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SUSTAINABILITY AND RESILIENCE ASSESSMENT OF A PLANNED FLOATING CITY

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ABSTRACT

Coastal urban spaces are home to a large portion of the global population. In recent times, climate change and the increasing need for new housing due to population growth are profoundly influencing these delicate realities, threatening the lifestyle of millions of people living near the coast. In response to these challenges the whole world is mobilizing with new ideas, investing in new and revolutionary projects, building ingenious infrastructures. The Korean city of Busan, in collaboration with the United Nations, has proposed the world first floating city design scheme, OCEANIX Busan. This adaptive solution to sea level rise envisions to accommodate a community of more than 10,000 residents and visitors, with the capacity to expand and house more than 100,000 people, being at the same time fully sustainable with solar panels, wind turbines, locally sourced recyclable materials and other green solutions, and with all the water used treated and recycled. Although this topic is not entirely new and there exist numerous case studies and research papers about this idea, for some reason a floating city has not yet been successful. Various designs have been presented at different times but, so far, no one has truly succeeded. Besides, it's not an everyday thing to build a floating city. These trailblazing projects face with huge responsibilities and challenges but if they turn out to be feasible and their realization turns out to be possible, floating cities could be really a way to adapt to the effects of sea level rise caused by climate change. This thesis focuses on exploring the challenges that the OCEANIX project would face and proposes, comparing and analyzing, on a theoretical basis, technical and planning elements of the world first floating city design. Through this approach, this work aims to provide enough tools to allow the reader to formulate an opinion about the real sustainability and feasibility of this innovative floating city scheme.

PREFACE

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

This thesis has been undertaken relying in part on the author's personal expertise from his scientific background in Environmental Engineering. Therefore this work will primarily concentrate on the theoretical assessment of the technological feasibility and environmental sustainability of the projects, developed as a resilient response to sea level rise. Factors like political implications, costs and financial models, building codes and detailed technical analysis, which would all require a separate work, will not be taken into account.

1. INTRODUCTION

1.1 Background

According to the American NOAA (National Oceanic and Atmospheric Administration), global average sea level has risen more than 20 centimeters since 1880, reaching a new frightening record in 2021, with almost 10 centimeters above the sea level compared to 1993, showing how the rate of global sea level rise has increased significantly over the years (Climate Change: Global Sea Level, 2022). On top of that, as the global temperature continue to warm, an increase in the sea level is inevitable, threatening the lifestyle of millions of people living near coastlines. To cope with this new challenge the whole world is mobilizing with new ideas, investing in new and revolutionary projects, building ingenious infrastructures.

Shanghai has already encircled 520 kilometers of its shoreline with protective sea walls to keep itself dry in anticipation of a rise in the water level of up to 2 feet (more than 60 centimeters) by 2050 (Shanghai Takes Measures Against Rising Sea Levels, 2015). When hurricane Sandy's surge hit Manhattan in 2012, it left 500,000 homes in the dark (Sandy: New York Devastation Mapped, 2012). As a consequence, in New York a similar project is now being designed: a seven-mile-long flood protection system that features protective walls and berms, recreative community spaces, bicycle paths and more (Ferrell, 2021). But are sea walls a viable solution in the long term? The Center for Climate Integrity has estimated a cost of 400 billion dollar to protect cities from the rising ocean by 2040 (Morrison, 2019). Clearly, an unsustainable cost.

On top of that, increasing coastal land pressure due to population growth is forcing numerous nations to come up with new innovative ideas to deal with the demand for developable land around the coast. The cumulation of these challenges gave birth to the idea of expanding urban access to nearby marine spaces, making the concept of "living on the water" an innovative possibility that is starting to be taken into consideration. In line with these remarks, rather than trying to resist the sea's advancements, some experts, engineers and technologists believe it is time to stop fighting the oceans and begin to work alongside them. "We have to start living with the water as a friend and not always as an enemy," said Koen Olthuis, founder of the Dutch architect firm WaterStudio. They are completely reconsidering how society build cities, designing and building floating platforms for now able to host single villas or offices, but that can be in the future expanded for entire cities which will be designed to adapt to rising and falling water levels (Adnan, 2020). Currently, floating buildings, due to their adaptive nature, are becoming every year more popular and are much more accepted by the general public as a strategy to adapt to sea level rise and flood

events. Surely, they are not the only solution to these problems, but they can be considered as valuable parts of a vaster arsenal of adapting strategies.
The idea to create floating cities is not new and, over the years, numerous designs and plans for floating cities on the sea or inland water have been proposed. In 1895, Jules Verne already wrote about a constructed floating island in his novel l'Ile a Hélice (De Graaf, 2012). In 1960, during a time when many cities in the world were experiencing the height of urban sprawl, the idea of a "floating city" became a crucial point of Kenzō Tange's plan for Tokyo, as a way to accommodate the city's continued expansion and internal regeneration. Although the plan did not become a reality, this was the starting point of a new era of floating cities (Adnan, 2020). More recently, there have been a ton of creative design for floating buildings, most of which could be implemented in future floating cities. However, what is lacking is an urban design philosophy created specifically for floating urban communities, which is preventing from realizing these trailblazing installations (De Graaf, 2012).
"We live in a time when we cannot continue building cities the way New York or Nairobi were built" U.N. Deputy Secretary-General Amina Mohammed said during a meeting at a High-Level Round Table on Sustainable Floating Cities (New York, 3 April 2019). The convention brought together designers, explorers, marine engineers and collaborators of both private and public organizations, foundations and academic institutions in the UN Headquarter to share cutting-edge ideas about sustainable floating cities. "We must build cities knowing that they will be on the front lines of climate related risks, from rising sea levels to storms. Floating cities can be part of our new arsenal of tools" (United Nations, 2019).

1.2 Focus of this work

Many coastal communities around the world already live with the threat from sea level rise and coastal flooding. Along the cost the impacts of climate change can drown neighborhoods, wreak economic havoc and put people's lives at risk. These impacts, together with a concentrated population migration, which is lowering the spatial growth potential, are deeply affecting the world's coastal urban water bodies. In response, several coastal urban communities around the world, like the city of Busan, where sea level is expected to rise by more than 70 centimeters by 2100, are actively promoting the development of marine cities (Yang et al., 2022). This work will be mainly anchored on one of these marine spaces, OCEANIX City, proposed by the United Nations as the world's first sustainable and self-sufficient floating city design scheme. The floating installation, in fact, envisions to supply all the energy with solar panels and wind turbines, using locally sourced recyclable materials, promoting green development, and with all the water used and waste produced treated and recycled. This floating community is set to be built, as its first iteration, along the coast of Busan, a critical port city in South Korea, and it envisions to initially accommodate a community of 12,000 people, with the capacity to expand and house more than 100,000 people (Oceanix.com, 2022). Focusing particularly on the OCEANIX floating city design, but without leaving out other ideas and concepts from case studies of existing floating communities' schemes, the purpose of this thesis is to present an overview of the concept of floating urbanization, valuating, under a critical lens, if it can truly be a valuable resilience tool to cope with climate change. For the first time, in fact, in this trailblazing project, the idea of a floating city is combined with the concept of sustainability and carbon neutrality, in a way that distinguishes it from current pioneering research.

By collecting and reviewing information coming from documents, databases and research papers, comparing and analyzing, on a theoretical basis, both technical, social and planned elements of the world first self-sufficient floating city design, this thesis ultimately aims to provide enough tools to allow the reader to formulate a critical judgment about the real sustainability and feasibility of these innovative floating communities. The project of OCEANIX itself faces with huge responsibilities and challenges but if it turns out to be feasible and its realization turns out to be possible, floating cities could be really a way to adapt to the effects of sea level rise caused by climate change.

1.3 Structure of the thesis

Following these introductory chapters, the first section of the work will give a brief overview of the problems and challenges that marine urban realities are facing, before focusing on the concept of "resilience" and on the various measures coastal communities are adopting to address these issues, aiding in the understanding of how far-reaching and imminent the concept of "living on the water" is. The idea of resilience, central in this work, will be examined further in light of its different components and approaches to the problem of sea level rise. Hence, the fundamental trade-off between adaptation and mitigation measures will be applied when taking into account both regeneration projects and new construction projects. Among these, the OCEANIX City project will receive considerable attention in the following part of the work, where it will be firstly examined in light of the technical and design elements, which contributed to its status as one of the most exciting urban projects to date. After exploring the different technologies and planning components of the project, using a SWOT analysis approach, starting from the single perspective and progressing to the regional one, social considerations will then also be covered. Although the nature which constitutes the foundation of OCEANIX City has the potential to address issues like housing shortages and sea level rise, in fact, it also needs to address social accessibility. Humans are by default social beings who prefer to live together as a community, so the isolation that derives from living in a separated floating installation is discussed to understand if it can be one of the issues preventing this idea from becoming a reality. Ultimately, a critical analysis will be provided to better highlight the differences between the concepts of “new construction” and “regeneration”, two distinct ways to approach resilient urbanization.

2. SEA LEVEL RISING

The average height of the entire ocean surface, known as the global mean sea level, has long been considered a useful indicator for determining what is currently happening to the climate and what may occur in the future (*Understanding Sea Level*, n.d.). Long-term data and scores coming from tide gauges, located all around the world, have been used for more than 100 years as an integrative measure of the state of the climate system. Also, since the early 1990s, more recent measurements have been retrieved from satellites altimeters, which determine the height of the ocean by measuring the return speed and intensity of a radar pulse directed at the water surface. Since long-term changes in the sea level are primarily caused by a combination of melt water from glaciers and ice sheets and thermal expansion of seawater as it warms, these methods can provide measurements that cover both the ocean and cryosphere (ice covered portions of Earth). Sea level rising due to thermal expansion is estimated by scientists using moored and drifting buoys, satellites and water samples collected by ships (using different methodologies if temperatures are measured in the upper half of the ocean or in deeper areas). While to estimate how much of the increase in sea level should be attributed to actual mass transfer (the movement of water from land to ocean) experts rely on both direct measurements (field surveys of melt rates and glaciers elevations) and satellite-based measurements, that are able to capture small changes in Earth's gravitational field when water shifts from land to ocean (*Climate Change: Global Sea Level*, 2022).

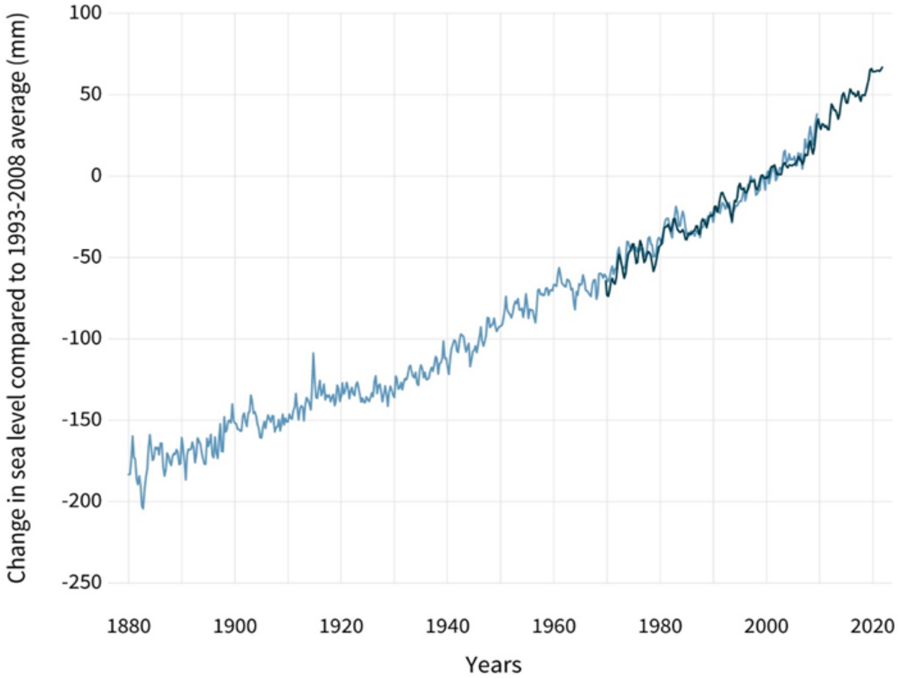

FIGURE 1: Seasonal (3-month) sea level estimates. NOAA Climate.gov image based on analysis from Philip Thompson's sea level data (University of Hawaii Sea Level Center, 2022).

As presented in *Figure 1*, according to the American organization NOAA (National Oceanic and Atmospheric Administration), global mean sea level has increased 8 to 9 inches (20 to 23 centimeters) since 1880, reaching a value of 3.8 inches (about 96 millimeters) above 1993 levels in 2021, making it the highest annual average in satellites records (1993 to present). The results show also how the rate at which sea level is rising is increasing every year at a faster rate, without signs that show a possible reduction in the trend in future years. Data show how from the 1970s up to the last decade or so, melting and thermal expansion were contributing in a similar way to sea level rise, but in recent decades, especially due to the current increase in GHG emissions, the melting of mountains glaciers and ice sheets has accelerated:

- Over the past few decades, the average loss from glaciers, as measured by the reference network of the World Glacier Monitoring Service, has quintupled. Starting from 6.7 inches (about 170 millimeters) of liquid water in the 1980s, it grew reaching 18 inches (about 460 millimeters) in the 1990s, 20 inches (about 500 millimeters) in the 2000s, and 33 inches (about 850 millimeters) in 2010-2018.
- Between 2012 and 2016, the Greenland Ice Sheet lost 247 billion tons of ice mass annually, a seven-fold increase from the 34 billion tons lost annually between 1992 and 2001.
- Between 1992 and 2001, Antarctic ice loss increased by nearly a quadrupling to 199 billion tons per year, from 2012 to 2016.

As a result, the increase of sea level due to ice melting from 2005 to 2013 was nearly two times the amount of sea level rise due to heat expansion (*Climate Change: Global Sea Level*, 2022).
The NOAA's graph shows how, from 2006 to 2015, the average annual rise in sea level was 0.14 inches (or 3.5 millimeters), which was more than two times the average rate of 0.06 inches (about 1.5 millimeters) per year that prevailed for the majority of the twentieth century. By the end of the century, studies estimate that the global mean sea level is likely to rise at least one foot (about 0.3 meters) above 2000 levels by 2100, even if GHG emissions follow a relatively low pathway in coming decades. The sources that state this are numerous and well established in the scientific community. Every four or five years, NOAA leads an interagency task force and performs a study that reviews the latest research on sea level rise, reporting the likely and "unlikely but plausible" scenarios for different GHG emissions and global warming pathways. In the 2022 report, as shown in *Figure 2*, the 0.3 meters scenario seems to be related to the lowest possible greenhouse gas emissions and warming (1.5 degrees C). While on a pathway with very high rates of emissions, that can trigger rapid ice sheet collapse, sea level could be as much as 2 meters higher in 2100 than it was in 2000. It must be noted also that past and future sea level rising are not homogeneous

throughout the entire world and can vary locally. Local or regional sea level rising may be more or less than the global average because affected by located factors like ground settling, tides, upstream flood control, oil and groundwater pumping, subsidence, shoreline erosion, regional ocean currents or whether the land is still rebounding from the compressive weight of Ice Age glaciers. The results could be much more different (*Climate Change: Global Sea Level*, 2022).

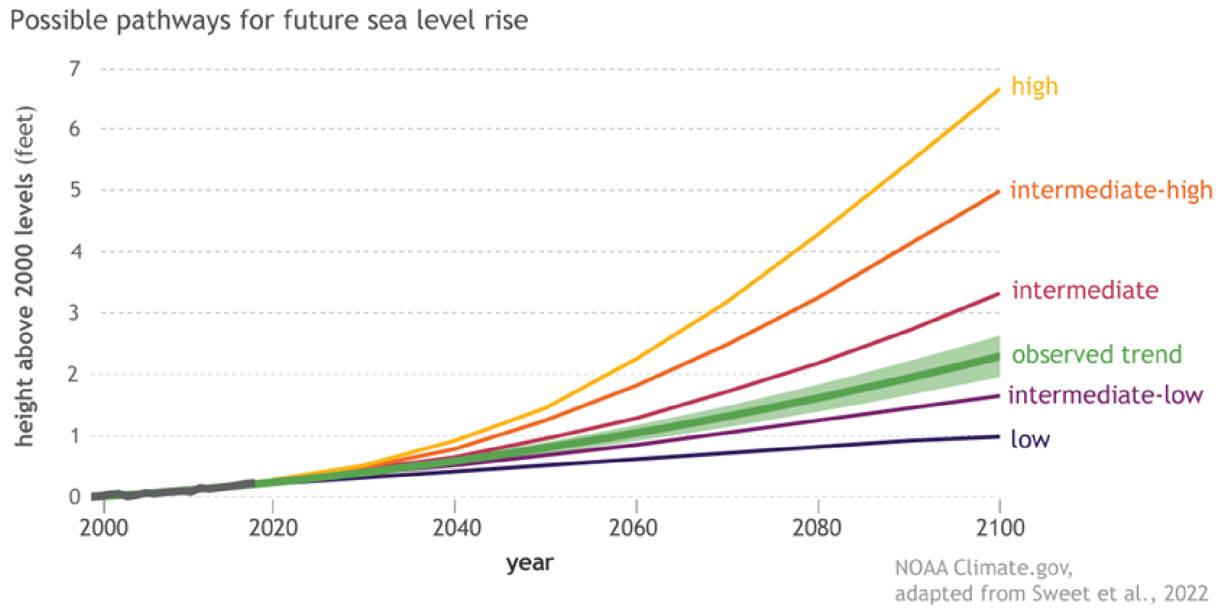

FIGURE 2: Observed sea level from 2000-2018, with future sea level through 2100 for six future pathways (colored lines).

Historically, people have lived in delta and coastal regions for a number of good reasons. In these areas, reliable water sources are more available and waste can be easily disposed in the river, which carries it downstream. The amount of fertile land offers also excellent opportunities for agriculture. The resulting food surplus frees up a sizeable portion of the population to produce other goods and services, making the economy more valuable. Because of the good connections by water transport, these goods can then be transported easily to other cities around the world (De Graaf, 2012). Is therefore not surprising to know that, according to the U.N. Atlas of the Oceans, globally, eight of the world's ten largest cities are located near a coast, where sea level plays also an important role in urban settings considering flooding, shoreline erosion, and hazards from storms (*Climate Change: Global Sea Level*, 2022). However, as cities expand, more and more people are relocating to these coastal and maritime vulnerable areas, leading to the creation of a number of issues. Experts predict that, up until 2100, 5 billion people, more than 150,000 people daily, will relocate to urban areas. In particular, it is estimated that half of the world's population will reside within 100 kilometers of the coast by 2050 (De Graaf, 2012).

Historically, the first communities in these areas were primarily constructed on slightly elevated sites in coastal plains, such as hills, dunes or sand ridges. This not only provided the city with military and strategic advantages but also safeguarded it from frequent flooding. As cities continued to grow, following the mechanization of agriculture and the shift from a rural to an industrial economy, cities were forced to spread out into marshes and places that were lower in elevation than the historic city center. As a result of the increased flood problem, these new urban areas started to build dikes to protect buildings and people (De Graaf, 2012). Higher seas mean not only a direct threat on coastlines and infrastructures of this cities (roads, bridges, subways, water supplies, oil and gas wells, power plants, sewage treatment plants, landfills, …), but also more deadly and destructive storms, pushed further inland than they once did, or more frequent high-tide flooding (high-tide flooding is now 300% to more than 900% more frequent than it was 50 years ago). Sea level rising can be a threat also in the natural world, creating stress on coastal ecosystems that provide recreation, protection from storms and habitat for fish and wildlife, indirectly damaging also valuable fishing industries. As sea level increase, saltwater can also contaminate freshwater aquifers, many of which fundamental for the sustainability of municipal and agricultural water supplies and natural ecosystems (*Climate Change: Global Sea Level*, 2022).

3. RESILIENCE

It is not the objective of this thesis to reiterate the relevance and extent of the various effects deriving from climate change. This remains an acquired fact and a premise of the thesis itself. Nor is it of interest the quantification of the frequency of cities' contributions with respect to the phenomena deriving from the change in the global climate: whether the role of cites is great or not, this thesis starts from the assumption that it is still a duty to act.

If it is true that, globally, cities physically make up only a very small portion of the land, nevertheless, they are certainly more densely inhabited and connected than ever before (*What Is Urban Resilience?*, 2022). According to the UN World Urbanization Prospect of 2018, about half of the world's population lives in cities rather than rural realities, making urban areas the home to the majority of people on the planet. Additionally, urban areas are expected to account for about 70 percent of the global population by 2050, up from 30 percent in 1950 (UNHabitat, n.d.). Cities represent places where the Earth's greatest wealth is concentrated, with high entropy in terms of resource flows (generation and dissipation) and where almost two-thirds of final energy consumption occurs, especially in the civil and transport sectors (Morello et al., 2014). Although this has increased social and economic benefits, it has also increased vulnerabilities. Cities are centers of social and economic activity, where unexpected events can have an impact on thousands or millions of people (Büyüközkan et al., 2022). "Today's new normal requires models of governance that mitigate risk and respond to evolving challenges" states the Network for Resilient Cities. However, experts reveal that actual reactive and siloed decision-making models, valued for traditional development, will not produce the fundamental strength and flexibility needed for society to survive in the face of the acute shocks and chronic stresses of the 21st century (*What Is Urban Resilience?*, 2022). New frameworks are therefore needed for addressing the new challenges that are threatening humanity.

"Humans' survival as a species depends upon adapting ourselves and our […] settlements in new, life-sustaining ways, shaping contexts that acknowledge connections to air, earth, water, life and to each other, and that help us feel and understand these connections, landscapes that are functional, sustainable, meaningful and artful" (Spirn, 1998). This is what ecological urbanism aims to achieve. It combines insights of ecology (the study of how living organisms interact with their environment and the factors that influence both) and other environmental fields, including climatology, hydrology, geography, psychology, history and art, with the theory and practice of city design and planning, as a means of adaptation. This ecological approach to urban design, based on a tradition of basic concepts and values, will be critical in the future for cities and their designs, offering a solution to both acute and chronic issues (Spirn, 2014).

Acute shocks are sudden, severe events which can pose a threat to a community over shorter periods of time, like hurricanes, earthquakes or terrorists attacks. Chronic stresses can often amplify the effects of these intense shocks, weakening a community's foundation over time, with recurrent flooding, insufficient infrastructures, irregular planning, high unemployment, a lack of unequal public transportation systems or social safety nets for example (*What Is Urban Resilience?*, 2022). It is rare that an urban community experiences just one kind of difficulty at once.
The majority of people nowadays live in cities, where urban planning and urban design constitute a strong tool for adaptation (Spirn, 2014). In fact, although no urban area is completely invulnerable from these unforeseen dangers or disaster situations, natural or man-made, cities can even so develop greater resilience to such destructive forces (Holling, 1973). No matter how well one comprehends the past history, ecosystems and the enduring context of a city, no matter how meticulously one attempts to anticipate the future: there will always be unforeseen events to which a city must adapt (Spirn, 2014). At first, the idea of resilience was used to describe how ecological systems managed the risks they faced and the effects that changes had on them (Holling, 1973). In this case, resilience can be defined as the capacity of these system to react to unanticipated risks, changes and events by either mitigating or preventing their effects (Büyüközkan et al., 2022). In addition to ecology and ecological urbanism, this concept has definitions also in a wide range of other fields, making it an extensive research topic in disciplines like supply chain management (Sheffi, 2008), psychology (Powley, 2009) and security management (Hollnagel et al., 2006).
"Urban resilience", instead, is a concept that focuses in particular on the measurable ability of any city's systems to endure, adapt and prosper despite possible future acute shocks and persistent stresses they can encounter, protecting their social structure, economy, technical systems and infrastructures, while positively transforming towards sustainability (Büyüközkan et al., 2022). Therefore, a resilient city is one that evaluates, plans and takes action to be ready and to respond to hazards, whether they are natural or man-made, sudden or recurrent, expected or unexpected (UNHabitat, n.d.). For planners, policy makers, urban transformation specialists and researchers who deal with the management and planning of actions to be taken before and after disasters occur, evaluating urban resilience to cope with disasters and unexpected events has become crucial (Sajjad et al., 2021). A resilient city can thrive despite of rising challenges, improving its overall trajectory and the well-being of its residents by strengthening its underlying structures and developing a deeper understanding of the risks that threaten its stability (*What Is Urban Resilience?*, 2022). Cities have evolved into hubs of caution and concern, particularly in light of the COVID-19 pandemic, which first appeared a few years ago and whose effects are only now

beginning to fade. Therefore, developing resilient cities has become an even more important issue in the context of preventing these disasters (Büyüközkan et al., 2022).

According to experts, urban resilience responds to three major convergent global megatrends: globalization, urbanization and climate change (*What Is Urban Resilience?*, 2022). Urbanization and globalization can both support sustainable growth, raising productivity, if correctly managed to foster innovations and new ideas. However, at the same time, it is estimated by the World Bank that over 4.5 trillion dollars are invested annually in urban infrastructures around the world (urbanization accounts for more than 80 percent of the world's Gross Domestic Product), of which about 9 percent to 27 percent is thought to be needed to make them climate resilient and low emissions. City planners thus must act quickly to prepare cities for urban growth and offer the essential infrastructure, affordable housing and social services their increasing population requires (UNHabitat, n.d.). In fact, resilience is more than just physical robustness, being less effective if restricted to a narrow discipline (Little, 2004). It is about dynamic and complex systems, characterized by multiple pathways of development, interacting periods of gradual and rapid change, feedbacks and non-linear dynamics, thresholds, tipping points and shifts between pathways, with different interactions across temporal and spatial scales. A resilient city must be built with a multidisciplinary approach if society wants to take urban resilience seriously (Godschalk, 2003).

Because cities are where most resources are consumed, they are primarily to blame for the human ecological footprint (De Graaf, 2012). "The pandemic has exposed the cost of urban inequalities, the fragility of human life, and the vulnerabilities that underpin global economies. Meanwhile, the impacts of the climate crisis are accelerating. Melting ice is accelerating sea level rise at a massive scale." These are among the first words the UN Deputy Secretary General said during the Second UN Roundtable on Sustainable Floating Cities (New York, 26 April 2022). She also added: "More than half a billion urban residents already face rising sea levels and more frequent or severe storms. […] Cities are also responsible for over two thirds of all greenhouse gas emissions, and if we do not make them an integral part of climate action, we will be in real trouble". Starting from these remarks it seems reasonable to think the way cities are designed can be considered key to the SDGs and the Paris Agreement on climate change, as said by Secretary-General António Guterres (United Nations, 2022).

The challenges are huge: every year climate change is destroying, directly or indirectly, billions of dollars' worth of infrastructure, forcing millions of people to find a new home. It is at the local level that these detrimental effects are primarily seen (for instance, the local desertification of agricultural areas, the rise in sea levels with consequent flooding and erosion of coastal areas, the drying up of water courses in mountain areas, heat waves with consequent repercussions on the local health system and so on); and it is at this level, specifically, that many of the practical steps are needed to be taken and the resources available to address the issue are needed to be used (for instance, the promotion of low-carbon dioxide emission public transportation, incentives for plants to produce energy from renewable sources, adaptation and mitigation measures, measures to support energy investments in housing, …) (Morello et al., 2014). Nearly all cities are at risk and about 70 percent are already experiencing the effects of climate change, according to the Urban Climate Change Research Network (UNHabitat, n.d.). In particular, it is estimated that coastal cities will be among the first to tackle a wave of climate-related issues by 2050 (Adnan, 2020), like flooding from sea level rise and severe storms, affecting two out of five residents, who will have their home within 100 kilometers of the coast (De Graaf, 2012), as about 90 percent of megacities are located near the shore (UNHabitat, n.d.).

Some have already acted against this, like Shanghai, which is facing a danger of flooding, with annual rainfall twenty percent higher than the global average, and which, as predicted by experts, is going to experience sea level rises of up to 60 centimeters by 2050. To keep itself dry, the Chinese metropolis has taken measures against rising sea levels by surrounding 520 kilometers of its shoreline with protective sea walls, virtually encircling half of the city and reducing the threat of potential flooding to some extent. Apart from safeguarding its coast, Shanghai is equipping itself with alternative methods to protect its rivers, such as a mechanical gate rising and falling once a day to regulate the water level in the river running through the center of the city (*Shanghai Takes Measures Against Rising Sea Levels*, 2015). When Hurricane Sandy's surge hit Manhattan in 2012, it left 500,000 homes in the dark and close to 20 billion dollars in damages (*Sandy: New York Devastation Mapped*, 2012). "The hurricane exacerbated the challenges across the city," said Jainey Bavishi, New York City's Director of Recovery and Resilience and deputy NOAA administrator, "whether it would be inadequate infrastructure, lack of affordable housing or existing environmental hazards" (*Sea Level Rise and Coastal Flooding*, 2018). As a consequence, the city of New York is designing a similar project to Shanghai: a seven-mile-long flood protection system that features protective walls and berms, recreative community spaces, bicycle paths and more (Ferrell, 2021). In this way, the city envisions to create a common space that can both serve as a lively waterfront area for social interactions and a means of protection for its residents. But are these strategies actually a wise decision for developing future resilient cities? Are sea walls a viable solution in the long term? The Center for Climate Integrity (an environmental advocacy group that supports forcing polluters to pay for climate crisis costs) has estimated a cost of 400 billion dollar to protect cities from the rising ocean by 2040 using sea walls only (Morrison, 2019). Clearly, an unsustainable cost.

If it is therefore true that addressing mitigation and adaptation strategies, at an urban level, does not mean solving global climate change, planning can still set itself some specific goals. In particular, the ultimate ambition of urban planning is to assist in enhancing the environmental quality of places and ensure the physio-psychological well-being of the local communities. Making the urban environment comfortable, in fact, means encouraging its use and increasing its appeal, thus, to this end, the urban planner is called to design resilient cities (Morello et al., 2014). Urban resilience necessitates that urban areas look holistically at their risks and capacities, including through valuable engagement with the most vulnerable members of their communities. This is of course a difficult job. Urban governance is frequently siloed, with separate teams developing disaster recovery plans, looking into sustainability issues, focusing on livelihoods and well-being and analyzing infrastructures and land-use planning. However, the needs and requirements of today's interconnected world cannot be satisfied by this compartmentalized strategy. Cities are systems, not silos. People and places make up villages, towns and metropolis, which often experience sudden change (*What Is Urban Resilience?*, 2022). Acting in an urban context means getting involved where the majority of the world's population now lives, thus, influencing people's sociocultural behavior and way of life. Therefore, in order to accomplish the objectives set by environmental policies, it is believed necessary to act on the physical space, bearing in mind that this will directly impact how people will behave (Morello et al., 2014). To correctly plan for a resilient urban future, it is important to approach problems and develop solutions in a site-based, integrated, inclusive, risk-aware and forward-looking way (*What Is Urban Resilience?*, 2022) to, in the end, allow those who live in resilient cities to adopt more sustainable lifestyles from an environmental but also social and economic point of view (Morello et al., 2014). Solutions developed through resilience methodologies will, in fact, allow cities to benefit from resilience dividends, aiding in the prevention and mitigation of shocks and stresses that could negatively affect the city's residents, economy, infrastructure and natural environment (*What Is Urban Resilience?*, 2022).

