions. By 2050, the amount of sea rise is predicted to be 15-25 cm, and depending on our future emission, 77cm is anticipated in 2100. (Abram, Reef, and McGregor, 2021)

What will happen if sea levels keep rising?

Sea level rise and subsequently flooding is associated with a lot of risks. A higher sea level will worsen storm surges and cause more and more tidal floodings. These will damage coastal regions as well as certain inland regions, city infrastructures, threaten human lives, the economy as well as damage to fauna and flora and their habitats. (SeaLevelRise.org, 2020)

Fig 3 : Sea level rise prediction world map 2100.

ARCHIMEDES AND THE SYRACUSIA

The inspiration of building a floating city emanates from the story of Archimedes and his ship the Syracusia, considered to be the very first floating city.

Indeed, it is necessary to reinterpret the stories and the designs behind older floating vessels such as Archimedes's Ship or Christopher Columbus' galleon 'Santa Maria'. Before Columbus' voyage which led to the discovery of America, cabotage was the main form of ancient seafaring. The term is derived from the French word 'vercaboter' meaning travelling near coasts. The Egyptians, Greeks, Phoenicians, and Romans followed mapped sea routes across the coastline as the risk of going in the high seas could mean getting lost at sea and eventually death at that time. (Nenova, 2015)



Fig 4 : Archimedes Thoughtful by Domenico Fetti. (1620)

The Greek Inventor

Archimedes (287-212 BCE) was a Greek mathematician and mechanical engineer, a pioneer in numerous fields. He is praised for his formula; Archimedes' Principle, known as the law of buoyancy.

"THE LAW OF BUOYANCY STATES THAT ANY OBJECT IMMERSED IN A FLUID WILL EXPERIENCE AN UPWARD FORCE EQUAL TO THE WEIGHT OF THE DISPLACED FLUID."

The Impossible Task

One day, Archimedes boasted about his abilities in one of his letters to Hiero II, the ruling king of Syracuse. "Give me a lever and a fulcrum and I will move the Earth!!!" he declared, implying he could move any heavy object in the world. Impressed by Archimedes' claims and knowledge, Hiero II tasked him to design and build the biggest and largest vessel he could ever invent. Archimedes exceeded all expectations when he designed the Syracusia, one of the first liners of antiquity. Syracusia was a 110 m ancient Greek ship capable of carrying a cargo of some 1,600 tons and a capacity of 1942 passengers and 200 soldiers. (Nenova, 2015)

The first liner of antiquity

Indeed the ship was a marvel in terms of design and can be considered to be among one of the first, if not the first floating construction. As described in Athenaeus' book Deipnosophistae, the ship was three times the size of the largest merchant ships of that time. It was embellished with sumptuous decors of exotic woods alongside towers, marble statues, promenades, a gymnasium, a library, and a temple dedicated to the goddess Aphrodite. All these elements can be considered to be the foundation of ancient 'smart cities'. The hierarchy of the spaces within the ship as well as the technological mechanism involved can be compared to today's urban designs typologies in respect to comfort and aesthetics of emerging smart cities. (Athenaeus, Of Naucratis and Charles Duke Yonge, 1854)

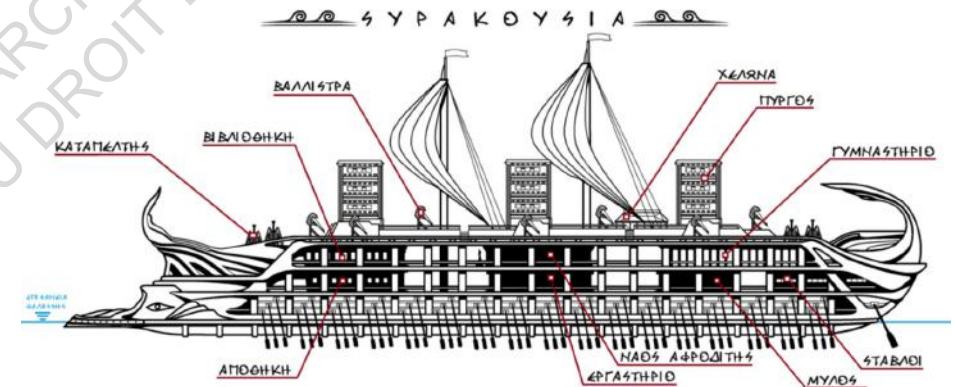


Fig 5 : The syracusia, one of the largest ships of antiquity.

Approximate Dimensions of the Liner

Details of Syracusia extracted from a text of Athenaeus and are as follows:

- Length of Ship – between 55 meters (other sources say 110 meters)
- Capacity of Cargo – About 1, 800 tons and 1940 passengers
- Material – Timber equivalent to build 60 standard ships (40m long and 6 m wide)
- Construction period – One year, built by around 300 workers

In comparison, modern Ships can reach lengths of more than 400m and carry 30 000 tons. They can reach heights of more than 60 m. They can even be described as floating skyscrapers.

EVOLUTION OF SHIPS

The largest transport ship of antiquity

When Syracruisa was built by Archias of Corinth following Archimedes' blueprints, it turned out that it was so enormous that the ship couldn't be admitted in any harbour in Sicily. Hiero II decided to gift the ship to Ptolemy, the king of Egypt of that time, the Alexandrian port was the only existing port where the ship could be received. History suggests the vessel's name changed from 'Syracrusia' to 'Alexandria' and was able to make only one voyage alike the titanic. (Nenova, 2015)

Evolution of Ships

Ships have always been made with wood since antiquity. The size of the ships was defined by the tallest available tree (70m) hence the hulls could only be shaped up to those ranges. However, during the era of the industrial revolution, the discovery of metallurgy changed completely the process of making ships. Metal could be molded in different shapes and sizes enabling ships to reach greater dimensions. This meant that larger ships could transport much more merchandise and commerce over longer distances would be more profitable. Since the 1950s the carrying capacity of cargo ships has evolved from 500 - 800 TEU (one forty-foot container is two TEU) reaching 21 000 - 25 000 TEU. (Jean-Paul Rodrigue, Comtois and Slack, 2020)

Ships have also diversified with time ranging from the early fishing ships, explorers' sailing vessels, warships, and passenger ships in the early era. Cargo ships and Oil tankers made their appearance in the 19th century alongside the first cruiser ships.

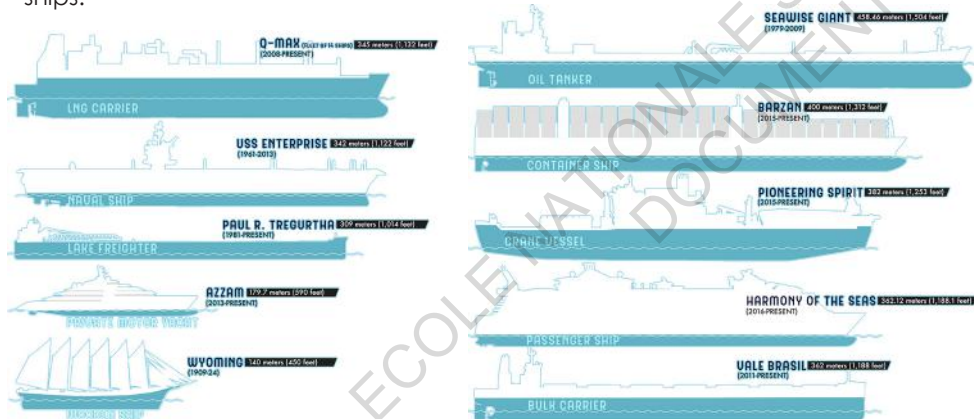


Fig 6 : Biggest ships available today. (140m to 458.46m)

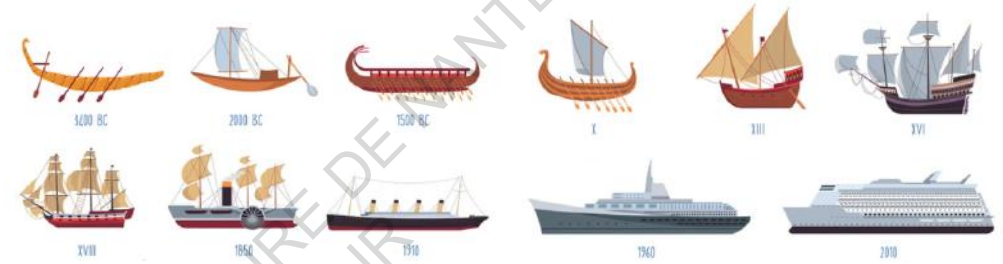


Fig 7 : Evolution of Boats and Ships. (3200BC-2010)

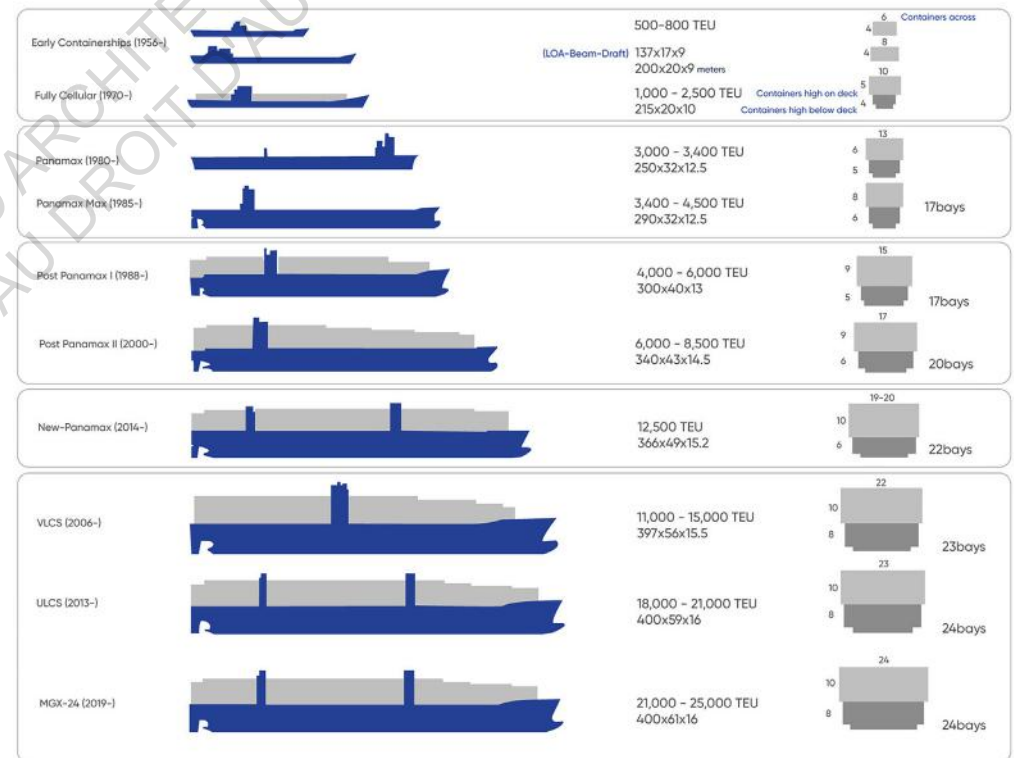


Fig 8 : Evolution of container ships. (1956-2019)

EVOLUTION OF HARBOURS

Port Louis - Mauritius - Colonisation

Ports have always been the gateway to the world. Indeed during the colonisation period in the 17th century ports were essential elements in the development of commerce for emerging colonies. Such an example is Port Louis, the capital city of Mauritius. First colonised by the Dutch settlers in 1606, Port Louis became a point of revitalisation in the perilous maritime voyage from Europe to India. In the 1700s the island became an administrative centre under French rule due to its key geographical position. The mountain range off Moka protected the island from strong winds as well as cyclones. The harbour was named Port Louis in honour of King Louis XV. The harbour was developed under British rule in the 1800s and activity boomed prior to the opening of the canal of Suez.

During the French colonisation, the governor Mahé de La Bourdonnais developed the city alongside a series of infrastructures meant to canalise the rainwater and decrease the risk of flooding. Urbanisation of the island in the late 1970s helped the harbour in maintaining its role as a centre for commerce. Port Louis soon became a business and administrative hub as the tourism industry expanded leading to development in amenities such as shops, restaurants and hotels as well as public infrastructures such as roads and sewers. (Ranvir Singh Guttee, 2015)

Port Hamburg - Germany - Geography

Germany's largest seaport, Hamburg, is found on the river of Elbe. It is one of the busiest ports in Europe after Rotterdam and Antwerp handling millions of TEUs (20-foot containers) annually. The branching of the Elbe makes it an ideal location for housing a port infrastructure comprising various facilities including warehouses. The skyline of the harbour is defined by the Elbe philharmonic Hall by Herzog and De Meuron. It remained a free port when Hamburg joined the German customs unions enabling duty-free import and export until 2013. Today Hamburg is one of the major cruise destinations in Europe especially for ferries and cruises travelling the Baltic and Atlantic Seas. With its three passenger terminals capable of processing the largest cruise ships in the world. The port also possesses numerous amenities for shipbuilders, including shipyards capable of constructing new ships as well as repair and reconditioning of yachts and liners. (Oscar, 2015)

Port of Singapore - Singapore - Land Scarcity

The port of Singapore has been ranked as the top maritime capital of the world and the second busiest harbour in terms of total shipping tonnage. The port transships around one third of the world's shipping containers across Asia, Europe and the USA alongside about half of the world supply of crude oil annually. It is defined as a key location as a communication channel among

Fig 9: The Port of Hamburg (Germany)



600 ports across 123 countries. The success of the harbour is the result of an economic necessity to compensate for Singapore's lack of resources in terms of land and natural resources. The ports are an answer to the economic problems; by importing resources, industries such as oil refining have taken birth and contributed to the country's GDP (Gross domestic product). Today Singapore is known as the third largest foreign exchange centre in the world. (Lim and Singapore Shipping Association, 2000)



Fig 10 : Typical drydocks in harbours for repair and maintenance of cruise ships.

EXPANSION OF HARBOURS

Singapore

Singapore, despite being considered as one of the smallest countries in the world, has evolved into a maritime hub over the last century. In order to accommodate the increasing population, the city expanded onto the sea through land reclamation. In fact, since its independence in 1965, the domain expanded by about 25%. However, this process proved to be a bane for the marine ecosystem; nearly all of the original natural shores and mangrove forests were lost alongside two third of Singapore's coral reef. Indeed Singapore, being an island, is also prone to be affected by the rise of sea level as Singapore is a low lying island, with approximately 30% laying 5m beneath sea level. Thus the land reclamation was defined to be 4m above mean sea level resulting in enormous amounts of resources required to refill the sea. (Glaser, Haberzettl and Walsh, 1991)

Port Louis

As the expansion of the city is limited by the mountain range of Moka, the alternative was to reclaim land and build on the ocean. Today about 25-30% of the city is built on landfills. The Caudan Waterfront became the new face of the harbour due to the booming tourism industry and today there are plans to expand the harbour to accommodate more activities including new cruise ship destination, Freezone warehousing and the expansion of the current commercial port. (MPA, 2017). The architecture changed over time to resist cyclones. Wooden colonial houses were replaced by concrete buildings as they proved to be more resilient and required less maintenance. Today, concrete, being the cheapest available material, is the norm for most novel construction. As concrete redefines the tapestry of the city, the ground becomes more and more impermeable leading to water accumulation in canals and consequently causing floods in the city. (Ranvir Singh Guttee, 2015)

Transformation of Singapore over time



Fig 11 : Land reclamation of Singapore. (Past, Present and Future)

Transformation of Port Louis over time

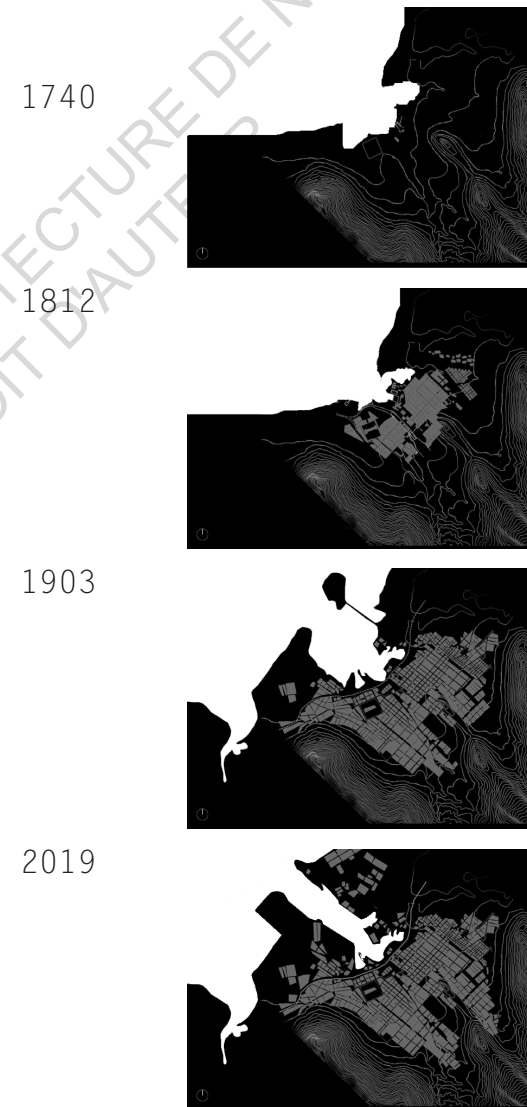


Fig 12 : Land reclamation of Port Louis from 1740 to 2019.

LAND RECLAMATION

What is land reclamation?

Land reclamation is the process whereby dry land is created artificially by covering bodies of water such as rivers, swamps, lakes, and the sea. The purpose of this process is diverse in terms of activities, often for early agriculture in the modern age, then for industrial purposes, and today mostly for port and urban expansion. The process involves the extraction of resources such as sand, soil, and gravel and is also used to create coastal barriers. (Julián Blasco, 2016)

There exist three common methods of reclaiming land:

1. Derelict method: This process is used mostly in inland areas where the purpose is to regenerate the land to promote agriculture growth after these inland areas had been affected by natural calamities such as floods or forest fires and even sometimes due to human activity.

2. Empoldering method: This process is generally a more advanced method whereby a low-lying land (a

polder) is reclaimed from the sea. First, piles (columns) are used to stabilise the seabed foundation followed by the erection of a dike (an area of land higher than the sea level) whose purpose is to prevent seawater from leaking into the encapsulated area. Then the seawater is removed by pumps to create usable land. Reeds (a type of grass) are grown in these areas as primary fertilisers followed by dense vegetation to prevent soil erosion. (Eisma, 1982)

3. LandFill: This process is the traditional method of reclaiming dry land by the removal of water from wet regions such as swamps and the sea. Several steps are involved in this process. Similarly to empoldering, firstly piles are planted in the sea bed as the founding structure. Then dikes (sand walls) are erected to protect the enclosed area. The next step is filling the enclosed area with sand to create new land. The sand is compressed and a tapered wall is built along the sea-facing side to prevent erosion by waves. Finally, vegetation is implemented to decrease the risk of soil erosion. (Julián Blasco, 2016)

Landfill Process



Fig 13 : Phases in the landfill process. (Left to right)

Dredging

Deepening rivers and ports so that ships can pass more easily can cause range of tides.

Land Reclamation

Similar to dredging, reclaiming of land changes topography of estuaries and cause potential change in tidal range

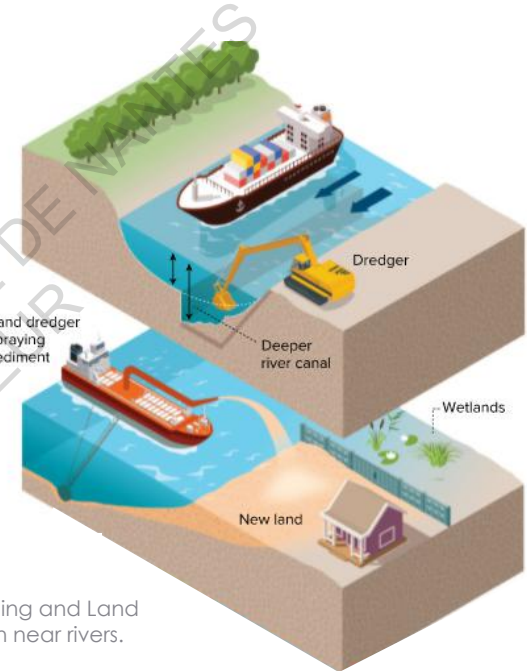


Fig 14 : Dredging and Land Reclamation near rivers.

Since the colonisation era, numerous countries have developed new urban areas near the harbours. This enabled rapid economic growth with import and export of goods as well as migration of population. The demographic growth of these areas has led to a phenomenon which is urban congestion. As the city expanded, land became more and more scarce and the typology of towers or skyscrapers rapidly came into place. In fact, due to geographical constraints on one hand and the arising problem of land scarcity in cosmopolitan zones, countries particularly those possessing massive coastlines such as China, Bahrain, Netherlands, Japan Singapore, Bangladesh, and Mauritius have been reclaiming land from the sea. (WorldAtlas, 2016)

Needless to say, land reclamations have adverse impacts on the intervening regions. Alongside enormous costs and resources involved in land reclamation, water pollution, waste, and damage to ecology are often the undesired outcomes of our ambition to extend our territorial capacity. (Sheppard, 2019)



Fig 15 : Factors involved in land reclamation.

LIFE CYCLE OF SHIPS

On the other hand, the life cycle of the large cargo and cruise ships that visit those harbours is also a factor to consider. Alang and Chittagong shipbreaking yards are regarded as the cheapest places to dismantle ships, however the poor working conditions of shipbreakers are quite awful and reprimandable. (CNN, 2020)

In fact, on average cruise ships have a lifetime of about 30 years. Eventually, the ageing cruise ships will cause them to become unseaworthy or too expensive to operate and they are discarded as follows:

PASSED ALONG

At the end of their services they are transferred to smaller cruise operators, a process known as 'second-hand tonnage' and ultimately they will be repurposed as smaller-scale cruise operations in countries such as Korea or Russia or will even be repurposed as car ferries.

SCRAPPED

If the ship gets dilapidated they will be taken apart and sold for scraps and their parts will be recycled. Most of these ships are sent to shipbreaking yards like Chittagong in Bangladesh or Alang in India where the labour cost is cheap. Despite being an

attraction in the past, these ship breaking yards have reached poor safety records today and tourists are no longer welcomed. Amidst the non-existent safety measures, on average it is claimed that one worker dies weekly and one is injured daily. Having no financial security, these workers having no proper formations are forced to work in unfavourable and dangerous conditions to earn a living.

ABANDONED AT SEA

Certain ships don't even make it as far as the ship breaker's yard. Sometimes storms create harsh sea conditions and are responsible for the abandonment of ships. Such an example is the ocean liner America which ran aground off the Canary Island and broke in two during a storm. The ship collapsed into the ocean and today only a remnant of the vessel is visible at low tide.

SUNK

Sometimes natural disasters are not the cause as ships are intentionally sunk to create artificial reefs for recreational diving. The oil, electronics and armaments are removed before sinking. The goal is to create structures housing sea creatures and coral for scuba-diving tourist attractions.

RUSTING AWAY

Some ships are destined to remain in a limbo state. Indeed as the cost of repairing or retrieving ships is enormous, the owners prefer to abandon the ship and as it is hard to find ownership of those vessels, they are towed into ship graveyards where they will rust away. This however may have nefarious impacts on the environment.

REPURPOSING OF SHIPS

Certain ships are turned into permanent floating moored hotels, restaurants or convention centres. They can also be used as movie sets

and very few cruise ships are transformed into museums. They are usually moored near ports and shipyards where they can be maintained regularly. These museums are often open to the public where the visitors can discover the cabins and crew quarters and learn about the ship's history. (Yeginsu, 2020)

Unfortunately, in these recent years, several cruise ships have been decommissioned due to the pandemic of covid-19. Lack of revenue and lack of passengers have given no choice to companies who deem it more profitable to sell the ship for scrap. It is necessary to suggest alternatives to the fate of those as they can be resources in the combat against sea level rise.

Fig 16 : Workers at the Shipbreaking Yard of Chittagong.



CHAPTER 2

HYPOTHESIS

A hypothesis against the problem of sea level rise.

A. THESIS STATEMENT

The key factors to determine the project.

B. ASPECTS TO CONSIDER

THESIS STATEMENT

In the next few decades, several issues will arise as a consequence of the rise of the sea level for communities near coastal regions. In the near future, it is suggested that islands would be submerged causing migration of the indigenous population. This brings devastating ramifications such as loss of identities, history and culture of the migrating population. (United Nations, 2020)

The impacts and constraints of the current methods in reclaiming land from the sea cause more damage to the environment by destroying coral reefs, mangrove forests and creating sea pollution along the coast. Moreover, as inland areas are constrained by topography, cities are densifying by adopting skyscrapers. However, this method is not sustainable as it adds to the heat island effect and the amount of carbon footprint is multiplied exponentially as concrete is used as a

primary element for the core structure and foundation of those buildings. Therefore, this thesis puts forward the project of a floating city by recycling decommissioned ships, oil rigs and other marine structures. (Antony Lau, 2015)

In fact, floating technology alienates the concept of deep foundations thus minimising damage to the seafloor enabling the creation of a more protective environment for marine life to thrive. (Czapiewska, 2013) It also opens up an array of potential to create a functioning ecosystem between man and water. Several advantages can be derived from living in a floating city near water and they are as follows:

Permeability - Ecology

By using floating technology the impact of the buildings on the marine environment is significantly reduced

Fig 17 : Coral reef regeneration.



as compared to other methods such as land reclaim. The layout of the floating structures can allow sunlight to pass to the underwater layer. This will allow the growth of marine creatures, coral reefs and help create a thriving environment.

Cost-effective - recycling

Building a floating structure from reusing decommissioned vessels is a cost-efficient solution. The building can be prefabricated off-site, towed and assembled to desired locations. The configurations of the 'prefabricated' building can vary in distributions from dense to dispersed configurations. Through this method, production can be done on an industrial scale under regulated conditions.

Sustainable - energy

Indeed in recent years, oceans have been used as the stage for harnessing renewable energy such as offshore wind energy, solar energy or tidal energy. By incorporating these characteristics into floating buildings, we can aim for net-zero carbon emission. Moreover, floating structures possess the ability to adapt to sea rise as the buildings are not constrained by water depth and will the structures will adapt to the new rising sea level.

Modular - mobile home

Floating buildings can adapt to the demands of the existing structure, as such they are not rooted compared to traditional buildings and therefore can be displaced. The reconfiguration of the layouts allows for various advantages such as improvement of the circulatory system between buildings or the expansion of the city over time.



Fig 18 : Ship Recycling.



Fig 19 : Wind powered turbines.



Fig 20 : Modular and mobile houses.

ASPECTS TO CONSIDER

Several aspects are taken into account in the design process for the floating city and they are as follows:

Floating technology:

The floating structure should be buoyant and stable on the water so as to allow the creation of a comfortable and safe environment for the users. As such, the floating technology should be up to date and performant enough to withstand forces under adverse conditions such as storms.

Mooring:

The mooring system is crucial for the stability of the floating city as it enables the anchoring of the floating structures to the seabed. The chains or wires used for mooring should allow flexibility so as to adapt to change in water levels and should be resilient to external lateral forces from surges or underwater currents.

Water Depth:

The water depth is an important factor to consider as it relates to the minimal distance between the waterline of the floating structure to the bottom of its hull and will also factor in grounding the floating structure in place.

Connection:

Proper circulatory networks are important in the planning of any city. Therefore, access to the shore or hinterland, access amongst the floating units and travelling on water are amongst three factors essential for the development of the community.

Interaction:

Some activities will be restricted in certain areas however the proximity to water allows for other types of activities that can promote social interaction such as sailing competitions or scuba diving explorations.

Energy Production:

Renewable energy is a key factor to create a sustainable community. Energy from the sun, the wind and the waves are to be incorporated in the project design to create an autonomous and energy-plus building.

Resource Management:

Production of food is an aspect to consider using by techniques such as aquaponics and fish farming. Recycling, composting or treatment of resources must also be implemented to minimise the impact on the environment.

Materials:

The materials used should be durable and therefore must be treated to be resistant to the saltwater environment. Recycled materials must be reinforced and regularly maintained to ensure the durability of the floating structures.

This thesis will explore a modular design of floating units capable of forming a floating city with respect to aspects such as recycling of marine structures, waste management, energy and resource production.

Recycling and Off site Production



Clean Energy



Reef Regeneration



Maritime Festivals

Fig 21: Beneficial aspects of a floating city.

CHAPTER 3

STATE OF THE ART

Retrospective of utopias.

A. TRITON PROJECT

TOKYO PLAN 1960

Existing floating communities.

B. URBAN RIGGER

SCHOONSHIP

Prospective of utopias.

C. LILYPAD

OCEANIX

TRITON PROJECT

Floating cities have always been portrayed in a utopian perspective as seen in the fiction novel of Jules Verne's *Propeller Island*, published in 1895 or as a dystopia in the 1995 film *Waterworld*. One of the earliest 'real' concepts of a floating city is the project of Triton City. Triton City was conceptualised by Buckminster Fuller, known for popularising the geodesic domes, in the early 1960s. Commissioned by a wealthy Japanese entrepreneur, Fuller designed an anchored floating city, consisting of tetrahedral blocks capable of accommodating various programmes such as apartments, stores, schools and parks. Located offshore of Tokyo Bay, the floating city blocks could communicate with each other via bridges and also with the mainland. (Behance, 2020)

"They are ships with all an ocean ship's technical autonomy, but they are also ships that will always be anchored. They don't have to go anywhere."

(R Buckminster Fuller, 2002)

Fig 22 : Triton City by Buckminster Fuller.

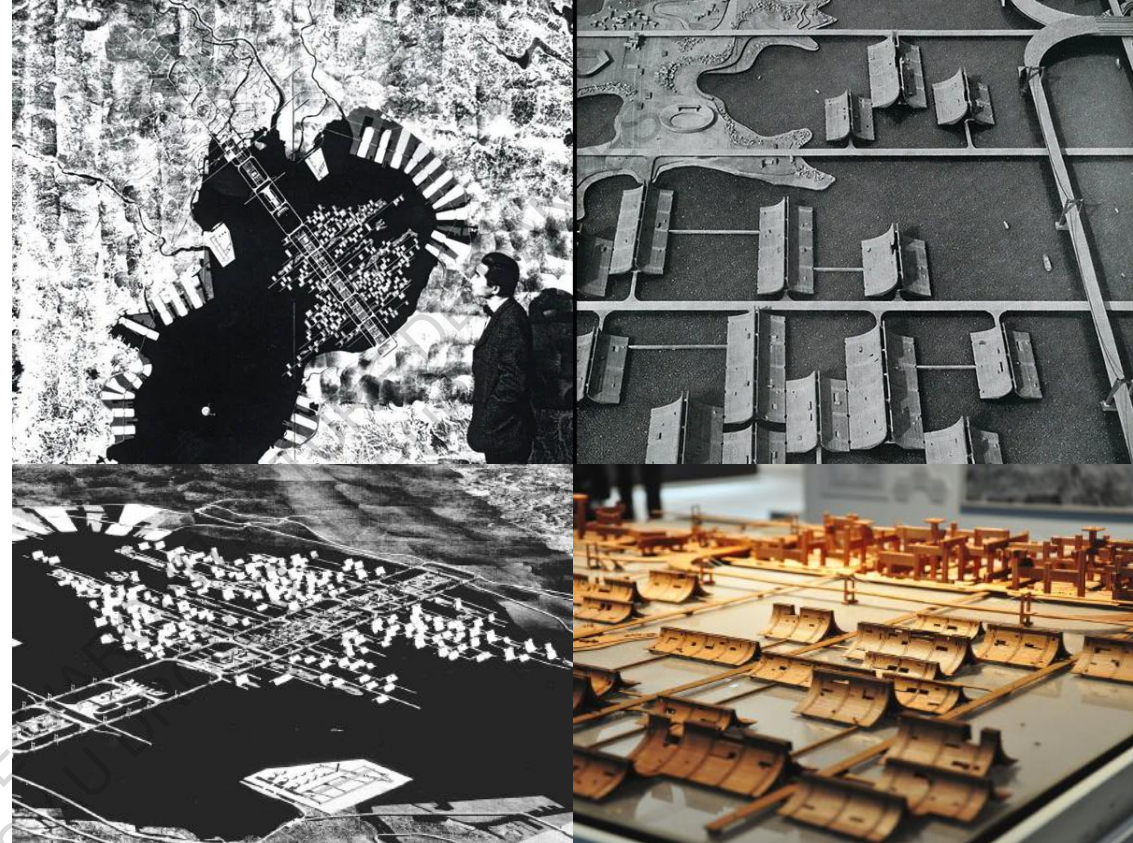
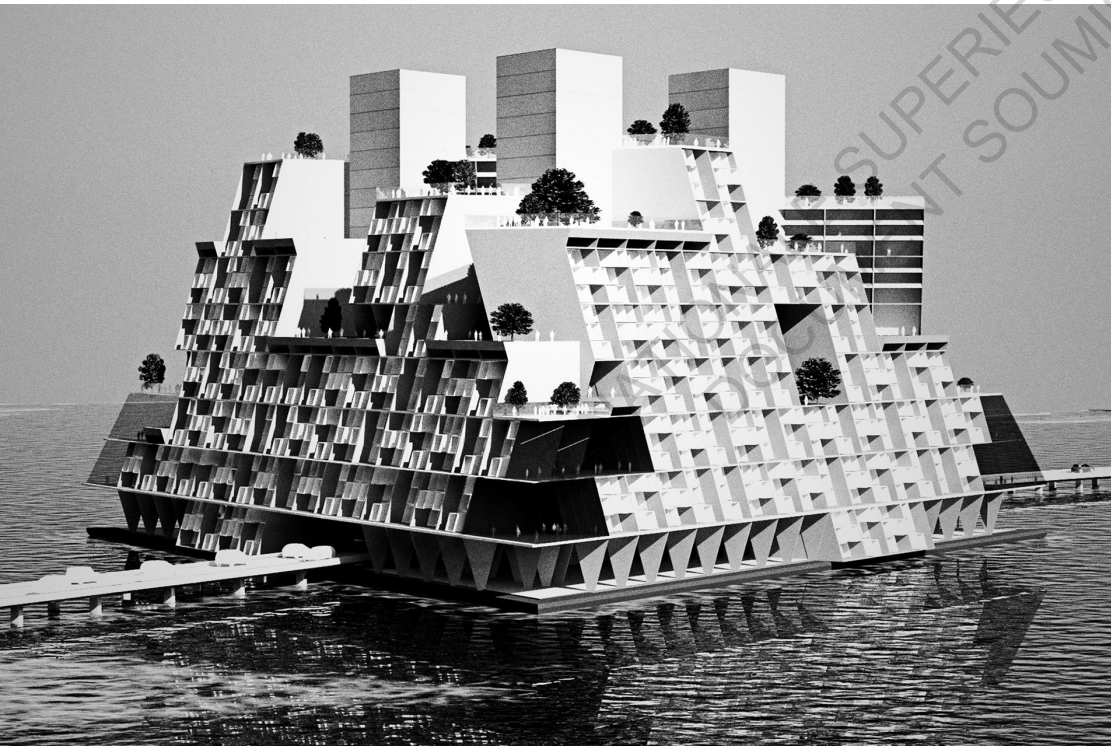


Fig 23 : Tokyo plan 1960 by Kenzo Tange.

TOKYO PLAN 1960

Around the same period, the architect Kenzo Tange proposed a new master plan for Tokyo. The aim was to cater for the urban expansion due to the demographic growth of Tokyo at the height of industrialisation. Tange's plan considered circulations tailored for vehicles along a central spine including a hierarchical level depending on the speed of the vehicles. The plan also favoured pedestrian circulation across the civic spine branching towards residential areas. These linear formats allowed an organised smooth movement within the city.

The Triton project and Tange's Tokyo Plan remained as a series of paperwork due to the fact that science and technology presented limitations as well as other factors such as the death of the Japanese undertaker which brought to end the Triton project. (ArchEyes, 2016)

URBAN RIGGER

Even though there is no clear history of floating architecture, the earliest prevalent forms of similar architecture are described as floating homes. These consist of a dwelling mounted upon a boat and are believed to have evolved from barges and narrowboats back in the 18th and 19th centuries. Those types of floating vessels were initially used for the transportation of goods along rivers. (WATERWAYS ASSOCIATION, 2014). They developed into houseboats capable of accommodating families and became quite popular due to the economic crisis of World War I. The low cost and prefabrications methods allowed for a temporary source of housing during that era.

Today, emerging novel architecture inspired by houseboats are being popularised in countries such as Denmark and Netherlands. Such an example is the Urban Rigger Project in Copenhagen Harbour. Designed in 2016 by Bjarke Ingles, the Urban Rigger project aims to create affordable housing capable of accommodating 100 students. Shipping containers, mounted on floating platforms, are repurposed as studios, green courtyards, terraces and community rooms. The design stacked as LEGOs proposes a 'puzzle-like structure' allowing flexible variation in sizes as well as replication near most water bodies. (URBAN RIGGER, 2020)

Fig 24 : Urban Rigger Project by BIG architects.



Fig 25 : Schoonschip project by Space&Matter.

SCHOONSCHIP

Following a similar principle, Space&Matter was commissioned by Schoonschip to develop the project of a 'floating habitable jetty' in Amsterdam. This project is the result of years of planning, including the involvement of the future inhabitants during the early developing stage. In fact, Each of the 46 floating structures is designed by an architect as per the needs of the client, providing diversity and customisation of the homes. Completed in 2021, this project is tailored by the strong sense of circular community, ecology and pioneering in terms of floating infrastructure. (Space&matter, 2021)

Characterised as 'proof of concepts' for future urban design. The Urban Rigger and the Schoonschip project possess the key principles in defining the urban landscapes of tomorrow.

LILYPAD

In fact, most floating projects have been classified as utopias and still remain concepts on paper at this point. The lily pad project of Vincent Callebaut is such an example. Designed as a solution to land reclamation, the city was conceived back in 2008 as a tenable solution to rising seawater levels. Dubbed as an 'Ecopolis' and inspired by the lily pad plant, the project was meant to travel the ocean riding on the sea currents such as the gulf stream much like a cruise ship. Yet the design is different as it is classified as a Seastead. (Callebaut, 2017)

Seastead is a term used to merge the concept of sea and homestead, the idea is characterised by the urban scale rather than the individual scale of a houseboat. Seasteading is defined as the establishment of temporary or permanent settlements in areas of the open sea outside the jurisdiction of any country. Although characterised as a viable solution in Callebaut's project, Seastead presents sometimes disadvantages in terms of practicability; seastead is difficult to access from the mainland as the coral reefs and infrastructures may cause damage to the existing marine ecosystem and resilience; as the adverse harsh climate in open sea can hinder the stability of the structure. (Carly Jackson, 2015)

Fig 26 : Lily pad Project.



Fig 27 : Oceanix project.

OCEANIX

Nonetheless, seasteading is still believed to be the key to the threat of rising sea level and urban congestion compared to land reclamation methods which have more adverse effects on existing landscapes. The OCEANIX project, designed by BIG architects in support of UN-Habitat's New Urban Agenda, is the vision for future floating communities. (Gibson, 2019)

Indeed, by adopting the seastead characteristics as well as a modular design, Oceanix aims at a sustainable expansion over time allowing a community to evolve into a village and eventually into a floating city. By including aspects such as renewable energy, food production and waste recycling anchored within the UN's 17 sustainable development goals, the project aims at a conceivable idea. However, due to the pandemic crisis, the project still remains in the conceptual stage at this time. (United Nations, 2015)

CHAPTER 4

BACKGROUND STUDY

Understating floating technology.

A. SHIPS

BUOYANCY

METACENTER

Types of floating structures.

B. OIL RIGS

OTHER FLOATING STRUCTURES

FLOATING BREAKWATERS

Materials for the water context.