On the topic of resilient climate change policies, in particular those related to sea level rise, many people define the basic trade-off as that between two categories, mitigation and adaptation measures (Tol, 2007). The majority of cities and nations seem to implement mitigation policies to address the human causes of climate change, for example by reducing greenhouse gas emissions, but have often failed to apply adaptation policies. Experts have stated that, even with vigorous global mitigation efforts, past and current emissions indicate that the climate will continue to change, thus, it is required that adaptation and mitigation are considered as counterparts, rather than alternatives (Jabareen, 2013). In fact, although they are two different ways to face the problem, they both present positive effects that should be valued and recognized, also considering possible synergistic effects that could arise combining both the categories (Wong, 2015).

Mitigating a problem means to reduce its effects where they are more severe and finding temporary solutions when better options are not feasible. A mitigative practice that is commonly performed to cope with the sea level rise is, precisely, the building of sea walls or barriers, near the coastline or along riverbanks, as advocated by the protective measures applied by metropolis like Shanghai and New York. They are generally chosen due to the relative low cost in the short run and for their possibility to be designed to accommodate future increases in the water level (Wong, 2015). However, considering climate change, due to the scale of the problem, mitigation could not be enough, especially in the long run, being able to reduce impacts only to a limited extend. The risk is that without adaptation, the impact of sea level rise would be substantial, almost wiping out entire countries by 2100 (Tol, 2007).

In Jakarta, where close to 90 percent of the metropolitan region already lies below sea level, climate change, along with urban development patterns and the geographic condition of being a low-lying delta city, reinforce each other in a troublesome spiral. Not forgetting that the Indonesian capital is also experiencing one of the fastest land subsidence rate in the world. The result is inundated homes and a paralyzed metropolitan infrastructure, along with increased health hazards due to the spread of garbage-laden and highly polluted water. As a result, Jakarta has sketched on metropolitan responses as well as neighborhood measures and, with the help of the Dutch government, has developed a city-wide climate adaptation strategy that includes a Sea Defense Wall Master Plan (*Sea Level Rise and Coastal Flooding*, 2018).

Facing problems with adaptation solutions means to adapt to the changing climate instead of fighting it, adjusting to actual or expected scenarios, and learning to live alongside the whole problem. In this sense, by working on reducing the negative effects produced by climate change, adaptation strategies are directly linked to territorial planning and governance (Morello et al., 2014). When it comes to resilience against external threats, cities must be organized to possess the capacity for improvement. By repeatedly being exposed to an existing shock, adaptation projects (characterized often by a complex structure) aim to develop the capacity to valuate in advance and prepare for a similar future shock and adverse effects (Kim & Lim, 2016). Only anticipating what is expected to happen, the damage could be prevented or minimized, sometimes even taking advantage of the opportunities that may arise.

The choice of choosing one option over the other is an argument often overlooked by many experts, and often a reason for debate. Some believe that mitigating at higher extends, climate change and its impacts would be lower, and the adaptation required would be less, however other consider that by mitigating more, less resources would have been left for adaptation and climate change impacts could be higher (Tol, 2007). This is not easy work. But it is undeniable to say that mitigation alternatives definitely help in reducing potential negative impacts when they are more severe, containing the problem, although they generally represent only a temporary solution, especially considering longer future prospectives. In the short run, mitigation approaches surely are a good option and represent valid allies to face sea level rising and other climate change effects, however, they should be considered as a provisionary measure until a better and definitive solution is taken. It is worth to say also that adopting these installations (flood walls, barriers, wet gardens, …) is often a matter of economic, social and organizational limitations. For some governments and administrations, it can be more profitable to soften the problem solving it momentarily, rather than fixing it completely.

For instance, as a response to its climate-related issues, Jakarta's city officials have additionally launched the Socially Inclusive Climate Adaptation for Urban Resilience Project, a five-year effort project, that costs 1.3 billion dollars and aims to relocate close to 400,000 people from riverbanks and reservoirs through a participatory process. "We have short term plans on building a sea wall. For the long run, there are plans to relocate residents at risk" said Aisa Tobing, Senior Adviser in the Jakarta Research Council (*Sea Level Rise and Coastal Flooding*, 2018).

In general adaptation and mitigation consider different time scales, different costs and often different sectors of application, making a direct comparison between the two measures hard and, in most cases, without a clear meaning (Tol, 2007). Climate change adaptation and mitigation are related challenges. Both require a local approach, the involvement of decision makers and stakeholders, as well as adequate tools, data, science, knowledge, communication and policy support (Morello et al., 2014). For these reasons, they shouldn't be considered as just two separate alternative options for climate change and sea level rising. If people mitigate more, less adaptation is needed, but at the same time less adaptation is possible or desirable. Adaptation and mitigation strategies should therefore be studied and recognized together (Tol, 2007).

3.1 Regeneration to face sea level rise

Cities and urban systems are the areas most responsible for climate change, but they are also the areas where its effects are felt the most (Mariano & Marino, 2022). Waterfronts of most cities located alongside coasts or riverfronts are especially experiencing this wave of change. Moreover, the increasing urbanization in flood-prone areas, in particular, has led to a large increase in invested capital and population, raising, as a consequence, flood risk. A flood that these day would cause a huge damage and loss of life, in fact, would have caused much lower damages 100 years ago (De Graaf, 2012). These issues, along with the need for new infrastructures, tightening mobility regulations and the necessity to make cities more sustainable, especially in peri-urban areas, have highlighted the requirement for a new way to consider and conceptualize urban spaces.

Urban communities have recently attempted to respond to all these requests following the idea of "urban regeneration", as opposed to the development of new urban areas. But what does this concept mean? All initiatives whose goal is to recover and redevelop any existing urban space in cities, while also promoting social inclusivity, sustainability, energy and financial efficiency, fall under this concept. These initiatives are translated into investments and projects that aim to recover underutilized assets, transform obsolete infrastructures and redistribute opportunities, in order to increase the prosperity and quality of life in urban areas. In practical terms, the regeneration process takes place through recovery interventions at the level of infrastructures and services, limiting the consumption of the territory to protect environmental sustainability.

But in the context of climate change adaptation, how can traditional cities urbanize so that the risk of flooding in the surrounding areas is not increased? One technical solution could be the use of flood proof urban development (De Graaf, 2012). Through multiple technical measures like the creation of flood proof buildings, temporary and permanent barriers and even floating structures, both environmental and physical aspects of a city can be improved. Both ordinary buildings and critical infrastructure need to be secured, to ensure the operation of entire urban areas during a flood. Electricity networks, water supply, healthcare, communication and transportation are all vital infrastructures that must continue to function for a city to work properly. Hotspot structures within these networks, in fact, contain power plants, transit systems hubs, water and wastewater treatment facilities, fire stations and hospitals, which are all essential hotspot infrastructures that must be present and operative in order to keep daily life as normal as possible during floods, as well as for quick and efficient recovery following climate-related disasters. The degree to which both high value assets and crucial urban infrastructure are impacted, either directly or indirectly, can determine the degree of flood vulnerability (De Graaf, 2012). As a result to these technical measures, outdated, blighted and dangerous areas of a community can be transformed into attractive, safe, sustainable and climate-adaptive neighborhoods. In other words, urban regeneration is a comprehensive strategy that combines vision and action, aiming to address the multi-faceted issues which deprived and outdated urban areas face in order to raise their standard of living.

By erecting temporary or permanent barriers, buildings, infrastructures and service systems can be shielded from flooding during extreme events. When a flood is expected, temporary barriers are put in place, while dikes or flood walls are permanently built to protect flood-prone areas (De Graaf, 2012). This is one of the most straightforward and effective way to protect against rising sea levels. Flood walls, and especially dikes, levees and embankments, were also historically constructed to reclaim land from the sea, shielding entire areas that would ordinarily be submerged most of the time; the Netherlands and the Rhine delta are among the most notable examples. In fact, despite having the lowest lying delta in the world, the Netherlands has not experienced serious flooding since 1953 and, thanks to the same Dutch dikes, flooding has not claimed a single life in the country for more than sixty years. This approach is also still widely used in other parts of the world, for instance as a cheaper and more sustainable option for large dams close to cities in Belgium, or as a means of protection from the incessant rains brought on by typhoon seasons in Japan and China. Additionally, in the US, similar systems were constructed after the aftermath of catastrophic hurricanes, like after Katrina, in New Orleans. In the city, in fact, a new network of embankments, floodwalls and pumps was built to prevent the low-lying parts of the city from being swamped. The same is happening, as previously mentioned, as a response to the hurricane Sandy in New York.

This last protective system, in particular, is planned to be located in Hunds Point, Bronx, and it is currently under construction. Although this area was largely spared by Hurricane Sandy, flooding is still a risk. Rising sea levels and climate change increase the threats to locals, who already face difficulties from poverty, isolation and environmental degradation. Thus, the project, one of the winning entries of the "Rebuild by Design" competition, held in 2014, following the events of the hurricane, envisions to construct a bicycle-pedestrian road infrastructure, elevated above sea level, designed taking into account an integrated, defensive and adaptive approach. Its main objective will be, in fact, to safeguard the urban settlement, infrastructures and coastal vehicular mobility from sea level rise while also ensuring green coastal mobility (Mariano & Marino, 2022).

However, the metropolitan area of New York is not the only area affected by the effects of climate change in the East Coast. With 2.5 million residents of New York and New Jersey residing within a designated flood zone, in fact, the entire Tri-State Region in the East side of the US is another region susceptible to flooding, with a situation expected to get even worse with rising sea levels. To solve these problems a cross-disciplined team suggested stopping future construction on flood plains in favor of focusing on new housing in Brooklyn, Queens, Long Island and New Jersey neighborhoods along "corridors" and transit spines inland on higher ground. While this development on high, dry ground would be densified, existing homes in wet areas would develop into a new elevated communities, built along docks (Knight, 2017).

Other methods to protect existing communities from flooding may involve the use of dry proofing constructions (also called dry flood proofing) or wet proofing constructions (also called wet flood proofing), for example by renovating or retrofitting buildings in flood-prone urban areas. In dry flood techniques water is prevented to enter the buildings with flood shields, panels or flood resistant doors, while wet flood techniques allow temporary floodings of the lower parts of buildings, thanks to specific designs and the use of particular building methods. In both cases, to prevent damages, the buildings are made waterproof by treating the facades with coating or applying water resistant building materials with low permeability. Alternatively, materials that can be easily repaired or replaced are also used (De Graaf, 2012). Houses designed to withstand flooding are present all around the globe, either as brand-new constructions or as a result of retrofitting flood-prone buildings (Williams, 2016). A building that has undergone renovations and retrofitting will use less energy, potentially have lower rent and probably look better from the outside (Mostafavi & Doherty, 2016).

Spaulding Rehab, for example, a waterfront hospital located in Boston, US, is one of the country top medical facilities for rehabilitation of survivors of strokes and accidents. This innovative building has been planned with climate change in mind. The first floor is 30 inches (about 75 centimeters) above the 500-year flood levels (an elevation much higher than required by state regulations), while a swimming pool and other non-essential services are located on its lower floor so that the whole construction can flood without affecting patient care (Wilson, 2015).

And there is also the Hafencity neighborhood in Hamburg, Germany, where the bottom floors have been designed and transformed to withstand the inevitable flood with its waterfront buildings placed on mounds and a gate system that closes off their ground floors in case of a flood. With this relatively inexpensive solution the city is avoiding the destruction of the area's picturesque waterfront charm, that could happen building dikes. "The solution is not complicated, you just close the door and there is someone responsible for this in every building," said Susanne Bühler, Head of Communications for HafenCity. "Only the promenades are vacated in case of flooding" (Hales, 2015).

Wet and dry proofing, small mounds or temporary barriers are the best options for making an already-existing urban area resistant to flood levels of less than one meter. In this situation, only the first lowest meter of the regenerated building would need to be made flood-proof. Temporary barriers are best suited for brief floods, such as with a duration of days or weeks and a relatively low flood level, but they are only useful if the flood can be predicted. If not, permanent barriers

can be a preferable option, also especially if the occurring flooding frequency is higher. Mounts are also good for low flood levels due to the low cost of ground displacement (De Graaf, 2012).
Elevating the entire structure above the anticipated flood level could be another way to protect a building from flooding. In this case, such a building must have its connection to the infrastructure protected from the rising water in order to continue operating (De Graaf, 2012). However, due to the difficulty and cost of transforming the building, it is difficult to imagine this method used in a regenerative context. Consequently, it is more frequently used in new construction projects or planned neighborhoods.
However, threats posed by water can come not only from the ocean, rivers or other surrounding bodies of water; cities can be threatened also by water coming from the sky. Paved surfaces appeared alongside the rise of the motorcar in the early 20th century. Rainwater, rather than being absorbed by plants, evaporated or filtered through the ground back to rivers and lakes, was suddenly forced to slide over impermeable pavements and roads into drains, pipes and sewers. However, their maximum capacities are based on scenarios like occasional and decennial storms hence, once they become blocked or they reach their maximum capacity, the water simply rises because there is nowhere else for it to go. The reality of climate change and the increasingly frequent and intense rainfalls have exposed the hubris of this approach. The US National Weather Service described the “breadth and intensity” of the rainfall that came with Hurricane Harvey in late August 2017 as “catastrophic” and “beyond anything experienced before”. This extreme event left over a million people homeless, destroying 185,000 homes in Houston alone and causing at least 44 fatalities. Therefore, now that climate change is both a reality and a threat, many architects and urban planner are promoting innovative ideas for cities to treat stormwater as a resource rather than a threat (Knight, 2017).
For instance, over the past ten years, Chicago, US, has made significant investments to rethink stormwater management, including the creation of more than 100 "Green Alleys": public areas and streets made by permeable pavements and bioswales that allow stormwater to filter and drain into the ground. In this way, according to senior landscape architect Jay Womack, who was hired to design some of these streets, about 80 percent of rainfall is diverted from the sewage system, and the road no longer floods. “We try to create porosity and permeability so that water can move in the ways that it moves in the hydrological cycle” said Womack. “It’s very simple, but it’s very difficult for people to grasp, because we’ve not designed like that in a century” (Knight, 2017).
Lessons learned from cities like Chicago are being used also in China, where the government has ordered the construction of sixteen "Sponge Cities", allocating between 400 and 600 million yuan (around 55 to 85 million dollars) to each urban area, testing out possible solutions to solve

problems of freshwater shortages and recurrent flooding, which many Chinese cities are experiencing as a result of rapid urbanization (Knight, 2017). To cope with such challenges, these new eco-cities are envisioned to provide a way to incorporate the water cycle into town planning, using the urban landscape to retain rainwater, waterproofing the paved surfaces or, for example, reducing water flow using trees and green areas, while keeping it clean all along the way. Additionally, smart buildings and public spaces are being built to adapt to the new environment. As a results, buildings are painted in light colors to reflect more heat rather than absorbing it and roofs are covered in grass to increase water absorption (Campbell, 2022). Chicago architectural firm UrbanLab was, for instance, commissioned to design the layout for a new city center within the larger urban area of Changde, situated in the Yangming archipelago in the Hunan province, China. The region, a low-lying land river basin, is frequently flooded due to the regular heavy rainfalls, hence, to cope with this problem, rather than including barriers against water, like flood walls or dikes, the American firm envisions to combine the dense metropolis with a natural setting, placing important buildings on islands in a massive lake at the center of its urban project, where water will be free to flow (Knight, 2017). Then, another example of a successful water-friendly city is the 34-hectare "Qunli stormwater park", situated in the northern Chinese city of Harbin. Thanks to an eco-friendly and innovative systems, in fact, the installation is able to collect, clean and store stormwater, while also protecting the local natural habitat and offering a beautiful green public space for recreational use (Campbell, 2022).

3.2 New construction to face sea level rise

The twentieth century was the century in which the world population irreversibility grown in number and shifted toward material, urban environments and lifestyles. Changes in settlement types and perhaps even the concept of the city itself went hand in hand with this significant transformation (Mittner, 2018). The following century was then characterized by an even bigger wave of change, distinguished by aspects like globalization, population grow and climate-related issues, which deeply affected new urban realities. With them, cities and new urban communities were forced to deal with every day more common issues like poverty, but also the lack of access to jobs, healthcare and education. On top of that, environment-related problems, like pollution and the damage caused by climate change and natural disasters, started to be more common, perceived more predominantly in cities than in rural areas (Murphy, 2022).

Because these challenges of rapid urbanization and changing climate have become much more pressing, it appears to be even more of a necessity to find alternative designs approaches that will allow society to consider the large scale differently than it has been done in the past, when sustainability, for instance, was primarily a matter of the architectural object and building, rather than the larger structure of the territory of cities and towns (Mostafavi & Doherty, 2016). Luckily, when challenges arise, great thinkers can come up with solutions. To accommodate the typical demands of the recent centuries, in fact, many neighborhoods and even entire cities have been newly planned and constructed from the ground up. What they all have in common is the search for a new urban beginning (Mittner, 2018).

With Constantinople replaced Byzantium in 300 AD, to give one early example, planned cities are not a new concept. Planned cities can be defined as any large community that is carefully planned and engineered, typically on previously underdeveloped land, to provide the majority, if not all, of the advantages that cities historically built around naturally supporting geography, such as a river for trade routes, do. With these ideas in mind, new planned cities and urban areas are also designed to avoid the problems that have plagued other older cities, including for example the overcrowding in São Paulo (Brazil), water shortage in Chennai (India) or wealth inequality in London (UK). But in the face of all these problems, will these purpose-built cities be able to truly help uplift communities? Though they have high aspirations, many global projects have problems that will seriously impair their capacity to assist their potential populations, if not properly addressed (Murphy, 2022). The aim of ambitious programs in the forthcoming decades should therefore especially focus on a better control of the development of metropolises and urbanized regional pattens, with an exceptional view to people's environmental behavior (Mittner, 2018).

On top of that, in addition to the difficulty in accommodating the typical demands of the population, which is currently growing with a resulting increase in resources required to support it, recent urbanization was indirectly forced to deal also with the problem of land scarcity. In fact, although creating a new city from the ground up may seem like a good idea, the reasoning does not stand if there is no location to begin with. To cope with this situation, new planned urban communities are investing in the creation of multifunctional spaces to increase the efficiency of land use. This idea, central in the concept of the "15-minutes cities", allows for the use of urban space for more than one function, for example integrating urban planning with flood control strategies in costal or flood-prone cities (De Graaf, 2012).

However, since space is increasingly scarce in and nearby cities, many city planners came up with the idea of using water surfaces for urban purposes, following a multifunctional approach. In fact, given that about two third of the entire Earth's surface is covered by water, it is not odd to state that the oceans, seas and lakes are not yet optimally used. According to expert, to accommodate five billion people in marine-based communities with the same average urban density as today's land-based cities, easily attained due to the relatively low-density value of average urban areas, only 0.8 percent of the world's sea surface would be required (De Graaf, 2012). Hence, the construction of floating buildings, for instance, could be a way to use water bodies as a multi-purpose resource. In densely populated areas, in fact, floating urbanization allows for the multipurpose use of space without raising flood risk. Floating structures also increase the urban area's ability to cope with flooding. As water changes in height, floating and amphibious structures allow for the vertical building movement, adapting to the rising water level during extreme events, while being fixed horizontally by a mooring system. In these extreme occasions they also provide additional emergency shelters. The two systems have virtually the same operational principle; the only difference is that while floating structures have water present all the time at the site, amphibious structure are based on the ground and can begin floating once a flood occurs. They can both be useful options even for high flood levels that exceed three meters and, additionally, these technologies' costs hardly change with the depth of the flood, in contrast to the majority of other flood proofing methods. Floating and amphibious buildings are also most appropriate for longer flood durations (De Graaf, 2012). Of course, protective flood walls, wet gardens and flood resistant buildings can still be useful for climate-related issues. However, the use of these mitigative solutions could not be enough considering the scale of the problem. Sea walls can surely be designed to accommodate future increase in height of the sea level, but it cannot be the definitive measure. The real solution entails adapting the behavior of the city to accommodate life on the water, not segregating it.

When considering whether a coastal city should expand to its marine environment, understanding also its environmental impact must be prioritized. According to research done by the International Association for Hydro Environment Engineering and Research (IAHR), which focused on the monitoring of water quality and potential biodiversity losses under floating installations (using high-tech drones), floating structures pose no environmental risk if properly developed (Adnan, 2020). Moreover, in the context of climate change adaptation, floating installations can offer much more than a valuable sustainable alternative. In fact, beside its adaptability to sea level rise, a floating structure can provide both ecological and economic advantages compared to the destructive practice of land reclamation. Being isolated from the seabed, floating installations are less susceptible to earthquakes, and the general flexible and reversible modularity of their design, which is advantageous for coping with hazy future developments like climate change, reduces the overall cost and facilitates expansion and relocation of the platforms with minimal perturbance of the marine ecosystem. Floating buildings can even be adapted to enhance local marine activity by providing a diverse underwater habitat for fish and other marine organisms. For these reasons, the development of floating installations is gaining success over the general public, so much that it has been recognized by the American Society of Civil Engineers (ASCE), through its Future World Vision Initiative, as a crucial step towards sustainable and resilient future cities (Wang, 2022). According to Rutger De Graaf there are currently two main applications of floating urbanization in marine coastal cities. The first application involves the development of floating installations in port areas that have lost their primary function and are no longer used for commercial. This is usually the case for the shallowest and closest ports to the city's center. As more modern deep sea ports are developed to accommodate newer bigger ships, in fact, the industrial activity leaves the older ports, shifting to new locations. Waterfront development and floating urbanization both present an innovative option to give these areas a new economic purpose and, at the same time, prevent urban sprawl by achieving urban densification and multifunctional use of space (De Graaf, 2012).

FIGURE 3: Rendered aerial night view of OCEANIX Busan (OCEANIX/BIG-Bjarke Ingels Group).

Once completed OCEANIX Busan (as illustrated in a possible future render in *Figure 3*) will serve as a prime example of this application. Planned to be located in the calm and sheltered waters of the Korean port city of Busan, this installation has been envisioned to not only effectively withstand the effect of climate change, adapting to sea level rise, but also to supply autonomously food, energy and freshwater, helping endangered coastal cities and island nations to carve their future with sustainable innovations. This "world's first prototype of a resilient and sustainable floating community", as defined by the same company that designed it, will initially comprise three hexagonal platforms, spanning a total of around six hectares across the interconnected neighborhoods, which will be able to accommodate a community of thousands of people (*Oceanix.com*, 2022).

Docked in the port of Copenhagen a similar project, but at a much smaller scale is present. Designed by Bjarke Ingels's firm (the same firm that helped in designing OCEANIX Busan), the project, named Urban Rigger, consists of nine shipping containers stacked on top of a floating platform to create a low-cost accommodation for a dozen of students. The installation comprises fifteen studio residences over two levels, with container arranged to frame a common garden in the center of the floating platform. On top of that, each unit is powered by solar panels and warmed up using thermal energy coming from the saltwater of the port (Mairs, 2016).

The floating pavilion of Rotterdam is another example of a successful floating installation. This marine structure, made by three transparent floating domes, is intended as a unique floating venue in the center of the city, which can be rented for countless social purposes, like exhibitions, dinners, presentations, conferences and more. The pavilion is located in the Rijnhaven port due to its moderate waves. Its nautical use by inland ships, in fact, has been decreased since the port is destined to be a future leisure port. This and other similar projects are springing up all over Rotterdam, which aims to cut its carbon emission by fifty percent in order to become the World Capital of CO2. The city has also the ambitious plan to construct a community of floating homes, and this charming Floating Pavilion is its first prototype (Lisa, 2013).

Next to Rotterdam, other developed port cities like London, New York and New Orleans face similar difficulties regarding the revitalization of their old port districts. Among these, New York has already expressed interest in the floating urbanization approach. Therefore, it is likely that the first floating neighborhood will be located in its old port areas. In San Francisco, the Seasteading Institute (a non-profit organization created to assist in the development of autonomous, mobile communities on seaborne platforms operating in international waters (*The Seasteading Institute*, n.d.)) is developing floating communities for new generations of pioneers to experiment with new forms of governance. In Japan, the Shimizu Corporation (a local architectural, civil engineering and general contracting firm (*Shimizu Corporation*, n.d.)) has created a design for self-supporting floating islands with high rise skyscrapers, which together could form a nation of a million citizens. Coastal cities like Jakarta (Indonesia), Ho Chi Minh (Vietnam), Manila (Philippines) and other urban realities which are experiencing rapid growth in flood-prone plains, could also take advantage from floating urbanization, as a way to preserve agricultural land, provide affordable housing and reduce flood risk (De Graaf, 2012).

The second application of floating urbanization in marine cities, as described by De Graaf, involves the multifunctional use of water retention areas. In fact, one way for cities to adapt to more frequent extreme weather events is the development of a greater amount of surface water to increase the water retention capacity. These new water surfaces may then be used for commercial applications, due to the high land cost and property values, typical of coastal cities. Thanks to this innovative form of floating urbanization, future residents or project developers may purchase a portion of the newly created wet areas to build floating structures, enabling municipalities to recover part of the costs associated with the development of these areas. In the Netherlands, for example, a number of municipalities, including Delft, Amsterdam, and Rotterdam, have sold or are in the process of selling water plots (De Graaf, 2012).

In the Dutch capital in particular, in the Buiksloterham district, a floating village made by 46 floating homes is currently providing shelter for citizens and visitors. This is a prime example of an adaptation project where an entire newly planned community has embraced the concept of "living on the water", learning to live alongside the problem of sea level rise, while also taking advantage of it. This innovative project, called Schoonship, has been a massive success thus far. In fact, besides being able to host more than 100 people, the city is able to sustain itself, letting people live independently from the mainland through the use of solar panels and water pumps, treating separately wastewater coming from toilets and showers and with the possibility to grow food directly on the roof of some homes. Additionally, this village plans to be sustainable not only from the ecological point of view, but also in a social sense: residents form a closed community, working together to solve problems and coordinate plans, even renouncing to use their personal cars for a more environmentally friendly shared electric mobility (Adnan, 2020).

Likewise in Amsterdam, in Ijburg, a similar floating community has been designed by architects and urbanists to include both 75 floating houses and waterside dike houses. These buildings share countless characteristics with land-based housing, for example their interior volume and comfort level, and thus they are often compared to conventional land-based accommodations. Additionally, differently from Schoonship homes, which can be considered to all effects boats, they are financially classified as immovable properties due to the mooring systems that fix the buildings in place (Adnan, 2020).

These are just some of the latest additions to a string of proposals considering floating installation as a new way to live on the water. But these projects are not only that, each of them, each in its own way, proves the importance of innovative design solutions to pioneer the expansion of coastal cities to adjacent and even offshore sea and are only the first steps toward a marine floating city. But is it possible to develop entire floating cities on the open sea? Is there even a reason to build a floating city? Building relatively small and contained floating neighborhoods is one thing, expanding the idea of floating urban development to include entire floating metropolis is quite another. And more importantly, could floating communities really offer a solution to some of humanity's most pressing issues, including resource scarcity, population grow, climate change and the lack of available land?

One of the best examples of a country currently experiencing these issues is the Maldives. With about 1190 islands, which over 80 percent of them are no more than a meter above sea level, the country is likely to disappear over the next few decades if nothing is done. Thus, building a floating city of thousands of houses next to Male, capital of the nation, could be the solution to the tiny country's agonizing need to find a new home for its people, as some of its coral reef islands face an impending threat from the rising sea level. Waterstudio, the company in charge with the design, will soon unveil the first floating island with six to eight reasonably priced floating homes that people can see, feel and walk. “We are working on the master plan, which we have already partly presented to the government and the president of the Maldives, in which we make affordable floating islands. We can provide them with a whole floating city of 20,000 houses next to Male, where the locals can live in floating houses” (Adnan, 2020).

But the idea to create floating cities is not new at all and, over the years, numerous designs and plans for floating cities on the sea or inland water have been proposed. In 1895, Jules Verne already wrote about a constructed floating island in his novel l'Ile a Hélice (De Graaf, 2012). In 1960, the idea of a “floating city” became a crucial point of Kenzō Tange’s plan for Tokyo. In fact, during a time when many cities in the world were experiencing the height of urban sprawl, a distinctive characteristic of that industrial era, Tange, considered by many as the leading figure in the Metabolist movement, attempted to impose a new physical view on Tokyo, proposing the first model of a floating community, designed as a blend between traditional Japanese style and modernism. In this way the project would be able to accommodate the city’s continued expansion and internal regeneration (Adnan, 2020). This, as well as other iconic buildings Tange designed over the course of his long career, allowed him to later won the prestigious 1987 Pritzker Prize for Architecture. Although the plan did not become a reality, this was the starting point of a new era of floating cities.

More recently, there have been a ton of creative designs for floating buildings, including the ones mentioned before, most of which could be implemented in future floating cities. However, no design has, so far, managed to prevail over the others. What is lacking, is an urban design philosophy created specifically for floating urban communities, which is what, the majority of time, is preventing the realization of these trailblazing installations. Many designs for floating cities still continue to be distinctly inspired by land-based cities and are concentrated on the building scale. Others have a futuristic design similar to those of sci-fi spacecrafts. What is still missing is a comprehensive knowledge regarding urban densities, building typologies and a larger perspective and imagination regarding what it would be like to actually live in a floating city. Therefore, it is necessary to create urban design tools that are familiar with floating cities. These includes feasible options for community spaces, a clear separation between private and public, mobility, logistics and transportation, densities, land use, and, most importantly, a greater knowledge and comprehension of the potential way of life in floating environment (De Graaf, 2012).

4. THE OCEANIX CITY PROJECT

The intent to build a first prototype of a floating city together with a host city was unveiled to the public in April 2019 during the First inaugural UN High-level Roundtable on Sustainable Floating Cities. During this event, co-chaired by UN-Habitat, OCEANIX, the MIT Center for Ocean Engineering and the Explorers Club, a first pioneering concept of a future floating city able to host thousands of residents was shown: OCEANIX City. Another design was then unveiled 3 years later, on 26 April 2022, during the Second UN Roundtable on Sustainable Floating Cities held at the UN headquarters in New York, adapting for the first time the concept to an already existing coastal urban fabric: that of the Korean city of Busan (Busan Metropolitan City et al., 2022).

FIGURE 4: Rendered aerial view of OCEANIX City (OCEANIX/BIG-Bjarke Ingels Group).

OCEANIX City (illustrated in the *Figure 4*) is a pioneering floating city project, that has a strict connection with the UN Sustainable Development Goals, as the objective is not only to design a city that can effectively withstand the effect of climate change and adapt to sea level rise, but also to design a city that will be able to supply autonomously food, energy and fresh water, helping endangered coastal cities and island nations carving their future with sustainable innovations. For the first time the concept of a floating city is combined with the concept of sustainability and carbon neutrality, in a way that distinguishes it from current pioneering research. OCEANIX City will in fact be designed around an organic sustainable system, which will base its foundations on the 17 United Nations Sustainable Development Goals (illustrated in *Figure 5*), channeling the flows of energy, water, food and waste to create a blueprint for a modular maritime metropolis, proposing a sustainable future for all (*Oceanix.com*, 2022).

FIGURE 5: United Nations' Sustainable Development Goals (OCEANIX/BIG-Bjarke Ingels Group).