C. FLOATING MATERIAL

BIOROCK TECHNOLOGY

SHIPS

Understanding the anatomy of a ship.

The most omnipresent form of a floating object around the globe is the ship. Ships have evolved to cater for various types of uses, mainly for transportation purposes with ships such as ferries, cargo ships and oil tankers but also for leisure with ships such as yachts or cruiser ships on a much larger scale. The latter is comparable to a floating building, so to conceptualise a floating building it is essential to understand the fundamental elements of a ship.

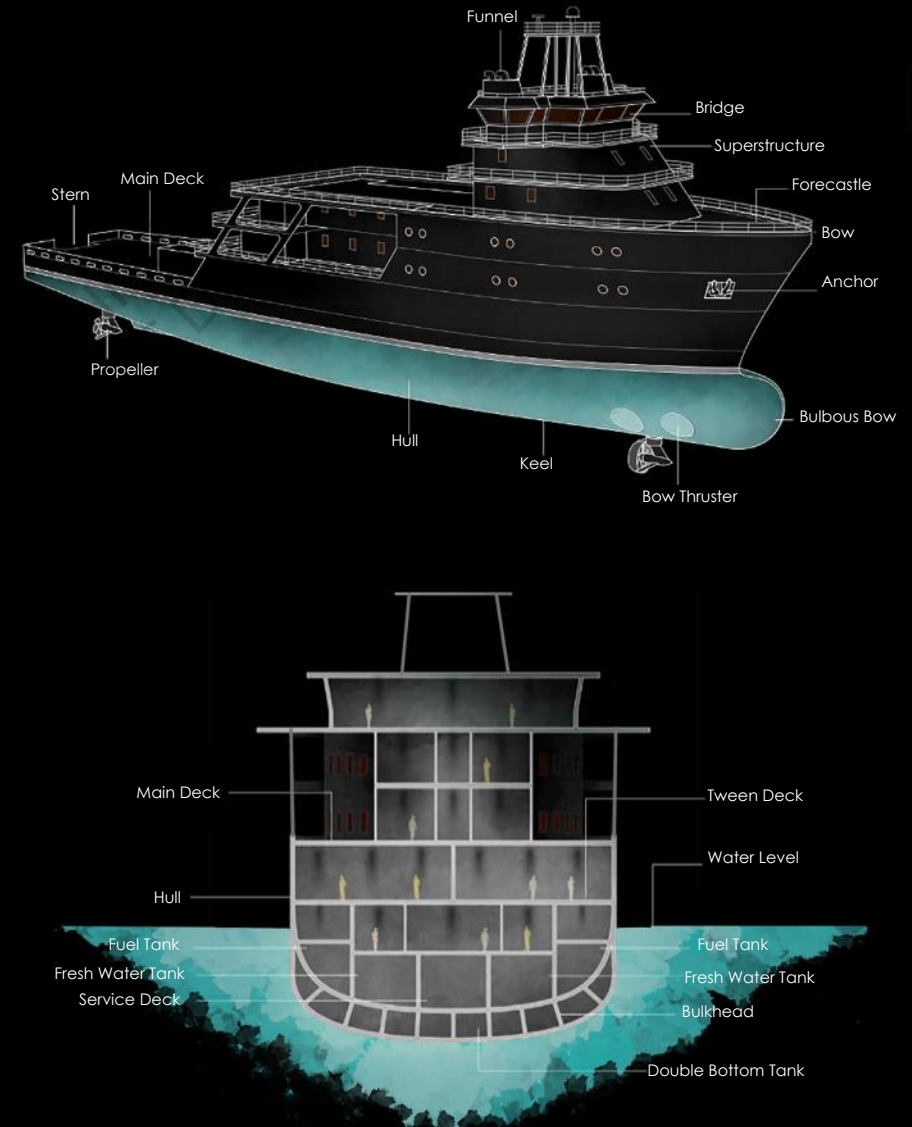
A ship is equipped with a series of essential parts allowing it to navigate water or simply float on water. The most important part is the hull which is the watertight body of the ship. The hull determines the size of the ship and the space within the hull will be distributed into compartments. This distribution allows for a more efficient structural rigidity of the vessel. The vertical partition walls that divide the ship's interior into watertight compartments are known as bulkheads. Their purpose is to reduce the intake of seawater in case of damage or water leakage. These walls can be flat or corrugated providing additional stiffness to the hull.

The bulbous bow is a protruding element found on most ships whose aim is to reduce drag caused by waves during travel in the open sea. The correct shape, size and design of the bulb are essential as it determines the flow of water around the hull. This results in improving fuel efficiency, speed and stability of the ship.

For navigation, sails once determined the speed and power of the ship alongside rudders connected to a wheel allowing ships to steer. Today sails have been replaced by diesel engines as they proved to be more effective to control larger vessels. Propellers are implemented on the sides to allow precise navigation in harbours.

The hull of the ships is the most relevant part determining the floating technology. In fact, it has been adopted in architecture throughout the ages where the first colonists used the hulls to create their first settlements. (Abhishek, 2020)

Fig 28 : Anatomy of a ship.



BUOYANCY

How does a ship float?

When a ship is placed on water, due to the force of gravity, the weight of the ship will displace an equivalent amount of water in respect to its weight. Archimedes has theorised a principle that explains this phenomenon.

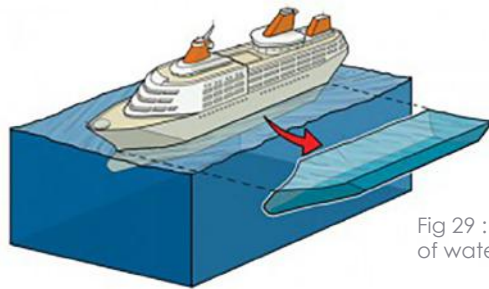


Fig 29 : Displacement of water by a ship.

The archimedes principle's formula is as such $F_b = -\rho g V$

F_b = Buoyant force

ρ = The density of water (approximately 1025kg/m³)

g = Force of Gravity on Earth (approximately 9.81 m/s²)

V = Volume of water displaced

This principle states that when a body is immersed in a liquid it receives an action of an upward vertical thrust) whose intensity is equivalent to the weight of the fluid displaced by the body.

So in other words, the buoyant resultant force on a ship is equal to the weight of displaced water by the ship, which is an upward force exerted by water so as to oppose the weight of the immersed ship.

In order for the ship to float, the overall density of the ship must be less than the density of water. The size of the ship does not matter as long as the gravitational force is constant as well as the water displaced. (Soumya Chakraborty, 2019)



Fig 30 : stabilizer, extended in dry dock.

Larger ships have a bigger keel which is the structural backbone of a ship or boat, running lengthwise from end to end along the centre of the bottom of the hull. This enables the ship to avoid rolling over as it helps in countering the rotating forces produced by waves pushing the ship sideways in water.

Indeed, bigger boats such as cruiser ships are generally more stable than smaller boats as numerous elements and principles are applied to get a lower centre of gravity. As such, heavy objects such as the engine, machinery, fuel, and ballast are placed at the lowest position of the vessel underneath the seawater level and cabins and public spaces are placed on the upper decks.

In addition, modern ships are equipped with stabilisers fins. The stabilisers are similar to wing flaps on an aeroplane. Extended beneath both sides of the vessel under the water, their purpose is to prevent the vessel from excessive rolling from side to side. This helps the ship in navigating more effectively. The stabilisers are especially useful in the open sea under harsh conditions such as high waves and strong wind. (Grant, 2015)

METACENTER

How does a ship maintain its stability?

The centre of gravity

The center of gravity of an object is the area where the mass of the object appears to be concentrated. This area is defined by a point called the centre of gravity. In a uniform object, the centre of gravity is right at the centre, and this point is obtained by intersecting lines of symmetry of the object. Heavier smaller objects are more stable than lighter taller objects as the centre of gravity is much lower in the former. Thus the lower the centre of gravity the more stable the object is.

For a human body, the centre of gravity is above the waist as the mass of the upper half of the human body is greater than that of the lower half. Laying down is much easier than standing up as the centre of gravity is lower and hence less effort is required to keep the body in equilibrium. (Kiat, 2018)

Metacenter and center of buoyancy

The centre of buoyancy is the resultant center of an immersed object which displaces a certain amount of water. The Metacenter is the theoretical point, in the plane of the centre of buoyancy. A ship is stable in water when it experiences a positive meta center. Otherwise it will topple over if the resultant metacenter is negative.

Positive metacenter

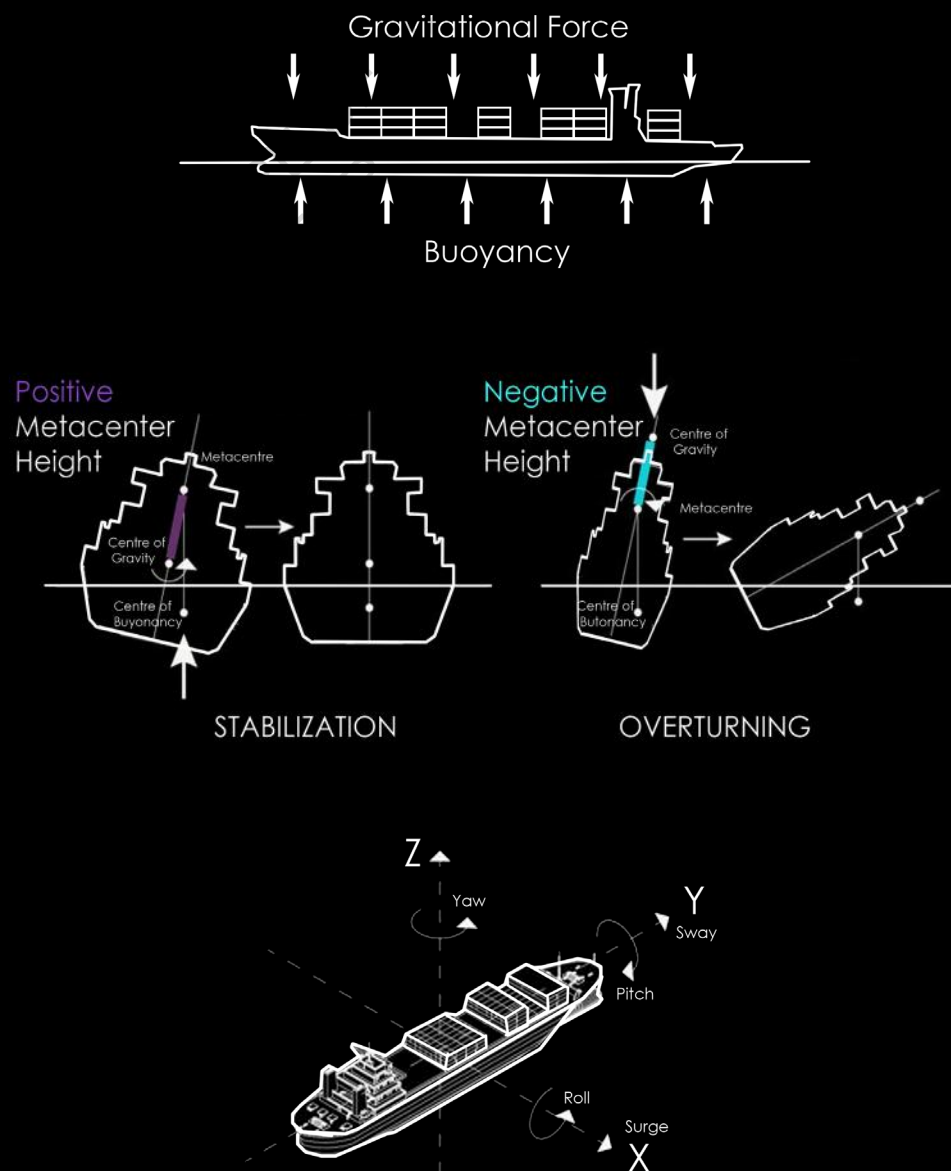
For equilibrium to happen a positive metacenter is needed, meaning where the metacenter is above the center of gravity. The center of buoyancy is also situated below the center of gravity. As a result of the positive metacenter even if a ship is tilted, the buoyant force opposes the gravitational force returning the ships to the equilibrium position.

Negative metacenter

When a negative metacenter is obtained as a result of its position is below that of the center of gravity, the buoyancy force will act with the gravitational force and push the ships towards capsizing.

Floating vessels may experience six types of motions in water that affect their stability and therefore it is imperative for the vessel to possess a low center of gravity and a positive metacenter. (Soumya Chakraborty, 2019)

Fig 31 : Factors influencing ships stability.



OIL RIGS

Semi-permanent floating objects.

An oil rig is a floating platform used for the extraction and processing of resources such as oil and natural gas. It is equipped with various types of machinery and storage units. As these structures are found in the high seas, they are usually fixed off the ocean floor and in some cases are able to float on the surface.

There exist numerous types of rigs with each posing its own capacity and capabilities. For example, jack-up rigs operate at depth of water up to about 150 meters which are relatively shallow sea regions. A semi-submersible rig, on the other hand, can operate at a depth of about 3000 meters. (Bejger and Piasecki, 2020)

Fixed platforms such as compliant towers are moored to the site of exploitation. Mooring is a term that defines the use of equipment such as mooring lines consisting of up to 10 wires or chains to anchor structures to the seabed in order to protect them against the forces of waves, currents or the wind. Their base is made with concrete so as to obtain a lower centre of gravity and make them more durable and stable in harsh environments.

Similarly, jackup rigs are anchored to the sea bed with concrete foundations. The jack-up rigs in particular are made with steel legs that can be raised, much like a construction crane. This enables the height of the self-elevating platform to be modified enabling flexibility. (Armes, 2021)

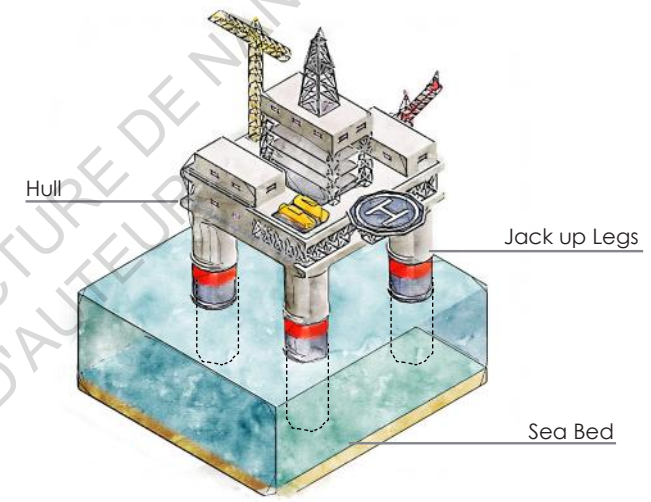


Fig 33 : Compliant tower type rig.

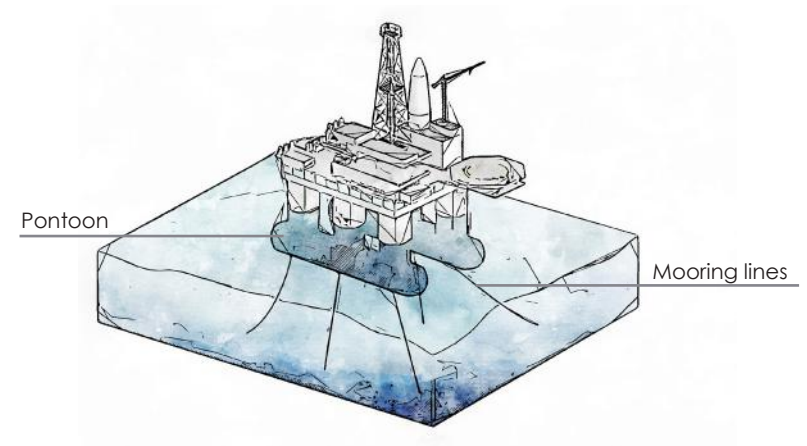
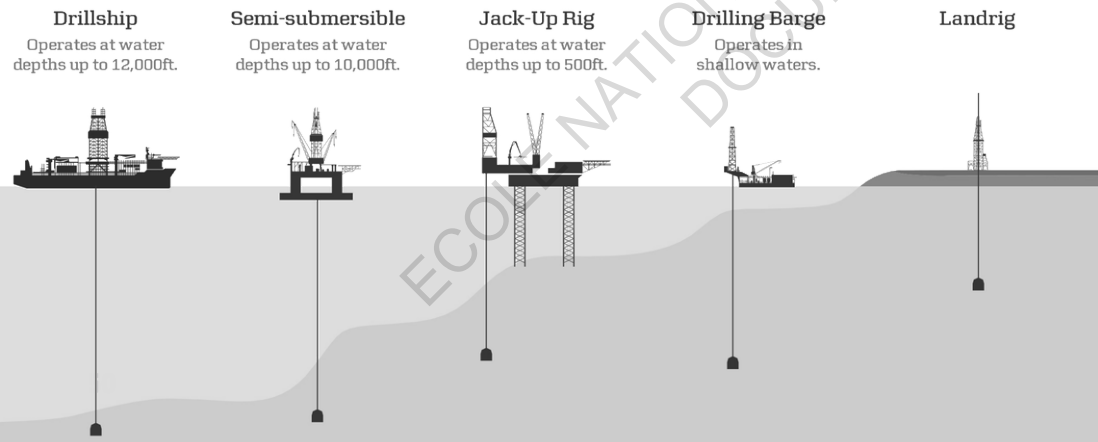


Fig 34 : Semi-submersible rig.

Fig 32 : Types of drilling platforms.



OTHER FLOATING STRUCTURES

Semi-submersible rigs are floating structures used to drill wells in places inaccessible to jack up-rigs. Their characteristics are that they are buoyant and do not need legs to rest on the seabed. However, as the floating deck is supported by submerged pontoons, it is necessary to keep them stationary by mooring. The floating technology is deemed to be more eco friendly in terms that the damage to the seafloor is kept minimum compared to fixed platforms or jackup rigs.

Another type of floating structure is offshore wind structures. It is a type of floating structure which, similar to semi-submersible rigs, offers new opportunities in deeper offshore regions. In those areas, there is much higher wind potential and this allows for the acquisition of more energy via wind turbines. Given they are floating structures they must be moored to the site. (Rigzone, 2016)

Fig 35: Mooring of floating structures.

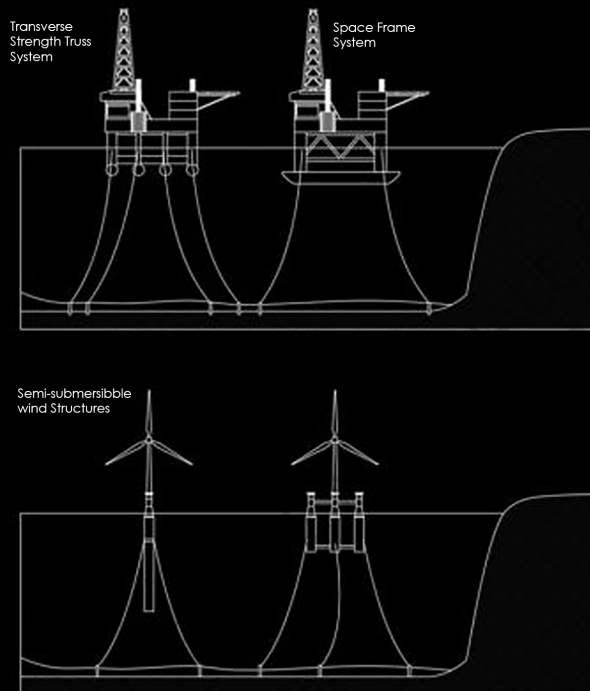


Fig 36 : Semi-submersible ship Blue Marlin moving an oil rig.

As semi-submersible rigs are designed to operate in deep-sea regions of up to more than 1000m, they are built offsite and carried onto the site by heavy-lift ships. These ships are made specifically for that purpose and can be classified into two categories Semi-submersible ships and project cargo ships.

The semi-submersible ship is capable of carrying oversized cargo, ships and yachts. They function with a series of ballast tanks that can control the submersion of ships. When the ballast is full, the ship will drop below water level allowing cargo to be floated onto the deck. The water ballast is then drained and the semi-submersible alongside its cargo is raised above the waterline.