The energy needed on site will, in fact, be harnessed from abundant, clean, renewable energy sources like the sun, winds, waves and sea currents, water will be treated and replenished autonomously, resources will be recycled and used more consciously and innovative urban agriculture, like aeroponic and aquaponic, will be present to fulfill a primarily plant-based diet, to reduce strain of space and the use of both energy and water. The attention is driven mainly on closed-loop processing, that will turn waste into energy, agricultural feedstock and recycled materials, aiming to reduce material footprints and end of life emissions. A flexible pedestrian-friendly roadway will accommodate small electric vehicles, autonomous delivery robots, bikes and pedestrians, replacing all fuel-based mobility to reduce carbon emissions and promoting a healthy lifestyle. The buildings will be designed keeping a low-rise structure to balance weight evenly, maintaining a low center of gravity able to resist wind and reduce wave perturbation, while at the same time prioritizing locally sourced materials, with a special view toward maintenance and disassembly at the end of life. Using wood and bamboo, a 100% renewable material that is both strong and light, buildings will be lightweight and also able to age with character and maritime appeal (*Oceanix.com*, 2022).

The floating platforms, each able to accommodate thousands of square meters of mixed-use services, will maintain their connection with communities on the nearest coast via link-span bridges or other infrastructures and methods of transports (boats, ferries, electric vehicles, …), connecting the floating port and framing the sheltered lagoon holding floating recreation, art and performance outposts. OCEANIX City is envisioned to feel both like home for residents and an incredible destination for visitors who want a taste of a sustainable lifestyle. On each platform residents and tourists will gather, work and play in an activated public environment, characterized by site-specific buildings, defined by their soft lines, and shaded terraces, which embrace the comfort of indoor-outdoor spaces, helping to activate the network of vibrant public spaces. OCEANIX City will be an adaptable, sustainable, scalable and affordable model for communities to live in harmony on the water (*Oceanix.com*, 2022).

The following chapters will be divided into two sections, each of which will evaluate a key component that forms the basis of this ground-breaking project. The "practical" aspects of the OCEANIX project, including the design, technologies and construction of the installation itself, will be covered first. A scalar approach is used to describe each component of the floating community with a different focus, starting at the level of the single individual perspective and progressing at the conclusion to a larger regional scale. After that, this thesis will discuss the project's "social" component. The viewpoint of the people will be taken into consideration when addressing issues such as whether or not this project is socially acceptable, whether or not people want to live on the water and what impact the floating environment will have on the floating communities.

4.1 "PRACTICAL" CONSIDERATIONS

4.1.1 Individual's Perspective

There are various ways to define a city depending on its size and population. For instance, a metropolis is a large city or urban area that serves as an important economic, political and cultural center for a nation or region, but also a significant hub for regional or international connections, trade and communications. Such cities exist all over the world, with New York, Tokyo, Shanghai, London, Paris and many more, serving as remarkable examples. Most cities begin small and expand gradually until they can support a so-called metropolis' population. It is unknown whether the idea of a floating city will ever develop into a significant metropolis, but it should not be an impossible goal (Ko, 2015).

Anyhow, the first step in the designing process of a city, should be the choice of its starting capacity, from which the floating community can gradually grow. In this regard, contrary to how traditional cities are very often planned, the OCEANIX project bases its foundation around the single individual. The floating city will, in fact, be designed starting from the perspective of a single resident, addressing its demands and scaling accordingly its surroundings, expanding platforms, buildings, infrastructures, technologies and services in an organic way to accommodate the ever-increasing population.

In OCEANIX City the single human is not only a citizen living in a floating environment, but it is also a sort of unit of measure from which size the entire project. Thus, the single resident, or visitor, will be the focal point, from which all the concepts, ideas and key principles will be developed (as illustrated in *Figure 6*). This approach can help significantly when designing a project that plans to organically transform and adapt over time as the demand to live in it grows. In particular, energy and waste production, food and water consumption will be managed according to a people-oriented perspective. It is envisioned, in fact, that the floating city will:

- produce 30 kWh per person per day to reach "Net-Zero Energy";
- produce 800 grams per person per day of waste to be treated in "Zero Waste Systems";
- supply 600 liters per person per day to reach "Fresh Water Autonomy";
- supply 1888 grams per person per day of "Plant Based Food".

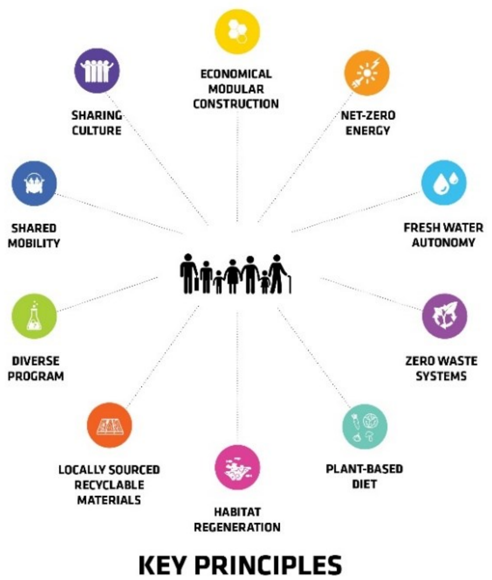

FIGURE 6: Key principles of the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

But is this a good approach? Can the single be used to design a project that will be used by many? The answer is not obvious and requires proper treatment. Of course using the single as a unit of measure provides means for an easy sizing. If an installation intends to host a thousand people, it is obvious that the same installation will require N x 1000 resources (where N is the resource per person). From there, designing will be simpler. However, one point of inquiry that could arise is about the degree of representability that a single resident will have in relation to the collective. Knowing how much waste a single resident will produce cannot be enough to correctly size the waste management of the whole city, for example. Other similar considerations can then be done for energy production, or water and food consumption. By definition, a representative fraction of a population is defined to be a sufficient and suitable means to provide all required information about the population itself. Perhaps one single person is insufficient.

4.1.2 Platform’s Perspective

When shifting the focus from a single person to a collective, things get usually more complicated. Zooming out the perspective, as a camera that moving up has a much higher and broader view compared to one fixed on a single subject, more aspects become visible and need to be accounted. When viewed from this angle, people can be observed forming connections and exchanging knowledge and information, which results in a complex network that forms the very foundation of the floating city. From this perspective, also, the complex environment that supports this community is much more apparent. From the lone individual, now a member of a community, the focus has shifted to the single hexagonal platforms, each able to accommodate up to 300 residents (as shown in *Figure 7*).

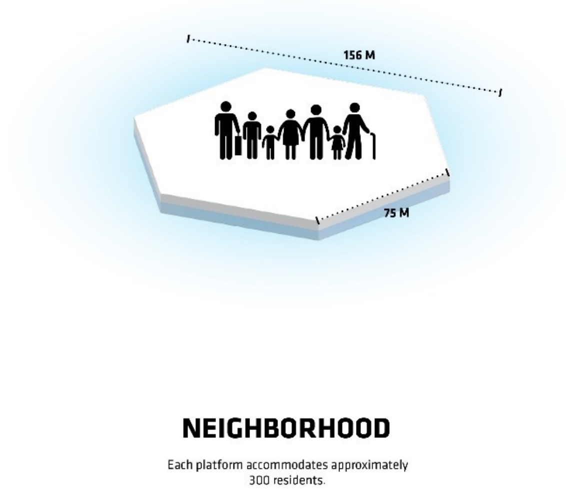

FIGURE 7: Dimensions of a neighborhood platform as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The following chapters will discuss about these elements and the general layout of the city in which they are located, after which a theoretical focus will be placed over the technology and technical elements that make this urban project one of the most innovative and trailblazing ones to date.

4.1.2.1 Design in the OCEANIX project

In the last two decades the concept of living on the water has been revisited with a new idea. Instead of realizing multiple independent floating houses, forming a floating community or resident district, experts introduced the idea of realizing a complete city state, made by a very large floating installation which floats on the water, a so called "floating city". Among the challenges that lie in this concept, the environment in which the floating community is located is surely one of the most predominant. It is the environment that determines which and what kind of force are acting on the installation. Thus, the design of the overall project is heavily dependent on the surroundings, especially on which external loads are working on the platforms, whether they are natural or anthropic. Strength and stability of the project are also influenced by the magnitude of these forces. It makes sense that a floating city would operate better in a calm bay than in the open sea, where storms and huge waves are more frequently present (Ko, 2015).
As already mentioned before, the intent to build a first prototype of a floating city together with a host city was unveiled to the public in April 2019 during the First inaugural UN High-level Roundtable on Sustainable Floating Cities. During this and following events a first pioneering design of a future floating city was shown: OCEANIX City (Busan Metropolitan City et al., 2022). A modular structure with uniformed shaped platforms and branch-like arrangement was chosen. With this layout the city aims to host cutting-edge and sustainable technologies, effectively adapting to sea level rise, while organically expand over time as the demand to live in it grows. There are still no publicly available details about how engineers, architects and planners came up with this design. However, there are a number of goals, demands and requirements that base a design of a floating city, and thus are common to the majority of all floating city projects.
According to Ko, the individual platform's shape and configuration should enable simple layout for future expansion, adopting fewer costly connections, while being statically and dynamically stable on its own. If necessary, the platforms' design should permit circular layouts so that they can effectively fit behind a breakwater structure. The platforms should also be linked together in a way that yields a cluster that is dimensionally stable. The floating structures should be also uniformly shaped to keep down the construction costs. Additionally, the form of a single floating platform should provide enough water experience in the floating community (Ko, 2015).
Considering these requirements, modular hexagonal-shaped platforms were chosen as the design elements for the OCEANIX floating city. Inspired by the ability of bees to use as few resources as possible thanks to hexagonal honeycomb cells (*Oceanix.com*, 2022), this geometrical design is a

straightforward choice that will facilitate the growth of the floating community, achieved by simply adding more platforms in all way possible to the configuration. Platforms with a hexagonal shape are, in fact, symmetric from all sides, making it simpler to configure the floating community in various ways without worrying about how the platforms will fit together. For example, hexagonal-shaped platforms make it simpler to build circular clusters: whereas the pentagonal-shaped platform needs ten platforms to build a circle, the hexagonal-shaped platform only needs six (Ko, 2015). A platform with a hexagonal modular shape also gives the city a higher floor space usage. A hexagon, because of its 120° angles, is a shape that best fills a plane with equal size units, leaving no wasted space. With this straightforward structure the pull of surface tension in each direction is also most mechanically stable (Adnan, 2020). Additionally, the more sides a platform has, the more opportunities there are to build homes close to the water, which is advantageous for having an increased water experience. Utilizing this shape has only the drawback of requiring more connections on some platforms. Due to the many sides a hexagonal has, to maintain a dimensionally stable cluster as the city expands, more platforms are required next to each other (Ko, 2015).

Each floating platform, able to accommodate between 10,000 to 15,000 square meters of mixed used space (as illustrated in *Figure 8*), will be designed to host up to 300 residents (*Oceanix.com*, 2022). This diverse environment is envisioned to feel both like home for residents and an incredible destination for visitors who want a taste of a sustainable lifestyle.

FIGURE 8: Platform program diversity as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

On each platform residents and tourists will gather, work and play in an activated public environment, characterized by structures made with locally sourced materials, defined by their soft lines and shaded terraces, which embrace the comfort of indoor-outdoor spaces, helping to activate the network of vibrant public spaces. The form of these buildings (illustrated in *Figure 9*) will be developed promoting building diversity and providing comfort and lower cooling costs while maximizing the roof area for energy capture (*Oceanix.com*, 2022). In fact, consuming energy as efficiently as possible will be a central theme in the floating city. Cross ventilation will be encouraged in buildings, greatly reducing the need for carbon-intensive air conditioning. Then, in order to maximize sunlight access, windows and architectural will be designed to lower the amount of electricity needed for heating and lighting (Oceanix | Helena, n.d.).

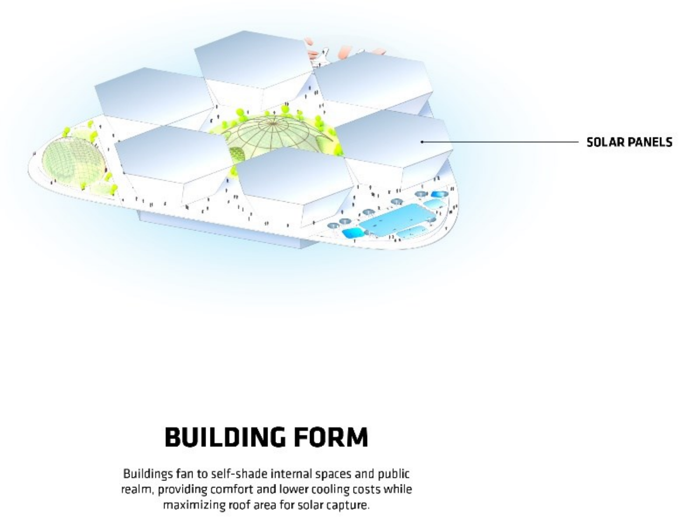

FIGURE 9: Platform buildings form as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

On a floating city, the design, the type and the draught of the platforms are also heavily influenced by the dead load provided by buildings and houses. Aside from the floating platform itself, in fact, they provide the most of its value. Hence, affordable dead loads need to be managed accordingly. In addition, to prevent tilting and rotation, structures such as houses and buildings need to be spread out over the entire surface. Another crucial factor to take into account is wind loads, which can affect the stability of both buildings, especially high-rise ones, and floating platforms. Then, in comparison to structures on the mainland, buildings on floating platforms have fewer options of being founded on steel or concrete platforms. In fact, in order to support the dead load of the

building and, to a lesser extent, the overturning moments of the building, high-rise buildings located on land are typically founded on extremely long foundations and piles. And on floating platforms, these pile foundations are either no longer possible or very limited (Ko, 2015).
For these reasons, the buildings in the OCEANIX project will be designed with light materials and keeping a low-rise structure (up to 20 meters as illustrated in *Figure 10*) to balance weight evenly, maintaining a low center of gravity able to resist wind and reduce wave perturbation (*Oceanix.com*, 2022).

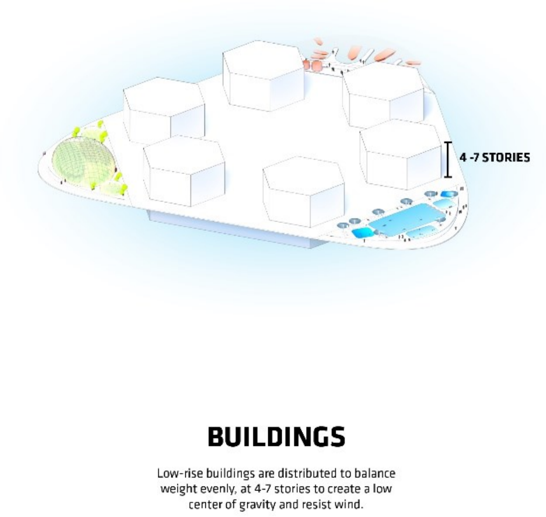

FIGURE 10: Platform buildings height as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

To make sure that the floating city stays put, an additional, but necessary, strong mooring system will be also installed. There are several mooring systems in the market, each with its own characteristics, performances and operational principle. Although there are no information or data regarding which one will be chosen, it is reasonable to assume that the city will adopt a cable or chain mooring system, due to its ability to handle very well both horizontal and vertical forces and displacements. More specifically, a "taut-leg" system could be chosen because this system is able to anchor at an angle the platforms directly to the seabed. This angle determines how effectively the vertical and horizontal loads are transferred to the anchorage. A good solution could be to apply the mooring lines under an angle of 45° (Ko, 2015).
To assist even more the stability and equilibrium of the floating structures, stabilizing structural elements, such as water-ballast-tanks or aircushion supported pontoons, will be introduced to

minimize the rotation and tilt effects of floating structures. Modern technology currently present allows for the use of extremely precise sensors to measure tilting displacements, after which these stabilizing elements can counteract by adopting precise amounts of air or water to offset the tilt. However, there hasn't been any research done on this aspect, and it's not even clear if it will work for a big platform (Ko, 2015).

Of course, the aesthetics and comfort of the build will also be given special consideration. Materials like wood and bamboo will be chosen for their maritime appeal and their ability to age with character. The whole architecture will be designed to be site-specific and responsive to the social, political, environmental and economic aspects of each location. Additionally, to promote building diversity (illustrated in *Figure 11*), buildings and structures will have distinct identities. The modular structure will, in fact, include three types of platforms, each designed to serve a specific purpose: living, research and lodging (*Oceanix.com*, 2022).

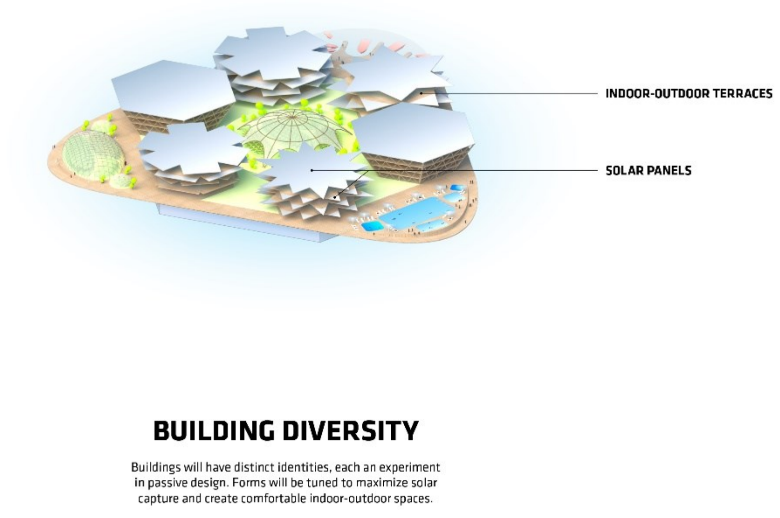

FIGURE 11: Platform buildings diversity as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The living platform (envisioned to allocate for the Busan's project 8,500 square meters of building footprint, with 20 meters of max height) will provide diverse housing options for sustainable and circular living, while the presence of alleys, in the heart of the platform, full of local food vendors, crafts and bookshops, will encourage gathering between residents (*Oceanix.com*, 2022). *Figure 12* below depicts a potential rendering of a living platform.

FIGURE 12: Rendered view of a living platform in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The research platform (envisioned to allocate for the Busan's project 10,500 square meters of building footprint, with 25 meters of max height) will be a co-working and maritime research hub, equipped with a shared winter garden. It will provide job opportunities driven by innovating solutions to climate change, including a habitat regeneration center, maker spaces and dorms, all in a temperature-controlled environment to provide respite from Busan's cold winter months (*Oceanix.com*, 2022). *Figure 13* below depicts a potential rendering of a research platform.

FIGURE 13: Rendered night view of a research platform in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The lodging platform (envisioned to allocate for the Busan's project 6,500 square meters of building footprint, with 20 meters of max height) will be designed to maximize waterfront views with its harbor-view guest rooms. The elongated ground level will accommodate local organic dining and eco-retail, while skylight greenhouse amenities and communal terraces will create a unique destination for visitors (*Oceanix.com*, 2022). *Figure 14* below depicts a potential rendering of a lodging platform.

FIGURE 14: Rendered view of a lodging platform in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Each platform will then have three performative petals (illustrated in *Figure 15*), accommodating docks, windbreaks, production areas and gathering spaces. Additionally, low edges will allow residents to have direct access to the waterfront (*Oceanix.com*, 2022). The goal of this layout is to give the floating community as much "water experience" as possible. In fact, compared to larger platforms, thanks to the smaller platforms' flexible and open configurations, it will be easier to interact with the aquatic environment, providing both visual and physical experience. Visual experience is about being able to see the water, while physical experience is about activities on the water such as swimming, sailing or diving (Ko, 2015).

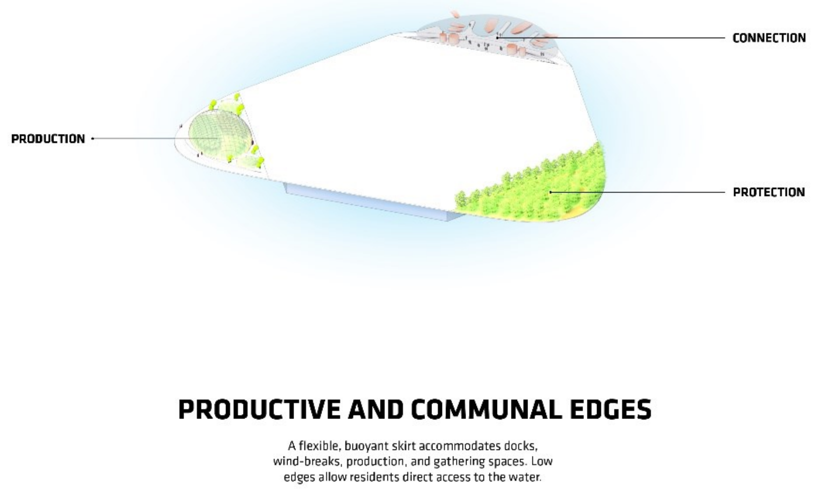

FIGURE 15: Platform productive and communal edges as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

4.1.2.2 Technology in the OCEANIX project

As already mentioned, excessive urbanization in coastal areas is likely to cause an increasingly severe flood-related problem. However, this is not the only problem coastal urban realities are facing. In these areas, in fact, the process is also severely constrained by the availability of space, food, energy and other resources. Additionally, traditional urbanization often leads to the degradation of land and ecosystems. Although necessary, increasing agricultural production won't be sufficient to meet the growing demand for food, biofuels and carbon sequestration and, on top of this, in order to increase agricultural productivity, it is frequently required to extract more water, use more fertilizers and deplete more energy. Once more, this will result in an expansion rather than a reduction in the cities' ecological footprint. Therefore, the issue brought on by coastal cities' behavior needs to be addressed both in the coastal cities themselves and in their future expansions (De Graaf, 2012). According to Rutger De Graaf, what is needed are cities that:

- Increase land availability rather than create land scarcity;
- Decrease flood risk rather than create flood risk;
- Produce food, water, energy and nutrients rather than merely consuming resources and creating waste;
- Have positive impact on the environment and create ecological habitat rather than degrade ecosystems.

This cyclic resource metabolism, as De Graaf also calls "adaptive urban development", needs to be correctly managed in order to be the outline for future productive cities (De Graaf, 2012). With these considerations in sight, with also a view of a sustainable horizon for future generations, OCEANIX proposes a blueprint of a pioneering floating city project that has a close relationship with the UN Sustainable Goals, channeling the flows of energy, water, food and waste while at the same time safeguarding the delicate marine ecosystem (*Oceanix.com*, 2022). But can a floating city be built with the technologies available today? Probably. Failure is likely not a technological issue. Architects and engineers already know how to build floating installations. It is not science fiction. The subject behind the creation of floating residences has been covered in literature for tens of years (De Graaf, 2012).

Then why hasn't the idea of a floating city come to fruition yet? Most likely, it is a matter of complexity. A regular city is already enough complex on its own, let alone one that must be able to autonomously sustain food production, gather minerals and energy from the ocean's surface, synthesize biofuels from seaweed and microalgae using sunlight, while also staying afloat. Each of these procedures calls for a sizable amount of resources, time, money and government interventions.

Although there are technologies and concepts that can help coastal cities become adaptive cities, the actual implementation is still only being done in small-scale pilot projects that have a minimal overall impact on the urban system. Additionally, the majority of practical case studies on the subject are restricted to individual buildings. There is a lack of knowledge regarding how these technologies and concepts might be applied to create functional neighborhoods or even cities that are flood proof. Thus, in the upcoming years, it will be crucial to conduct research in scaling up flood proofing technologies beyond the scale of a single structure. Critical infrastructures and hotspot buildings within these installations should be considered in such a research as well. In fact, in order to maintain daily life during an extreme flooding event, critical infrastructure, like energy production and water management systems, sanitation and healthcare, must function. Flood-proof buildings alone cannot create a flood-proof city. Additionally, the development of a reliable system to assess and select different flood proofing options for various critical infrastructures, as well as the interdependencies between them, is crucial (De Graaf, 2012).

Adopting an interconnected network, in fact, will aid in the creation of a diverse ecosystem, where each component can communicate with the others, enhancing the productivity, encouraging a circular vision and making it easier to manage the entire project. By having a project designed around an interconnected system, all the interactions between resources (like food, waste, energy, …), natural elements (like wind, sun, rain, …), and technological choices (like wind turbines, water storage, compost gardens, …) can be greatly aided, in a way that makes it possible to spot potential relations between the various elements or, if needed, correct inefficient resource allocations. To make reading easier such elements will be grouped in this thesis, not in the same order, according to the ecosystem adopted in the OCEANIX City project, illustrated in the following *Figure 16*.

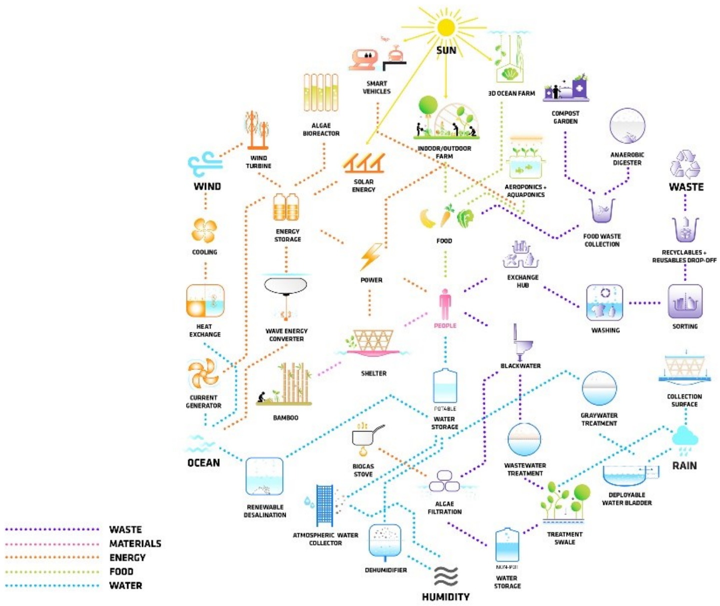

FIGURE 16: OCEANIX City project's internal ecosystem (OCEANIX/BIG-Bjarke Ingels Group).

In a floating city land use is also crucial. Being limited by their inherent nature, the platforms must be able to distribute a variety of technologies and technical elements, all of which must be compatible with an urban scenario, scaled down to be small and compact. Meanwhile the same area, must provide enough space for housing, offices, commercial facilities, infrastructures, green areas, recreation and much more. Thus, a comprehensive use of the available land is key in a complex project like OCEANIX City. An option could be to "hide" in the lower compartments of the platforms some uncomfortable or noisy technologies, like energy or water production machinery and storage systems, leaving communal areas, workplaces and residences in the upper ones. A possible rendered section is illustrated in the following *Figure 17*.

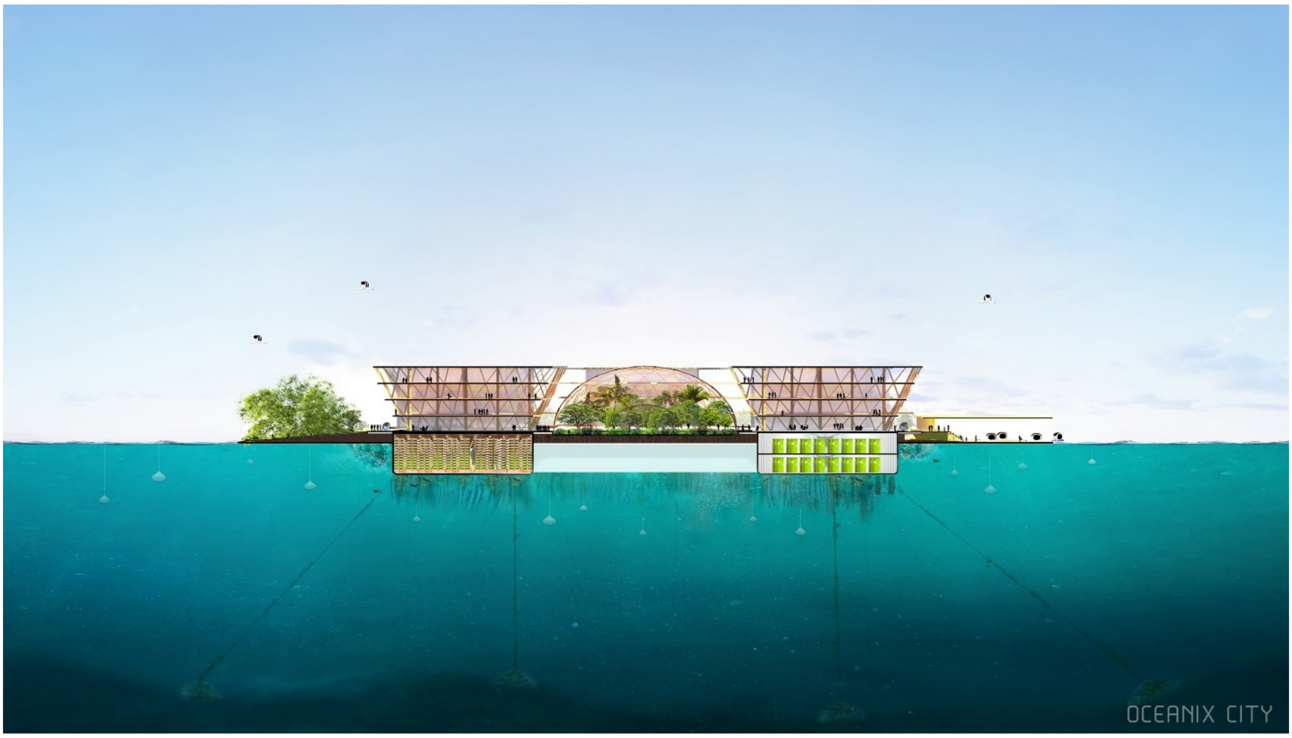

FIGURE 17: Rendered internal side section view of an OCEANIX City project's neighborhood platform (OCEANIX/BIG-Bjarke Ingels Group).

The fact that so many floating projects have been completed shows that it is technically possible to adapt installations to floating environments. Large cruise ships and other offshore projects like oil platforms and gas rigs, so massive that one could almost consider them to be floating cities, have adopted scaled down decentralized technologies as a way to address the issue of land scarcity. In addition, other smaller floating systems, including artificial reefs, shallow and deep water mooring systems, floating energy production installations and floating wetlands are already available on the market (De Graaf, 2012).

Just like cruise ships and offshore installations, floating cities probably won't be connected to the mainland's electricity and water networks, hence decentralized technologies for producing water and energy will be primarily used (De Graaf, 2012). The introduction of pipelines to transport gas and energy from the land would, in fact, present many difficulties and challenges, given that these systems can be highly susceptible to external forces from the surrounding environment or the floating city itself (for example waves, movements and torsion of the floating platforms, earthquakes, ...) (Ko, 2015). The application of decentralized systems on a project like OCEANIX City will also represent a great opportunity because not only floating installations will provide a great testing and developing ground, but even a growing market for them. This will make it more appealing for businesses to fund both the research and the development of these technologies. Lower cost and better quality will be the result. Also new jobs will be created. In the end, decentralized sustainable technologies will be better able to compete with the land-based outdated infrastructures that were often created during the industrial revolution and that are currently dependent on fossil fuel inputs. Therefore, by creating a new city model and producing more effective and competitive clean technologies, floating cities also give land-based cities the means to become more sustainable (De Graaf, 2012).

Technology needs to be also modular. The very nature of a floating city is based on this attribute. Because it is modular, a floating installation can gradually expand over the course of time, by steadily adding new platforms on the outer side of the existing floating community, without having to worry about whether the platforms are going to fit together or not. Technology must behave the same. By leveraging current existing options rather than future ones, technical components, like food and energy production technologies, water filtration systems or waste management systems, need to be designed with future implementation in mind, being continuously iterated once new concepts emerge or when demand begins to outpace supply.

Ultimately, technology needs to be social. The project could be promoted implementing technologies designed to engage the public and boost the overall project participation. Due to floating urbanization, citizens may have new opportunities to participate actively in the production of food and energy, in the supply of water, as well as in the management of waste of their city. As a results floating communities will become more independent. Nowadays, in fact, it is very difficult for citizens of land-based cities to contribute to sustainable development; even if people want to act sustainably, the current way cities are designed do not offer the right environment for them to do so. More and more people must go to supermarkets to purchase food and are in some shape or form constrained to the utilization of fossil fuels. Because of the way today's cities are constructed, a sizeable portion of the population has no choice but to drive to work. Instead, in a floating community, people can play a much bigger role in energy, waste, food and water management. In OCEANIX City, to get to work, resident will use shared water-based electrical modes of transport. They don't have to feel bad about living in an ecosystem-demanding city because the sustainable floating model benefits environment and its biodiversity (De Graaf, 2012).

This innovative and sustainable lifestyle takes especially shape in the project of OCEANIX City, which plans to be resilient, inclusive and self-sustainable, adopting an integrated system which lays its foundation on six main key concepts.

- Net-Zero Energy: affordable, abundant clean renewable energy from solar, wind, waves and sea currents. An energy management that aims to avoid wastes and surplus (as much as possible) while still covering the entire demand.

- Fresh Water Autonomy: the water supply will be carried out via the latest water harvesting, filtering, recycling and distillation systems.
- Zero Waste Systems: closed-loop processing will turn waste to energy, agricultural feedstock and recycled materials, aiming to reduce material footprint.
- Habitat regeneration: Biorock (the patented technology chosen for the platform lower side coating) is a unique ocean technology able to produce the only marine construction material that grows, heals itself and becomes stronger with age.
- Plant-based food: the food supply will consist of organic produce from high yield, decentralized, soilless and permaculture systems. Plant based diet seems to be the most probable choice.
- Shared mobility: shared and multimodal mobility will grant an integrated, mixed and productive community, replacing all fuel-based cars, reducing carbon emissions and promoting a healthy lifestyle (*Oceanix.com*, 2022).

Of course, new technologies and innovations in water and waste management, energy production and sustainable construction, which all call for new ways of working, new skills and new knowledge, even if they are technically and financially feasible, won't necessarily be adopted. Innovations, which are often hardly evaluated and improved, frequently serve as lone showpieces that do little to advance the overall transformation of the urban system. Additionally, demonstration projects are often not broadly replicated. As a result, they continue to be marginalized and are unable to change the accepted daily practice of urban water management (De Graaf, 2012). According to Brown and Keath, sustainability operators and strategists should put more of an emphasis on supplying the resources and tools needed for projects to be replicated and improved rather than just demonstrating technology (Brown & Keath, 2008). To realize flood-proof ecocities, a commercial market for innovations must be also established. There are currently, in fact, very few incentives for local residents and developers to demand sustainable progress. Awards, subsidies, increased developer competition and binding targets and regulations with regard to water management, such as on water-resistant buildings, source control, water quality, quality of the urban landscape and integration with water management, could all be used to create these incentives. Making innovations more competitive than conventional accepted practices is crucial for a smooth transition from current cities to flood-proof ecocities (De Graaf, 2012).

The following segment of this work will be dedicated to the theoretical presentation of the different technical and planning elements of the OCEANIX City project. The analysis of the main technologies is performed through a S.W.O.T. (strengths, weaknesses, opportunities, threats) approach, with the intent of classifying each technical element as more or less feasible for this type of floating city project, thus, always keeping in mind the architectural, structural, social and environmental characteristics and limits of such project. SWOT analysis is a strategic planning method utilized to analyze the strengths, weaknesses, opportunities and threats related to a project or a business. Identifying them is essential as it can help individual plans for achieving goals. Given the SWOT analysis, decision-makers must often assess whether the goal is achievable. Assuming a goal is unattainable, another goal must be decided, and the process is repeated to achieve the best result. The SWOT analysis identifies:

- Strengths of the project that makes it superior to others;
- Weaknesses that make the project vulnerable or at disadvantage to others;
- Opportunities in the environment that the project can take advantage of;
- Threats in the environment that can cause trouble for the project.

The choice of the specific type of technology (for example the type of wind turbines operative mode, the type of procedure to filtrate wastewater, …) to be used will be done considering the most reasonable option for the type of application, since specific information regarding these choices has not yet been clearly released.

4.1.2.2.1 ENERGY

With the mounting tension brought on by global climate change and population growth, the whole world is starting to recognize the need for more creative and sustainable solutions. Societies and economies are changing, temperature and sea levels are rising, and there is no doubt about the fact that human activities are the first responsible for these impacts. To mitigate this, new concepts and ideas that were once thought to be radical or unfeasible, are now being taken seriously and can be found under development all over the world. Designing and planning around the concept of sustainable and renewable energy sources would go a long way to reduce these humans' effects on the environment.

Cities should invest more in key areas such as electrification, hydrogen, bioenergy and carbon capture, utilization and storage. Moreover, clean power generation but also network infrastructures, support infrastructures and end-use sectors are crucial areas which sustainable urban areas must consider essential in order to transform energy systems (Yang et al., 2022). But to make this possible a ton of research is still needed, especially if one of the ideas is to build a self-sufficient, climate-proof floating city.

The offshore environment houses an abundant amount of renewable energy, which can be exploited by urban areas that are located close to the ocean. Many of the world's biggest city are in fact coastal cities, whose vicinity with clean, renewable energy sources can provide excellent opportunities to meet power demand, reduce energy losses due to transport and reduce the investments for long infrastructures. For these reasons, in comparison to more inland realities, a floating city like that of OCEANIX can undoubtedly benefit even more from its unique geographical location. Surrounded by the sea, a floating city can benefit from tides, waves and currents to generate electricity or from seaweeds, algae and other marine microorganisms grown locally to produce biofuel and valuable chemicals.

Although still in development and not yet fully commercialized, floating photovoltaic panels could be another source of energy. In fact, four-fifth of all solar energy that reaches the earth is stored thermally in the ocean, making the ocean “the largest solar conductor in the world”, said Bob Nicholson, former president and director of global market development of OTEC International (Adnan, 2020). This kind of technology emerged nearly a decade ago, driven mainly by the lack of available land, loss of efficiency at high operational cell temperature, energy security and decarbonization targets. At present, inland freshwater bodies allocate the vast majority of active projects and installations, but, with an increasing interest toward this type of technology, industries are currently moving forward with the development of floating solar systems for use in marine environments (Oliveira-Pinto & Stokkermans, 2020).

Countries like Japan and Singapore are investing heavily in floating solar farms because of their limited land availability or very expensive land property. The European Union has proposed a massive ramping up of renewable energy to reduce its reliance on Russian oil and gas. On the lake Oostvoornse Meer, in the South-West of the Netherlands, a circular floating solar farm has been built. This is no normal solar array, like the many new solar farms being installed in lakes, reservoirs and coastal areas across the world, because of its ability to track and follow the Sun as it moves, capturing as many rays as possible. This installation, named Proteus after the ancient Greek sea god, is covered in 180 moving panels and it is able to produce up to 73 kilowatts of peak power. "If done well in the right place, floating solar has the potential to provide much needed low carbon energy without taking up land and whilst improving water body condition" said Alona Armstrong, senior lecturer in energy and environmental sciences at Lancaster University and co-author of a study that aims to review the environmental benefits and risks of floating solar farms; "Our research shows that floating solar cools the water body and reduces phytoplankton biomass” (Gerretsen, 2022).

Conventional solar panels can also offer useful advantages, especially when integrated with other offshore renewable energy productions, like wave, tides and wind technologies; besides, since water covers more than two-thirds of the planet's surface, using only a form of energy would be inefficient. In a maritime context in fact, not only sun energy, but also wind energy can play an important role in achieving sustainable energy production. Wind can operate Vertical Axes Wind Turbines (VAWTs) or start sea wave motion, that can be exploited with Wave Energy Converters (WECs). Tidal Stream Generators can take advantage of ocean currents and tides to produce electricity, and Ocean Thermal Energy Conversion (OTEC) systems can exploit the temperature difference between deep cold water and surface warm water, recovering the thermal energy trapped in the ocean. Combining different forms of clean technology could also help overcome one of renewable energy’s biggest obstacles: its reliance on variable weather conditions and its inability to store and transmit steady power when needed. Interconnection between different energy sources and technologies is key.

Another innovative technology uses microorganisms and microalgae to produce energy. Microalgae are unique photosynthetic organisms able to absorb nutrients from the water, synthesizing them into useful sugar and bioenergy due to their ability to capture light. Essential for the Earth’s self-regulatory system and present in almost every water body of the planet, they are considered valuable allies for future implementation on countless industrial sectors. Microalgae can, in fact, be used to obtain valuable chemicals for pharmaceutical and cosmetic applications and, even if a cost-effective market is not fully developed yet, their ability to manufacture food for themselves using seawater and solar energy would aid in the development of a sophisticated technology for a future biofuel industry.

A floating city could surely consider this as an additional source of income, selling this biofuel to other coastal cities, just as Saudi Arabia and other middle eastern nations do with fossil fuels to other countries. In a self-sufficient environment, such as that of a floating city, systems utilizing microalgae may also be combined with other systems to increase the overall efficiency. For example, wastewater or urban groundwater could be treated with these organisms for biogas production, recovering at the same time heat with heat pumps or heat exchange systems.

In Paleiskwartier Den Bosch, in the Netherlands, for instance, a shallow pond is used as heat collector for the nearby buildings. Solar energy is collected in summer, storing heat in an aquifer thermal energy storage, and then used in winter for heating the houses, offices and apartments. The entire surface required to collect enough heat is about 80 square meters per house (De Graaf, 2012).

Undoubtedly, all of these technologies offer a potential sustainable alternative for current energy production methods and could make a significant contribution to the future energy mix. But is the existing technology concerning green energy production really capable of being developed for a floating city? Probably. Failure is likely not a technological issue. Society already knows how to build sustainable and efficient installations on land, and it is also capable of creating floating structures. It is not science fiction, engineers and architects have been doing this for decades (De Graaf, 2012). The combination of the two is what is problematic. This makes it crucial that new opportunities and concepts are developed using the expertise and success of inland renewable energy projects. Once more knowledge of the topic has been gained by carefully examining the technical feasibility and challenges involved, the development of sustainable energy production technologies in aquatic and floating environments can be put into practice.

Additionally, the types of applications for which these technologies will be used should be considered. Whether the energy is produced for offshore or near-shore projects make a difference. If a project is near the coastline or has a direct territorial relation with an inland urban reality, the likelihood of integrating energy production with an existing system is higher. For example, a project like OCEANIX Busan, designed to be an organic expansion of the urban fabrics of the Korean city, could use some energy supplied by inland plants, or even export energy to the land once a self-sufficient system is fully developed. Connections and network infrastructures, made possible by the proximity to inland urban areas, undoubtedly would alleviate part of the stress which an isolated community in the middle of the sea would experience. When moving to open waters, it is also advisable to investigate the scale of the technologies. For offshore projects, like future iterations of the OCEANIX one, to be completely self-sufficient, all of their resources, including energy, must be produced locally. And in a project where efficient land use is a priority, this calls for the adaptation of all technology to the urban scale, since the distance from the coast makes impossible or very inconvenient to import energy from mainland plants, which undoubtedly have a larger territorial expansion. When designing a new floating neighborhood, for example in a city like Amsterdam, sustainable energy could be provided by conventional regional tidal or wind plants far from the city, as well as small solar panels installed on roofs. Instead, in the middle of the ocean, solar, wind, wave and other sources of energy can be exploited only with urban scale installations and decentralized technologies, each with its own performance and operational principles. Hence, to develop a reliable floating energy production system, that is both affordable and resilient to harsh marine environments, research activities should focus initially on nearshore applications and then move to the open seas.

In keeping with this idea, OCEANIX itself has, in fact, unveiled OCEANIX Busan, the world's first prototype of a resilient floating city, as the first buoyant expansion of the South Korean port city of Busan. When fully developed, the floating prototype will take advantage as much as possible of its location to harness energy from clean and renewable sources, via the use of urban scale solar panels and vertical wind turbines on top of physical infrastructures offshore and in the city or exploiting the waves and currents of the surrounding sea with floating and underwater installations. *Figure 18* shows an example of how these technologies might be used in practice.

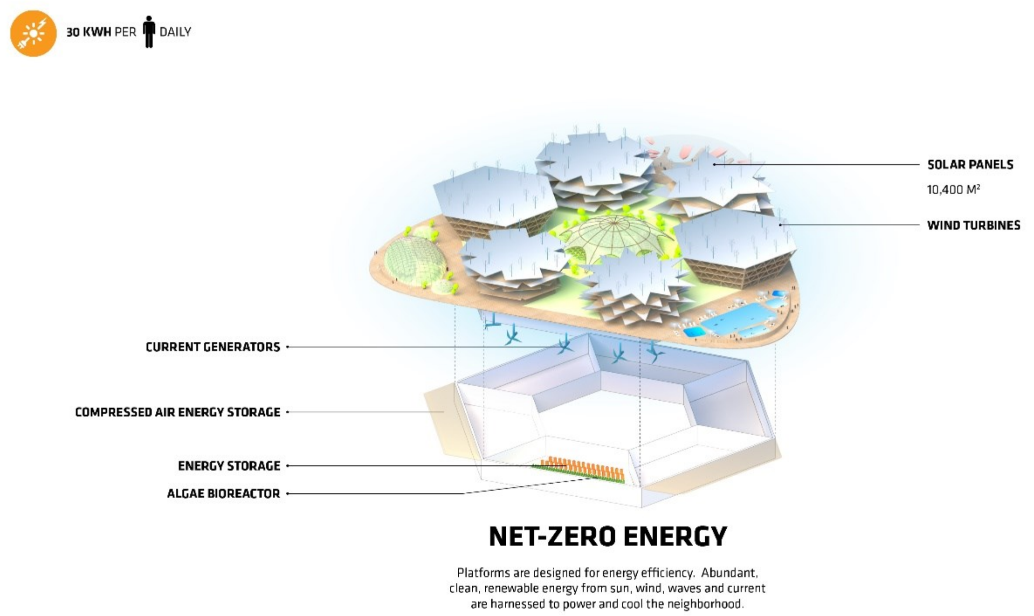

FIGURE 18: Net-Zero Energy as envisioned for the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The idea of "Net-Zero Energy" serves as the project's theoretical foundation. Achieving this concept means to be able to have a null energy production–consumption value, with the goal of avoiding energy wastes as much as possible, while still being able to completely satisfy the city's demand, optimizing therefore the capability of installed energy generating plants present in the city, in accordance with the crucial role of space saving.

It is estimated that the daily per capita energy use of the residents will be around 30 kWh, or around 300,000 kWh considering the floating city fully developed, with its 10,000 inhabitants (*Oceanix.com*, 2022). This value is much higher than the standard energy demand usually required in the mainland housing, and it is probably due to the completely different needs and nature of the OCEANIX project. Planning to be completely autonomous, without relying on external connections once fully developed, all the energy produced on site needs to satisfy agricultural demand, mainly composed by aeroponic and aquaponic (two high energy demanding urban agriculture techniques), transport demand, that plans to be almost entirely based on electric mobility, housing and service demand. Clearly, bigger quantities of energy are therefore needed.

According to literature, the average annual rate of new renewable energy capacity in Busan is 14.3%. This value is estimated to be higher than the national average value (12.1%), but, comparing it with other seventeen cities and provinces in the country, the self-sustainable energy

capacity value of the city is only 11th. Moreover, the ratio of new renewable energy in the power supply composition of Busan was only 2.1% in 2017 (Yang et al., 2022). Therefore, completing this pioneering project, that envisions to use abundant, clean, renewable energy sources, the city of Busan will surely be a step closer to manage energy in a more sustainable way.
The following chapters will provide theoretical insights on the various technologies chosen by OCEANIX. A SWOT analysis will be given for each technology included in the "energy kit of parts" (shown in *Figure 19*).

FIGURE 19: Energy kit of parts of the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Solar energy

Photovoltaic technology is considered a clean energy source, as there is no polluting or climatic emission during the energy production. It is likely one of the most widely used renewable sources in the world, serving as one of the most crucial factors for the transition to a more sustainable future in energy production. Some experts, in fact, even estimates that deploying photovoltaic technologies in upcoming years could help reduce up to 50% of the world's carbon emissions, effectively suppressing a 2 °C rise in the global temperature by 2050.
Concerning the OCEANIX City project, in particular, to ensure Net-Zero Energy, many buildings in the platforms will be provided with solar roofs, which can be topped also with wind turbines, to harness as much energy from the sun as possible. If not enough, additional smaller dedicated photovoltaic platforms and energy outpost will be installed to provide enough energy for the

neighborhoods. The production of electricity through photovoltaics will therefore not be dedicated exclusively to rooftops (*Oceanix.com*, 2022).
Unfortunately, the exact technological choices and planned elements have not been provided yet. Due to the more developed applied science behind solar applications, there exist a huge variety of solar PV panels, but no exact typology, information or quantitative data has been made public. For this reason, all the considerations, comparisons or analysis on the specific technological choice adopted in the project (not only with solar, but with almost every technology) will be done considering the most reasonable option for the type of application.
Currently, there exist three major types of solar panels, often used in residential and commercial installations: monocrystalline, polycrystalline and thin-films panels (Zito, 2023). They are different form one another, with different properties, performance and characteristics, however, they all relay on specific properties of semiconductors (mainly Silicon, in fact it is estimated that about 90% of photovoltaic modules installed in the world are based on crystalline silicon) to absorb solar energy in dedicated photovoltaic cells, transforming it into electricity. Monocrystalline modules are more performant (from 15% to 22% efficiency), but more expensive, while polycrystalline modules are less efficient (from 13% to 17% efficiency), but more affordable (Zito, 2023). The remaining slice of the market is composed of thin-film technologies that use other semiconductor materials such as amorphous silicon (a-Si), Copper-Indium-Gallium Selenide (CIGS), Cadmium Telluride (CdTe).
Probably, among several choices, for the project of OCEANIX Busan the most likely typology to be installed could be the Monocrystalline Silicon one because, apart from its higher efficiency, this type of modules are able to produce the same level of power as that of the other typologies but taking up less space. And for a floating city, where efficient land management is key, this is surely one crucial factor.
But also, less common and even under development solutions could be considered. For example, OCEANIX Busan could use special solar panels that not only produce energy but are able also to harvest water out of the air humidity. Launched in 2015 by the Zero Mass Water startup, this particular panel, called Source, is able to provide up to 5 liters of water per day, eliminating the need for 54,000 single-use plastic water bottles over its 15-year lifespan. The panel works drawing ambient air with fans, pushing it through a water-absorbing material. Collected water is then mineralized and cleaned from pollutants, making quality drinking water a readily available resource (*How Do Hydropanels Work?*, 2022). Surely a nice addition for the whole OCEANIX City project.

Table 1: SWOT analysis of solar energy

STRENGTHS	***WEAKNESSES***
-sustainable and renewable energy -abundance of potential solar energy -zero carbon emissions -high technological development -low maintenance cost (long-run) -broad range of applications -payback period	-dependent on external conditions (sunlight) -high initial investment cost (short-run) -not negligible space requirements (land use) -require energy storage
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -increase the technological development of solar applications -covering peak energy consumption -decentralization -new jobs -raising social and environmental awareness	-PV panels initial production and end-of-life not so highly sustainable compared to the energy production period (hazardous/rare materials involved, uncertainty in the recycling, …) -public perception, misinformation, social acceptance

Wind energy

In a maritime context like that of the waterfront of Busan, wind can play an important role in achieving sustainable energy production. There exist two main typology of wind turbines, vertical axis wind turbines (VAWTs), designed with the main axis perpendicular to the wind streamlines and vertical to the ground, and horizontal axis wind turbines (HAWTs), designed with the main axis parallel to the wind streamlines and horizontal to the ground (*Wind Explained*, 2022).

When it comes to wind energy harvest, vertical axis wind turbines (VAWTs) are surely the most reasonable choice for this type of application, as they don't need nearly as much space as horizontal axis wind turbines to work properly. They also offer other advantages over traditional horizontal axis wind turbines (HAWTs), like the reduced noise and reduced danger for flying animals. They can also operate in conditions deemed unsuitable for horizontal axis turbines, such as in irregular and slow wind. Another crucial advantage of some VAWTs is that their conformation makes it possible for them to work with wind coming from any direction, making them ideal for

installations where wind conditions are not consistent, or situations where the turbine cannot be placed high enough to benefit from steady wind. Also, the vertical design allows to locate the main components at the base of the turbine, facilitating service and repair.
Vertical axis wind turbines (VAWTs) come in a variety of forms and designs, each with its own operational principle, applications, performance and power rating specifications. However, despite the different shapes, technically, VAWTs can be categorized in to two main groups based on their operational principles: the Savonius model, with helix shaped blades, and the Darrieus model, with H-shaped or "egg-beater" blades (*What Is Vertical Axis Wind Turbine (VAWT) and How Does It Work?*, 2020). Both typologies are more complex than conventional horizontal axis turbines from a hydraulic point of view, and they work in a very distinct way. In fact, regardless of how the turbine is structured (and of which type it is), one part will rotate in a wind-opposite direction, while the other part will rotate along the wind direction, therefore actively inducing the rotating motion. For this reason, some VAWTs typically need a certain amount of power, feed through an electric motor, to "start-up" the rotation. They can be used both for industrial application and for civil applications, and it is mostly in this field that they are starting to become a popular option for producing renewable energy at home, whether they are employed in on-grid or off-grid energy production.

Table 2: SWOT analysis of wind energy (Vertical Axis Wind Turbines)

STRENGTHS	***WEAKNESSES***
-sustainable and renewable energy -ease of production even at low wind velocity -energy production independent from wind direction -reduced space requirement -broad range of applications -contained costs of installation and maintenance	-dependent on external conditions (wind velocity) -size depend on the available roof space (land use) -some types of VAWT must be energy-feed to start the rotation process -require energy storage
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -increase the technological development of wind applications	-some maintenance interventions require the disassembly of the entire turbine -not negligible visual impact

-covering peak energy consumption -decentralization -new jobs -raising social and environmental awareness	-public perception, misinformation, social acceptance

Wave energy

Seas and oceans contain huge potential renewable energy resources in form of offshore wind energy and ocean energy (often referred as "Blue energy"). This blue potential derives especially from waves, tides and currents, and in less form from thermal and saline gradients. Compared to the previously mentioned energy sources, ocean waves offer greater level of consistency and are more predictable than solar and wind energy. In fact, although the power spectrum produced by waves is larger, waves host both enough potential and cinematic energy that can be harnessed producing electric current up to 90 percent of the time, far performing other renewable applications. Higher wave power can be found in places where stronger winds are present, for example in the Southern Ocean and in the North Atlantic, mainly between 40° and 60° North and South latitude. But in these regions, characterized by extreme and uneven weather conditions, the demand for toughness of the design and the service life of most devices is stricter, meaning higher production and maintaining cost. Therefore, areas with more consistent climate, with long swells with amplitude of 2 to 3 meters or less, even if the maximum energy yield is lower, are preferred. For these reasons, the calm and sheltered reality of the port of Busan surely is a reasonable choice for this type of application ("*Wave Energy Converters*", 2023).

Although many attempts to harness this resource with Wave Energy Converters (WECs) and other equipment date back more than a hundred years, nowadays wave power is still not widely employed all around the world. It is estimated that in 2020, about 16 MW was produced with operational wave power plants, a value about 5 orders of magnitude less than the 2 to 3 TW of potential energy which the ocean is estimated to hold. This is mainly due to the cost of ocean energy, still very high compared to other renewable alternatives. There are also social and economic, as well as infrastructural and environmental barriers preventing further developments of this form of renewable technology. But although these negative aspects it is not to be doubted that transforming ocean energy into electricity could play an important role in meeting the rising energy demand, diversifying energy supply, increasing energy security and protecting the environment, also boosting the economic growth in the coastal regions ("*Wave Energy*

Converters", 2023). In fact, while marine energy potential does not have a uniform oceanographic distribution, it is available in most of the coastal countries (Stingheru et al., 2018).

A standard Wave Energy Converter (WECs) works exploiting the potential energy contained in waves converting it into electricity using particular turbines or other power take-off systems. In the last decades a huge variety of design has been invented, resulting in thousands of patents and pilot technology, each with its own operational principle, applications, performance and power rating specifications. Oscillating Water Columns (OCW), Overtopping Devices, Wave Absorbing Devices are the most popular methods for wave energy conversion. Depending on the design some apparatus can work by capturing the energy at the surface of the water or capturing the energy at a low water depth, for example exploiting pressure fluctuations. For these reasons, due to their versatility, WECs may be found floating or submerged beneath the surface of the water and under floating platforms, or they may also be located on the shore or on the seabed in shallow water ("*Wave Energy Converters*", 2023).

Table 3: SWOT analysis of wave energy

STRENGTHS	***WEAKNESSES***
-sustainable and renewable energy -abundance of potential wave energy -waves are more predictable and stable in time compared to sun and wind -high variety of pilot technologies -broad range of applications -submerged applications have lower visual impacts	-high cost during all the life of the equipment (production, installation, maintenance, …) -dependent on external conditions and locations -not so high efficiency (only a small fraction of the wave can be exploited) -early stages of development -noise -floating applications can have negative visual impacts -uncertainty on the impacts on marine ecosystems -require energy storage
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public)	-other renewable technologies seems to be a better option -small market for the ocean energy technology

-increase the technological development of wave energy applications -increased interest toward ocean-power sector -decentralization -high unexploited potential -new jobs -covering peak energy consumption -raising social and environmental awareness	-public perception, misinformation, social acceptance

Tidal energy

Tidal energy is a form of renewable energy produced exploiting the movement of water bodies induced by tide variations. The highly regular and predictable nature of tides, due to the regular pattern tuned by the Earth's rotation and the Moon's orbit around the Earth, allow to generate a flow of energy that is more consistent in time than the one generated by solar or wind applications. Although this, tidal applications are not yet widely used, because of their relatively high cost and limited availability of sites. In fact, to work efficiently, tidal energy plants should be placed only in water bodies characterized by significant tidal range, so where there is a big height difference between high tide and low tide water surface level, and as a result, high tidal current velocities. To add to this, semidiurnal (two high tides and two low tides per day, with the same height between the two) and mixed semidiurnal (two high tides and two low tides per day, but with different height between each two) tidal zones are to be preferred when positioning a new tidal energy plant, and South Korea, having a mixed semidiurnal tidal zone with high tidal excursion (up to 1.5 meters), certainly meets these requirements (*Korea Hydrographic and Oceanographic Agency*, 2023).

Currently, this renewable energy technique, compared to others, is still in its early development, and very few commercially sized plants exist, producing a small amount of power. In any case, South Korea, home of the OCEANIX Busan prototype, plays a leading role in the development of this technology, as it is already home of two big plants, one currently being the largest tidal energy plant in the world (Sihwa Lake Tidal Power Plant), with a total capacity of around 254 MW ("*Sihwa Lake Tidal Power Station*", 2023).

While there are many different tidal energy production methods (Tidal Stream Generator, Tidal Barrage, Dynamic Tidal Power, Tidal Lagoon), the only real feasible option to be implemented in the OCEANIX project would be Tidal Stream Generators. This technology functions similarly to underwater wind turbines: moving masses of water generated by tides run through this machine operating a turbine that, rotating, generates energy. However, due to the higher density of water compared to air, the potential power generated by a single turbine can be greater than that of a similar rated wind turbine, operating with similar wind speed. There are, in turn, different iterations of TSGs, like axial turbines, crossflow turbines, flow augmented turbines, oscillating devices, venturi effect devices, tidal kite turbines, each with its own operational principle, applications, performance and power rating specifications ("*Tidal Power*", 2023).

Table 4: SWOT analysis of tidal energy

STRENGTHS	***WEAKNESSES***
-sustainable and renewable energy -zero carbon emissions -highly predictable energy source compared to sun and wind -consistency -high durability, high energy density and power output -easy to predict the payback period, given the reliability of the energy generation -high variety of technologies -broad range of applications	-high initial investment cost -narrow energy production considering the occupied volume (compared to other renewable solutions) -require energy storage
OPPORTUNITIES	***THREATS***
-preexisting know how (South Korea already features two of the most important tidal energy plants in the world) -chance to solidify South Korea's position as a world leader in the technology (Busan perspective) -covering peak energy consumption -decentralization -high unexploited potential -new jobs -raising social and environmental awareness	-swimming sea life can be killed by the rotating blades -limited site availability -salt water can corrode submerged metal parts -the apparatus can introduce negative impacts on shore sediment transport -public perception, misinformation, social acceptance

Bio energy

Microalgae are microscopic photosynthetic organisms which are commonly found living in rivers, lakes and seas. They are considered unique and potentially valuable microorganisms due to their capacity of capturing light through photosynthesis, which they use to synthesize sugars and energy, both necessary for their life (Bruno & Congestri, n.d.).

The application of microalgae in the industrial sector is not a new practice, in fact, their commercial cultivation has more than 40 years of experience, which has contributed to the development of different cultivation systems, starting from more classic open-air cultivation systems (natural water bodies such as lakes, lagoons or ponds, in the past, and artificial ponds) to more recent closed photobioreactors. Open-culture system are generally located outdoors and relay on natural light for illumination. They are relatively inexpensive to install and maintain but suffer from several problems such as a tendency to be more easily contaminated and, especially, a huge land use required to correctly operate. On the other hand, closed systems (tubular or flat plate, airlift or bubble-column photobioreactors for example) are smaller in size and can better be monitored at laboratory scale to control cultivation conditions and minimizing contaminations. They are for these reasons a better choice for the OCEANIX application. Major drawbacks, instead, are related to higher costs associated with the constant monitoring required and the need to feed the microalgae with nutrients and light (Xu et al., 2009).

Microalgae are often called "green factories" due to their ability to produce countless compounds of great application interest, while consuming only CO2, mineral salts and solar energy. For years now, large-scale cultivation systems have been employed, increasing their use in several sectors:

- in aquaculture as food for mussels, crustaceans and larval stages of fish;
- in nutraceutical applications for their high nutritional value;
- in pharmaceutical applications for the continuous discoveries of valuable bioactive molecules for the treatment of diseases;
- in bioenergetic production for the high oil content (biodiesel, ethanol, gasoline production) and the production of hydrogen;
- in environmental applications for their ability to bioremediate polluted water (absorbing nutrients in wastewater), soils and air (absorbing CO2 for the photosynthesis) (Bruno & Congestri, n.d.).

For these reasons, producing these valuable microorganisms in various laboratory or greenhouse located on the platforms, could benefit the project of OCEANIX City in several ways.