On the other hand, project cargo ships are non-submersible and use a series of cranes for loading cargo as well as a ballast to ensure stability. They can have between 13000 and 19000 deadweight tonnage allowing them to transport container cranes, bridges sections or suction piles. (Boskalis, 2020)

FLOATING BREAKWATERS

Floating breakwaters are devices used to protect harbour or coastal regions from mild waves. Compared to the conventional fixed breakwater, floating breakwater has minimal impact on the marine environment. They are particularly effective in protecting small craft harbours, marinas and sometimes even shorelines affected by erosion. In general, there are four categories of floating breakwater which are box type, pontoon, mat and tethered float.

Box type breakwaters are most commonly used. They have either hollow interiors or they have a light core made with lightweight materials such as polystyrene. pontoons are very effective in terms of design factor efficiency and are used widely in harbours and marinas. The mat types are less effective but cheaper as they are made with tires and require unskilled labour and equipment for fabrication. Lastly, tethered floats are rarely used but can be installed for deepwater. (Ruol, 2013)

Fig 37 : Types of pontoon and mooring systems.

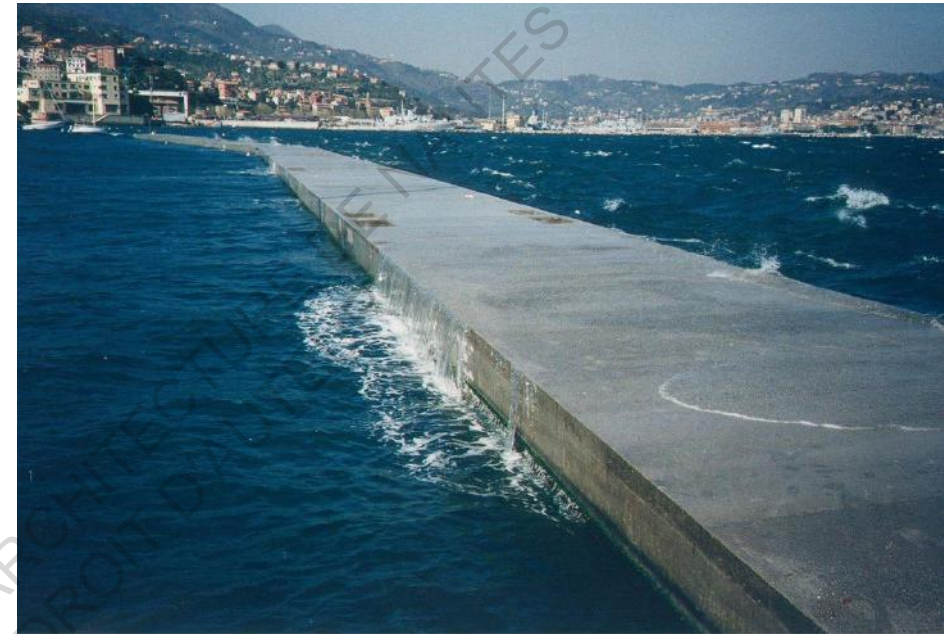
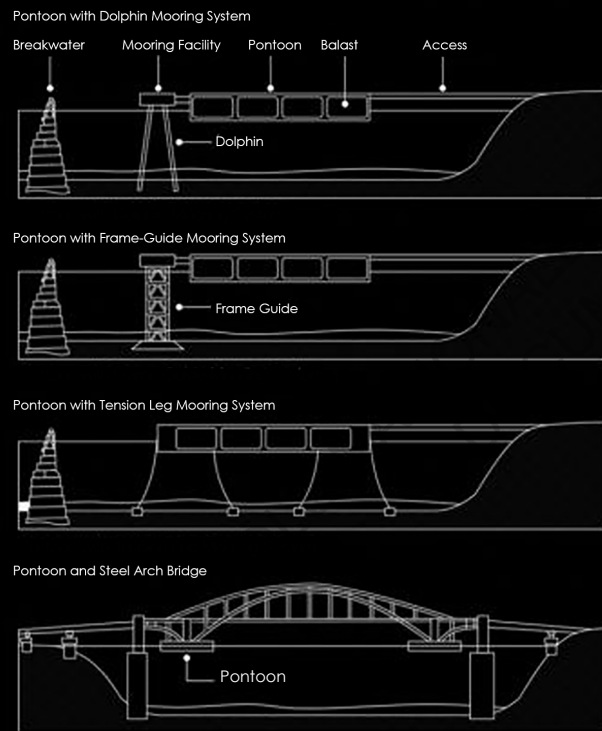


Fig 38 : Typical floating breakwater.

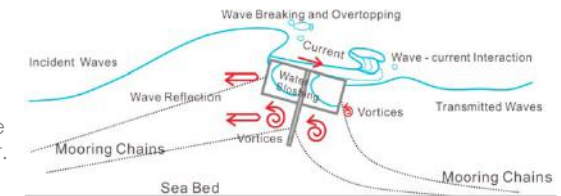


Fig 38.5 : Fuction of a water ballast type floating breakwater.

These types of floating structures have the following advantages:

They can be applied in areas with poor foundation that prohibits the application of fixed breakwater.

They are cost efficient and can be used with depth exceeding 6 meters.

They don't affect water circulation hence marine creature migrations.

They can be easily displaced in areas where ice formation is common.

They can be easily arranged in numerous layouts or configurations.

They have a very low profile, presenting minimal intrusion of the horizon especially in zones with high tide ranges.

FLOOD CONTROL STRUCTURES

Today, there are two main methods of flood control alongside coastal regions and river banks; these are levees and floodwalls.

The levee or dike is a structure built parallel to the course of a river or alongside coastlines. They can be naturally formed or be artificially built. The main purpose is to prevent the course of rivers from changing and to protect the nearby region from flooding. Another purpose is to regulate the flow of rivers so as to provide shipping lanes for maritime commerce. They are built along the sea to provide protection against high floods by dissipating waves energy attaining the coastlines or for the empoldering process or as boundaries for areas prone to floods. Levee can also be used for the construction of coastal reservoirs whereby its function is to separate salt water from freshwater. This allows freshwater fishing or other freshwater activity by providing protected calm water conditions. (National Geographic Society, 2012)

Levees are usually permanent earthworks but can also be regarded as temporary construction erected with sandbags in case of a flood emergency. Levee has been used in ancient civilisations in the past and can be found today all around the globe. Failure of levees due to damage or erosion can result in major disasters. (Dutchdikes, 2015)

Fig 39 : Component of a Dike.

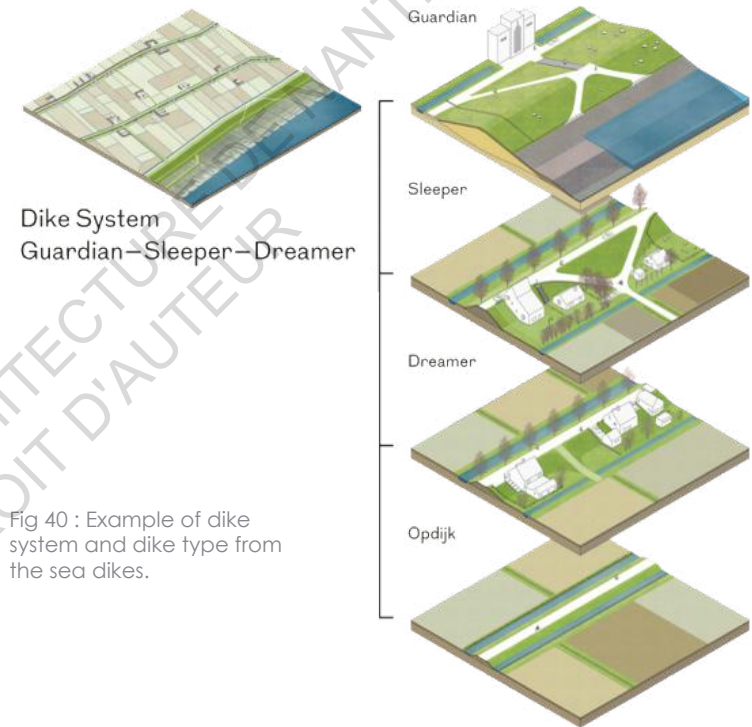
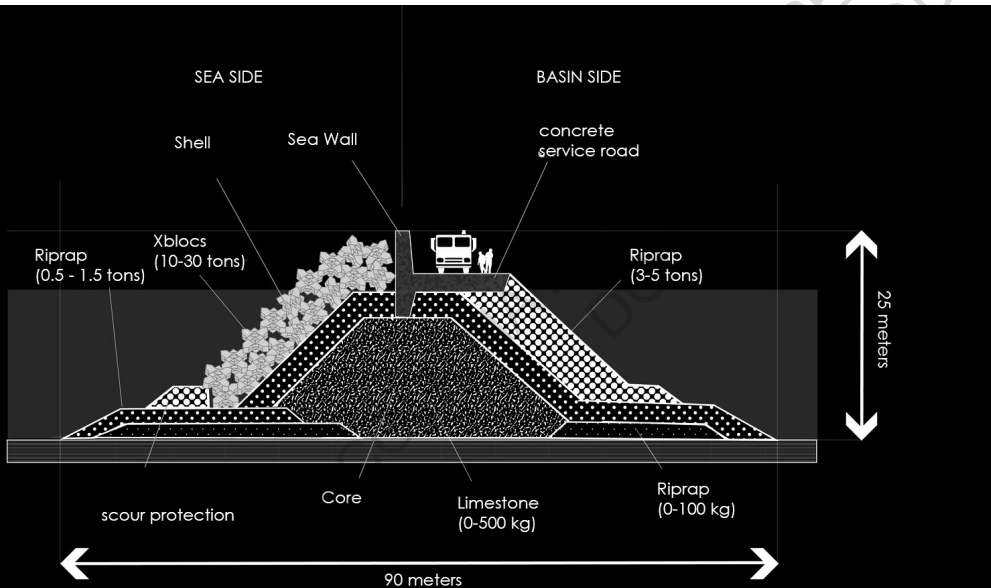


Fig 40 : Example of dike system and dike type from the sea dikes.

Floodwalls are artificial constructions designed to temporarily contain excess water from floods due to extreme or seasonal weather events. They are built with prefabricated materials and can even have floodgates that allow the passage except during periods of floods.

They are built in areas where land is scarce or where dikes would interfere with other interests such as the use of embankments or classified historical sites.

Fig 41 : A floodwall at Zruč nad Sázavou, Czech Republic.



FLOATING MATERIAL

Besides metal pontoons and timber decks, floating concrete is a material widely used for the construction of platforms for floating buildings. They are less dense than traditional concrete which sinks as they are usually made as a composite material. Their cores are made with a lightweight material which is usually polystyrene. The polystyrene counterbalances the weight of the concrete exterior making it lighter than water thus allowing it to float.

One such example of application is through the Rhizolith island project was meant to revitalise mangrove cultivation for the protection of coastlines. The project was to enable the growth of mangroves by protecting seedlings from predators whilst allowing the growth of their roots. The prototype consists of two parts, first the head which harbours the plant's stem which is made with lightweight concrete and secondly, the fins which are porous, made with a dense ultra high performance concrete keeping roots below the waterline, allowing them to flourish. This system ensures stability in water and helps to mitigate the force of currents. (AIA New York, 2019)

Fig 42 : Rhizolith project by APTUM architecture.

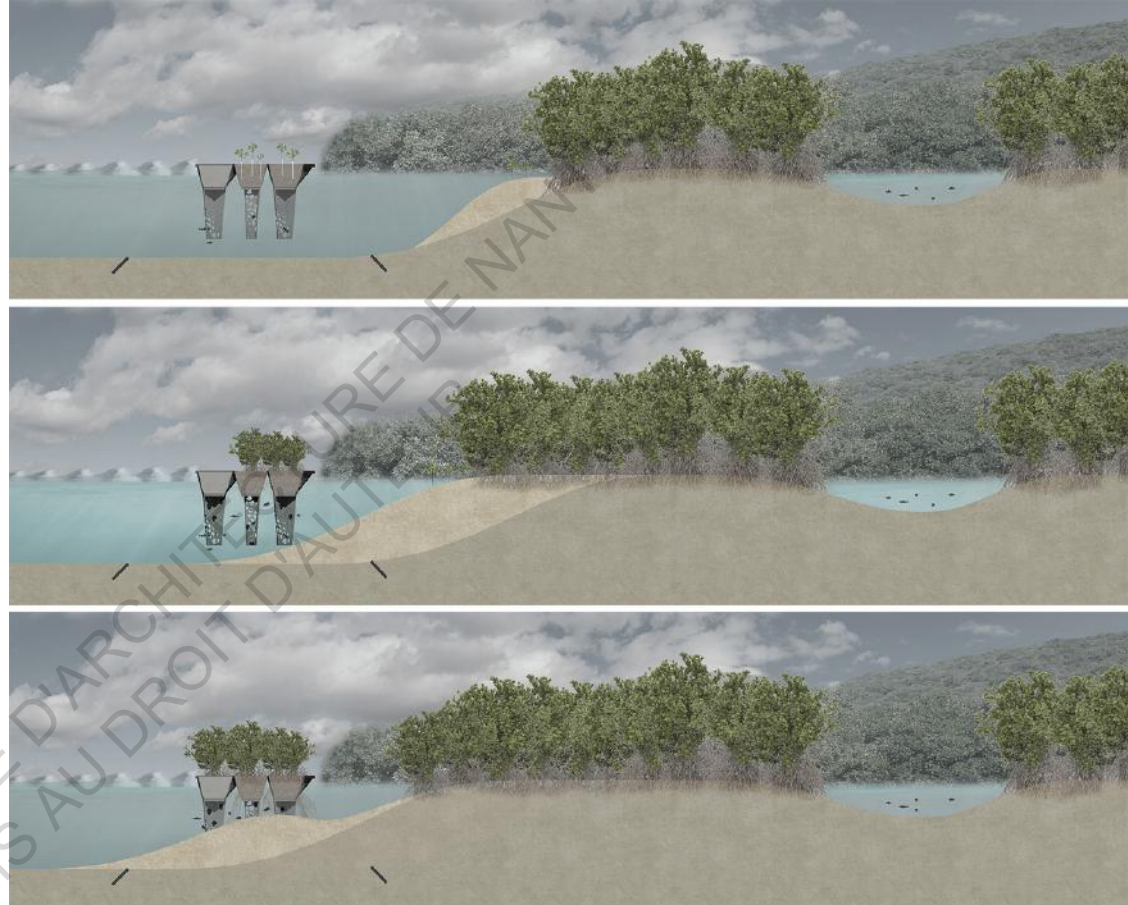
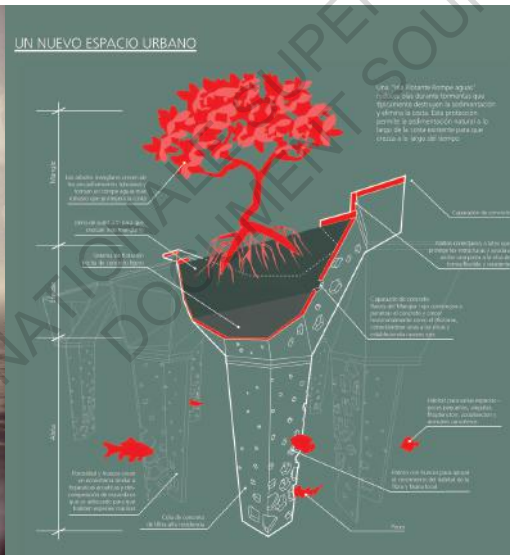


Fig 43 : Shoreline regeneration over time.

The Rhizolith island project is projected towards sustainable development in time.

During the first years, the mangrove seedlings are protected inside the floating encasement tubes.

Then as the roots flourish the structure will be anchored and will form a protective barrier.

The mangrove will create a habitat for marine creatures and in about 10 years a natural environment is formed allowing for the existence of an aquatic ecosystem. (AIA New York, 2019)

BIOROCK TECHNOLOGY

Biorock technology also known as mineral accretion technology is the process by which a safe low voltage electrical current is passed between metal electrodes, usually an anode and a cathode in seawater. The current is low and safe and can be applied to any steel structure regardless of size or shape. This causes crystallisation of dissolved minerals on the structure that grows into a white limestone which is naturally present in corals or white sand beaches. The substance formed during this process is referred to as biorock. It has similar properties to that of concrete and can also be stronger as the biorock is able to grow, heal itself and become stronger over time.

This process was developed in 1976 by architect Wolf Hilbertz in order to find alternative construction materials. It was later developed for reef restoration as well as for shore protection initiatives. In fact, It has been tested that when fragments of broken corals are tied to the biorock structure, they can grow four to six times faster than their actual growth as they do not need to spend additional energy to form their own calcium-based skeletons. As biorock projects can be powered by numerous electrical sources which include windmills, photovoltaic solar panels or tidal current generators, they can be placed in zones where conventional electrical power is unavailable. (Global Coral Reef Alliance, 2018)

Fig 44 : Two years of mineral accretion material growing on iron bar.



Fig 45 : Biorock reef indonesia.

Electrified Reefs

Artificial reefs can be constructed using biorock technology allowing corals to thrive and imitate a natural reef. The base structure is made with metal rebars and can be placed virtually anywhere in the ocean. The Coral benefits from dissolved oxygen created during the process forming a rich environment that also attracts marine organisms, particularly tropical fishes.

Biorock is able to survive strong hurricanes and can regenerate coral reefs, seagrass, salt marshes, oysters, mangroves and coastal ecosystems where natural recovery is no longer possible. Due to the electrical current which deters bull sharks, they can greatly increase settlement, survival, and growth of marine organisms. Indeed, floating biorocks reefs are being tested to filter and clean polluted coastal waters worldwide. (Baragona, 2016)

CHAPTER 5

CASE STUDY

Utopian city movements

A. THE GARDEN CITY

THE WALKING CITY

THE SPATIAL CITY

Ideology for automated design.

B. THE FLATWRITER

Principle for growth of a city.

C. THE MODULAR CONCEPT

THE GARDEN CITY

In 1898, Sir Ebenezer Howard published a book entitled Garden cities of To-morrow. This led to the emergence of a movement spread throughout the globe namely in the United Kingdom and the United States; the city garden movement.

In his book, Howard described the idea of living in harmony with nature, a method of urban planning in which communities were enveloped by 'green belts'. These communities would consist of a proportionate amount of residences, industries and green spaces where the parks and gardens were meant to be sources of leisure and fields were meant to be sources of production.

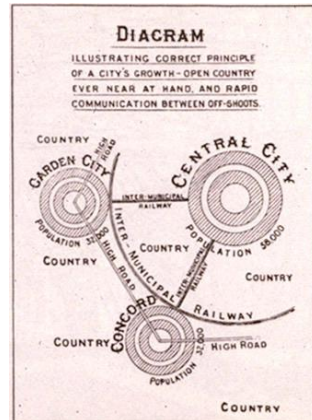


Fig 46 : Principles of city growth.

The idea was to merge the essence of the countryside with that of the city by reconciling the best of the two worlds. In England, the Letchworth Garden City and the Welwyn Garden city were built according to Howard's concepts alongside others later all over the world. (Moreira and Duduch, 2021)

The garden city concept is perhaps one of the most influential urban planning ideas still relevant today as they are founded on a series of principles namely:

- Engagement of community with strong vision and leadership.
- Capturing of land value for the advantage of the community.
- Ownership of land by the community including long term stewardship of assets.
- Affordable housing types for various segments of the population.
- Homes integrated with gardens to promote a healthy community.
- Easy commuting distance with jobs within the Garden city.
- Production of food by the resident.
- Green spaces include parks, community gardens, tree-lined streets, open spaces with a buffer to avoid urban sprawl.
- Accessible and integrated transportation systems
- Amenities such as shopping or recreational facilities. (Planning Tank, 2020)

Fig 47 : The Garden City Concept.