Table 5: SWOT analysis of bio energy (indoor photobioreactors)

STRENGTHS	***WEAKNESSES***
-sustainable and renewable energy -more than 40 years of experience -microalgae can become an alternative source of biofuel (biodiesel, methane, hydrogen, …) -can work also for environmental purposes (wastewater filtering, air filtering, …) -indoor solutions (photobioreactors) have low land use -microalgae can be used to produce high-value chemicals for other sectors (pharmaceutical, cosmetic, …) -microalgae can be used as an alternative source of food -broad range of applications	-higher cost (building and maintenance) compared to outdoor solutions -constant maintenance required -high quantities of energy (light, temperature), water and nutrients required compared to outdoor solutions -knowledge and experience required
OPPORTUNITIES	***THREATS***
-increase the technological development of microalgae applications -increased interest toward energy production from microalgae -possibility to interact with other valuable sectors (pharmaceutical, cosmetic, …) -covering peak energy consumption -decentralization -high unexploited potential -new jobs -raising social and environmental awareness	-outdoor solutions (not convenient in OCEANIX City) seem to be a more feasible choice -negative energy balance of biofuels coming from microalgae compared to standard biofuels -public perception, misinformation, social acceptance

Energy storage

As emphasized numerous times, one of the fundamental ideas underlying the OCEANIX project is the concept of “Net Zero Energy”. This idea enables the development of a system in which energy requirements are entirely met by energy derived from renewable, emission-free sources. There are of course challenges with this aspect, the most significant of which is related to one of the main drawbacks of renewable energy, namely its reliance on the weather and its inability to store and transmit power when needed. Because of this, the OCEANIX project should take into account a specific type of energy storage that can guarantee the effective use of these resources. Although there are currently a number of commercially available energy storage technologies, new long-term and short-term storage concepts are constantly being developed and improved to lower capital costs and boost energy conversion efficiencies. Most recent commercial systems use batteries, or Battery Energy Storage Systems (BESS), to store energy from renewables, like solar and wind. But traditional battery systems bring with them further disadvantages like shorter service life and higher maintenance, cooling and ventilation required, general lower reliability and higher space needed. Furthermore, batteries are generally made of toxic and harmful components, that can be a threat for marine environments and strongly diverge from the concept of sustainability, central in the OCEANIX project. To avoid these problems, two different alternative storage systems where considered: compressed-air energy storage systems and flywheel energy storage systems.

Compressed-air energy storage (CAES) is a form of mechanical energy storage able to store energy using compressed air. The procedure is simple: pressurized air is pumped in special storage tanks or underground natural reservoirs, then, when energy is needed, the stored energy is retrieved allowing the air to expand through a turbine to produce electricity. With this technology, energy generated during low demand can be released during peak load periods, making it exceptional to support highly intermittent energy sources like photovoltaics and wind satisfy fluctuating electricity demands. Commonly used as a large-scale, long term energy storage technology, able to store tens or hundreds of MW of power capacity in underground geological formations, CAES need to be scaled back to be compatible with OCEANIX City and other dwelling applications. ("*Compressed-air Energy Storage*", 2023).

Unfortunately, due to the size of installations of their larger counterparts, as well as their associated costs and tendency to be included in utility-scale storage applications, there are currently only a few prototypes of small-scale CEAS systems. Therefore, additional research and studies are required to develop a useful energy storage system that uses compressed air to provide energy for residential applications (Castellani et al., 2018). If technological development will be able to create smaller commercially feasible installations, then also smaller realities as commercial and residential buildings will be able to take advantage from the numerous benefits of this technology.

Due to its high capacity, high power rating, and long-duration storage, a common large-scale CAES apparatus offers a wide range of advantages for energy storage in a variety of applications, allowing for energy savings and low maintenance costs. However, it has the disadvantages of low power density, high transportation losses and possible water loss through evaporation. Moreover, since the compression of air results in an unwanted temperature increase that not only reduces operational efficiency but can also cause damage, managing thermal energy is a persistent challenge in large-scale design (Simons et al., 2021).

Table 6: SWOT analysis of renewable energy storage (Compressed-Air Energy Storage systems)

STRENGTHS	***WEAKNESSES***
-environmental advantages (compared to commercial batteries) -large-scale CAES systems can store large quantities of energy -energy can be stored for more than a year (long-term applications) -cost-competitive energy storage technology -start up is faster than conventional generation plant -broad range of applications	-most systems need a constant heat management to operate efficiently -energy losses in the compression and expansion processes
OPPORTUNITIES	***THREATS***
-increase the technological development of compressed-air storage applications -renewable energy sources can be integrated in the same system -covering peak energy consumption -decentralization -new jobs -raising social and environmental awareness	-large-scale typologies are dependent on suitable geological formations -other conventional energy storage technologies can be more efficient -small-scale applications not fully developed -public perception, misinformation, social acceptance

Flywheel energy storage (FES), instead, works by accelerating a rotor (flywheel) to a very high speed, maintaining the energy in the system as rotational energy. FES is one of the earliest forms of energy storage and it uses the principle of energy conservation to operate the system: energy stored in the flywheel rises when new energy is introduced, increasing the angular speed of the rotor, and it decreases in a similar way when energy is removed due to demand, slowing down the angular speed (Pullen, 2022).

For high-power, high-cycle applications, flywheel energy storage systems provide a straightforward, reliable and sustainable storage solution, but apart from their use in the transport sector (usually present on the shaft of internal combustion engines) and the power industry (used as an Uninterrupted Power Supply for power grid stabilization), this form of energy storage have not made it past successful niche applications (Pullen, 2022).

FES systems are well suited for short-duration applications, and in recent years their implementation in solar and wind project, to improve power quality, has increased. They find, in fact, exceptional use in maintaining voltage and frequency and in providing steady power during electrical disturbance. Compared with several other energy storage they can provide energy in a matter of minutes without the needing time to start up. An exceptional long life (if designed properly a FES system can last up to 20 years), no emissions, low maintenance cost and roundtrip efficiency of about 90 percent are of the main advantages of flywheel systems. Also, compared to batteries, this storage system can operate under a wider range of temperatures and has no toxic impact on the environment. Low specific energy, leakage losses (windage and bearings), initial investment cost, lead time and a sizable footprint, especially when made of steel, are some inherent drawbacks. Although significant progress has been made, FES are currently inappropriate for use in energy storage applications of medium-duration to long-duration. As a result, current research and development activities are focused on continued improvement of power loss and increasing the energy density (Simons et al., 2021).

Table 7: SWOT analysis of renewable energy storage (Flywheel Energy Storage systems)

STRENGTHS	***WEAKNESSES***
-environmental advantages (compared to commercial batteries) -solid experience coming from transport and industrial sectors -fast start up -long life -low maintenance cost -roundtrip efficiency of about 90 percent -can operate under wide range of temperature	-high initial investment cost -lead time -low specific energy -leakage energy losses (windage and bearings) -sizable footprint (especially if made of steel)

-broad range of applications	
OPPORTUNITIES	***THREATS***
-increase the technological development of flywheel energy storage applications -renewable energy sources can be integrated in the same system -covering peak energy consumption -decentralization -new jobs -raising social and environmental awareness	-minor progress in their use in medium and long-duration applications -other conventional energy storage technologies can be more efficient -public perception, misinformation, social acceptance

Heat exchange

Heat exchangers are used to support processes of heat transfer between two sources that are at different temperatures. They find exceptional use in engineering applications, from simpler refrigeration, heating and air conditioning system to more complex power and chemical processing plants, but also food processing systems, automobile radiators and waste recovery units. Air preheaters, economizers, evaporators, superheaters, condensers and cooling towers used in a power plant are a few examples of heat exchangers (Balaji et al., 2021).

The OCEANIX project's floating platforms house a variety of heat exchange processes, where temperatures rise and fall continuously. Hence, for the whole installation to function properly, efficient temperature management is required in numerous applications, from energy production systems to wastewater treatment, from heated greenhouses to residential buildings.

There are several heat exchangers on the market, each with its own properties, operational principle, applications and performance. They can be classified based on different criteria, for example based on the nature of the heat exchange process (direct contact type, regenerator type, recuperator type) or the direction of the fluid flow (parallel flow, cross flow, counterflow), based on the mechanical design (concentric tube type, shell and tube type, multipass type), the physical state of the working fluid (condenser type, evaporator type) or the compactness (Balaji et al., 2021). The possible options to choose from are many and there is not a single right choice. However, to obtain the best outcome possible, in the project of OCEANIX City a BAT (Best Available Techniques) approach should be performed, choosing the best possible alternative for each application.

As already stated before, microalgae will find applications in the OCEANIX project for their ability to bioremediate polluted water. In wastewater treatment, common types of heat exchangers, such as double pipe heat exchangers as well as plate and frame heat exchangers, play a vital role in maintaining optimal temperatures, promoting the growth of the microorganism ("*Heat Exchanger*", 2023). Due also to their biological activity, wastewater from bioremediating processes will emerge decontaminated from major pollutants but at a higher temperature. Special heat exchangers must therefore be used to cool the water, reducing the overall temperature and at the same time, because of the mostly organic nature of wastewater, be able to resist grease, floating or coarse materials and sediments.

In CAES systems, changes in pressure are correlated with changes in temperature: typically, removing compressed air from the tanks results in a reduction in internal pressure, which results in a decrease in temperature, while storing more pressurized air follow a rise in temperature. As a result, heat exchangers are required to control the operation of these systems as well. The heat extracted could then be used as a secondary form of energy. In this instance, due to the entirely different nature and characteristics of the pressurized air, a different device with a different design and working principle will be used.

Similar observations could be made considering other simpler systems, like greenhouses temperature regulation or heating and cooling systems in domestic environments. Therefore, in light of the foregoing considerations, it seems crucial to consider heat exchangers as pivotal installations for a proper operation of the OCEANIX project, in particular viewing it from an energy perspective.

4.1.2.2.2 FOOD

The world's population has increased from 1 billion in 1800 to over 8 billion people today, and it is expected to reach about 11.2 billion by the end of the century according to UN estimates (United Nations, 2017). With the growing society new pressure is placed on the land, increasing the demand for more areas to accommodate the projected population. As a consequence, urban areas expand, radically transforming the surrounding landscape and having a direct impact on nearby agricultural lands, which are typically the first areas to be affected by this outward expansion; globally in fact, urban sprawl is the main factor causing agricultural land loss (Güneralp et al., 2020). According to a landmark study report produced by the United Nations FAO (Food and Agriculture Organization) in 2021, about 33 percent of the world's soil is "moderately to highly degraded" (FAO, 2021), and yet, to feed the estimated 9.8 billion people by 2050, the world's farmers still need to produce 60 percent more food (De Graaf, 2012), increasing the land area dedicated to farmland to 22 million square kilometers (nearly the equivalent size of North America). Modern urban cities are dependent on an agricultural system that is based on massive inputs of energy, water and artificial fertilizers. In the US for example, to produce and deliver 1 kJ of food to a consumer, it is required at least ten times the amount of fossil fuels. Such a food supply can only exist with relative cheap fossil fuels, which soon will no longer be available (De Graaf, 2012).

This growing tension gets worse if the relation is between agricultural lands and low-lying coastal cities, particularly susceptible to sea level rise, coastal flooding, coastal erosion and saltwater intrusions. For these reasons, in a world where more frequently each year climate change forces the juxtaposition between ocean and coastal urban realities, threatening already vulnerable primary sector productions, many countries are promoting alternative food production systems to achieve both sustainable development and economic growth. One school of thought, inspired by the cumulation of these challenges, developed the idea of expanding urban access and food production to nearby marine spaces, making the concept of "living on the water" an innovative possibility that is starting to be taken into consideration. In this way, water ceases to be a constrain and a limiting factor and instead turns into an opportunity, opening up previously unimaginable cultivable areas for agriculture.

This practice is already in use in a number of places around the world, for example in Rotterdam, where residents and local consumers are able to supply themselves with high-quality dairy products coming from the first self-sufficient floating dairy farm. Started with about thirty cows in 2019, today the installation is able to provide milk and other products to the citizens and stores of the city, while also serving as an educational resource for the community. It was in fact created with both innovation and education in mind, daily experimenting with new methods to produce higher-quality food and even testing various methods to grow vegetables on water, while welcoming visitors from all over the world, keeping in mind a variety of different goals, including those of city planners, farmers, students, consumers and many more. Floating installations should go hand in hand with the concepts of resilience and sustainability, being adaptable to climate change and contributing directly or indirectly to the UN Sustainable Development Goals, and this farm is undoubtedly an outstanding example. In fact while the fresh milk is sold to consumers, via a 24/7 vending machine, the manure will be treated separately, reusing it as a source of nutrients for the plants, parks and gardens of the Dutch port city. Floating solar panels are also integrated in the build to supply energy to the systems, while rainwater is captured and then purified for drinking by special installations on the roof (*Floating Farm*, n.d.).

A modest system that could undoubtedly serve as a model for larger projects, like the one of OCEANIX City, especially in light of the advantages of modularity and scalability that come with water installations as opposed to land-based structures. By being modular, a floating farm can in fact be customized with a variety of food productions (in 2021 a second farm for eggs and vegetables was built (*Floating Farm*, n.d.)), to diversify food sources, reduce environmental footprint and better locate food supply chains.

More instances of water-related food production systems can then be found elsewhere in the world, for example in China, where in recent years it was constructed the world's largest floating fish farm, Guoxin 1. Able to produce more than 3,700 tons of fish annually, this humongous ship has already achieved several records. Being the first of a larger project, that calls for two more ships, Guoxin 2 and Guoxin 3, China believes the vessel will demonstrate highly efficient and environmentally friendly aquaculture (Tse, 2022).

Or, for instance also, in the US, where it was recently developed a new simple, replicable and sustainable form of ocean farming, called 3D ocean farming, which grows kelps, mussels, scallops and valuable seaweeds using the entire water column, reducing the overall footprint. “It requires no freshwater, no fertilizer, no feed, no land, making it hands-down the most sustainable form of food production on the planet” said Bren Smith, executive director of GreenWave and one of the most influential people in this new field (Bioneers, 2021). This technique may actually be a valuable source of food in the future for the world's expanding population, relieving the strain on semi-intensive and intensive food productions. According to numerous studies, seaweed, which is actually the most nutritious plant on the world, a good source of protein and the planet's top carbon collector, will be the future source of human food security and a valuable solution to soften the changing climate, being the cornerstone of a strong economic growth and a sustainable way of life (Yong et al., 2022).

Expanding urban access to nearby marine spaces, for example introducing floating farms and 3D ocean farming into the urban fabric, could benefit marine and coastal cities by achieving higher levels of resiliency, being able to adapt to the changing climate, but also by creating a new system able to shorten food supply chains, empower local producers, produce local quality food that is less prone to disruptions. Today, production of goods usually takes place further from where consumers buy them and many cities depend on long food supply chains.

When hurricane Sandy hit New York in 2012, for instance, the entire city ran out of fresh food within days. Due to the city's reliance on the thousands of food trucks that enter it every day, when flooding occurred, the chain of supply for food was shattered and trucks were unable to enter the city (*Floating Farm*, n.d.). For these reasons, developing these sorts of systems, a city could benefit on the reduced dependence of the transportation system, indirectly lowering its environmental footprint and the number of additives needed to maintain a longer shelf life, and on the increased citizen awareness on healthy organic food production.

But probably, these new food production techniques cannot succeed on their own; to be effective, they must be viewed as a part of a much larger toolbox of adaptation strategies. This key concept is central in the OCEANIX project, where organic production is planned to be efficiently grown in aeroponic and aquaponic systems, while being complemented by traditional outdoor farms and greenhouses (*Oceanix.com*, 2022). *Figure 20* shows an example of how these technologies might be used in practice.

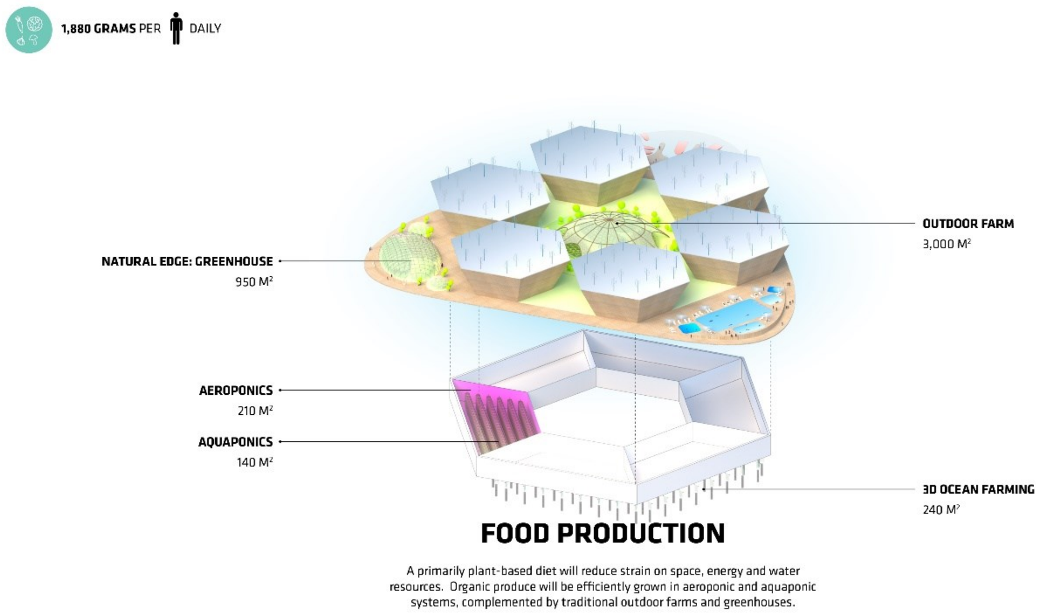

FIGURE 20: Food production as envisioned for the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

In the project, a primarily plant-based diet will be provided through communal farming, located in the sheltered heart of each neighborhood, allowing residents to embrace sharing culture and zero waste systems. Residents will grow their own food in daylit outdoor farms, reducing strain on space, energy and water resources (*Oceanix.com*, 2022). Through high yield, decentralized, soilless and permaculture systems the project of OCEANIX will be able to supply an organic plant-based diet that can satisfy an estimated daily intake of about 1880 grams per capita, consisting of a breakdown of about 470 grams of protein, about 470 grams of carbohydrates and about 940 grams of fiber and other nutrients (*Oceanix* | *Helena*, n.d.). This value is in line with the estimations provided by the UN Food and Agriculture Organization (FAO), one of the most reliable sources for anything related to food consumption. While the value is undoubtedly comparable to the global average value, obtained through comprehensive and quality dataset for 2018 analysis, local and regional realities must also be taken into account. Each continent has a different average food consumption per capita, so future installations should be site-specific and adapted considering the local needs and eating habits of the population. Using for example the OCEANIX Busan prototype as a reference point, the average amount of food consumed per person in Asia in 2018 was 679.7 kg (1.86 kg per day), with rice coming in second after vegetables in terms of consumption. The value proposed in the project is consistent with the data, but it should be reexamined, for example, depending on whether it will be built along the African coasts (1.48 kg per day, mainly cassava and wheat consumption) or North American coasts (2.36 kg per day, mainly milk and wheat consumption) ("Worldwide Food Consumption per Capita," 2021).

The OCEANIX City project aims to create a self-sufficient, remote community in the sea that can autonomously meet all of its food demand. But is this feasible, and is cutting the connection with outside communities really a good idea? Probably not. No nation or city can supply all of its food demand on its own; instead, they rely on other nations through interactions and trading in the global market. This is one of the key ideas presented in the book "Seasteading", by Joe Quirk and Patri Friedman. The authors also stress the importance of having a comprehensive design for a floating city, in order to produce certain valuable goods to compete and interact with other existing cities. The ocean is one of the most valuable resources on Earth, and a floating city must be able to fully take advantage of it. Only becoming a valuable partner in the global economy, a floating city can mark its ground on the global map (Quirk & Friedman, 2017).

Of course, countless factors need to be carefully put on the table, one of which is the location of the floating city. Is there opportunity for community interactions and trade with other nearby urban areas? Does the location facilitate the process? These are all questions that need to be considered. If the floating city is located close to the coast, intended as the natural expansion of an already existing urban fabric, like the prototype of OCEANIX Busan, the possibility for interactions between the two realities are much more likely. Instead, if the city is planned as an isolated settlement in the middle of the ocean, it will be more challenging to import and export goods like food and resources. Additionally, when taking into account external connections, it becomes even more important to produce the proper amount of resources. If not, disposing of extra resources could be another issue to consider. And certainly the project of OCEANIX City has enough challenges to face already.

The following chapters will provide theoretical insights on the various technologies chosen by OCEANIX. A SWOT analysis will be given for each technology included in the "food kit of parts" (shown in *Figure 21*).

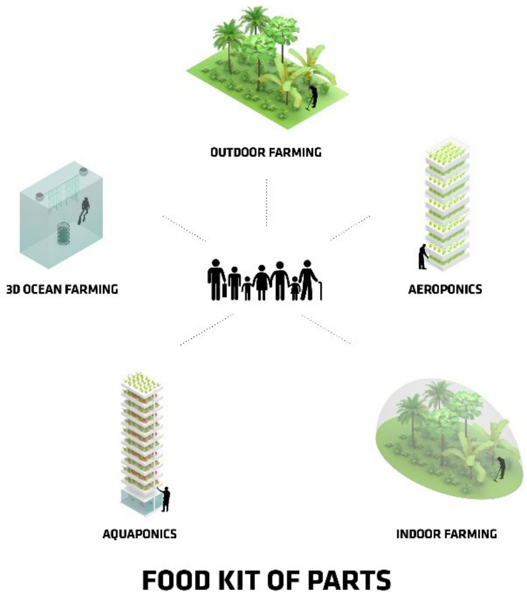

FIGURE 21: Food kit of parts of the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Aeroponics

In order to provide enough clean and fresh food for the expanding global population, which is also increasingly threatened by more frequent droughts, agriculture is mobilizing to develop new effective and sustainable alternatives to conventional food production. Developed throughout the previous century, aeroculture is suggested as a new cultivation technology that aims to resolve future food crises while also being effective and sustainable. This promising farming method is getting increasingly popular due to its cheap and innovative way to grow plants in the air, without the need for soil or a substrate culture. The basic principle of this techniques involves the cultivation of plants, suspended with the assistance of artificial supports in a closed or semi-closed environment, by spraying with atomizers nutrient-rich water on the plant lower stem and dangling roots. There are currently several typologies of aeroponics (low-pressure units, high-pressure devices, commercial systems), each characterized by different design, working principles and performance ("*Aeroponics*", 2023).

Compared to conventional cultivations this revolutionary food production technology presents several benefits. It has the potential, due to the system vertical design, to cultivate large quantities of plants in limited spaces, including indoor horticulture practices. This, together with the possibility to adopt aeroponics in areas where the soil is not suitable for plant growth, make this technology an exceptional choice for the OCEANIX City project. This plant growing system is, in fact, environmentally friendly and economically efficient compared to hydroponics and geoponics

due to reduced labor cost, less water usage (90% reduction), less fertilizer usage (60 % reduction), almost no pesticide and herbicide usage and maximized plant yield (from 45% to 75% increase) (Lakhiar et al., 2018). The soil free system allows also to remove mature plants, potential contaminations or diseased plants with ease, without disturbance to other cultivated organisms, while granting roots access to air, optimizing plant growth. In fact, the increased aeration and the presence of atomized nutrients has been found to stimulate plant growth and assist in preventing pathogen formations. Due to the circulation of CO2 within the system, aeroponics may also be able to help control carbon dioxide levels while speeding up plant photosynthesis. A general aeroponic installation also, usually allocated indoor, is not dependent on weather conditions and, due to the speed at which plants grow and mature, it is able to provide multiple harvests of a single perennial crop and accelerated cultivation cycle throughout the entire year, without any interference of soil, pesticides and residues.
But every system has its drawbacks, and aeroponics is no exception. High costs for long scale production, dependance of the system, high complexity of the systems, that require educated manpower able to provide appropriate quantities of required nutrients for plant growth and required sanitary conditions of the root chamber, are some of the principal drawbacks that characterize this type of cultivation. Although these negative aspects, aquaponics remains a fresh, clean, healthy, efficient and rapid food production system, able to provide valuable cultivations throughout the year, helping in conserve water, land and nutrients, overcoming all the constrains that are present in commercial soil culture production (Kumari & Kumar, 2019). Aeroponics is the way of the future and surely a nice addition to the OCEANIX project.

Table 8: SWOT analysis of aeroponics

STRENGTHS	***WEAKNESSES***
-sustainable alternative food source -water-efficient -nutrient-efficient -high yield -limited to no pesticide use -reduced net environmental impacts compared to conventional farming practices -reduced labor cost -limited space required -fast plant growth	-high cost for long scale production -high cost of the system -dependance on the system -high complexity of the system -technical knowledge required

-year-round production (in controlled systems) -easier and less damaging harvest -disease free product (in controlled systems)	
OPPORTUNITIES	***THREATS***
-increase the technological development of aeroponics -ease some of the stress associated with traditional semi-intensive and intensive food production methods -great educational and research value (roots and plant growth can be studied more in detail) -encourage local stakeholders' participation in decision-making processes -new jobs and local buying -decentralization -high unexploited potential -eco food tourisms -raising social and environmental awareness	-conventional cultures are less expensive -public perception, misinformation, social acceptance

Aquaponics

Aquaponic is a particular food production technology that combines two separate systems, aquaculture and hydroponics. Aquaculture, also known as aquafarming, consists in the controlled cultivation of aquatic organisms, like fish, mollusks and crustaceans, while hydroponics is the cultivations of plants and crops directly on water, in particular systems that do not involve the use of soil. Combining both animal and plant culture, in fact, this discipline seeks to take advantage of the positive aspects of the two productions, eliminating the drawbacks of each ("*Aquaponics*", 2023).

The idea behind is simple: by raising plants and fish in the same environment, a generic aquaponic installation is able to make use of the nutrients produced by fish byproducts as a natural supplement for the plants, which in return filter the water making it suitable for the aquatic fauna (Underwood & Dunn, 2017). It was firstly developed in the United States in the early 1970s and has recently experienced a resurgence due to its benefits and the recent rise in interest toward new sustainable cultures. There are different approaches to this technology (deep water culture, media-based aquaponic, Nutrient Film Technique, vertical aquaponic, …), each with different designs, operational principles, performances, advantages and disadvantages, but all are oriented toward an efficient water and nutrient use, producing the least possible impacts on the environment.

But the advantages of choosing aquaponics over conventional cultivation go beyond just the more effective use of water and nutrients. In fact, the integration of aquaculture with plant cultivation produces an increase in farming productivity and profitability of the whole system without any net increase in water consumption, creating a major farm diversification that involves both higher-value crops and higher-value aquatic species (Goddek et al., 2019). By recirculating the water, the system reuses otherwise wasted farm resources, reducing or even eliminating the need for nutrients, fertilizers and pesticides, creating a sort of Net-Zero Waste system. If managed in a controlled environment, the system is also capable of year-round productions. Aquaponics has, moreover, proven to be a flexible and cost-effective technology given that farms could be located anywhere: outside, in a greenhouse, on rooftops and in areas that are otherwise unsuitable for agriculture (Goddek et al., 2019). Being by its very nature fully scalable, aquaponic systems would find exceptional use in the OCEANIX City project since the limited land use and the high efficiency required. Due to aquaponics' many advantages, smart energy options, central in the OCEANIX project, like solar and biogas can also be integrated.

But of course, this system is not free of drawbacks. High upfront costs and energy requirements, higher operational costs compared to soil culture, daily maintenance required to manage two separate agricultural fields, limited selection of organisms that need accurate water quality testing to function properly are some of the main difficulties associated with this kind of cultivation technology (Underwood & Dunn, 2017). But despite these disadvantages, it is undeniable to underline how aquaponics surely possesses all the necessary qualities to participate in the OCEANIX project and can surely aid in addressing the water-food-energy nexus linked to the UN's goals for sustainable development goals.

Table 9: SWOT analysis of aquaponics

STRENGTHS	***WEAKNESSES***
-sustainable alternative food source -water-efficient -nutrient-efficient -limited space required -limited to no pesticide use	-high upfront cost -higher energy requirements -daily maintenance required -accurate knowledge from two separate agricultural fields required

-increased farm productivity and profitability -farm diversification -reduced net environmental impacts compared to conventional farming practices -flexibility in locations -scalable systems -year-round production (in controlled systems) -no need for soil	-water quality testing for both plants and fish required -limited plant and fish selection -multiple ways the entire system can fail
OPPORTUNITIES	***THREATS***
-increase the technological development of aquaponics applications -ease some of the stress associated with traditional semi-intensive and intensive food production methods -renewable energy sources can be integrated in the same system -strengthens collaborative opportunities between different food sectors -encourage local stakeholders' participation in decision-making processes -decentralization -high unexploited potential -new jobs and local buying -eco food tourisms -raising social and environmental awareness	-conventional cultures are less expensive -public perception, misinformation, social acceptance -strict regulatory requirements

3D ocean farming

In the era of climate change, which is marked by every year more violent storms, alternated with protracted periods of drought, conventional agriculture is more than anything else experiencing a period of crisis. Over the next 15 years, experts predict a price increase of over 140 percent for corn, while copious amounts of carbon and methane are emitted every day by semi-intensive and intensive food production practices all around the world. On top of that, increasing pressure due to population growth is increasing social and economic inequalities, accustoming the population to consider food insecurities as normal. If no action is taken, this system is doomed to fail. As a consequence, the global primary sector is mobilizing to develop new effective and sustainable alternatives to conventional food production. Among these new ideas and ground-breaking initiatives, 3D ocean farming stands out as a new revolutionary cultivation technology that aims to address future food crises while also being efficient and sustainable.

3D ocean farming is a simple, profitable and replicable form of aquaculture that uses the entire water column to grow restorative marine species, like shellfish, oysters, clams and fast growing, high value seaweeds. Sometimes called as “the farms of the future”, these underwater coastal gardens have a small footprint, due to the compact vertical arrangement of the cultures, low aesthetic and environmental impact, high yield and require no freshwater, feed, fertilizer or other input to work. In a generic 3D ocean farm, scallops in lantern nets and mussels in their socks can be found alongside vertically growing kelp and other valuable seaweed, which are attached to horizontal floating ropes fixed to the seabed with stormproof anchors. Below are located also cages for oysters and clams buried in the sea floor. This new typology of farm is relatively easy to replicate and cheap to build since gravity is not a limiting factor underwater (*3D Ocean Farming*, 2017).

This kind of system could surely be used in the OCEANIX City project and other marine installations, integrating it, for instance, in offshore wind farms or conservation zones as a way to restore existing installations, rather than depleting the marine ecosystem. But 3D ocean farming is not only an alternative food source, it can also be a valuable ally to face climate change and its impact. The marine organisms grown in this system, in fact, are particularly resilient and restorative species able to absorb up to five times as much carbon as land-based plants (via kelp forest), reduce ocean acidification filtering both nitrogen and phosphorus (via shellfish, oysters and kelp forest), while acting as storm surge barriers, protecting coastal communities (*3D Ocean Farming*, 2017). By feeding kelp to cattle, also, it is possible to reduce up to 90 percent the current methane production, as stated by experts (Bioneers, 2021). Moreover, these farms can work as artificial reefs, creating a thriving ecosystem that attracts hundreds of marine species that come hiding from predators or other dangerous sources. And it must not be forgotten that by developing this new kind of sustainable and relatively simple it is possible also to create new jobs and increase access to food where it is most needed.