"At the beginning of the twentieth century, two great new inventions took form before our eyes: the aeroplane and the Garden City, both harbingers of a new age: the first gave man wings and the second promised him a better dwelling-place when he came down to earth."

- Lewis Mumford (1946)

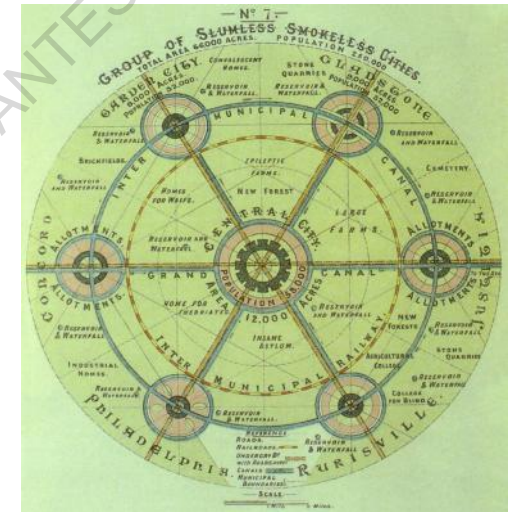
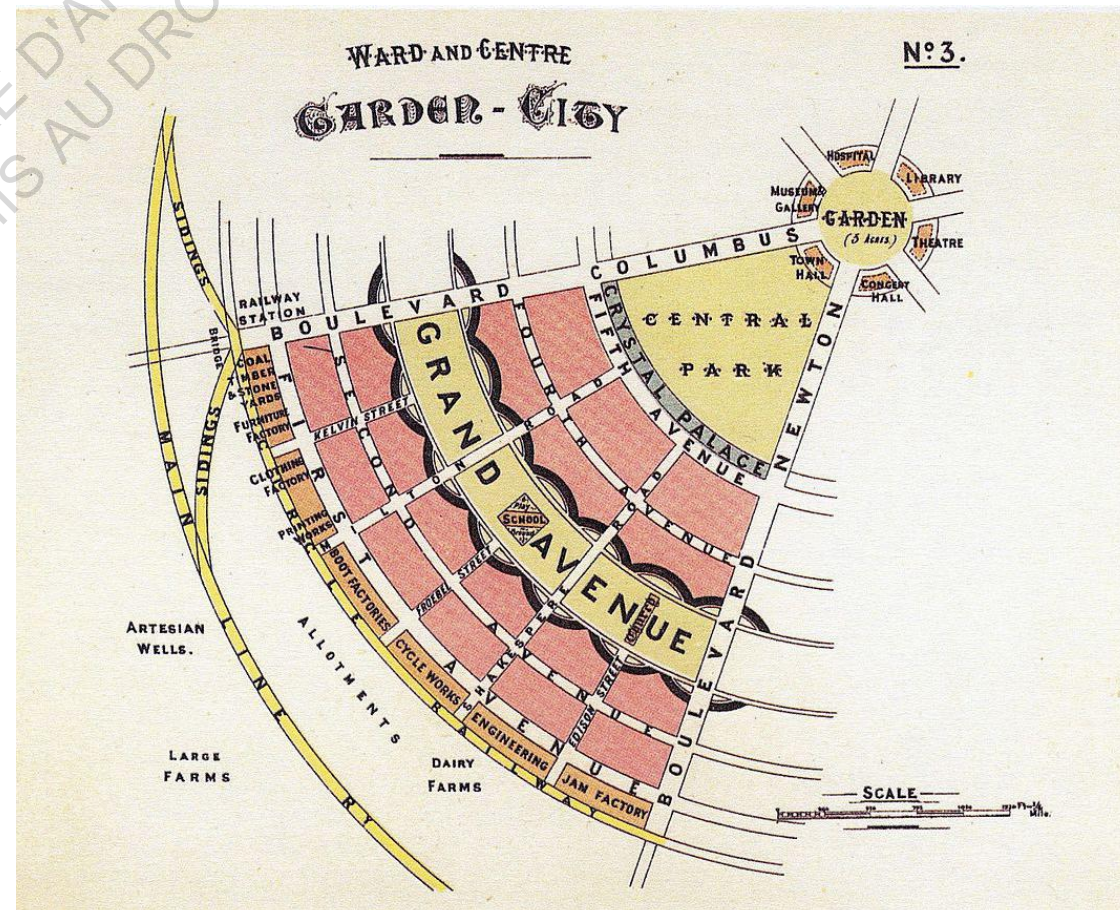


Fig 48 : Garden city intermediate layout.



THE WALKING CITY

Amongst utopian projects of the 1960s, the walking city of Herron by the avant-garde group Archigram offers perhaps one of the most interesting solutions in terms of a hypothetical answer for the sea level rise crisis, an entity capable of answering the inhabitants' immediate needs.

The idea was that of a vehicle, a travelling city that can scour the world at any given time with the use of retractable arms. Multiples of these 'vehicles' could potentially be connected together by those arms and form a metropolis. The units would each possess a comprehensive set of urban resources necessary for forming industrial, residential, commercial and administrative sectors. The arms of the walking city consisted of passageways to other cities, the ground or the sea allowing circulation of people and commodities.

The walking city was meant to be a technologically advanced structure operated by robots. The automation of the city was to be regarded as a living organism that would be independent and parasitic by tapping resources from other stations by exchanging commodities. Cedric Price, an architect who has a similar ideology as the Archigram group perceived the walking city as living creatures roaming and reforming the globe. (MoMA, 2016)

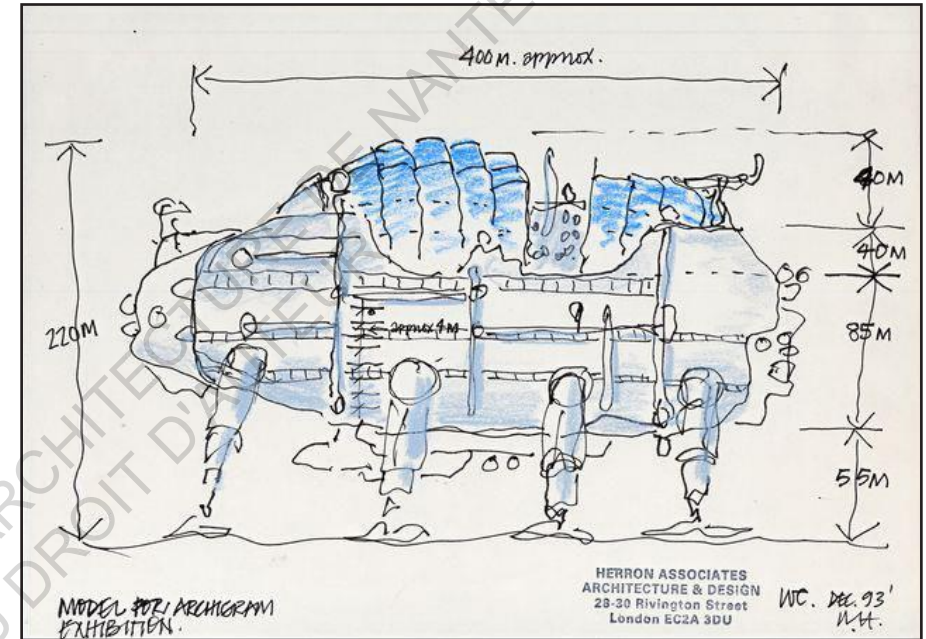


Fig 50 : Conceptual sketch of the walking city by Herron associates.



Fig 49 : Illustration showcasing Ron Herron's 'A Walking City'.



Fig 51 : Creation of a city using modules.

THE SPATIAL CITY

'Ville spatiale' or the spatial city is a theoretical approach developed by architect Yona Friedman in the late 1950s. Friedman believed that planifications of future housing should be in line with each individual resident's choice and a structure should be designed to do so. Intending to preserve the existing city layout and environment, Yona reached for the sky and conceived a second city above. This meant that the existing city would not need to be displaced and allow for the erection of a framework where the people would occupy the voids of the structure. The formats of layouts were integrated in a grid, in both the horizontal and vertical plans, which allowed for voids for light and air circulation for each residence. This format had the aptitude to be designed for any site and climate around the world.

This approach expanded on various principles for mobile architecture where the inhabitants could work and live in dwellings of their own preference. Friedman also breached the approach of the expansion of cities while restraining the use of land. Friedman projected the spatial city concept in real life scenarios suggesting that there was no need to demolish older parts of the existing city to create new buildings. By this approach, the city will be compacted upon the existing one and this will limit the city's outward expansions.

Fig 52 : Perspective section of the Spatial city.

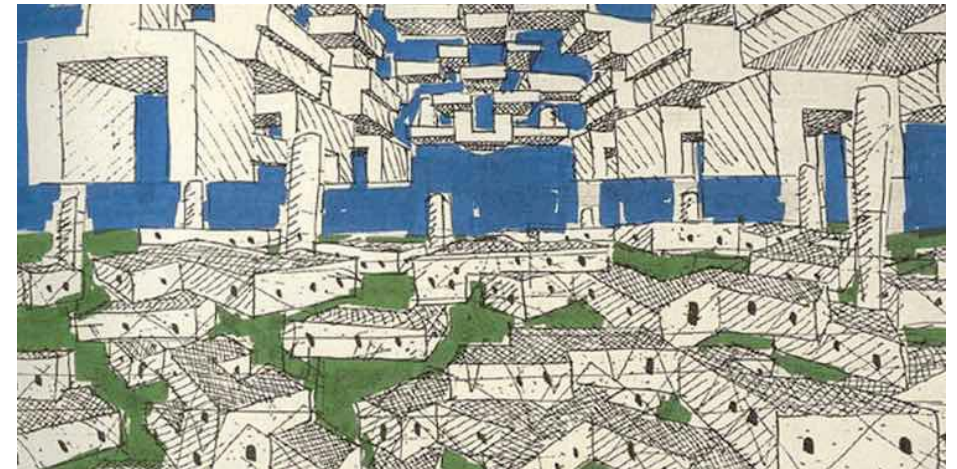
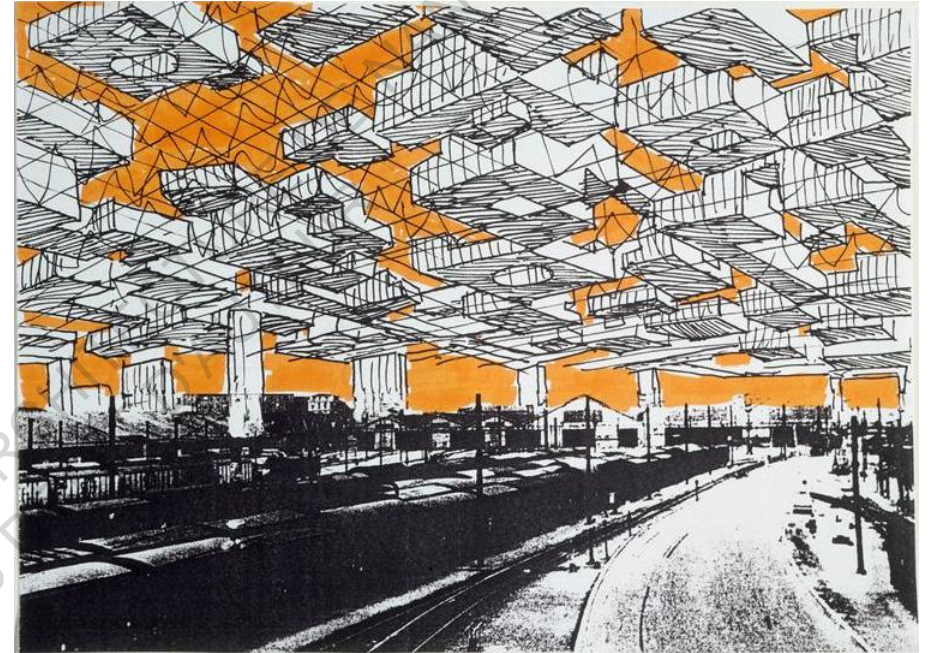
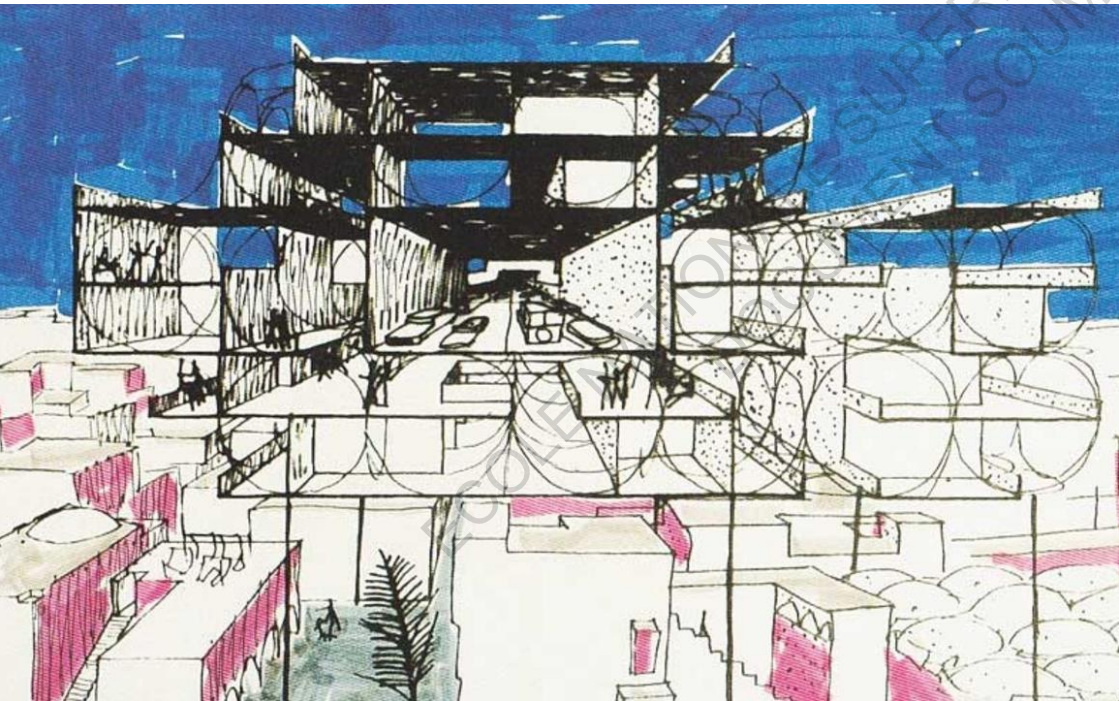


Fig 53 : Concepts of the Spatial city.

THE FLATWRITER

At first, Friedman studied the technical feasibility of the project, then his ideas and projects were the tools to allow people to think outside the box and reach for unconventional approaches that may yield plausible solutions for problems of the modern city. Friedman wanted to communicate his ideology via a model so he designed a program called 'FlatWriter'.

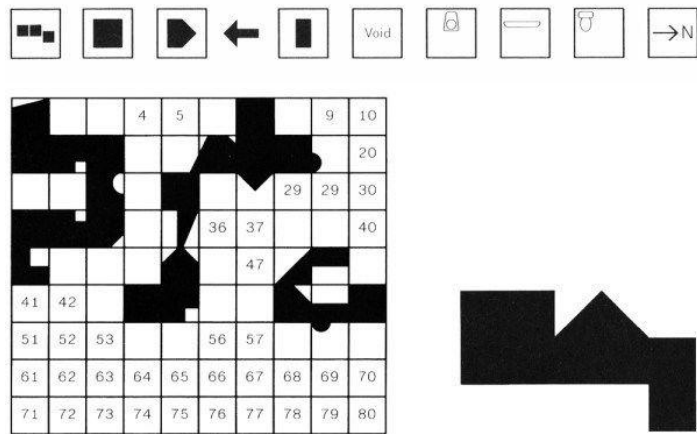


Fig 54 : Principle of layouts using the Flatwriter.

This program allows automation and free design of the dwelling of the inhabitant, facilitating the process of self-planning whereby the user would follow Friedman's manual for the creation and positioning of living spaces. This technique enables constructors to build a home with the use of an architect. Indeed the 'Flatwriter' title should be taken literally as a means to design an apartment. (Friedman-wordpress, 2013)

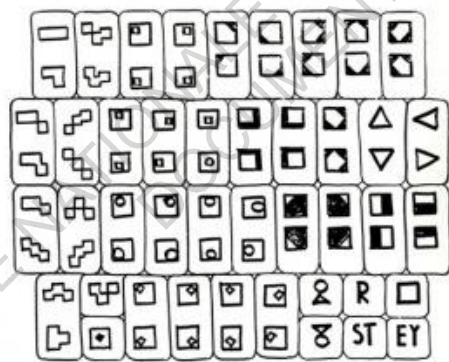


Fig 55 : The keys used in the 'Flatwriter'.

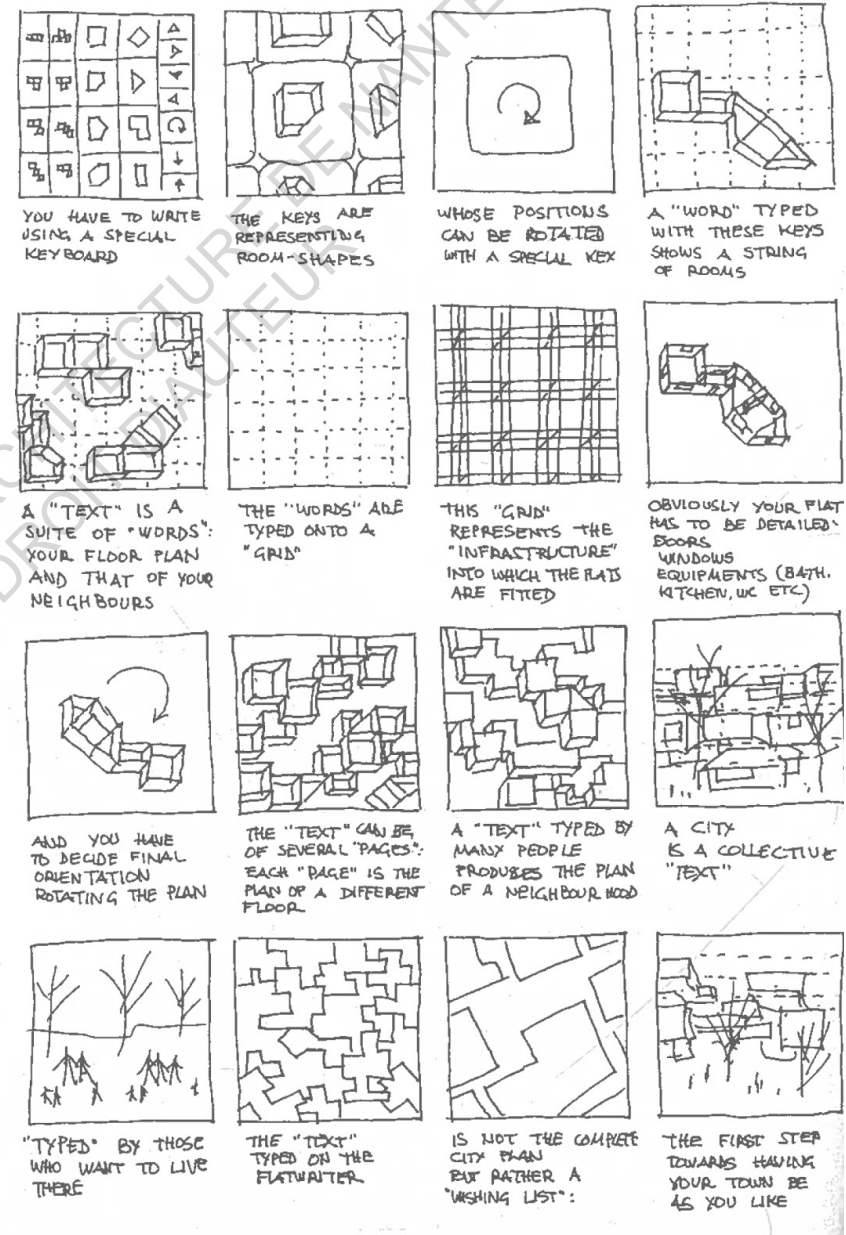


Fig 56 : Key concepts of the Flatwriter.