These qualities make 3D ocean farming "Hands-down the most sustainable form of food production on the planet" according to Bren Smith, executive director of GreenWave and one of the most influential people in this field. He also adds: "In the era of climate change, as water prices and feed/fertilizer prices go up, our food is going to be the most affordable food on the planet to grow, and the most affordable food on the planet to eat" (Bioneers, 2021). If this turns out to be true, 3D ocean farming may actually be a practical way to feed the world's population while also restoring the oceans.

Table 10: SWOT analysis of 3D ocean farming

STRENGTHS	***WEAKNESSES***
-sustainable alternative food source -simple and replicable system -small land use due to vertical arrangement -low visual impact -no input required (freshwater, fertilizers, …) -fast and high yield -profitable due to high value cultures -improve water quality (carbon, N, P reduction, indirect methane reduction, …) -can act as storm surge barrier -can function as artificial reef	-knowledge and experience required for large-scale applications -not suitable in all coastal locations -the introduction of foreign species could cause potential negative impacts
OPPORTUNITIES	***THREATS***
-increases the technological development of 3D ocean farming and seaweed applications -possibility to interact with other sectors (kelp for cattle industries, seaweed for fuel industries, …) -can be integrated with already existing marine installations (wind farms, …) -resilient and restorative cultures could help restore the oceans -ease some of the stress associated with traditional semi-intensive and intensive food production methods -encourage local stakeholders’ participation in decision-making processes	-public perception, misinformation, social acceptance -lack of a comprehensive policies linked to national and international strategies -lack of understanding of seaweed applications -competition with other marine food production

-new jobs and local buying -decentralization -high unexploited potential -eco food tourisms -raising social and environmental awareness	

Indoor/outdoor farming

The next frontier of agriculture will pass through the development of intelligent and technologically advanced cultivations system, with installations more compatible with the urban context and able to bring closer to urban places production, creating a new sustainable way of living. However, this doesn't imply that aeroponics, aquaponics, 3D ocean farming and other advanced food production techniques will be the only contributors to a better future for coming generations. The advancement of agriculture also entails modernizing existing conventional production methods, adapting them to suit the demands of a more sustainable and changing society.

In line with this statement, in fact, the OCEANIX City project intends to use advanced systems, including for instance aeroponic and aquaponic, to produce an ongoing supply of organic products, while at the same time still being supplemented by conventional outdoor farms and greenhouses. In addition to serve as food production facilities, outdoor and indoor plantations (greenhouses) will be used by residents and visitors also as parks and communal walkways. Perimeter organization will help define sheltered productions, as illustrated in *Figure 22*. Lodging platforms will host greenhouse amenities, while the heart of both research and living platforms will allocate temperature-controlled gardens and community green backyards, encouraging gathering between residents and promoting a healthy lifestyle (*Oceanix.com*, 2022).

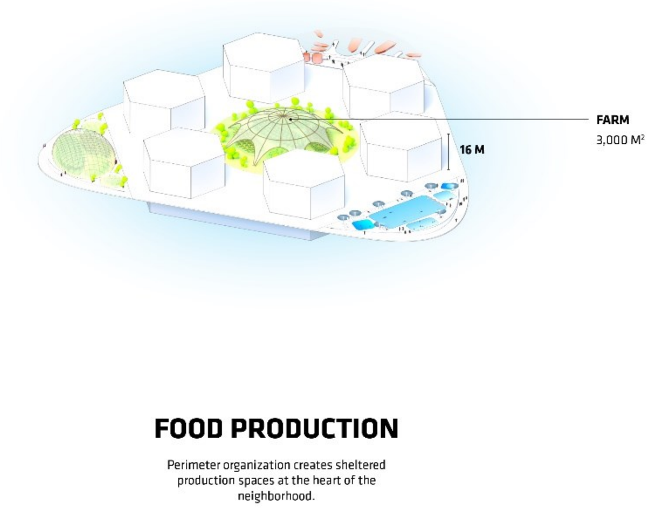

FIGURE 22: Platform food production as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

These multipurpose environments probably won't differ all that much from traditional land-based methodologies. Thanks to the greenhouses' controlled environment, both can offer plants that are healthier, safer and available all year. Given that the technology will be the same, the quality will likely remain the same, except for the fact that it will be floating. However, while some may simply choose to stop at this difference, others may see an opportunity. If the floating crops are exported, creating a brand around them may represent a new opportunity for the OCEANIX project, or other floating projects. This, in fact, could be not only a new source of income, but also a chance to engage and promote an interested public, who will eventually wonder why a product from a floating city is on the supermarket counters.

Table 11: SWOT analysis of indoor/outdoor conventional farming

STRENGTHS	***WEAKNESSES***
-provide cost-effective and simple means to grow fresh organic products locally -increase biodiversity of plants and animals -previous experience (infrastructure, technical expertise, developed legal and institutional framework) -year-round production (in controlled systems)	-initial investment cost -some regular maintenance is required -basic knowledge required

-versatility and heterogeneity of technologies and applications -low maintenance required	
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -ease some of the stress associated with traditional semi-intensive and intensive food production methods -introducing composting can enhance farm productivity and profitability -gardens can increase the value of surrounding neighborhoods -new jobs and local buying -raising social and environmental awareness -encourage local stakeholders' participation in decision-making processes -decentralization -eco food tourisms	-public perception, misinformation, social acceptance -competition with other organic food production

4.1.2.2.3 WATER

Due to the current population growth, as cities and industries also develop, the amount of water available is not always enough to meet the rising demand for it. Hence generally, to supply water to their residents, especially when water scarcity occurs, because of surface water shortage or decreased water quality for instance, many inland settlements rely on groundwater resources found in deep layers and aquifers. Due to their hidden underground nature, these reservoirs might seem not affected by urbanization, however, the reality is that often combined effects of unregulated water extraction and reduced infiltration due to urban impermeabilization lead to situations where groundwater is extracted faster than it can naturally replenish itself. This causes a change in the underground pressure and a gradual compaction of sediments, leading to land subsidence. This is a common problem in many cities, like Venice, Bangkok, Shanghai and Jakarta, where the overexploitation of groundwater resources has reduced drastically the average land elevation. In the Indonesian city especially, land subsidence rates of more than 10 centimeters per year are not unusual and decreases that range from 20 centimeters to about 200 centimeters have been reported, considerably lowering parts of the city, exposing them to more severe flooding and saltwater intrusions.

Overexploitation of water due to farms irrigation has also prevented some rivers to reach the sea, removing their deltas from maps. The Colorado river and the Rio Grande in the US, the Yellow River in China, the Indus in Pakistan and the Nile in Egypt are example of rivers where the discharge is severely reduced, considerably dropping the water flow, hence threatening several coastal areas (Pearce, 2018). This significantly lowers these delta areas' productivity, further stressing the ability to produce food.

Hence, in order for highly urbanized settlements to reduce their burden on the environment and to address the issue of water scarcity, it is crucial that cities renounce the linear resource flow that defines them. Moving towards a circular system flow, in fact, cities will be able to better manage water, using their internal sources before extracting it from other external areas. This doesn't mean that to reduce their negative impacts on the environment cities should become completely self-sufficient and isolated communities. However, urban areas should use their internal resources in an optimal way, for example capturing rainwater or developing combined sewer systems for wastewater (De Graaf, 2012).

The effects of growing water scarcity deeply influence, either directly or indirectly, the majority of the 17 Sustainable Development Goals (SDGs), adopted by the United Nations in 2015 to balance the social, economic and environmental dimensions of sustainable development. Consequently, the proposal to promote the use of rainwater while combining the use of wastewater and desalinated water is consistent with the sixth SDG's objective: "Ensure availability and sustainable management of water and sanitation for all" (Ricart et al., 2021).

To reach this goal, water usage needs also to be conscious, approaching its local management in a holistic way and encompassing all the aspects of an integrated urban water cycle, including water supply, sewage and stormwater management (De Graaf, 2012). In general, when unregulated urbanization happens, cities tend to over-impermeabilize natural soils, covering them in concrete, asphalt or waterproof paved surfaces, removing vegetation and preventing them to absorb naturally rainwater, increasing the runoff. This enhances pluvial flooding and erosion of natural streams. Surely, not the correct way to proceed. For instance, rainwater is a valuable resource that is frequently overlooked and, as a result, is not used in most cities. Moreover, in areas with a high density of impermeable surfaces, rainwater is often allowed to enter sewage system, diluting the wastewater. However, there are numerous uses and opportunities for this resource. Rainwater can

be used to flush toilets or, once it has been collected in specialized tanks and storage systems, it can be used to irrigate urban green spaces or even as an alternative resource for the agricultural sector, reducing the overall extraction of water from external sources. The possibilities are several. The Marina Baja region, in the south-east of Spain, for example, stands out as an original case study in which different non-conventional water resources have found to be subjects of a beneficial dialogue between urban tourists and agricultural users. Thanks to the authority of the local water consortium, several agreements have been established between local stakeholders, by which irrigators exchange their conventional water sources to the urban-tourist users by reclaimed water during drought situations, obtaining various economic compensations in return, in addition to a subsidized reclaimed water price. This case shows that, to achieve a good level of inclusion between different alternative water sources and guarantee essential supplies to different sectors with different interests, the management of water should be accompanied also by new water governance models that must involve local stakeholders and seek out mutually beneficial configurations through user cooperation, because it is essential to adapt to water availability. Threats, however, still exist, necessitating continuous review of the agreements reached between the interested parties as well as the replacement and renewal of infrastructure (Ricart et al., 2021).
In line with this, in Australia a new discipline has been created, combining landscape architecture, water management and transition management: Water Sensitive Urban Design (WSUD). This new field of study aims to create a new system that will consider water environment, infrastructure service design and all the opportunities related to the management of water, in the earliest stages of the urban planning decision-making processes. In this way WSUD will reduce the demand for drinking water, minimize wastewater generation and preserve the natural hydrological regime of catchments, through water efficient installations and methodologies (De Graaf, 2012). Although this concept was designed as a tool for inland cities to achieve better water management, nothing prevents from applying similar considerations to floating urban projects.
In fact, not only mainland urban areas, but also floating city would need a sizable amount of fresh water. As a floating city is quite literally living on the water, its residents still require dedicated systems to be able to use freshwater and sewer systems to dispose wastewater. And getting significant amounts of water shipped from external sources wouldn't be a cost-effective strategy. Therefore, to satisfy the demand of its inhabitants, a self-sufficient floating installation must allocate its water source locally, either by converting freshwater from seawater using on-site evaporation or osmosis processes, or, for example, by collecting rainwater and atmospheric humidity.

Given that these facilities are underground in mainland cities, it is easier to implement them when the floating platforms have available internal spaces. Wastewater, also, must be stored until it is treated, because it cannot simply be dumped into the open ocean where the floating city is located. These facilities may also be located on the mainland, but then again, concerns about the pipelines' susceptibility to outside forces and events can cause difficulties to this theory (Ko, 2015).

OCEANIX itself has set the achievement of "Fresh Water Autonomy" as one of its fundamental objectives for its floating cities. The company aims to achieve a per-person water usage nearly seven times lower than the global average, more than eleven times lower than that of the average United States citizen and more than two times lower than the average citizen of the Democratic Republic of the Congo (*Oceanix | Helena*, n.d.). This will be achieved via the latest water harvesting, filtering, recycling and distillation systems, allocating large amounts of fresh water to its residents without importing it from external sources (*Oceanix.com*, 2022). *Figure 23* shows an example of how these technologies might be used in practice.

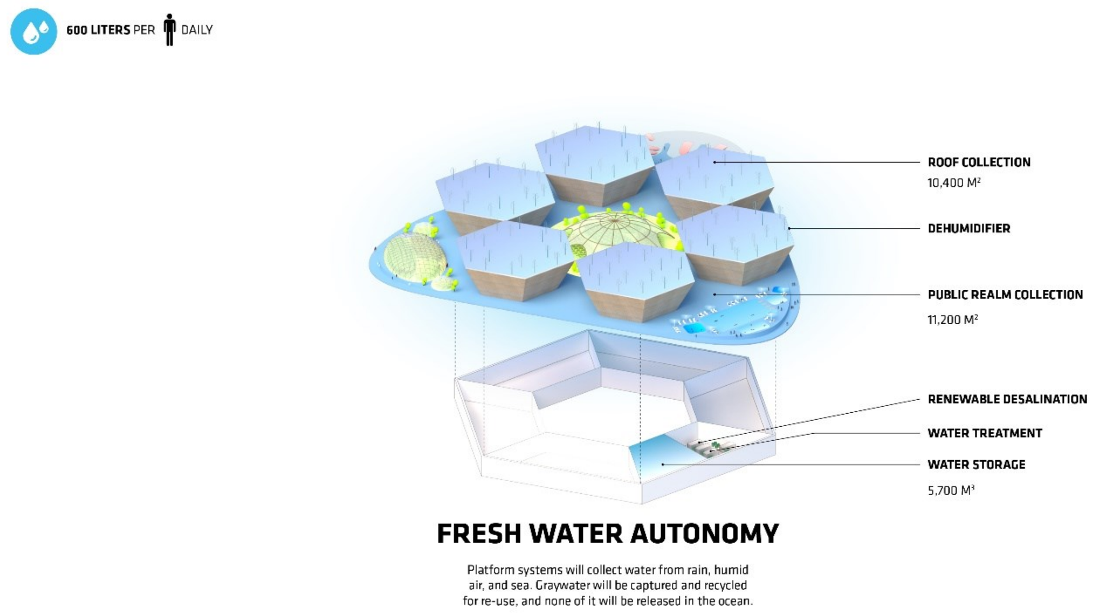

FIGURE 23: Fresh Water Autonomy as envisioned for the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The company has estimated that, for each person, about 600 liters of water will be needed. This number deviates significantly from some average mean estimates found in literatures; it does not represent the average values of daily per capita water consumption for domestic application of some countries, nor the water availability or the amount of water that a person should drink each day. Although there are no information or data regarding the exact procedure used to evaluate this number, it is reasonable to assume that this sum was calculated considering also all the essential processes that are behind the proper operation of the city. The single person should, in fact, be viewed as a reference unit, used to size the water consumption of the entire project, and not as an estimation for the single household application. Water will be used in the floating city as a key component in some energy-producing technologies, as a coolant or as a medium to grow microalgae, in the washing center, as irrigation for plants in parks and especially in the food production area, being fundamental for aquaponics and indoor cultivation systems, for example (*Oceanix.com*, 2022).

The following chapters will provide theoretical insights on the various technologies chosen by OCEANIX. A SWOT analysis will be given for each technology included in the "water kit of parts" (shown in *Figure 24*).

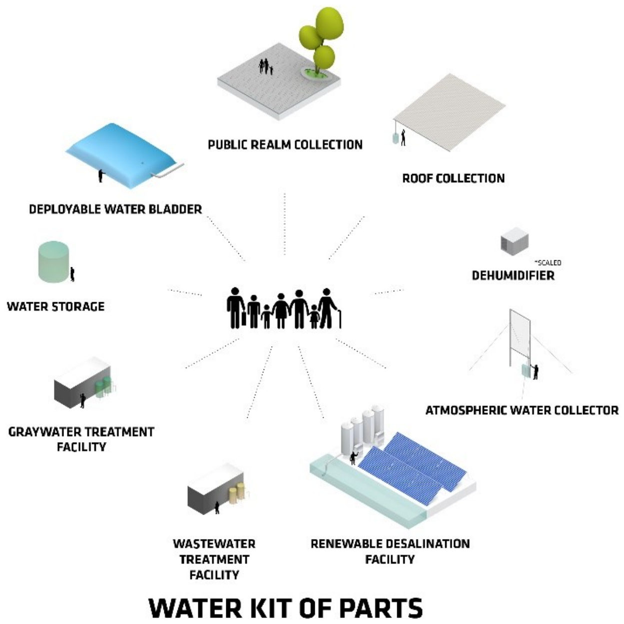

FIGURE 24: Water kit of parts of the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Reclaimed rainwater use

Water scarcity, defined as a long-term water imbalance which occurs when the level of water demand exceeds natural water availability and supply capacity (Omer et al., 2020), is estimated to pose significant risks to both societies and economies in the coming ten years. In particular, due to the growing global water consumption, it is estimated by experts that, in order to meet the water needs in the coming decade, more than 160 percent of the volume of freshwater on Earth will be required. In this context, non-conventional water resources are being taken into consideration to address water scarcity and reduce water-related conflicts between regions and sectors (Ricart et al., 2021).

Among these freshwater resources, rainwater appears to be one of the most cost-effective and simple to manage. So much so that rainwater harvesting has become one of the primary alternative water supply methods in many conventional urban areas (Toosi et al., 2020). And nothing will prevent floating cities from using it in a similar way in the future. As one of the simplest and oldest way used to self-supply water for domestic use, agriculture and industries, rainwater has, in fact, been used for centuries in many nations and will likely continue to be used for many more.

By reclaiming and storing rainwater from land surface catchments, by using roof collection or public realm collection systems for example, harvesting it from where it falls, rather than allowing it to travel as runoff, rainwater harvesting can be used in urban areas for both potable and non-potable uses, significantly alleviating water consumption, while also acting as a flood control measure (Ricart et al., 2021).

Of course, regarding its potable use, it is important to note that in general, only areas with extreme water scarcity patterns, where water is too valuable to use just once, have found to use rainwater for drinking purposes also. For instance, Singapore was the first nation to combine fresh and reclaimed water in a reservoir to create recycled drinking water, known as NeWater, in 2002 (Qian & Leong, 2016). Later, to achieve net-zero urban water (the capacity to meet a population's water demand while substituting unsustainable practices with long-term, locally sustainable alternatives), similar initiatives have been proposed in other water-scarce regions and cities, for example in arid regions of California and Florida, in the US. However, public perception, misinformation and social acceptance, rather than water quality, have haltered these projects (Archer et al., 2019).

When used for agricultural purposes, instead, reused water has met with moderate success due to countless economic and environmental benefits, including higher profitability of cultures irrigated with reused water, pressure reduction on overstressed conventional water sources, successful groundwater recharges and higher crop yields for some plants, due to the presence of nutrients remaining in the reclaimed water. Unfortunately, in these cases, when the purpose of water harvesting is to support agriculture, designs seems to revolve around one large public construction. Rainwater instead should be gathered using decentralized interventions, focusing also on landscaping, building urban wetlands to improve water quality or green spaces to reduce the impact of the urban heat island effect, creating a better living environment for residents and tourists (Ricart et al., 2021). However, due to the initial high costs, particularly when creating separate distribution infrastructures, these urban reclaimed water designs are less common. Despite this, there are some

instances, like in the city of Alicante, in Spain, where decentralized unconventional water interventions are used for both public (cleaning streets and watering green spaces) and private (irrigating private gardens in some low-density urban areas) purposes. This initiative has made it possible to use recycled water to irrigate more than 80 percent of public green spaces, saving more than one million cubic meters of freshwater annually (Seguido et al., 2019).
Therefore, according also to experts, a transition to more water-sensitive urban realities is needed to collect, transport and store water as long as possible in order to slow runoff and promote infiltration, recharging aquifers and reducing floods, to also avoid the collapse of sewage systems and treatment plants, while , in return, preventing the degradation of water bodies due to pollutant emissions and, in the end, to better manage its later use in accordance with its fit-for-purpose principle for specific urban (watering gardens, cleaning streets, etc.) and tourism (accommodation facilities, toilets flushing, cooling towers, etc.) purposes. Regarding the urban-tourist contexts in fact, rainwater is still an underutilized, yet renewable, alternative water resource for water-stressed cities around the world. Nonetheless, since the late 1990s, rainwater harvesting has been increasing in countries such as the United States, Australia, the United Kingdom, Sweden and France, or countries of the Mediterranean region such as Spain, Italy or Greece (Ricart et al., 2021).
Lack of widespread public support, often related to erroneous public perception, misinformation and social acceptance, as well as the economic and technical implementation, are considered as some of the main obstacles and drawbacks that challenge to the diffusion of these methods in urban environments.

Table 12: SWOT analysis of reclaimed rainwater use

STRENGTHS	***WEAKNESSES***
-provide cost-effective and simple means to capture rainwater -provide means to conserve water and ease the strain on freshwater resources -previous experience (infrastructure, technical expertise, developed legal and institutional framework) -provide an alternative source of water during interruption of conventional drinking water services -versatility and heterogeneity of technologies and installations	-dependent on external rainfall -regular maintenance required -initial investment cost -require water storage -cleanliness, health and safety of generated water needs to be checked and confirmed (water collected can be contaminated by external factors)

-broad range of applications -low environmental impacts	
OPPORTUNITIES	***THREATS***
-increase the technological development of rainwater harvesting applications -possibility to interact with other sectors (agricultural, energetic, …) -renewable energy sources can be integrated in the same system (for example solar panels that can also collect rainwater) -limitation on the continuity of conventional water transfers and groundwater extraction -decentralization -new jobs -covering peak water consumption -raising social and environmental awareness	-public perception, misinformation, social acceptance -competition with other freshwater productions

Renewable desalination facilities

According to NASA datasets, more that 70 percent of the planet is covered in water, with oceans holding the vast majority of it. However, only a small portion of this water (about 3 percent) is considered as freshwater, with then only a small fraction found liquid and readily available to be used (about 1 percent). Yet the world is becoming more and more reliant on this precious resource for power, irrigation, industrial practices and daily consumption (*Freshwater Availability Toolkit*, 2021). On a daily basis, in fact, 10 billion tons of water are used worldwide (*Average Daily Water Usage*, 2023).

A solution to protect this valuable resource might be to convert seawater into freshwater. This can be done using particular processes able to remove mineral components from saline water, turning it to suitable water for irrigation and human consumption. These practices, heavily used on cruise liners, submarines and passengers' vessels that require large amount of drinkable water, can provide freshwater onboard, for drinking, washing, cooking and other water dependent machinery, mainly using particular generators that exploit evaporation phenomena to produce water. This process, in particular, relies on seawater and heat to operate, both of which are available in plenty on the ship. It starts when seawater is evaporated by various heat sources, coming from the ship's main engine components for example, producing evaporated freshwater. The vapors are then condensed using cold seawater and the cycle repeats. Other ships instead can use reverse osmosis methodologies to produce freshwater. However, due to the high cost and high membrane maintenance required, this method is not frequently used in on board applications (Karan, 2021).

But if this technology is already being put in practice, why isn't freshwater produced on an industrial scale? Unfortunately, it is not as easy as it seems. Seawater purification practices date as far back as the ancient Greeks, but when scaled up to include cities, regions and countries, desalinating seawater has historically proven to be too expensive, particularly when compared to the use of nearby local and regional freshwater sources (Gerbis, 2020). Additionally, large-scale desalination is often perceived as controversial because of its direct effects on the environment (high energy requirement and impacts on marine ecosystems) and for its supply-oriented development (fostering a sense of security based on an unlimited resource that can distract from the problem, enabling more water consumption and increasing the pressure on the local water system) (Ricart et al., 2021). However, desalination still provides a high-quality water supply and, as advancing technology continues to drive costs down and drinkable water continues to become scarcer and more expensive, more cities are turning to seawater conversion as a way to meet their water essential demand (Gerbis, 2020). To introduce some data, desalination plants are in operation in over 150 countries, as a research estimated in 2018, producing about 87 million cubic meters of clean water each day and supplying over 300 million people. In terms of volume capacity, Saudi Arabia, the United Arab Emirates, the United States, Spain, Kuwait and Japan are the top desalination users worldwide. Saudi Arabia, for instance, provides to its inhabitants about 70 percent of freshwater through desalination, while the US, with Florida, California, Texas and Virginia as its largest users, is able to desalinate each day more than 5.6 million cubic meters of water (Alix et al., 2022).

As already mentioned before, there are different methods to desalinate water, each with its own advantages and disadvantages, performance ranges and applications. They can be divided in two major groups: those that uses special membrane to separate salts and minerals from drinkable water (reverse osmosis, membrane distillation, …) and those that uses thermal processes (solar distillation, natural evaporation, …). The most common are the reverse osmosis method (RO) and the distillation method. The first one is a membrane-based technique that employs applied pressure and semipermeable membranes to create a preferred path of water to pass through the membrane while rejecting salts, while the second one is a more traditional method that involves boiling and recondensing of water, leaving behind salts and impurities ("*Desalination*", 2023).

Some techniques perform better than others, and some have preferred application fields over others, but they all generally function and can be useful in countless occasions, even in a floating installation. So why are they not used more frequently? Why are conventional extraction techniques preferred? Once more, it has to do with money and business. Everything comes with a price and, ultimately, the main barrier to large-scale desalination practices seems to be this. In fact, until recently, converting seawater into freshwater has become roughly five to ten times more expensive than drawing it from lakes, aquifers, rivers and other conventional sources, with fluctuating prices that are influenced by the water's salinity gradient. Higher the amount of salts and minerals, higher the cost. However, RO filters have advanced significantly, and desalination is nowadays only half as expensive as it was ten to fifteen years ago. Therefore, the main obstacle to industrial-scale desalination is no longer technology but rather transportation, energy and environmental costs (Gerbis, 2020).

There are currently insufficient and unclear details available about the precise type of desalination technology that will be used in the OCEANIX City project, but due to its qualities, nature and dedication to upholding the UN Sustainable Development Goals, it is reasonable to assume that the facility and the technology selected will be characterized by minimal or no emissions, restricted land use, integration with other systems and an effective use of renewable and sustainable energy sources, to power the entire process. For example solar distillation processes, powered by solar energy, converted by photovoltaic cells, wave-powered desalination processes, that uses mechanical wave motions to operate, or off-grid renewable-powered desalination units, integrated with urban scale reverse osmosis technology, could be some appealing solutions.

Table 13: SWOT analysis of renewable desalination facilities

STRENGTHS	***WEAKNESSES***
-provide means to produce valuable freshwater from saltwater -provides means to conserve water and ease the strain on freshwater resources -high availability of saline water -production of safe and clean water with low turbidity -previous experience (infrastructure, technical expertise)	-high energy consumption -high capital and maintenance cost required -limited use for applications near the cost -large-scale installations may cause negative impacts on marine ecosystems -pre- and post-operation treatments required (remineralization, checks for soil and crop toxicity, …) -production of brine and other byproduct at the end of the process

-great development for urban uses and recently for agricultural uses too -increasing acceptance among farmers	-knowledge and experience required, especially for industrial-scale applications
OPPORTUNITIES	***THREATS***
-increase the technological development of desalination applications -investments opportunities (both private and public) -possibility to interact with other sectors (agricultural, energetic, …) -renewable energy sources can be integrated in the same system -growing desalinated water demand -limitation on the continuity of conventional water transfers and groundwater extraction -covering peak water consumption -decentralization -new jobs -raising social and environmental awareness	-some technologies have high greenhouse gas emissions (if renewable energy sources are not integrated into the system, fossil fuels will be the primary source of energy) -public perception, misinformation, social acceptance -lack of understanding of depurated water applications -competition with other freshwater productions

Greywater and wastewater treatment facilities

There is no denying the need for more drinking water in the world. Furthermore, it is abundantly clear that this demand will increase in tandem with population growth and the pressures imposed by climate change. Experts estimates that nearly 2 billion people will reside in water-scarce areas by the year 2050, and most model scenarios predict that these shortages will only get worse as a result of projected climate change (Adnan, 2020). Given these difficulties, the beneficial idea of using treated wastewater and greywater as a resource, finding a suitable application instead of disposing them, has quickly become crucial for water agencies all over the world. Wastewater and graywater, in fact, are both considered two of the few resources that are likely to increase in the future as population increases, which is a significant factor to consider given the large and rapid population growth, for example in Asia and Africa.

Therefore, adopting the reuse and reclaim of wastewater in urban areas can act as an effective method to preserve and extend the supply of available water, alleviating the pressure on existing water management, while also reducing possible direct emission into the water streams, thus serving as a great opportunity for water conservation and a crucial element of pollution prevention and control.

The use of partially treated or untreated wastewater has also found several applications worldwide for irrigation, being a common routine in many water-scarce continents in Asia and Africa. Adopting it for agriculture has been acknowledged globally as a successful practice and a crucial component of sustainable water management due to the benefit of recovering not only water but also nutrients for crops and plants (Nagara et al., 2014). Cultivations in fact benefit from the high concentrations of phosphate and nitrate that are contained in urban wastewater, hence, using it as a fertilizer could be even essential on the long run because the proven reserves of phosphate are finite. The circle can then be further closed by recovering nutrients from wastewater sludge rather than burning it, so that cities can start producing a net amount of beneficial fertilizers, or even by promoting urban agriculture with locally produced plant supplements (De Graaf, 2012). This development can help cities become less reliant on outside food supplies while also opening up a market for fertilizer produced in the area.

In addition to serving as a source of nutrients and water, urban water systems can also be used as a source of energy. Possibilities include the use of wastewater for the production of biogas, also recovering heat from the same wastewater streams using heat pumps, and the use of urban groundwater and surface water systems also as an alternative source of heat (De Graaf, 2012). Depending on its type and origin (from industrial processes, urban areas or agriculture), wastewater can be used in a variety of ways and applications, even in a floating city.

Around the world, for instance, there have been many direct and indirect water reuse projects launched, each with its own characteristics. Some have been successful; others that have taken controversial approaches, have often been completely rejected by the public and have thus been unsuccessful. The city of Toowoomba, which was experiencing a critical situation of water scarcity, for example, was the first and only urban area in Australia to submit a project to recycle water for drinking purposes. Although wastewater treatment plants are very effective at removing conventional pollutants, the project's implementation, during the initial planning stage, was obstructed by the lack of a sufficient and clear explanation of the purification system and the water quality. Additionally, the health-related issues presented were not found adequate and well justified by the stakeholders (Mainali et al., 2011). Similar events occurred in San Diego, California, where, due to rising demand and declining supply from an imported source, the city's drinking water supply was proposed to be supplemented with recycled water. However, even in this instance the idea of "toilet to tap" turned out to be emotionally charged for the general public and, despite the project receiving strong backing from a wide range of academic sources, community organizations and private business experts, it became entangled in political campaigns and turned into a political issue, which ultimately led to the project's cancellation (Mainali et al., 2011).

These examples highlight how the lack of treatment and the potential health risks are two of the major obstacles to the development of wastewater and greywater reuse systems. Some recent studies have in fact focused on the health effects of some existing emerging pollutants that can be found in reclaimed waters, including pharmaceutical components. These substances, which may be eventually released into natural or agricultural systems, and so reach the food chain, have been found not being fully removed after wastewater treatments (Ricart et al., 2021). In light of this, experts proposed to lower the flow's pollutant concentrations to reasonable levels by blending two parts freshwater and one part reclaimed water for agricultural purposes (Martínez-Alcalá et al., 2018). Along with these difficulties, cost appears to be another obstacle. The technology required to collect wastewater from users and the treatment needed to purify it for drinking applications are expensive, however, various wastewater qualities could be used in a fit-for-purpose way and thus the pressure on freshwater resources can be reduced (Nagara et al., 2014).

Despite some drawbacks, reusing wastewater can provide significant opportunities in conserving and extending available water and nutrient supplies, even in floating environments. The majority of experts are very confident that it will be a significant technology in the future, since wastewater and greywater reuses possess the most desirable characteristics from a sustainability point of view, which are frequently disregarded by decision makers.