THE MODULAR CONCEPT

Much like Friedman's spatial city, Big's oceanix project adopts a modular aspect enabling the growth of the floating city over time. Two hectares of modular neighbourhoods are designed to accommodate up to 300 people alongside other amenities to create a self-sufficient autonomous community. Each layer of the module is designed to be efficient; the roof for solar energy capture, the upper layers for living quarters and the lower layers for the structure of the public domain. (Oceanix, 2021)

The concept also follows the expanding characteristic of the garden city; the city is capable of growing. Transforming and adapting organically over time enables the evolution from neighbourhood to village, from village to city and so on. The village is formed by clustering together six neighbourhoods so as to create a sheltered ring for circulation purposes as well as to shelter the amenities inserted into the inner ring. Following the same principles, a community will be formed by connecting six villages together totalling about 10,000 residents. (Oceanix, 2021)



NEIGHBOURHOOD
300 RESIDENTS
2 HECTARES

Fig 57 : Module layout a floating neighbourhood.



Fig 58 : Oceanix growth over the years.

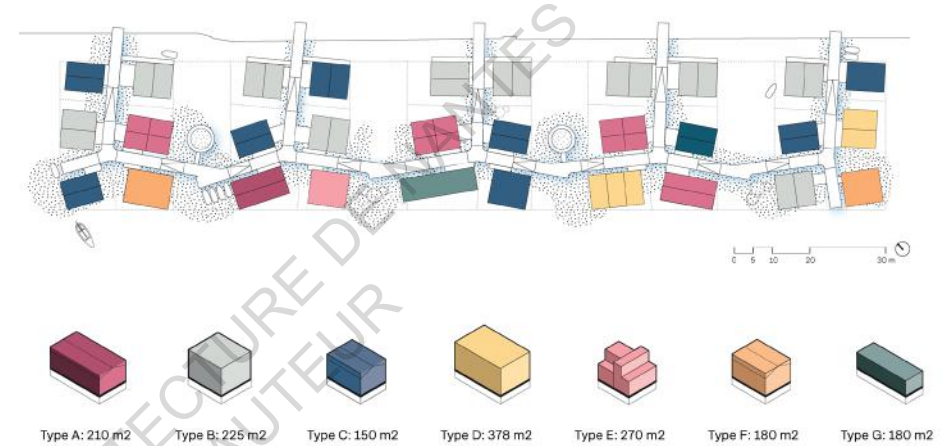


Fig 59 : Iterations of module sizes.

Schoonschip's Project also follows a modular concept which is much closer to Friedman's Spatial city in terms of volume and function. The linear and grid types structures allow for sustainable growth whilst minimising the area used by using home modules. Each module can be tailored to the user's needs.

One of the characteristics of the floating house is that the 'home module' can be mounted elsewhere and be dragged onto the site by tugboats. This method allows for fast planification and a reduction in carbon footprint compared to the typical conventional method of assembly. (Space&matter, 2021)

Fig 60 : Assembly of the modular homes.



CHAPTER 6

KEY PRINCIPLES

Fundamentals for the conception of the project

A. MODULAR CONSTRUCTION &
SOCIAL INTERACTION

ENERGY

FOOD PRODUCTION

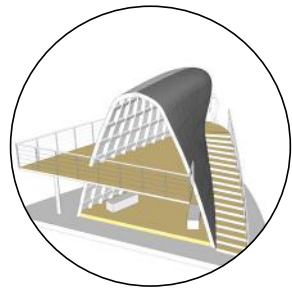
MOBILITY

HABITAT REGENERATION

WATER BASED ACTIVITY



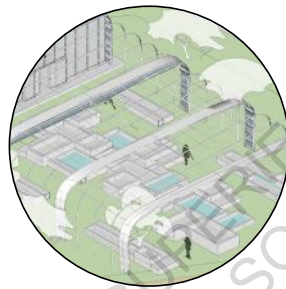
MODULAR CONSTRUCTION & SOCIAL INTERACTION



Ship Recycling



Co-housing



Green area

Fig 61 : General aspects to consider.

Interactions between the masses are crucial for any community. Modular construction allows for the growth of the community and the expansion of the city areas. The connections of the city with the mainland are essential for the exchange of goods and resources.



ENERGY



Renewable energy



Zero Waste System

Fig 62 : Energy aspects to consider.

A clean Energy production program is to be implemented by using solar panels and wind turbines are essential for powering the facilities of the floating city. A net-zero waste policy is also to be adopted so as to reduce the amount of waste produced, recycle and compost as much as possible. This policy aims to create a more resilient and ecological-driven lifestyle aspect for the city's residents.



FOOD PRODUCTION



MOBILITY



Hydroponics



Aquaculture



Desalination



Accessibility



Shared Vehicles

Fig 63 : Production aspects to consider.

Fig 64 : Mobility aspects to consider.

By implementing aquaponics in greenhouses; a combination of hydroponics (cultivating plants with water) and aquaculture (farming of fish, prawns or crayfish in tanks) the floating city is able to tap into the immediate environment for food productions. Desalination plants are also necessary as humans consume about 3.7 litres of water on a daily basis.

Living in the water context will require new methods of travelling which are seafaring by using water taxis or by commuting along floating pontoons.



HABITAT REGENERATION



WATER BASED ACTIVITY



Coral Reef



Mangrove



Sailing



Jet skiing



Flyboard



Scuba Diving

Fig 65 : Marine ecosystems to consider.

Fig 66 : Water related activities to consider.

Using the biorock technology, the foundation of repurposed oil rigs or ship structures can be transformed into habitats for marine creatures. The corals formed will attract fishes and microorganisms to rejuvenate the ecosystem. In certain areas, mangroves will be planted using the Rhizolith island method. The floating substructure will also contribute to the regeneration of the ecosystem.

Indeed, certain activities will be restricted due to a lack of stability of land. Nonetheless, the proximity with water allows the practice of certain activities such as sailing, jet-skiing, flyboarding, scuba diving, and many others.

CHAPTER 7

THE PROJECT

Conception of the project

A. THE PRELIMINARY MODULE DEFINITION

FLOATING MODULE CONCEPT

TYPOLOGY OF MODULES

Development of the project

B. RECYCLING OF SHIPS

RECYCLING OF MARINE STRUCTURES

Project perspective and prospective

C. DETAILED DEVELOPMENT

THE CITY GROWTH

THE PRELIMINARY MODULE DEFINITION

To begin the project, a technical approach is adopted. Modules of various shapes and sizes are built and defined by aspects such as design layouts, mobility of floating platforms, financial aspects and other factors affecting the conception of a floating city.

The modular characteristics of a puzzle allow testing for various patterns and layouts iterations in the water context.

Factors that influence the optimal size of a floating platform

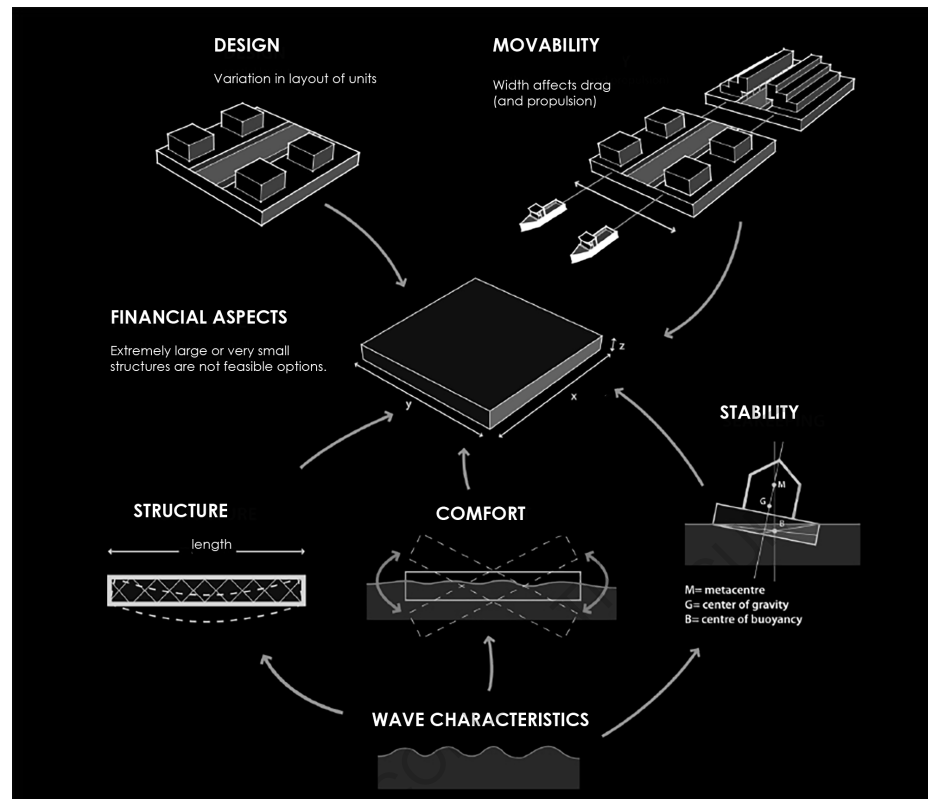


Fig 67 : Seasteading implementation plan.

FLOATING MODULE CONCEPT

I. DEFINITION OF MODULES SHAPE AND SIZES

Based upon research by Karina Czapiewska for the Seasteading implementation plan and upon the feasibility study of the construction of a floating city by Kelvin Ko, hexagonal modules are found to be apt for the shape of the floating platform. Hexagons enable connectivity with other platforms and possess properties that allow for optimal stability on water.

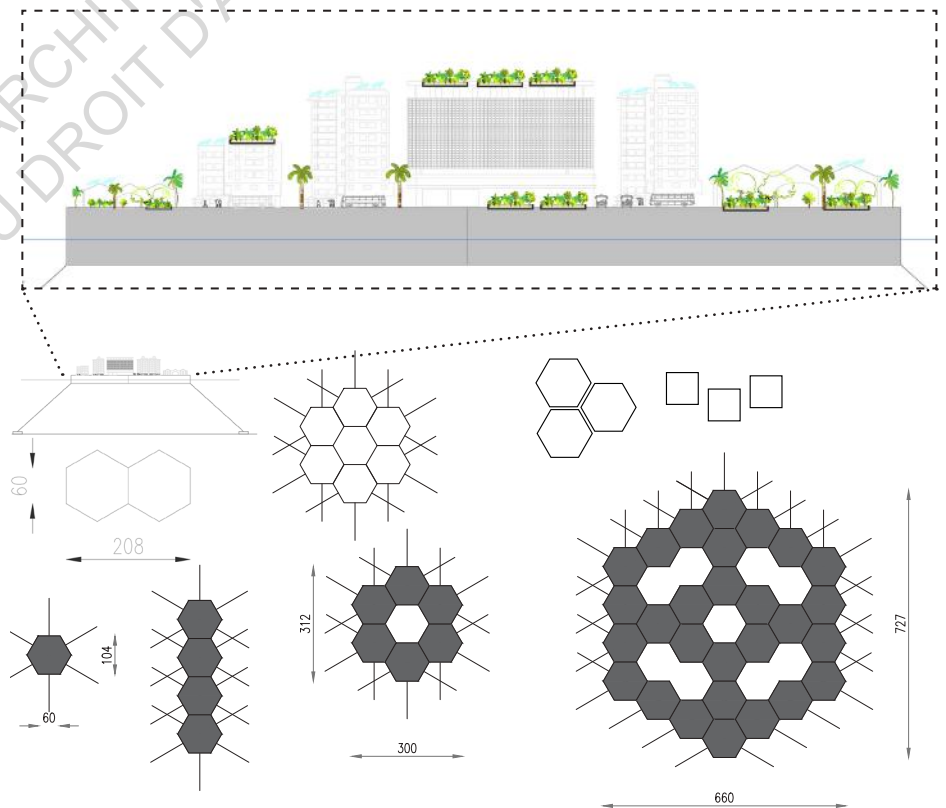


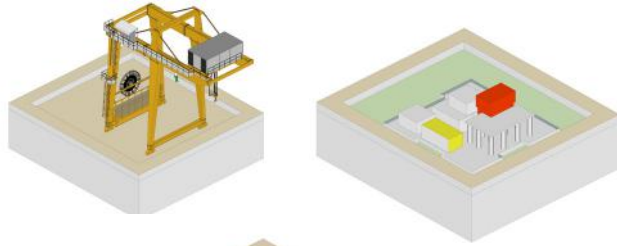
Fig 68 : Mooring arrangement of floating platforms.

TYOLOGY OF MODULES

The modules can be tailored to accommodate any urban infrastructure.

Some examples are shown below:

TECHNICAL AREAS
(DOCKS, PARKS)



FOOD PRODUCTION
(GREENHOUSES)

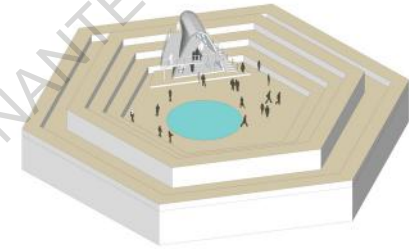


ENERGY PRODUCTION
(GREENHOUSES)

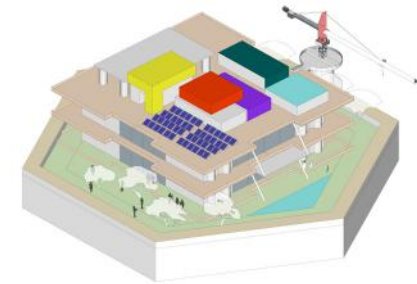


Fig 69 : Module Typologies - Technical infrastructures.

RECREATION
(AMPHITHEATRE)



ADMINISTRATIVE
(OFFICES)



RESIDENTIAL
(APARTMENTS)



MIXED USED
(TOWN CENTER)

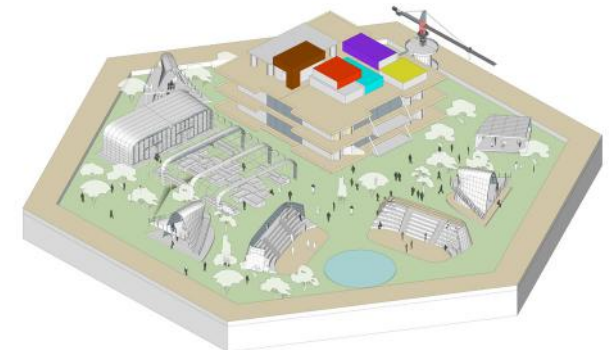


Fig 70 : Module Typologies - Social infrastructures.

RECYCLING OF SHIPS

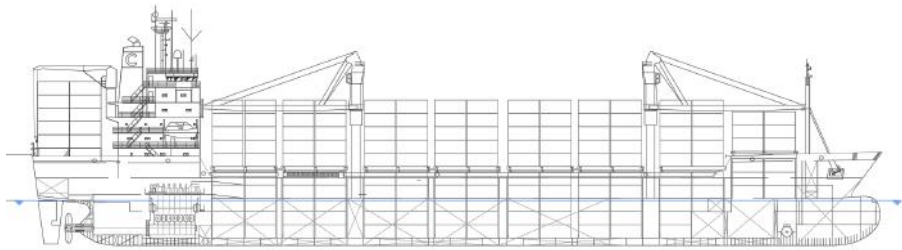


Fig 71 : Section of a decommissioned cargo ship.

II. RECYCLING OF WHOLE SHIPS (150m - 300m)

Decommissioned cargo ships can also be considered as floating units alongside the proposed modules. The ship can be recycled as a whole or in parts. The first factor to consider is the decommissioning of ships, following the removal of diesel and other chemicals, the ship will be remodelled.

The cargo will be replaced with prefabricated platforms which will accommodate living quarters. Certain parts of the ship will be fitted to grow vegetation for food production and solar panels as well as wind turbines will also be included in the design to produce energy.



Fig 72 : Principles of new space use within the ship.

III. RECYCLING OF PARTS OF SHIPS (5m - 30m modules)

In cases where the ships are too big or too old to be recycled, parts of the ship will be repurposed to create new units. These units will be placed onto the floating platforms to create various areas such as recreation zone, commercial zone, administrative zones and mixed-used areas.

The deconstruction of the ships is performed at shipbreaking yards under proper conditions and the selected parts are shipped onto the site and mounted on platforms using cranes. The size of the parts will vary upon the capacity of available cranes.

The proposed units may vary in size and can be utilised for various possible uses such as amphitheatres, commercial centres, schools, greenhouses, workshops, galleries and even repurpose to create small scale residential buildings and offices

Possible Use of recycled ship parts

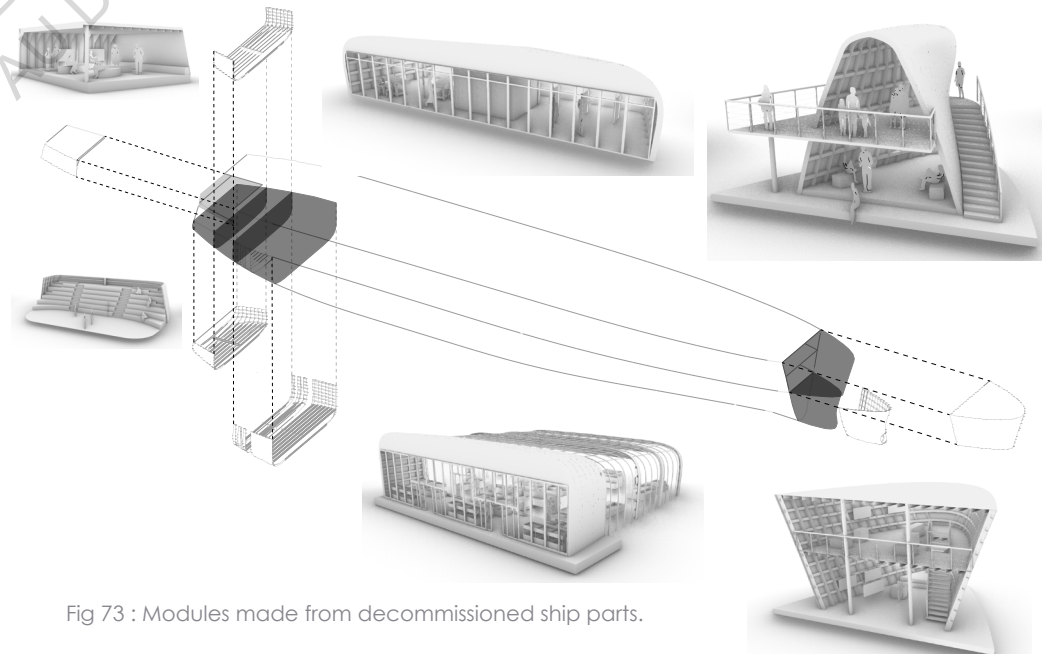


Fig 73 : Modules made from decommissioned ship parts.

RECYCLING OF MARINE STRUCTURES

IV. RECYCLING OF OIL RIG (150m - 300m)

Based on the principles of Antony Lau's offshore project for the estuary of Thames, a similar approach is adopted whereby:

1. Oil rigs are decommissioned and moved onto location.
2. Superstructures are removed.
3. The platforms are restructured to receive housing units.
4. Prefabricated units are mounted on the platforms.
5. The platforms are moored to the site.

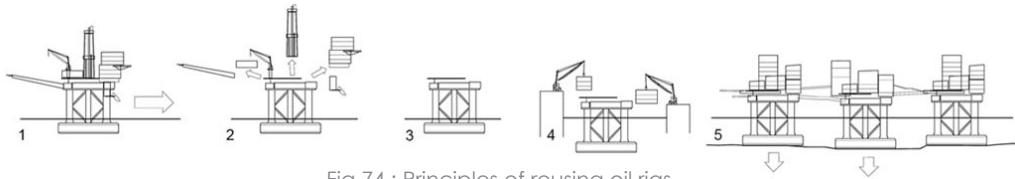
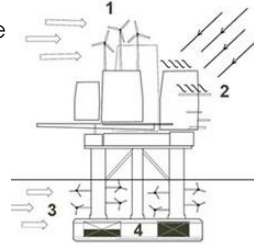


Fig 74 : Principles of reusing oil rigs.

Recycling/Ecology

By reusing marine structures, the carbon footprint is reduced on the amount of concrete produced for building an equivalent city on land. As long as there are ships, boats and floating platforms in production, there will be a constant source of decommissioned marine structure and thus the reuse of those structures benefits in both environmental and economical aspects. (Antony Lau, 2008)

Sustainability and Self Sufficiency

By using renewable sources such as wind, solar and tidal energy, the city will be more eco-friendly. Using fish farms and greenhouses enables the city to produce its own food. A zero-waste system is implemented where composting and wastewater treatment allows for the city's sustainability. (Oceanix, 2021)

Regeneration of coastal Areas

Old docks and wharf facilities are reused for the construction and maintenance of the floating city, This enables new economic opportunities as well as job creation. (Rhizolith, 2016)

Growth of the city

The city is able to expand over time by accommodating more and more modules which enable sustainable growth of both the population and infrastructures. (Oceanix, 2021)



Fig 75: Principles of new space use within the platform.

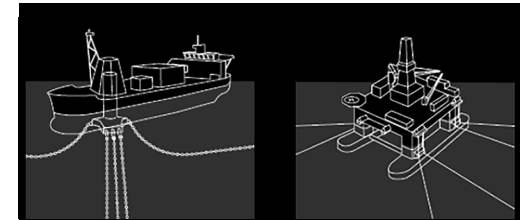
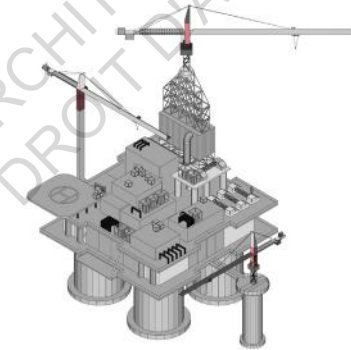


Fig 76 : Dynamic position system and Spread mooring.

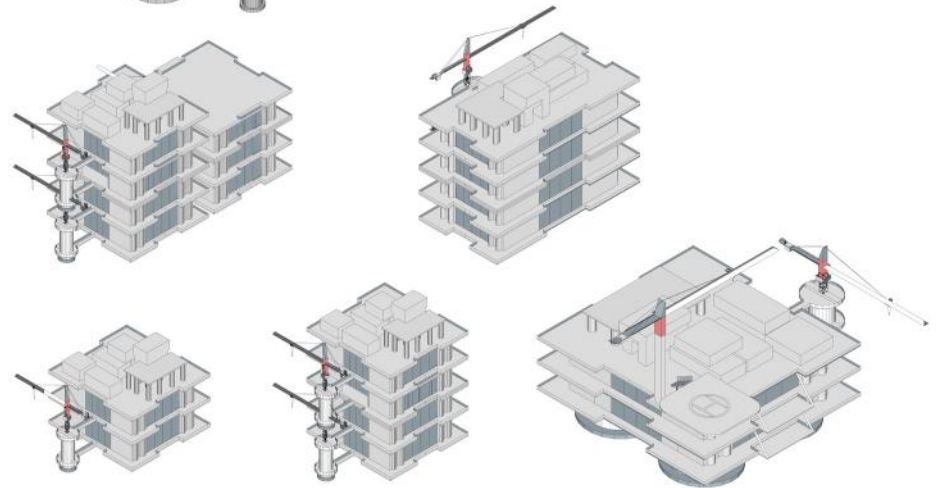


Fig 77 : Possible layouts of infrastructures using oil rigs.

DETAILED DEVELOPMENT

V. CONTEXT AND SITE LOCATION

The chosen site for the project is near Malé, the capital of the Maldives which is one of the countries particularly more vulnerable to the effects of sea level rise in the next few years. This is because more than 80 percent of its 1190 atolls stand less than 1 meter above sea level. The city is one of the most densely populated coastal cities and the project aims to enable decongestion and sustainable growth of the capital.

Area: 5.79 sq km
Population: 105,000
Density: 18,134/ sq km

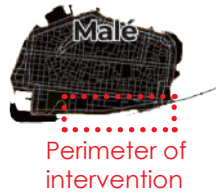


Fig 78 : Chosen site for the proposed project.

VI. PROJECT COMPONENTS

The floating project consists of three main components: Floating modules, platforms and decommissioned ships.

1 - Floating Modules

The floating modules are the core components of the project - They will define the preliminary areas for the layout of the new city. The modules are to be regarded as a blank canvas upon which the construction of residences, offices, markets, shopping centres, greenhouses are to be made possible.

2 - Petroleum Platforms

Decommissioned Petroleum platforms are transported on the site and moored in place. These platforms are transformed into apartments or offices, they will form the new 'skyscrapers' of the floating city. They are connected to the modules by floating pontoons.

3 - Decommissioned Ships

The ships, being autonomous floating units, are tugged onto location and linked to the platforms and modules. The ships can occupy a variety of programs much like those in a cruise ship. The versatility of cargo ships is that they can also be regarded as a blank canvas and thus can occupy novel types of areas such as a floating greenhouse.

4 - Floating pontoons

The final step is to ensure proper communication channels within the floating city but also with the mainland. They are usually in the form of floating pontoons for both pedestrian and vehicular access. Travelling by sea is also made possible by incorporating a water taxi system.

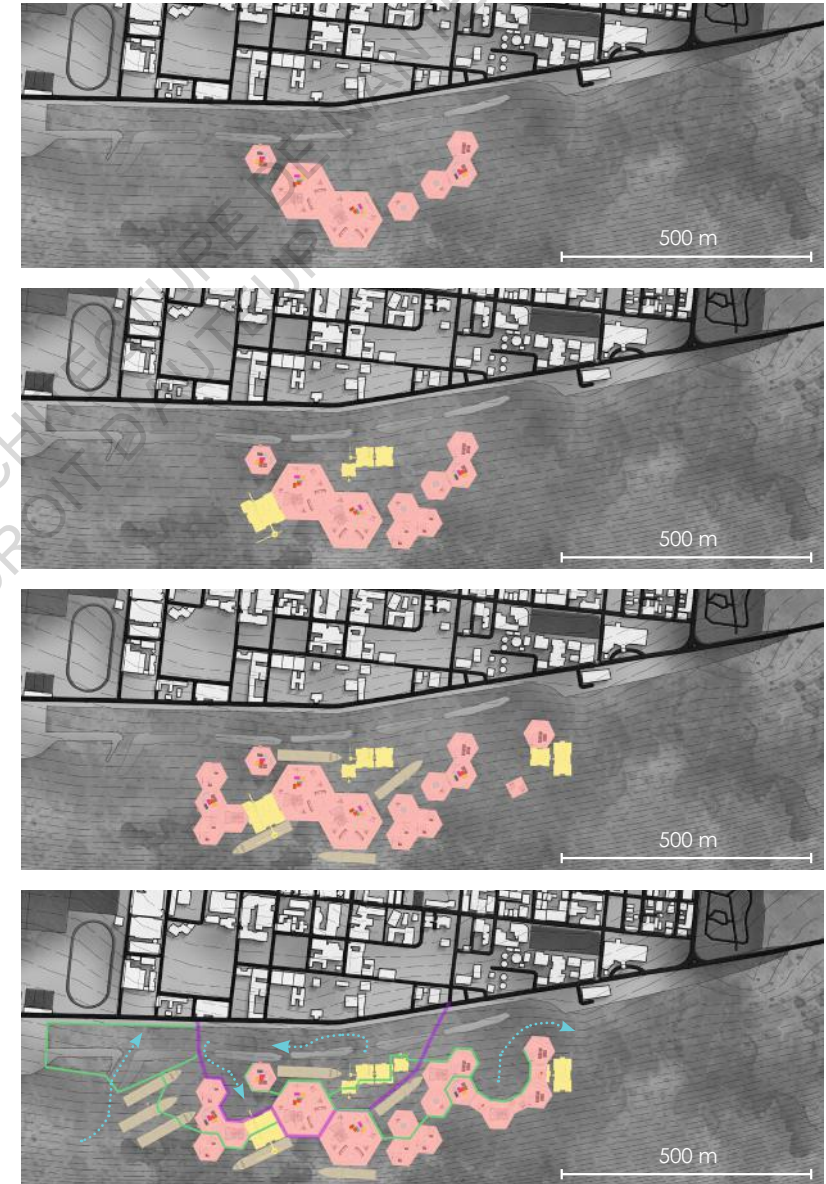


Fig 79 : Concept and development of the floating city.

VII. LAYOUT AND CONSIDERATIONS

The master plan shows one possible layout of the city.

In fact, the modules allow for indefinite iterations of possible layouts of the city. However, specific factors must be taken into consideration when changing the layouts. These are as follows:

Size, Shape and Dimensions

The size of the platform should be sufficient to accommodate a variety of infrastructures within the same clusters. The shape of the hexagon offers stability and optimal occupancy as well as the ability for interconnection.

Platforms distance and Interconnections

Another factor to consider is the layout of the floating structures. They must not be too closely packed so as to allow sunlight to reach the seafloor so as to allow the growth of corals and marine organisms. The use of interconnections such as floating pontoons has minimal impact on the seafloor. Connection with the mainland is necessary to allow trade and exchange of resources.

Mooring System

The vertical distance of the floating city with the seafloor is an important factor to consider as the Bathymetry (Sea contours) will determine the placement of the and length of mooring anchors. The type of seabed will also determine the type of mooring used.

Execution and Construction

The platform size will determine how and where it can be constructed; smaller modules can be constructed off-site whereas larger modules must be constructed as puzzle pieces and then joined together on site.

Reversibility

Cities constantly evolve within decades and as such, it is important to include concepts such as open floor plans which offers a certain margin of reversibility allowing the buildings to adapt to changes as per the need of the population for example transforming an office space into a school.

MASTERPLAN



Fig 80 : Masterplan showing layouts and context .

URBAN SECTION



Fig 81 : Urban section showing the new city profile.

THE CITY GROWTH

The city is designed to accommodate about 8000 residents. The city can receive more residents over time, by either incorporating more floating platforms or decommissioned oil rigs and ships. The modular aspect thus enables the city to grow as per the needs of the population.

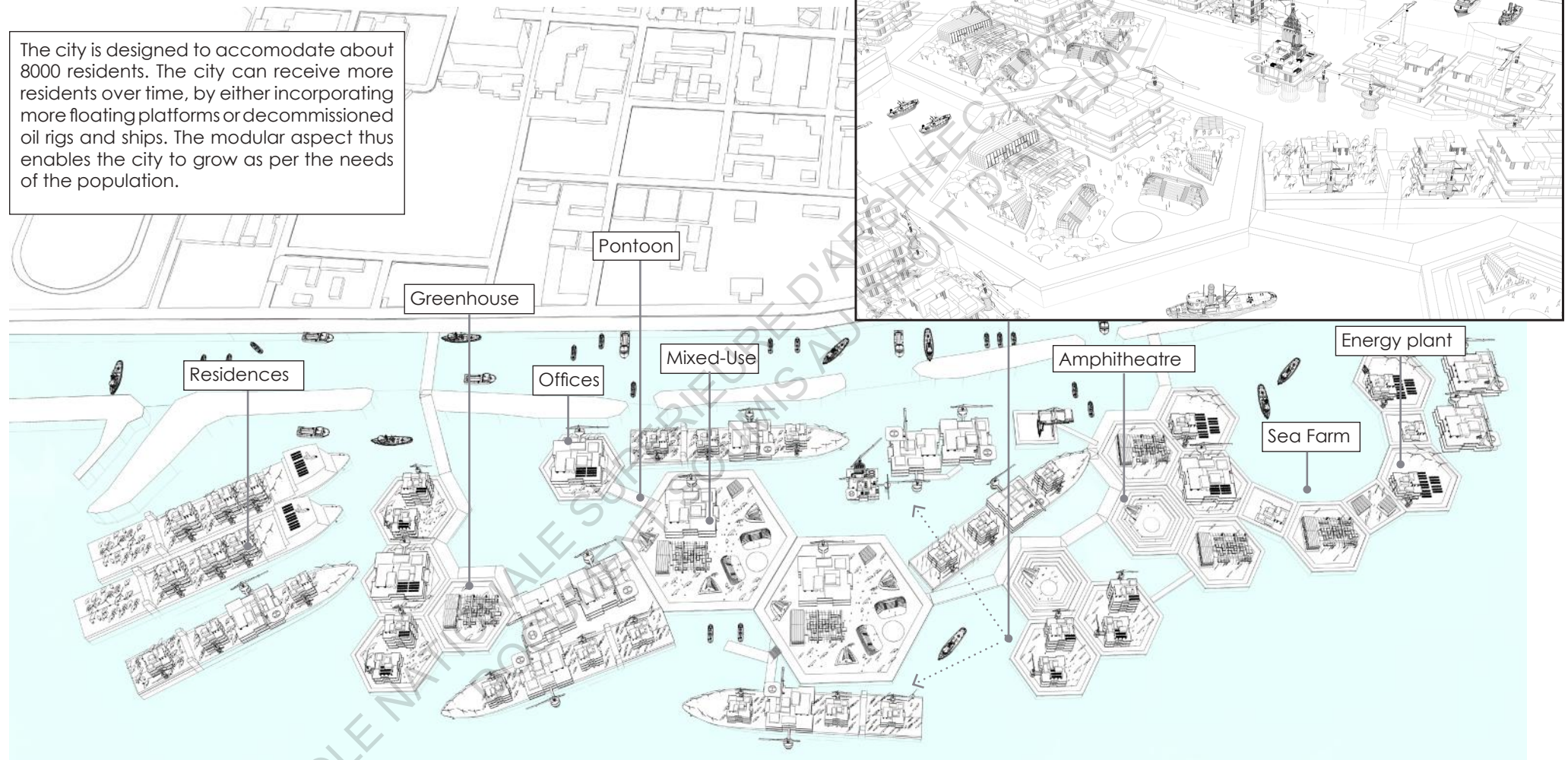


Fig 83 : Bird eye view of the project

Fig 82 : Overview of the project

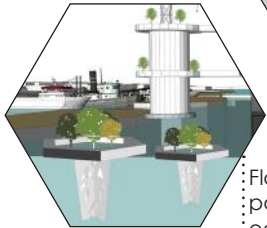
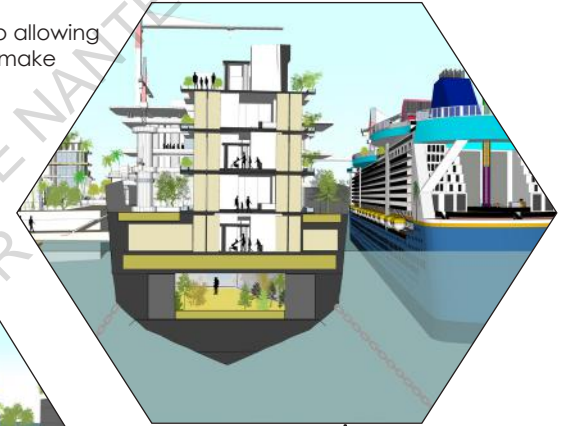
Fig 84 : Aspects of the project

Reused cargo ship harbouring mixed used spaces.



Recreational open space areas on floating platforms promote social interaction.

Interactive hub allowing cruise ships to make stopovers.



Floating mangrove pods for marine ecosystem.



Interconnecting pontoons and water taxis allow travel by sea.





Fig 85 : Scenery of the project

CONCLUSION

Concluding thoughts on the project

A. GENERAL CONCLUSION

GATEWAY FOR IMPROVEMENT

ECOLE NATIONALE SUPERIEURE D'ARCHITECTURE DE NANTES
DOCUMENT SOUMIS AU DROIT D'AUTEUR

GENERAL CONCLUSION

The main aim of the thesis of reusing recycled marine structures, in a modular approach, as a concept for designing future floating cities against the threat of sea level rise has been fulfilled. Each of the objectives which were set has been achieved.

New ships and marine structures cost millions of dollars, a lot of energy and resources to build and operate. Hence, the proposed project aims to bring those marine structures into a circular economy by recycling ships and decommissioned platforms. The project also aims at being a beacon of a new architectural concept that takes into consideration the cultures and traditions of its inhabitants. It further considers the aspects of the spatial city, allowing numerous iterations of layouts as per the need of the inhabitants and the garden city concept that allows expansion and creation of interactive hubs and the walking city promotes the possible change in the layout of the city.

Fig 86 : Postulate if sea level rise attains predicted levels.

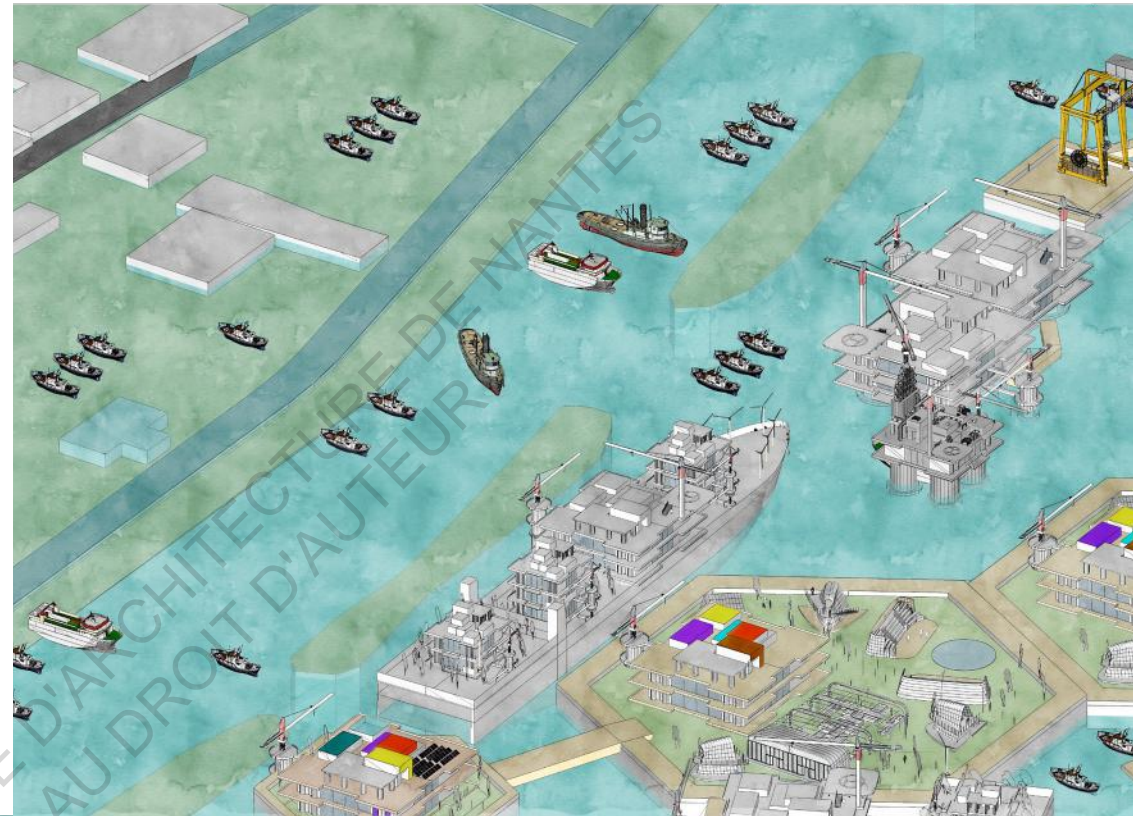
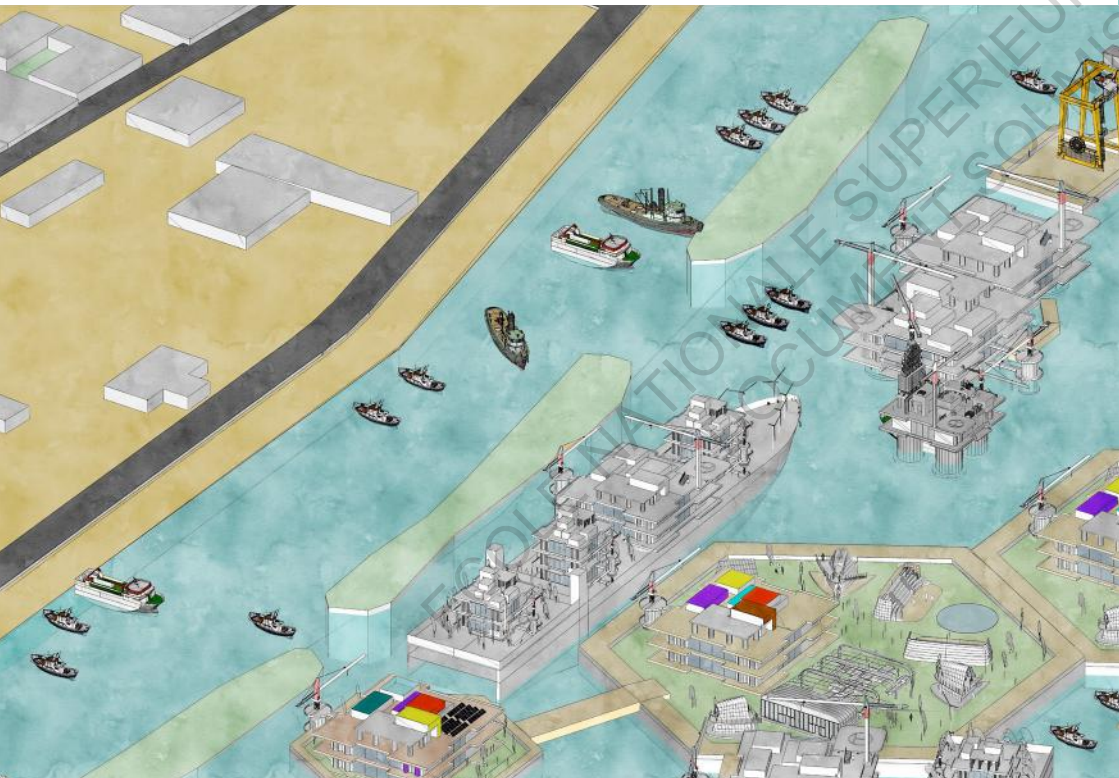


Fig 87 : Postulate if sea level rise exceeds predicted levels.