Table 14: SWOT analysis of greywater and wastewater treatment facilities

STRENGTHS	***WEAKNESSES***
-provides a great solution to recover water, energy and nutrients from wastewater -provides means to conserve water and ease the strain on freshwater resources -wastewater production is fairly consistent throughout the year and is independent of factors like rainfall	-high cost of turning wastewater into potable water -cleanliness, health and safety of treated water needs to be checked and confirmed -reused wastewater may cause health issues such as skin irritation or water-borne illnesses if it is not properly handled -knowledge and experience required

-reducing the amount of wastewater that is released into streams has the effect of reducing water pollution -wastewater can be used in a variety of ways, and the level of treatment can be changed depending on the intended use -previous experience (infrastructure, technical expertise, developed legal and institutional framework) -broad range of applications	
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -increase the technological development of wastewater treatment systems -possibility to interact with other sectors (agricultural, energetic, …) -renewable energy sources can be integrated in the same system -it is the only water source whose availability will rise as the population does -essential in areas with insufficient water supplies -decentralization -new jobs -raising social and environmental awareness	-public perception, misinformation, social acceptance -wastewater management is highly regulated (for example the reuse of industrial wastewater for agricultural purposes is prohibited if it contains urban runoff, hazardous chemicals, salts, or heavy metals) -competition with other freshwater productions

Atmospheric water collectors

Experts predict that a sizable portion of the world's population won't have access to clean, fresh and safe drinking water within the next decade (*Watergen | Water From Air*, 2022). Hence, it has become crucial to reach a certain level of understanding about water management, developing new, efficient and sustainable ways to provide freshwater to the growing population. However, when discussing about different sources of drinkable water, air usually goes unnoticed. Humid ambient air can, in fact, contain water vapor which can be extracted using different techniques, including particular condensation technologies, membranes that allow only the passage of vapor, collecting fog technologies, desiccants or pressurized air.

The production of freshwater from air humidity is one of the most significant and cutting-edge water extraction techniques currently available, used to address the growing issue of the global shortage of potable water. Air-to-water production could become a new revolutionary source of potable water, also directly at the place of consumption, eliminating the dependance on urban water systems and outdated, expensive pipes and infrastructures. Because air is a cleaner and more hygienic medium than soil, this technology could provide water untouched by human hands, eliminating the need for groundwater extraction and the possibility for soil contamination. Assuming also that its implementation turns out to be effective, atmospheric water collector systems could also reduce the need for plastic waste, including plastic water bottles, and carbon-intensive supply chains (*Watergen | Water From Air*, 2022).

Atmospheric water collectors, generally known as Atmospheric Water Generators (AWGs), come in many shapes and form. They can range from home-based generators, that can produce anywhere between 1 and 20 liters of water per day, to commercial-scale generators, capable of producing up to 10,000 liters per day (*Watergen | Water From Air*, 2022). Cooling-based systems are the majority, but hygroscopic systems are also becoming more popular. The first ones work using particular technologies of cooling and condensation, taking the air below its dew point and drawing moisture out of the air, similarly to how a home dehumidifier does, while the second ones produce freshwater by pulling it from the air via absorption or adsorption, using particular desiccant materials (Rao et al., 2022). Each of these installations have unique performance, operational principles and preferred field of application. Therefore, in a project like OCEANIX City, where the technology applied is only broadly presented, without a clear indication of the exact chosen technical element, it will be up to industry experts and engineers to install the appropriate AWG system. Of course, as for the OCEANIX project, it goes without saying that this system could be a useful technology also for other floating installations as well as other urban areas that struggle to supply potable water to their citizens. As a matter of fact, water is constantly present in ambient air.

"Our technology is set not only to have a significant impact on the lives of countless people and communities around the world but provides a solution that is both commercially available and affordable. It will also have a major economic impact on the water industry and will help solve drinking water stress in major global geographies" states Watergen, one of the leading corporations in the global AWG systems market (*Watergen | Water From Air*, 2022). The company has received many international awards thanks to its dedication to providing clean water to numerous underprivileged communities worldwide. Some of Watergen's installations, in fact, can be found in Costa Rican and Chilean schools, in Vietnam, Sierra Leone, India, Uzbekistan, Cambodia and in difficult areas like Gaza.

Of course, this technology isn't free of drawbacks. Their high operational costs and the large amount of energy consumed seems to be the major ones. In fact, unless the air surrounding the apparatus is extremely saturated with water vapor, an energy input, that depends on both external temperature and humidity, is necessary to extract water from the atmosphere. Despite that, due to recent technological developments, the energy-water ratio of AWGs has significantly improved, increasing the viability of using these systems to supplement the world's drinking water resources. Some technologies have, in fact, been complemented with renewable energy applications, like solar panels.

Table 15: SWOT analysis of atmospheric water collectors

STRENGTHS	***WEAKNESSES***
-provide a great solution to recover highly purified water from air humidity -provide means to conserve water and ease the strain on freshwater resources -provide an alternative source of water during interruption of conventional drinking water services -versatility and heterogeneity of technologies (from small home-based to large commercial units)	-knowledge and experience required -high initial and operational cost of some units -high amount of energy required -may have a high carbon footprint (if the energy is fossil fuel-based) -water input to output might be inefficient -dependent on outside conditions like humidity and temperature -cleanliness, health and safety of generated water needs to be checked and confirmed -some units generate noise -require water storage
OPPORTUNITIES	***THREATS***
-increase the technological development of AWGs systems -possibility to interact with other sectors (agricultural, energetic, …)	-public perception, misinformation, social acceptance -competition with other freshwater productions

-renewable energy sources can be integrated in the same system -useful in areas with insufficient water supplies -covering peak water consumption -decentralization -high unexploited potential -new jobs -raising social and environmental awareness	

Dehumidifiers

The sustainable and intelligent use of water and energy can pass not only through large and complex systems, which may require constant manpower or experience to be used, but also through simple appliances that are already part of everyday life, like dehumidifiers or air conditioner units. These devices by themselves are certainly not the solution to water scarcity, but they can certainly help floating installations, or even regular urban spaces, in progressing closer to a freshwater autonomy.

A dehumidifier is a type of air conditioner that lowers and regulates the amount of humidity in the air. This is typically done for health or thermal comfort reasons, to get rid of musty smells or to draw moisture out of the air to stop mildew growth. This technology finds uses in a variety of applications, from household and commercial to industrial ones. Large dehumidifiers are used in commercial structures like manufacturing facilities, storage warehouses, indoor ice rinks and closed swimming pools ("*Dehumidifier*", 2023).

Conventional air dehumidifiers work pulling moisture out of the air that passes through the device. They can also be combined with conventional conditioning systems, removing condensed water while cooling air in indoor environments. Apart from new emerging designs, condensate dehumidifiers and desiccant dehumidifiers are the two most popular varieties. Condensate types use a refrigeration cycle to collect water known as condensate, later normally treated as greywater. Some examples are electric refrigeration dehumidifiers, spray and makeshift dehumidifiers, thermoelectric dehumidifiers. Desiccant types (also referred as absorption dehumidifiers), instead, use hydrophilic substances like silica gel to bind moisture. Single-use hydrophilic substance cartridges, gel or powder are found in low-cost domestic appliances, while larger commercial units, to regenerate the sorbent, use hot air to remove moisture and exhaust humid air outside the room ("*Dehumidifier*", 2023).

Similar to AWG systems, but generally working indoor, some dehumidifiers can recover water contained in air humidity. However this water is regarded as a relatively clean type of greywater: unfit for drinking but acceptable, for example, for watering plants, though not garden vegetables. Dehumidifiers, in fact, generally lack filters and purifiers, which results in the water occasionally having traces of metals, like copper, aluminum or zinc, coming from the internal heat exchanger for example. Additionally, a variety of pathogens, such as fungus spores, may stagnate in the water, while beneficial minerals are largely missing in units that produce distilled water ("*Dehumidifier*", 2023).

Table 16: SWOT analysis of dehumidifiers

STRENGTHS	***WEAKNESSES***
-simple and effective system to reduce excess humidity in indoor environments -prevent and hinder mould growth and dust mites -help regulate indoor temperatures -makes the air healthier to breathe -versatility and heterogeneity of technologies -previous experience (technical expertise, developed legal and institutional framework) -user friendly -broad range of applications	-initial investment cost can be high -constant use of electricity -needs regular maintenance (graywater disposal) -might not work in low temperatures -some units generate noise -indoor environments must be closed -if not correctly regulated, it can make the air unpleasantly dry
OPPORTUNITIES	***THREATS***
-increase the technological development of dehumidifiers and other thermal regulating indoor appliances	-public perception, misinformation, social acceptance -conventional indoor regulation alternatives may be more efficient

Water storage

To meet the needs of their residents during times of low production, urban communities that don't have access to continuous and abundant water sources must rely on specific types of water storage. This makes it possible for initiatives and projects, like the one of OCEANIX City, to achieve and facilitate freshwater autonomy without importing outside water, coming for example from groundwater extraction processes. Both non-potable water, such as that used in agriculture, and potable water for human consumption can be stored. Useful during dry seasons, for example in both developing and some developed countries found in tropical climates, water storage can be used also to compensate for those water production methodologies that are able to produce water only when certain conditions are met. Along with rainwater harvesting technologies, for example, water storages in the form of tanks or deployable water bladders can be found, storing excess water gathered during heavy rains. Closed designs are typically preferred due to the minimal evaporation and contamination compared to open ponds and detention basins.

Table 17: SWOT analysis of water storage

STRENGTHS	***WEAKNESSES***
-cost-effective and simple methodology to store water for later uses -provide means to continuously supply water even during dry periods or interruption of conventional drinking water services -reduce water waste (water-effective) -previous experience (infrastructure, technical expertise, developed legal and institutional framework) -versatility and heterogeneity of technologies -broad range of applications (both potable and non-potable water) -low environmental impacts	-regular maintenance required -cleanliness, health and safety of stored water needs to be checked and confirmed
OPPORTUNITIES	***THREATS***
-increase the technological development of water storage technologies -possibility to interact with other sectors (agricultural, domestic, …) -renewable energy sources can be integrated in the same system -essential in areas with insufficient water supplies	-public perception, misinformation, social acceptance -water storage may not be necessary when water supply is reliable and constant

-decentralization -new jobs -covering peak water consumption -raising social and environmental awareness	

4.1.2.2.4 WASTE

The World Bank has estimated that about 267 million tons of plastic waste were produced globally just in 2016, accounting for about 12 percent of all municipal solid waste. Meanwhile, in the same year, an estimated 1.8 billion tons of CO2 equivalent greenhouse gas emissions were also generated from solid waste management. Currently, on average, the global municipal waste generated per capita each day is about 800 grams, but in some countries, it even reaches over three times the value; and, to make it even worse, around one third of all this waste is dumped openly. If the current waste management sector will proceed without improvements, solid waste related emissions are anticipated to increase to 2.9 billion tons of CO2 equivalent by 2050 (Umar, 2020). Much of this can be attributed to the activity of cities and urban areas, considered by many experts as the primarily responsible for most of the global pollution.

According to Rutger De Graaf, in fact, the metabolism of current cities can be even compared to that of parasites (De Graaf, 2012). It is undoubtedly a strong statement, but when it is considered how much local food, energy and other resources are used in most urban centers, this definition no longer seems to have much of an impact. As the city expands, in fact, rapidly consuming agricultural and productive land, these imported resources are used and then converted into waste materials, carbon dioxide, heat and wastewater. Furthermore, in worst case scenarios, waste products happen to be disposed into the surroundings areas, carrying with them further negative effects. Clearly not an efficient way to use these end-of-life streams. This parasitic behavior of cities is characterized by a linear flow of resources that results inevitably in resource depletion and accumulation of negative effects of urbanization in ecosystems. Therefore, it is crucial that cities, and floating cities in the future, transform themselves into productive urban centers that coexist in balance with their rural surroundings and ecosystem. To reduce the impact on the environment, the metabolism of such cities should be characterized by cyclical resource flows and productive use of waste streams (De Graaf, 2012).

By focusing on a circular economy, in fact, cities will be able to extend the life cycle of products. In order to achieve this, existing products need to be more reused, recycled, renovated and repaired to their highest extent possible. In this circular waste management, waste from one process or sector is a valuable resource for another. For instance, at the end of a product's life cycle, its components could be reused in a loop for new purposes, continuing to contribute to the economy for a longer period of time.

The EU and the European Commissions are among the first to commit to achieving a more circular and sustainable waste management system. In line with the twelfth SDG's objective to "ensure sustainable consumption and production patterns", the European authorities have, in fact, set common targets for all EU countries for the reduction of unsustainable patterns of consumption and production, that are considered as one of the root causes of climate change, pollution and biodiversity loss. Among the targets are:

- recycling of 65 percent municipal waste by 2030;
- recycling of 75 percent of packaging waste by 2030;
- creation of measure to promote and re-use of waste items;
- reducing landfill waste to a maximum of 10 percent of municipal waste by 2030;
- ban on landfilling of separately collected waste;
- creation of incentives for producers to put green products on the market and to support recycling schemes (*Circular Based Waste Management*, 2021).

The challenges that the world is currently facing are complicated and difficult, and the goals that nations and cities have set to address them can be even more complex. However, although some progress has been made in some urban regions, in other areas efforts have stalled. But how does this apply in a floating environment? How can floating cities manage waste better if regular cities already struggle with it? Surely managing waste offshore will be one of the major undertakings for a floating city.

When designing an urban environment on the water, already existing offshore installations, such as oil and gas rigs, can provide a certain level of experience, undoubtedly useful to comprehend all those dynamics that are usually not taken into consideration in a normal city on the mainland, but which make installations in the middle of the sea unique.

Due to the increasing global energy demand and the energy production development which happened over the last six decades, big offshore reservoirs have been explored and managed for production by offshore rigs, from Alaska to the Gulf of Mexico, from the North Sea and the North Atlantic to Australia (Zheng et al., 2016). These platforms, some fixed in position and some mobile, depending on their size, can host big communities and urban life rhythms typical of a city. Thus, they can produce a huge variety of both liquid and solid waste streams, including waste oil from engine rooms, production waste, back and grey water, bilge water, sewage, dry waste, galley waste, food waste and much more. Different regions have different responsibilities for waste handling logistics, in most cases involving owners, operators or both. However, in general, all the waste needs to be managed first on the rig or ship and, then, on land. This kind of logistic adds transportation costs, that have to be added to the already high expenses for the onboard labor, required space onboard and ashore waste management. And handling waste from the ship to the port and from the port to a waste treatment facility can be really expensive. Hence, to reduce costs, modern waste management systems are frequently adopted, allowing onboard separation of dry waste into fractions, reducing the volume up to 90 percent through shredding and compaction, facilitating recycling. Indoor food waste management systems are also adopted on oil rigs or production vessels to cut expenses. The presence of an efficient galley and food waste handling system, especially on fixed platforms, could, in fact, reduce or even eliminate the need to transport food waste, enabling controlled, hygienic and easy handling. In this way organic and inorganic food waste could be collected and grounded where it is produced. Thus, minimizing the work for the crew and maintaining a proper hygiene in the living compartments (*Offshore & Special Purpose*, 2020).

Of course, national and international laws governing safety and the environment, including those related to waste management, are also applied to offshore industry. And there are many and among the most disparate. One of these norms even states that discharge is allowed if the rig is more than 12 nautical miles from land and the food waste is grounded below 25 millimeters; but if waste cannot be grounded it has to be collected in a holding tank and then transported to land instead (*Offshore & Special Purpose*, 2020).

These and other technologies and methods have already found several positive applications. Therefore future floating city could easily make use of this offshore waste management. In fact, in contrast with a conventional city's waste disposal model, the floating project of OCEANIX City will focus on better waste management and reduction of material footprint through the use of "Zero Waste Systems". Closed-loop processing will turn waste into energy, agricultural feedstock and recycled materials, avoiding the creation of waste, via community compost gardens, anaerobic digestors and algae filtration systems. Packaging will be reusable and domestic items will be shared and fixed in dedicated exchange hubs. Food waste will be collected in pneumatic tubes converting it into compost and bioenergy (*Oceanix.com*, 2022). Wherever possible, reusable alternatives that are more affordable and cost-competitive than single-use products will be used in their place (*Oceanix | Helena*, n.d.). *Figure 25* shows an example of how these technologies might be used in practice.

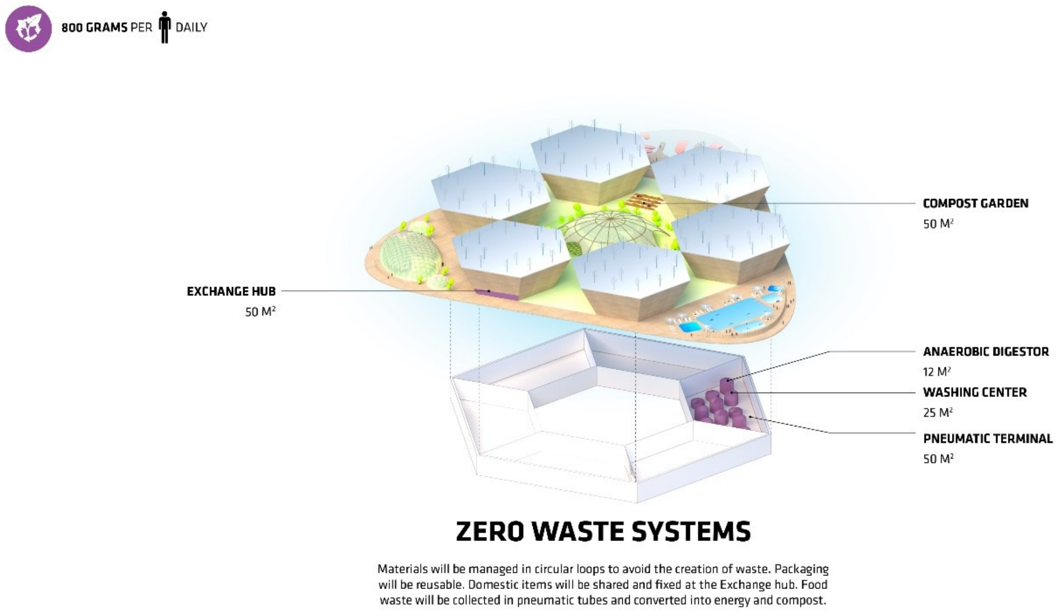

FIGURE 25: Zero waste Systems as envisioned for the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

For the fully developed project, it is estimated that the floating city design will account for a daily waste production of about 8150 kg, which translate to an average of about 800 grams of waste per resident per day, divided between organic (about 465 grams), sewage (about 155 grams) and recyclable waste (about 195 grams) (Yang et al., 2022). This implies that the average resident of the city will produce nearly two and a half times less waste than the average American citizen, with a waste footprint per capita up to 90 percent smaller than that of New York (*Oceanix | Helena*, n.d.).

In 2019, the port city of Busan generated about 3326 tons of domestic waste daily, including about 765 tons of kitchen waste, about 1929 tons of recyclable waste and about 632 tons of general waste. This results in a daily production of approximately 0.96 kg of household waste for each citizen. Although part of this waste generated is treated in heat and energy converting facilities, like the Haeundae Incinerator (with a capacity of 170 tons/day), the Myongji Incinerator or the Busan E&E (a fuel conversion facility), the remaining part is still disposed in landfills, like in the Sanggu Landfill (Yang et al., 2022). For this reason, incorporating a closed-loop waste management system in a project like the OCEANIX Busan prototype could not only contribute to the development of a fully sustainable and self-sufficient floating city, able to turn waste into energy, agricultural feedstock and recycled materials, but also develop a more environmentally conscious mindset, raising public awareness of these crucial aspects of urban management.

The following chapters will provide theoretical insights on the various technologies chosen by OCEANIX. A SWOT analysis will be given for each technology included in the "waste kit of parts" (shown in *Figure 26*).

FIGURE 26: Waste kit of parts of the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Anaerobic digester systems

Numerous countries are currently dealing with major issues related to environmental pollution, greenhouse gas emissions, growing waste production, rising energy demand and high energy import dependence. Moreover, most urban areas, where waste is mostly generated, face an even greater challenge due to a lack of landfill spaces and a high cost of waste disposal, failing to provide a sufficient solution to the problems mentioned above. Landfills, in particular, can be sometimes environmentally controversial, due to possible greenhouse gas emissions, as well as leaks in surrounding soils and water bodies when not properly managed. However, despite these difficulties, answers can often be found in the reuse and recycle of waste, in separated waste collection systems and in a general reduction of waste volumes. For these reasons, also due to an increased environmental awareness on waste-related issues and resource depletion and tighter environmental legislations, that forbids the immediate deposit of waste on future landfills, the amount of collected and recycled/reused waste and the subsequent demand for recycling are rising (Obrecht & Denac, 2011).

Rising energy demand and the depletion of the world's oil supply are also encouraging the development and use of alternatives, such as biogas or hydrogen. Energy consumption, in particular, has dramatically increased by a factor of 20 over the past century, and it is expected to keep increasing even in the future. According to the International Energy Agency's (IEA) reference scenario estimate, in fact, the global energy demand will increase by roughly 52 percent between 2005 and 2030, comparable also with the predictions of the World Energy Council, which estimate that energy demand will double by 2050. Despite this, fossil fuels will continue to be the primary energy source, providing about 75 percent of the increased global energy needs. However, as demand for fossil fuels rises, so do prices and emissions. Clearly, not a sustainable future. That is why renewable energy sources, which include biogas production mainly from anaerobic digestion technology, are seen as a long-term solution and a short-term reduction of the above-stated problems (Obrecht & Denac, 2011).

Anaerobic digestion can be defined as a biological sequence of processes by which naturally occurring bacteria break down biodegradable material, such as animal manure, sewage sludge, wasted food and other organics, in an oxygen-free environment. This process can occur naturally in some soils or aquatic environments, where it is usually referred to as "anaerobic activity". Some digestive processes, instead, can also be exploited by industries or in small scale domestic applications (differentiating between wet and dry digesters, or low-solid and high-solid systems) to manage waste or to produce fuel. Other systems are even used for industrial fermentation processes to produce drinks or food. Additional systems can then be installed by stakeholders for other different purposes, such as a waste treatment step, a means to reduce pathogens or minimize odors and vector attractions, a source of additional revenues due to the possibility of producing biogas or just as a way to improve public image. The different language used to describe the same processes and the countless applications reflects the varied historical uses and development of anaerobic digesters ("Anaerobic Digestion and Its Applications", 2015).

Anaerobic digester (AD) systems can thus truly play a big role in sustainable urban development due to their several impacts on countless environmental and industrial sectors, such as biogas and biofuel control, food production or integrated waste management, as previously mentioned. They are also frequently used as a source of renewable and sustainable outputs. The biodegradation processes, in fact, generate biogas, consisting of methane, carbon dioxide and traces of other gases. This biogas can be used directly as fuel, in combined heat and power gas engines or upgraded to natural gas-quality biomethane. The nutrient-rich digestate additionally produced can be even used as fertilizer. These and other applications of anaerobic digestion technologies make these systems important components of zero waste initiatives and exceptional allies to reduce the emission of greenhouse gases ("*Anaerobic Digestion*", 2023).

Anaerobic digesters will, in fact, be one of the key components in the waste kit of parts adopted by the OCEANIX project. The floating city, whose main objective concerning waste management is the creation of a zero-waste environment, will use these systems to dispose and treat the majority of the organic waste produced by its inhabitants during their everyday floating life activities (*Oceanix.com*, 2022). This project, but also other future floating installations, could adopt urban scale anaerobic digestors, benefiting from their ability to produce sustainable bioenergy, natural fertilizers, low emissions and overall positive environmental impacts. These systems do, of course, have some flaws. High maintenance costs and the need for specialized knowledge to manage these often-complex systems can be some obstacles that will hinder their development. Other challenges might include stringent legal requirements as well as inaccurate public perception.
But despite these impediments, due to the reuse of waste as a resource and new technological approaches that have reduced capital costs, governments in a number of nations, including the United States, the United Kingdom, Germany and Denmark, have recently given anaerobic digestion more attention ("*Anaerobic Digestion*", 2023).

Table 18: SWOT analysis of anaerobic digester systems

STRENGTHS	***WEAKNESSES***
-provide means to reduce organic waste disposal -provide a source of renewable energy (biogas) -provide a source of organic fertilizer (digestate) -cogeneration / three-generation (high efficiency) -lower environmental impacts -previous experience (infrastructure, technical expertise, developed legal and institutional framework) -broad range of applications -one time investment	-high initial investment cost -high maintenance cost -uncontrolled biogas emissions can cause negative impacts -unprofitable without feed-in tariffs -knowledge and experience required
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public)	-public perception, misinformation, social acceptance

-increase the technological development of anaerobic digesters applications -possibility to interact with other sectors (agricultural, energy, …) -provide means to generate leading / important alternative for fossil fuels -covering peak energy consumption -possibility to use existing infrastructures -legislative national and international support -decentralization -high unexploited potential -reuse and reduction of landfills -new jobs -raising social and environmental awareness	-competition with other renewable energy productions -strict legal requirements on emissions and byproducts

Algae filtration systems

Access to clean drinking water and affordable point-of-use water treatment still remain a problem in many developing countries, being needed mainly to reduce the spread of water-borne diseases. In some countries, in fact, piped water is often contaminated and only available for a few hours a day. As such, it must be boiled prior to consumption, but this requires either fuel that may be unavailable to the poorest families or wood that may cause deforestation. One solution is water filtration, but abundant low-cost materials are required (Roy, 2019).

Algae and microalgae cultures present an interesting and valuable step in the understanding of treatment and filtration techniques of wastewater, because they provide bioremediation coupled with the production of potentially valuable biomass, which can be used for biofuel production (Rathod, 2014). Additionally these organisms can contribute significantly to the global ecosystem because they are able to generate roughly half of the oxygen present in the atmosphere (Olson, 2015). They also offer an elegant solution to treatments due to their ability of assimilating excess inorganic nitrogen and phosphorus in natural water, which they use for their growth, and removing heavy metals, as well as some toxic organic compounds, while absorbing vast amounts of greenhouse gas carbon dioxide (Rathod, 2014). These abilities make them among the most important groups of organisms on the planet.

Therefore, developing algae filtration systems could provide a sustainable alternative to current wastewater treatment technology, considered energy intensive and expensive. Additionally, the lack of wastewater treatment in underdeveloped regions is also a major public health issue, and thus developing a second sustainable option, based on mass cultures of microalgae, could be undoubtedly a wise move (Olson, 2015).

"Researchers have been considering algae for wastewater treatment for quite some time" said Peter Lammers, chief scientist of Algae Testbed Public-Private Partnership (ATP3). Together with his team, Dr Lammers has begun a pilot project in Gilbert that focuses on using algae for wastewater treatment. He also added:" There is now an opportunity to utilize sunlight prevalent in the desert that directly creates net energy production, fertilizer extraction and clean water available to repurpose to other applications. […] Current sewage facilities' electricity bills can account for up to 60 percent of wastewater treatment practices (WWTP) operation costs today. The use of algal systems could ultimately eliminate these bills, while benefiting the industry by extracting fertilizer nutrients in the process". The uniqueness of his project is reflected in the algae used and the working conditions. By selecting low pH levels, high temperatures and algae native to Yellowstone National Park (*Galdieria Suphuraria*), thus, choosing factors that are detrimental to most pathogenic organisms, in fact, researchers were able to achieve better wastewater treatment with lower concentrations of disinfectants. Additionally, this method allowed to yield more energy-rich biomass than current treatment systems. Then, once the pathogens and nutrients have been eliminated and the pH has been brought to a neutral state, the treated water may be released as greywater for agriculture or, with further purification, even used for drinking (Olson, 2015).

This and other wastewater treatments based on algae filtration could be a nice addition to projects like that of OCEANIX City. Small-scale applications involve the placement of algae inside plastic reactors, similar to crops inside greenhouses, that are limited in size, thus the land area required is smaller than that of conventional wastewater treatment systems. And in a floating installation, where the effective use of soil is crucial, this is unquestionably a positive aspect. It also offers an environmentally friendly and reasonably priced alternative to current wastewater treatment techniques, another valuable factor to take into account considering the various commitments of the UN project. Natural nutrient abundance in wastewater makes it possible to support algal growth and the development of algae-based filtration systems, but despite this, further research on the topic is still required to investigate the costs, such as those associated with the fabrication of the reactor platform and the numerous maintenance procedures, as well as the overall technology's efficiency.

Table 19: SWOT analysis of algae filtration systems

STRENGTHS	***WEAKNESSES***
-sustainable technology -provide means to treat and filter wastewater -provide means to grow valuable microorganisms (algae and microalgae) -previous experience (infrastructure, technical expertise, developed legal and institutional framework) -indoor solutions (photobioreactors) have low land use -broad range of applications -microalgae can become an alternative source of biofuel (biodiesel, methane, hydrogen, …) -microalgae can be used as an alternative source of food -microalgae can be used to produce high-value chemicals for other sectors (pharmaceutical, cosmetic, …)	-high cost and energy (light, temperature) demand -constant maintenance required -knowledge and experience required -early stages of development
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -increase the technological development of algae filtration systems -wastewater is the only water source whose availability will rise as the population does -useful in arid regions or in areas with insufficient water supplies -conventional wastewater treatments are more energy intensive and expensive -possibility to interact with other sectors (agricultural, energy, pharmaceutical …)	-public perception, misinformation, social acceptance -reused wastewater may cause health issues such as skin irritation or water-borne illnesses if it is not properly handled -wastewater management is highly regulated (for example the reuse of industrial wastewater for agricultural purposes is prohibited if it contains urban runoff, hazardous chemicals, salts, or heavy metals) -cleanliness, health and safety of treated water needs to be checked and confirmed

-provide means to generate leading / important alternative for fossil fuels -legislative national and international support -decentralization -high unexploited potential -new jobs -raising social and environmental awareness	

Treatment swales

Swales are among the world's oldest and most common types of urban drainage and stormwater transportation systems (Burian & Edwards, 2002). Swales are linear, grass-covered depressions that are able to transport surface water over land from a drained surface to a storage or discharge system. Usually located close to the source of runoffs, swales can connect storage ponds and wetlands forming a network within a development. Because they are shallower and relatively wide compared to conventional ditches, they can also often provide short-term stormwater storage, reducing peak flows (*Swales*, n.d.). Furthermore, despite the similarity in appearance between a drainage ditch and a swale, a ditch is only intended to transport drainage water, while a swale can be designed also to treat water.

In dry weather, swales can provide open space benefits, functioning as component of parks or green belts; however, during wet weather, they collect rainwater, slowly leading it along their length, through the grass area, filtering the flow of surface water. During this process also, a portion of the runoff can be lost by evaporation, transpiration or simply by infiltration. Thus, if necessary, the soil beneath the swale can be lined with an impermeable material to safeguard an underlying aquifer. The ideal grass length is approximately 150 millimeters. Sediments and gross particles are deposited while oily residues and organic matter are retained to be broken down by microbial degradation and vegetation uptake (*Swales*, n.d.). This biological uptake and storage by vegetation is a limited but crucial treatment method offered especially by grass swales. This is one of the simplest designs, but due to regulatory demand for improved treatment of urban stormwater, other types of swales exist, including infiltration swales, bioswales, wet and dry swales (Ekka & Hunt, 2020). Each has its own characteristics, performance and operational principle, but regardless the type chosen, whether it is in a regular urban landscape or a floating city, swales can provide open space benefits and enhance the natural hydrological processes of infiltration, evapotranspiration and runoff, qualifying them as a low-impact development and green infrastructure practice (Dietz, 2007).