Our next frontier is building on the water irrespective of whether to expand cities that are experiencing land scarcity and in which there can be no more skyscrapers or to build defensive structures to protect low lying cities and coastal regions against floods or tsunamis.

However, there are still numerous aspects that need to be further developed and tailored to the targeted population. Indeed, floating cities remain concepts on paper even today, as the data which prove the feasibility of such projects on a large scale are yet to be assessed. The Oceanix project, being the most promising project, took years of research and convincing evidence to reach the stage of the world's first prototype.

I would like to add that climate change is a problem that can no longer be stopped. We can only curb its effects by adapting our future needs, greener architectures and un wasteful lifestyles so that our future generation can thrive.

GATEWAY FOR IMPROVEMENT

Further Research and Considerations

Platform's structure, shape, size and materials.

Structural calculations for the platforms need to be further developed as this will suggest the number of resources that need to be recycled and reused in the production and whether the new floating platforms can bear the load of new buildings. Sizes and shapes of the platforms will determine how maintenance works can be done and whether the platforms can be transported off-site or can be easily replaced. The type of materials used in the project needs to be further tested to resist corrosion or decay in the seawater environment.

Execution and Construction.

Aspect such as bathymetry need to be further studied so as to prove the feasibility of the city; whether semi-submersible ships are able to carry oil platforms onto the site or whether more damage is done to the existing coral reef through the process. An off-site production centre, as well as the implementation of new ships yards, is necessary for the maintenance of the floating units of the city.

Ship type.

For this project cargo ships are the chosen type of ships. However, there is the need to have more research done on what type of ships can be used; whether cruise ships or aircraft carriers that possess readymade amenities may also fit the floating city idea.

Interconnections.

Pedestrian and vehicular circulations are key factors for the layout of the city. Further studies need to be made with regard to the cost and type of pathway to be used; whether pontoons is a best-implemented solution for temporary and reversible emplacements or whether dikes are necessary for building permanent infrastructures for constant of vehicles over time as well as for the protection of the new city.

Mooring systems.

As different types of sea beds require different types of anchoring methods, a thorough study and research in this field is essential for designing platforms that ensure stability even amidst violent current surges.

Site location.

The site location of the project is perhaps the most crucial part of the design of the floating city. Numerous research on and breakdown on cost analysis will determine whether the floating city is the solution instead of land reclamation in the long run.

GLOSSARY

Aquaculture: Aquaculture, also known as aquafarming, is the controlled cultivation of aquatic organisms such as fish, crustaceans, molluscs, algae and other organisms of value such as aquatic plants.

Aquaponics: Aquaponics is a food production system that couples aquaculture with hydroponics whereby the nutrient-rich aquaculture water is fed to hydroponically-grown plants, where nitrifying bacteria convert ammonia into nitrates.

Ballast tank: A ballast tank is a compartment within a boat, ship or other floating structure that holds water, which is used as ballast to provide stability for a vessel, to reduce buoyancy, as in a submarine, or to increase draft, as in a semi-submersible vessel or platform to improve seakeeping.

Bathymetry: Bathymetry is the study of underwater depth of ocean floors or lake floors. In other words, bathymetry is the underwater equivalent to hypsometry or topography.

Buoyancy: Buoyancy or upthrust, is an upward force exerted by a fluid that opposes the weight of a partially or fully immersed object. In a column of fluid, pressure increases with depth as a result of the weight of the overlying fluid.

Cabotage: Cabotage is the transport of goods or passengers between two places in the same country by a transport operator from another country. It originally applied to shipping along coastal routes, port to port, but now applies to aviation, railways, and road transport as well.

Cruise Ship: Cruise ships are large passenger ships used mainly for vacationing. Unlike ocean liners, which are used for transport, they typically embark on round-trip voyages to various ports of call, where passengers may go on tours known as "shore excursions".

Hydroponics: Hydroponics is a type of horticulture and a subset of hydroculture that involves growing plants, usually crops, without soil, by using mineral nutrient solutions in an aqueous solvent.

Mooring: A mooring is any permanent structure to which a vessel may be secured. Examples include quays, wharfs, jetties, piers, anchor buoys, and mooring buoys. A ship is secured to a mooring to forestall free movement of the ship on the water.

Seasteading: Seasteading is the concept of creating permanent dwellings at sea, called seasteads, in international waters outside the territory claimed by any government. No one has yet created a structure on the high seas that has been recognized as a sovereign state.

Tugboat: A tugboat or tug is a marine vessel that manoeuvres other vessels by pushing or pulling them, with direct contact or a tow line.

Utopia: A utopia typically describes an imaginary community or society that possesses highly desirable or nearly perfect qualities for its members.

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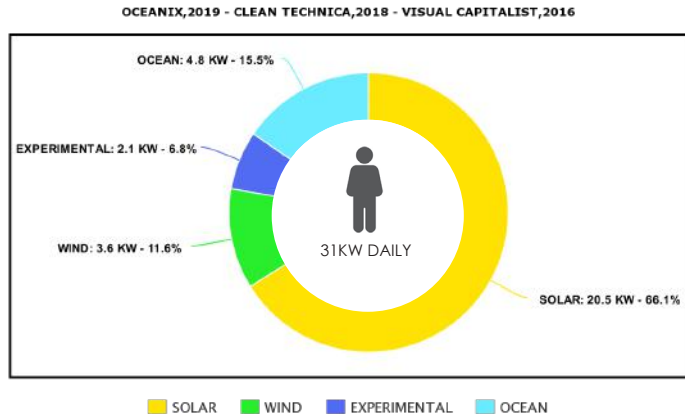
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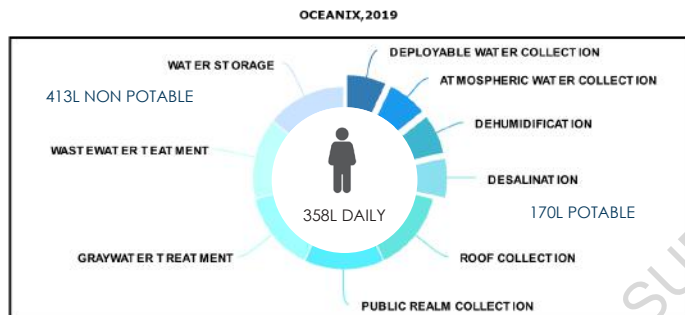
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References for production and consumptions of a floating city

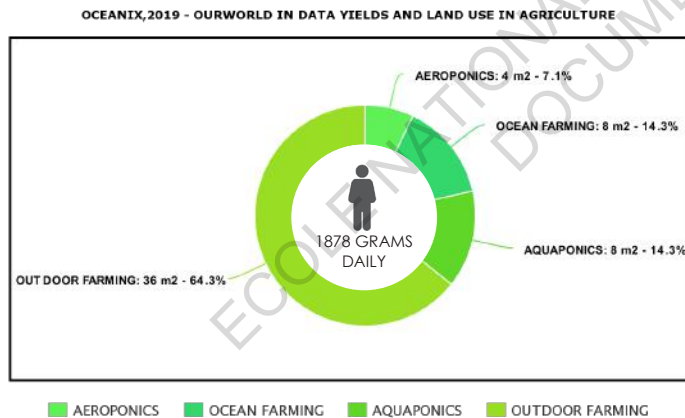
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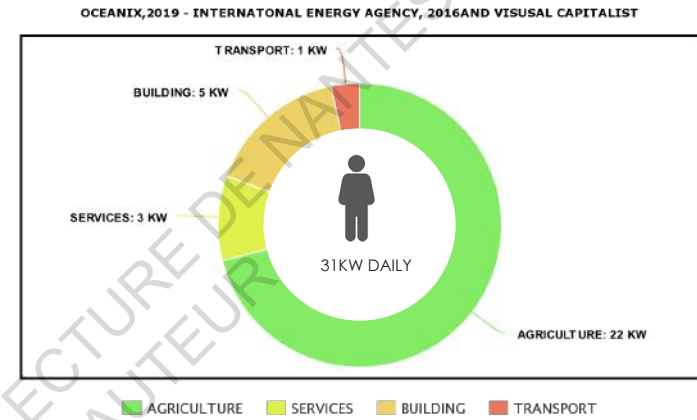
WATER SOURCES



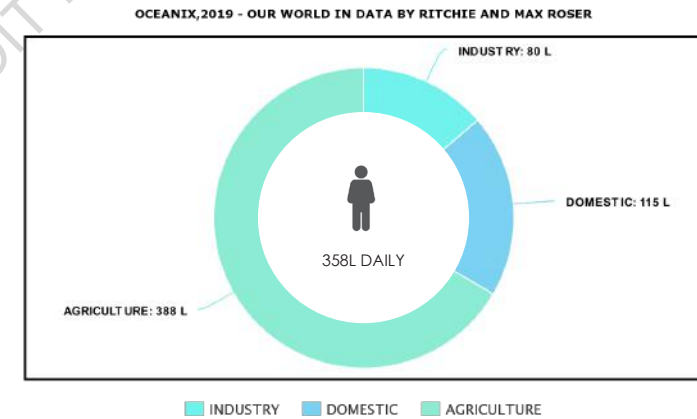
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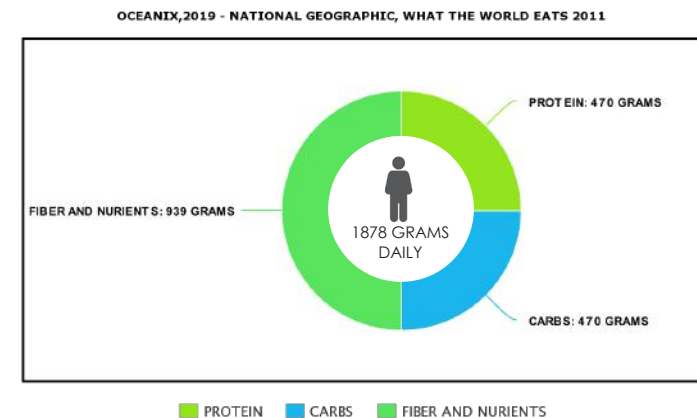
ENERGY CONSUMPTION



WATER CONSUMPTION



FOOD CONSUMPTION



The Floating Piers at Lake Iseo

By Christo and Jeanne-Claude,



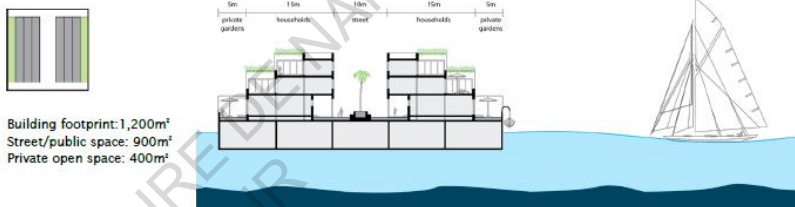

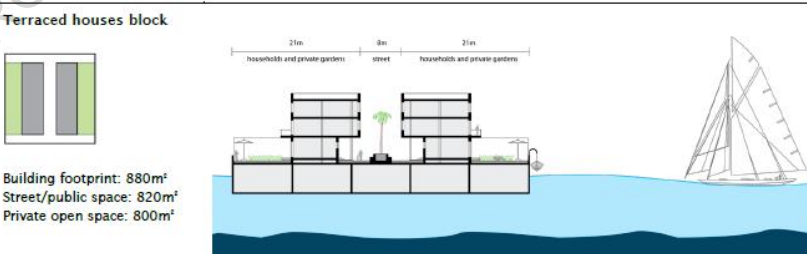
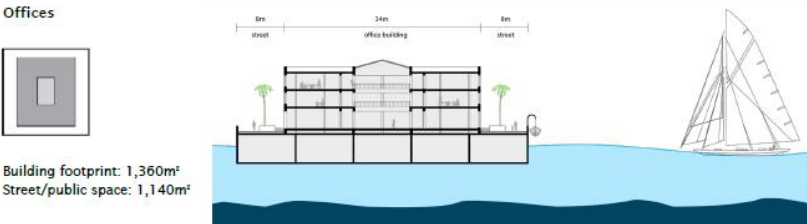
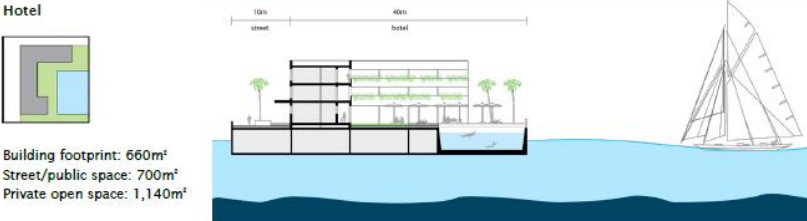
The Floating piers was an art project by artists Christo and Jeanne-Claude. It was a temporary installation of a modular floating platform consisting of 226,000 high-density polyethylene cubes covered with 70,000 square metres of yellow fabric. The project was released in 2016 at Lake Iseo near Brescia in Italy. The installation allow the passage between Sulzano, Monte Isola and the island of Sao Paolo.

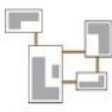



Extract of Seasteading Implementation Plan Final Concept Report

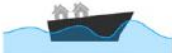
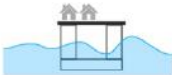


By Ir. Karina Czapiewska & Team

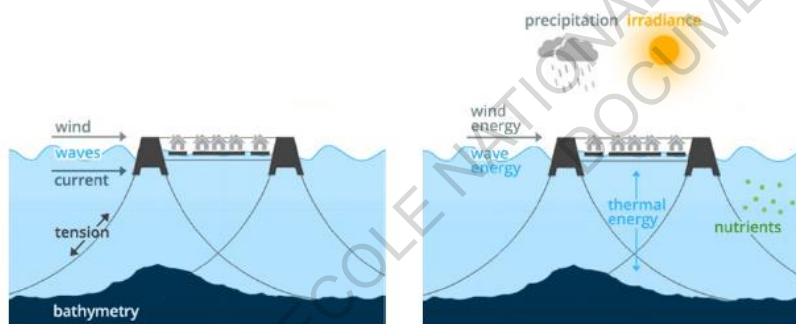
The Seasteading implementation plan is a report made by Karina Czapiewska of Blue21 and her team for the Seasteading Institute. The focus is based upon the feasibility of seasteads which can serve as concept for future seaworthy floating cities. Numerous aspects are covered and this report served as a guideline for the project.

Table 4.2: Overview of possible building typologies that can be constructed on a 50x50m platform.

FUNCTION
<p>Apartments block</p>  <p>Building footprint: 1,200m² Street/public space: 900m² Private open space: 400m²</p>
<p>Villas</p>  <p>Building footprint: 400m² Street/public space: 400m² Private open space: 1,700m²</p>
<p>Terraced houses block</p>  <p>Building footprint: 880m² Street/public space: 820m² Private open space: 800m²</p>
<p>Offices</p>  <p>Building footprint: 1,360m² Street/public space: 1,140m²</p>
<p>Hotel</p>  <p>Building footprint: 660m² Street/public space: 700m² Private open space: 1,140m²</p>

TYPE	DESCRIPTION	PROS	CONS
 <p>ISLANDS</p>	<p>Every building is located on its own platform (or hull). This enables maximum freedom of movement. Structures are connected with hinged joints.</p>	<ul style="list-style-type: none"> - Maximum water experience. 	<ul style="list-style-type: none"> - Less stability. - Needs protection by breakwater, which may obstruct ocean view.
 <p>BRANCH</p>	<p>The floating structures exist from several houses or other buildings. The structures can be connected with hinged or rigid joints.</p>	<ul style="list-style-type: none"> - Very good water experience. - Intermediate stability. 	<ul style="list-style-type: none"> - Needs protection by breakwater, which may obstruct ocean view.
 <p>BAY</p>	<p>Semi-large structures are connected to each other until they form one larger structure. Connections are rigid.</p>	<ul style="list-style-type: none"> - Nice bay-like experience. - Very stable. 	<ul style="list-style-type: none"> - Many different platform types. - Many rigid connections needed.
 <p>PLATFORM</p>	<p>Using a large structure as a (cruise)ship or oil platform as one unit.</p>	<ul style="list-style-type: none"> - Building shapes not limited by platform - Very stable 	<ul style="list-style-type: none"> - Little water experience, except from the edges. - Even the edge has less optimal water experience, because exposed to waves.

TYPE	DESCRIPTION	PROS	CONS
 <p>SHIP</p>	<p>Ships are a proven concept and large vessels are especially suitable for the high seas because of their shape and size. Wave attenuation is integrated into the ship itself. The structures are very responsive to waves and can experience a large amount of swell.</p>	<ul style="list-style-type: none"> - Integrated wave protection. 	<ul style="list-style-type: none"> - Wave attenuation only functions when ship is in motion. - Not optimal shape to create a city with public space, connections etc.
 <p>RAISED PLATFORM</p>	<p>A raised platform like an oilrig or an air container type of structure minimizes the surface that is in contact with the water's surface and thus minimizes the force of the waves.</p>	<ul style="list-style-type: none"> - Integrated breakwater. - Minimum contact with water surface reduces wave impact and wave influence. 	<ul style="list-style-type: none"> - Only suitable for large structures
 <p>BREAKWATER</p>	<p>An external structure is constructed to serve as a breakwater, and behind this the city can take any shape.</p>	<ul style="list-style-type: none"> - Large design freedom. - Breakwater could be integrated with other systems or functions. - Creates calm water behind structure that could be used for aquaculture, recreation etc. 	<ul style="list-style-type: none"> - External structure needs additional mooring solutions. - Is not able to withstand every wave type, which would result in swell behind it under some circumstances.
 <p>SUBMERGED</p>	<p>When the structure is submerged, the impact of waves is minimized. The force of waves decreased exponentially with the depth.</p>	<ul style="list-style-type: none"> - Suitable for almost every location. 	<ul style="list-style-type: none"> - Providing enough daylight would be a challenge. - Inhabitants need oxygen. - No contact with outside climate could also cause mental discomfort.



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2022