Different designs are provided to best fit the desired purpose, making this methodology extremely adaptable and used in a wide range of applications. Some designs, for instance, may permit overflows to allow transportation in periods of exceptionally heavy rain. In other, performance can be improved by adopting small gradients along their length and on their side slopes or by building check dams to reduce flow rates, which, in turn, lowers the chance of erosion. To improve their ability to remove pollutants, especially where they discharge directly to a watercourse, swales could be designed also to be dry between storm events (*Swales*, n.d.).

Ultimately, swales are generally simple in design. For example, in installations where runoff is transported through surface channels, incorrect connections are generally evident and can be fixed without the use of costly surveys or experienced personnel. Swales avoid the need for expensive gullies or roadside kerbs and reduce maintenance; only regular upkeep is required to keep a grass swale correctly operational (chiefly, mowing during the growing season, standard park maintenance, …). Additionally, they reduce risk to amphibians like toads and newts, which are frequently caught in gully pots (*Swales*, n.d.).

Table 20: SWOT analysis of treatment swales

STRENGTHS	***WEAKNESSES***
-provide cost-effective and simple means to sustainably manage rainwater runoff -low environmental impacts -provide means to passively filter rainwater -enhance the natural hydrological processes of evapotranspiration and infiltration -provide means to store rainwater and reduce its peak flows -previous experience (infrastructure, technical expertise, developed legal and institutional framework) -broad range of applications in urban areas -versatility and heterogeneity of technologies -low maintenance required	-initial investment cost -some regular maintenance is required -require water storage -dependent on external rainfall -uncontrolled infiltration can cause problems to possible aquifers located below

-reduce the need for expensive gullies or roadside kerbs -reduce local fauna related risks	
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -increase the technological development of swale systems -new jobs -raising social and environmental awareness	-public perception, misinformation, social acceptance

Community compost gardens

Although the practice of urban agriculture cannot be considered a reality linked exclusively to the most recent urban development, global interest in community gardening has especially increased more recently, probably due to the numerous challenges the global population is dealing with in the twenty-first century, including ecological crisis, climate change and a new sanitary crisis. Community gardening projects are, in fact, popping up in various forms all over the world, promoted by individual, collective and public actors. They can be found located on balconies and rooftops, in shared greenhouses and in proximity with neighborhoods, with their size varying greatly between each location.

Current cities can be found dotted with internal episodes of closed spaces, marginal areas, abandoned places, which find in the care of the land by individuals or groups, reasons for redevelopment and new vitality, starting from daily practice, with low cost and low impact. For instance, in Japan, community gardens have been installed on the rooftops of some train stations (Horton, 2014). Legal or unauthorized community gardens are frequently established on flood-prone riverbanks, in under development sectors and other unsuitable urban areas in Taipei City, in Taiwan (Bauwens, 2010). In more developed countries, like the United States or the United Kingdom, community gardens make use of wasted space providing local green areas for the population, a habitat for insects and animals, sites for gardening educations and charity opportunities for those that could not have a garden, such as apartment-dwellers, the elderly and the homeless (*Social Farms & Gardens*, 2023). Created to mainly satisfy needs related to food supplementation, community gardens are now an exciting way to enhance both the environment and the way of life of the citizens, who are compelled to live in crowded, stressful urban areas every day, bringing communities together, fostering better human relations and increasing public awareness of social and environmental issues.

When food and organic waste are disposed in landfills or other uncontrolled environments, they decompose generating methane, a greenhouse gas with effects far more potent than CO2, and other substances that can threaten the environment and its organisms. Thus, introducing composting systems into greenhouses and community gardens could reduce negative climate impacts, reducing the overall biodegradable waste volume, while retaining vital nutrients for growing cultures.

Composting is a relatively simple procedure that permits to create compost mixture from food waste, plants, manure and organic materials. Being abundant in plant nutrients and healthy microorganisms like bacteria, nematodes, protozoa and fungi, compost is able to improve soil fertility in gardens, horticulture, urban agriculture and landscaping, while lowering reliance on synthetic chemical fertilizers ("*Compost*", 2023).

OCEANIX has already stated that its future floating cities will host flexible, buoyant skirt dedicated to food production and communal farming in the earth of each neighborhood, allowing residents to embrace sharing culture and zero waste systems (*Oceanix.com*, 2022). Combining them with sustainable, user-friendly composting systems could only improve the situation.

Table 21: SWOT analysis of community compost gardens

STRENGTHS	***WEAKNESSES***
-provide cost-effective and simple means to sustainably grow fresh organic products locally -increase biodiversity of plants and animals -low environmental impacts -improve mental health and promote human relations -previous experience (infrastructure, technical expertise, developed legal and institutional framework) -year-round production (in controlled systems) -versatility and heterogeneity of technologies and applications -low maintenance required	-initial investment cost -some regular maintenance is required -composting require a basic knowledge to be efficient (compost can have adverse effects if not properly handle) -composting require time and work -compost quality and performance depend on its ingredients -some composting units can create unpleasant smell

-composting can enhance soil properties -composting can reduce neighborhood waste -composting can increase farm productivity and profitability -composting reduces the dependance on fertilizers	
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -ease some of the stress associated with traditional semi-intensive and intensive food production methods -community gardens can increase the value of surrounding neighborhoods -new jobs and local buying -raising social and environmental awareness -reuse of wasted spaces -encourage local stakeholders' participation in decision-making processes -decentralization -high unexploited potential -eco food tourisms	-public perception, misinformation, social acceptance -conflicts of interest and competition between gardeners -conventional fertilizers may be more comfortable to manage for the public (it might seem easier to buy them than to make compost mixtures at home)

Exchange hubs

Often, waste is an inevitable byproduct of human activity. It occurs in commercial activities, homes, offices and industries. Soil, water and air, as well as communities, animals and plants that depend on them, are all impacted by how people choose to manage that waste, thus, a responsible waste management is crucial. However, the achievement of sustainable and circular waste management, and with it the goals set by the United Nations, cannot be accomplished only through the use of new innovative technologies, advanced industrialized procedures and cutting-edge waste management techniques; in order to achieve it, it is also necessary to change common habits by

adapting to a more local and intelligent use of resources. It is important that everyone play their part.
One of the ways to better approach responsible waste management, keeping as much waste as possible away from landfills, is through the 3 Rs of waste management: Reduce, Reuse and Recycle.

- Reduce means to cut back the amount of waste generated. Avoiding the creation of waste in the first place is, in fact, the most efficient way to eliminate it. Reducing waste begins with the producer of the product and ends with the consumer. The first one controls the materials that are used, how the product is made and how it is packaged, while the second one chooses which items to buy and how many of them are required, thus, by reducing, a single individual can stop the issue at the source.
- Reuse means to find new uses for items that would have otherwise been thrown away. This method does not transform the item into a new product, like recycling, instead, it involves using the same item once more for its intended use or coming up with inventive ways to reuse it for another purpose. Compared to recycling, reuse typically saves more energy, money and natural resources.
- Recycling means to transform waste materials into new goods in order to reduce the consumption of virgin resources. It is generally the most used approach among the three. Recycling, in fact, helps reducing the quantity of usable valuable materials taking up space in landfills, transforming, through manufacturing processes, older materials or part of items into new useful materials and products. Recycling is also a great way to prevent pollution, reducing emission and energy consumption associated with the harvesting of new raw resources.

By keeping usable materials out of landfills, waste reduction, reuse and recycling can surely help decreasing landfill space. The three Rs also help lowering the amount of energy and raw materials needed to collect natural resources and manufacture new products, every year more complex and resource demanding. They also indirectly lower the greenhouse gas emissions associated with transport and shipping of items.
Therefore, by planning temporary or permanent events, highlighting the benefits of the three Rs and other sustainable tools, communities and municipalities could promote responsible waste management opportunities in their urban areas. Collection events could be held as an educational opportunity for people to properly recycle and manage unwanted dangerous waste, such as WEEE (Waste from Electrical and Electronic Equipment) or chemical products. Simple and household

items could be shared and fixed in dedicated exchange hubs, just like the project of OCEANIX City plans to do. Training sessions could be organized to assist neighborhoods, but also companies and businesses, in understanding how to abide by local, regional or national laws and regulations about waste. Exchange events and community hubs could also serve as opportunities to promote human relations, bringing neighborhoods together, encourage better possibilities for sharing and increasing public awareness of social and environmental issues. These sustainability-focused events are already common in many urban settings, and they keep growing every year thanks to the promotion of numerous green campaigns.

Table 22: SWOT analysis of exchange hubs

STRENGTHS	***WEAKNESSES***
-environmental benefit (reduction of waste disposal, reduction of GHG emissions, prevention of pollution associated with raw materials extraction, …) -saves energy -saves money -provide means for products to be used to their fullest extent -promote human relations -previous experience (infrastructure, technical expertise, developed legal and institutional framework)	-recycling have its own drawbacks (can be costly, energy demanding, pollutant, …) -reused and repaired products have lower performances -cost to develop, maintain and operate exchange hubs and collecting events
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -tax benefit could be available for donations, repairs, … -community exchange hubs can increase the value of surrounding neighborhoods -new jobs and local buying -raising social and environmental awareness	-public perception, misinformation, social acceptance -disposal is generally more cost-effective than upstream options (3 Rs)

Communal washing centers

In the last years more and more people are choosing to rent rather than purchase homes and cars as they get older. Recent graduates are even increasingly renting well into their late 20s and early 30s. For this reason, the rental property market is continuing to expand, thus, to maintain competitiveness, the provision of "must-have" and "nice to have" amenities is required. And laundry services are at the top of many applicants lists.

Washing centers and community laundry rooms are laundry service options for multi-housing, condos and apartments. And why not, even for floating cities. They overall offer a variety of advantages to the residents, the property owners, the community and the environment. Shared community laundry rooms are convenient, especially for those than cannot afford a washing machine, and can add value to the building and neighborhood. Additionally, community washing centers are more environmentally friendly. Shared machines and community washing services, in fact, save both energy and water, which is surely great for the city. Energy use depletes non-renewable resources and emits greenhouse gases, according to the U.S. Environmental Protection Agency (EPA), who also estimates that just washing machines and dryers use about 13 percent of the whole energy in a typical home (*The Environmental Benefits of Using Pick up Laundry Services Chic*, 2023). Conventional laundry methods contribute also to the global waste problem. Dryer sheets, lint and laundry soap packaging are just a few of the waste that end up in landfills. Laundry detergents and dryer sheets can also harm the environment when they are produced and then illegally disposed. Ultimately, having a washing center in a neighborhood could also support local business, create jobs and strengthen the economy while also promote waste conservation and public awareness on environmental issues.

Table 23: SWOT analysis of communal washing centers

STRENGTHS	***WEAKNESSES***
-environmental benefits (compared to individual washing machines) -energy-efficient -water-efficient -convenient -foster a sense of community and can be a place for residents to meet one another	-maintenance required -cost to develop, maintain and operate shared spaces and machines -lack of privacy -lots of machines together may produce noise

-previous experience (infrastructure, technical expertise, developed legal and institutional framework)	
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -increase the value of buildings and surrounding neighborhoods -new jobs and local buying -raising social and environmental awareness	-public perception, misinformation, social acceptance -individual washing machines offer a better sense of privacy and autonomy

Pneumatic collection systems (PTT systems)

To provide efficient waste management, a city needs to be supported by an equally efficient and well- organized waste transport and collection system. However, in a floating city, due to its constrained and limited nature, the use of conventional waste collection methods would be precluded. Hence, new and unconventional methods must be applied. For instance, in the OCEANIX City project, waste will be gathered and sent to various facilities, based on its typology, using pneumatic tubes, to be then managed in accordance with its end-of-life path.

This technology is able to propel solid objects, as opposed to traditional fluid-transporting pipelines, through a system of tubes using partial vacuum or compressed air. Pneumatic tubes, or capsule pipelines, also known as pneumatic tube transport or PTT, are not a revolutionary and modern technology. They were, in fact, used since the late 19th and early 20th century as a way to transport mail, money, paperwork and other small and urgent packages, mainly in offices, over relatively short distances, within a building or, at most, a city. A few pneumatic transportation systems were even built for larger cargo, to compete with train and subway systems, but they never gained popularity ("*Pneumatic Tube*", 2023).

Today this technology is still used on a smaller scale and where the fast and convenient transportation of small objects in a local environment is crucial. They are, for example, used in modern hospitals to send test tubes and samples between clinical laboratories for analysis, or in factories, where they are used to swiftly deliver parts across large campuses ("*Pneumatic Tube*", 2023). Pneumatic tubes are also used in waste disposal systems, such as the one in Mecca, Saudi Arabia, where 600 tons of garbage are sucked into 400 openings each day at a speed of 40 miles per hour (about 64 kilometers per hour) and transported to a far-off station, waiting to be disposed of (De Chant & Spertus, 2015).

Table 24: SWOT analysis of pneumatic collection systems (PTT systems)

STRENGTHS	***WEAKNESSES***
-provide means to swiftly transport small solid objects over short distances -safe and clean system -simple and reliable system -less operating and maintenance cost -modular -low land use (space-saving) -cost-effective -infinite availability of the source (air) -previous experience (infrastructure, technical expertise, developed legal and institutional framework)	-required installation of air-producing machines -air can easily leak -can produce noise -maintenance required -control and speed are more difficult due to the compressibility of air -suitable only for small and relatively light objects
OPPORTUNITIES	***THREATS***
-investments opportunities (both private and public) -increase the technological development of PTT systems -new jobs	-public perception, misinformation, social acceptance -other conventional waste collection systems are more efficient

4.1.2.2.5 MATERIALS

The concept of a floating city isn't new. From the chinampas of the Aztec Empire to the canal cities of Venice and Amsterdam, human communities have long existed on the water (Grau & Kekez, 2010). However, more recently, the threat posed by climate change and the introduction of new technologies have renewed interest worldwide in the concept of sustainable urban water-based communities. While there have been several different renderings of floating cities over the years, the plans proposed by OCEANIX at the UN roundtable, in April 2019, provided a glimpse of how the most modern iteration of a floating city would be built (BigRentz, 2019).

It seems appropriate to point out that the creation of a sustainable and climate-resistant floating city, able to accommodate thousands of people whose existing communities are most vulnerable to the threat of rising seas, passes not only through the implementation of new, efficient and innovative technologies but also through a thoughtful use of resources and materials, which encompasses its entire cycle of life. In fact, in order to be truly sustainable and self-sufficient, a floating city, like that of OCEANIX, must be planned taking into account every stage of its life cycle, from its initial construction up to its eventual dismantling in the future. Focusing only on the "present" perspective, considering only its maintenance and operational performances, would lack a comprehensive 360-degree vision, which is necessary for the project's proper development. Being able to meet the needs of the current population without compromising the capacity of future generations to do the same is what it means to be sustainable. Installing solar panels only because they provide clean energy from the sun, without taking into account their initial assembly or their final disassembly, isn't sustainable. Building structures out of wood or bamboo just because they are natural, appealing to the eye or safe materials, without taking into account where they come from, how they were produced or what will happen to them after their useful lives, is not sustainable either. These are all significant considerations to think about. An elegant strategy for dealing with the topic of materials and resources utilization, would be to analyze the floating city projects along a logical temporal thread. Similar to a cradle-to-grave approach, in fact, different stages of a floating city's life cycle will be considered in this chapter, from the moment natural raw materials are extracted from the ground and processed, through each subsequent stage of manufacturing, transportation, product use and, ultimately, disposal.

Prior to global supply chains and transportation, people were forced to construct using the materials that were locally accessible to them. There is still a ton of evidence for that, especially in areas where specific masonry or roofing materials define the visual character of the urban landscape. In the majority of time, the material was extracted, processed and sold all within a few kilometers, but the situation is now much more complicated. The creation of a global trade brought to society several benefits: it made possible the access to new cultures, it facilitated the spread of technology and innovations and it also made possible the use of previously unimaginable resources and materials; however, it also made aspects such as transport and logistic, with associated costs and energy required, much more predominant in the market. By adopting a more localized approach, businesses and communities may create new opportunities to assist both the environment and also themselves. Localizing a supply chain can reduce shipping and storage, hence reduce drastically emissions and energy usage. Transport has, in fact, the highest reliance on fossil fuels of any sector, accounting for more than 35 percent of CO_2 emissions from end-use sectors in 2021, according to IEA (IEA, 2023). Local sourcing not only promotes environmentally friendly manufacturing, but also supports in building consumer confidence. When customers make purchases with confidence, the business gains from elevated customer loyalty and positive brand awareness. This is especially reflected in most recent positive trends, for example in food and beverage sales, driven more than ever before by consumers, particularly millennials, who favor products with “green labels” that identify their origin. Shortening the supply chain helps the local economy. By sourcing locally, companies will be able to save money, lowering the costs associated with transportation and logistics, as well as generate more of it, luring new clients drawn by the efforts to keep a close-knit and quick-moving supply chain. Locally sourced businesses are more flexible and have greater control over their products and materials. The further they are from components of the supply chain, the less influence they have over them. Locally sourced materials and products are also good for the community, which can benefit from increased local economy, volunteering, fundraising and sponsored activities. Of course, when forced to choose products and materials with more travel miles than desirable, the key is to focus on responsible sourcing as opposed to locally sourced goods. In fact, the concept of sustainability must include also how people and communities in other nations are treated. Local sourcing can help local communities and economies, while responsible sourcing can show the supply chain traceability, necessary to guarantee that people in other countries or regions are treated fairly and with respect. Regardless of any necessary trade-offs between local and global sourcing, nobody can consider the exploitation of land, resources and people to be sustainable. Today, the topic of localizing supply chains is becoming more and more significant among consumers, architects and designers looking to deliver building projects that can be deemed as sustainable. OCEANIX itself has stated that its future floating cities will prioritize locally sourced materials for all of their buildings (*Oceanix.com*, 2022), as presented in *Figure 27*.

FIGURE 27: Locally sourced materials as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The selection of materials and the building process are almost as crucial as the amount of energy it takes to make and transport the resources. This is why OCEANIX is planning to use one of the most important non-timber sustainable forest resources: bamboo. By using bamboo as one of the primary building materials for its floating city, OCEANIX will benefit from the fast-growing speed, high CO2 adsorption potential and exceptional load-resistant properties of the plant, which make it as one of the most used sustainable materials for building today. Furthermore, considering the prototype of Busan, using this plant certainly satisfy the criteria for having a local origin resource. Bamboo's ability to grow in the tropical, subtropical, or temperate zones, in fact, makes them an abundantly available plant in the world (Chin, 2021) and, without a doubt, a handy resource for the Korean prototype. China and India, for example, where the majority of the world bamboo forest are located (Kaur, 2018), but also some part of Africa and Latin America, have used bamboo as a traditional building material since ancient times, from its non-processed form to highly engineered compounds, used in more modern times. Studies have reported that there were more than half a million units of houses constructed out of bamboo in Ethiopia in 2007. Bamboo framing systems were used in the replica of the Indian Pavilion for the 2010 Shanghai Expo, built in Bogotá (Escamilla et al., 2019), as support for several pedestrian bridges in Colombia and schools in Indonesia (Chin, 2021). Additionally in Indonesia, due to its high degree of flexibility, bamboo is used in a variety of organic shaped buildings, including commercial, institutional and touristic constructions (Nurdiah, 2016). Being classified as a "green material" has also made its adoption even more predominant globally. Bamboo constitutes part of the ceiling of the Madrid International Airport in Spain and part of the floor in the Clinton Library in Little Rock, US. It is used as a building material in the Tokyo Dong Wu Department in Japan, in the BMW exhibition hall and the IBM headquarters in Germany (Chin, 2021). Growing three times faster than most other plant species due to a unique rhizome-dependent mechanism, that permits to usurp about 17 times more carbon dioxide than a normal tree (Mohan et al., 2022b), bamboo is often used in many other applications, such as clothes, food and fuel industries, but the construction sector is where this natural material really shines. Its high compressive and tensile strength, which is comparable to concrete and streel respectively, make bamboo as one of the most used building materials after concrete. It can be used in walls, doors and windows, in foundations, although it doesn't last long if it comes in contacts with damp ground or water (so it has to be treated like wood and timber materials), roofing and flooring, and even as a concrete reinforcement and a steel substitute (bamboo scaffolding is commonly used in China and Hong Kong as an alternative to conventional metal ones) (Chin, 2021). Due to its relatively light weight compared to other conventional materials and its high elasticity value, is also a useful building material in earthquake-prone areas (Chin, 2021), like Colombia, Ecuador and Peru, which have adopted bamboo culms as a structural material within their building codes for walling and framing systems of up to two stories (Escamilla et al., 2019). Bamboo has been widely known as a sustainable building material also because it can be reused and, especially, easily cultivated and harvested in a relatively short time (Nurdiah, 2016). Hence, OCEANIX has planned to allocate several bamboo gardens in its future project, providing not only a direct local source of this useful material, but also creating thriving communal areas and shaded bamboo-based green public realms for its residents (*Oceanix.com*, 2022).

Of course, when building a floating city, sustainability takes into account a wide range of factors that go far beyond transportation and local sourcing, first and foremost construction itself. According to some publications and literature reviewed, floating structure are generally portrayed faster and less expensive to construct compared to land reclamation. When developers reclaim the land, it may take several years for the soil (generally sand) to stabilize, depending on the area. Such requirements, however, do not apply to floating cities; construction can, in fact, begin the day the platform is anchored (Adnan, 2020). Additionally, water depth has a much greater impact on land reclamation compared to floating structures. With increasing water depth, land reclamation costs and impacts will rise, due to the increasing quantity of materials needed to fill up the gap. Instead, floating structures maintain their size regardless of the depth of the water (Ko, 2015). Unlike land-based development, the construction of floating platforms also generally leaves no visible marks on the development site; rather, after the project is complete, it is disassembled and removed from the water's surface (Adnan, 2020). Dry docks can be used to create floating platforms, which can then be towed to their final location (Ko, 2015). They should be located as closed as possible to the final installation site, to reduce transportation and logistics. However, there are also methods that make it possible to build such a floating platform on still water. But up until now, only small-scale floating platforms have used this method of building directly on the water surface. Due to their modes of construction and structural strength, floating platforms can only be a certain length and width. Very large platforms can only be built on site because it is otherwise very difficult to tow the structure to the desired location. Longer elements experience significant bending moments as the structure gets heavier, which compromises the structural strength of the build. More reinforcement can be added to concrete structures to increase their stiffness, however doing so adds to the weight of the floating platform, increasing its draught and possibly preventing its ability to float. The floating structures must be connected to one another in order to realize floating districts and cities, thus, key components of the design are connections, hinges, bridges, jetties and joints which link the various floating structures. A city can be several to hundreds of square kilometers, while the longest known floating platforms to date are between 50 and 200 meters long. Therefore, building a large platform of one square kilometer "in one go" is not even currently possible (Ko, 2015). In addition to shorter construction timelines floating structures offer opportunities for prefabrication (Nillesen et al., 2021). The modular nature of a floating structure can benefit each step of its life cycle. By constructing individual floating structures with uniform shapes, both cost and impacts can be kept down. Repetition of an element results in a construction's increasing learning cycle, which lowers the number of man hours needed and also simplify the configuration possibilities (Ko, 2015). This is one key aspect in the project of OCEANIX City. By being modular, the city not only reduces the effects of its construction but also makes it simple to operate afterward. Using uniform and modular platforms the city can organically transform and adapt over time as the demand to live in it grows, while simultaneously making it simple to maintain the correct resource allocation as platforms get added, as once the initial phase is operative, it will become possible to monitor useful parameters as energy demand, space requirements and food production requirements, to then keep in mind while constructing the successive platform additions. These data are still being studied and have not yet been published, thus, in order to start realizing the concept of a floating city, more research is required on the construction techniques and scheduling of the hexagonal platforms. However, engineers and architects can retrieve knowledge on the topic from already existing floating structures. There are, for instance, several large floating projects that are already in existence around the world which can even reach lengths of more than 300 meters (almost twice the OCEANIX City standard platform) and heights of 20 meters. These projects can serve as good reference models for projects like the OCEANIX floating city. For example the floating breakwater in Monaco has a total length of 352 meters and a construction height of 19 meters. Typically, reinforced concrete is used to create such large platforms and pontoons. The larger the platforms, the heavier the structure will be, thus leading to a very large draught (Ko, 2015). Cost and impacts can be reduced even further by adopting lightweight, sustainable and natural materials (like bamboo in the OCEANIX project) and even ephemeral designs, that minimize the use of "heavy" construction methods, which possibly involve steel and concrete. Furthermore, if combined with local sources, which delivers low kilometers materials, this “light” construction approach results in low embodied energy and carbon emissions (Nillesen et al., 2021).

Once the platforms have been constructed, they usually need to be towed to their destination. Depending on their shape and size, floating communities can be moved according to different possibilities.

- Self-propelled floating structures can move freely thanks to built-in propulsion systems. When the community is made up of relatively smaller platforms, each one could have the ability to move autonomously and independently of each other, whereas a larger, heavier structure necessitates large propelling systems, which use a lot of energy. And this can be a drawback.
- Floating structures can be towed by ships. When designed to be towed they can benefit from a simple and fast-moving process. However, this method is preferred only for larger floating structures because of the vulnerability of smaller installations to dynamic movements like sway, roll and pitch. Additionally, tugboats should always be accessible if the development plan contemplates additional future movements.
- Floating structures can be transported by (semi-submersible) ships. As opposed to conventional ships, large semi-submersible ships can accommodate a range of platforms sizes (in regular ships, the platforms require to be lifted into place). Due to their dimensions, these ships can also host entire floating communities, eliminating the need to decompose the overall structure of the floating installation. However, due to the complexity of a floating community, several ships might be required. Additionally, the platforms’ dimensions must be constrained by the size of the ship (Ko, 2015).

Once the platforms are placed in the designated location, the actual operating life of the installation can start. Future floating cities are envisioned to be innovative and sustainable creations, designed to have as lower impacts on the surrounding environment as possible. The OCEANIX city makes this one of its primary goals, adopting several green and sustainable technologies and even taking a step forward by promoting "habitat regeneration". The project in fact, as illustrated in *Figure 28*, will be surrounded by wetlands and artificial reefs that will protect the floating city from waves and at the same time create a valuable habitat for many marine species (*Oceanix.com*, 2022).

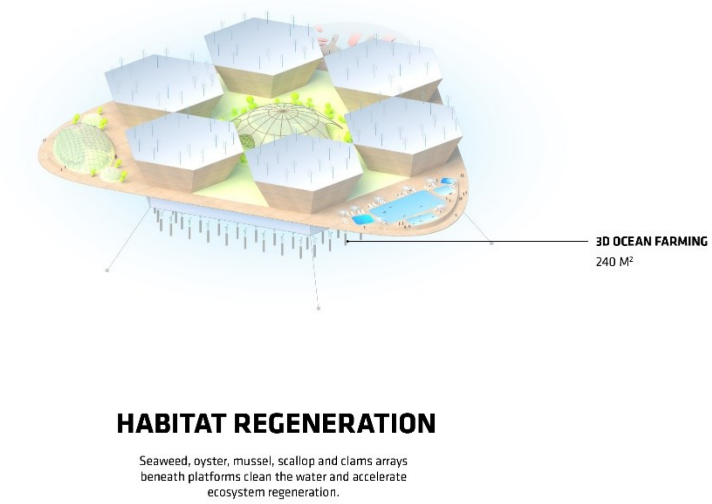

FIGURE 28: Platform habitat regeneration as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Beneath the platforms, seaweed, oyster, mussel, scallop and clams arrays will be placed to provide an alternative source of food while cleaning the water, absorbing CO2 and nutrients, solving part of the environmental problems affecting coastal areas and accelerating their ecosystem regeneration (*Oceanix.com*, 2022). However, this field of knowledge needs to be further developed as the effect of floating cities on water quality and ecology are not so well understood. Small platforms can be built to give fish cover and hiding places, but at the same time, covering water surfaces with floating platforms could block out sunlight, which would be detrimental to fish and plant life. Thus, is essential to leave part of the surface in a floating installation open. The knowledge on how much water should be left exposed and what is the largest size a floating platform can be without adversely affecting the water quality and ecology is an area of research that will be investigated in the upcoming years (De Graaf, 2012).

The majority of marine life is concentrated in a relatively small fraction of the ocean with shallow areas, near land-water interfaces and close to coral reefs and other similar structures. Cities, however, can also themselves serve as a valuable component of the ecosystem and a source of habitat. By incorporating innovative sustainable ecological systems and diverse agricultural cultures, in fact, a typical urban area can have biodiversity levels that are even higher than those of a rural area. Similarly, the development of floating cities will significantly extend the land-water interface and consequently boost the ecological potential of the coastline. Urban water systems can connect various natural areas, providing different migration path for fish and other animals. The Blue Connection (Blauwe Verbinding) in Rotterdam can provide a good example. This 13-kilometer water connection, between Barendrecht, a landscape park in Albrandswaard and the south of Rotterdam, can also serve as a water retention storage and a communal space with recreational amenities (De Graaf, 2012). In addition to complex urban water systems, also single structures and buildings can be used to create habitat. Below the platforms, mooring systems are installed to keep the floating structure in position, preventing them from drifting away under critical sea and weather conditions. In the OCEANIX project, but also in other floating installations, these systems can provide both a way to eliminate possible damage, restraining the infrastructures movements, but also an alternative foothold for marine species. These, together with Biorock systems, illustrated in *Figure 29*, can provide means to enhance the ecosystem below each platform.

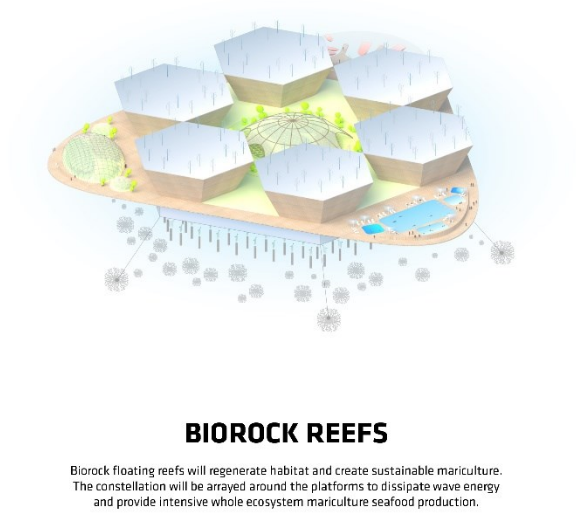

FIGURE 29: Underwater platform Biorock reefs as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Biorock is a unique ocean technology able to produce the only marine construction material that grows, heals itself, and becomes stronger with age (*Oceanix.com*, 2022). It can also rapidly regenerate coral reefs, oysters, seagrasses, salt marshes, mangroves, fisheries and coastal ecosystems that have not recovered naturally (Yang et al., 2022). Discovered by Wolf Hilbertz in 1976 ("*Biorock*", 2022), Biorock is an innovative marine material grown by low voltage electrolysis of sea water, which causes growth of limestone rock minerals dissolved in sea water over steel surfaces, completely protecting them from corrosion. Biorock reef structures can be any size or shape, varying consequently the dissipating wave energy performance, and are considerably more durable than regular Portland cement when grown slowly, at less than 1 to 2 centimeters a year (Goreau, 2012). Similar to coral reefs, Biorock shore protection reefs are open-mesh structures intended to let water pass through them. The electricity required for electrolysis, which is extremely safe due to the low voltage, can be provided by transformers, batteries, chargers, solar panels, wind turbines, ocean current or wave energy generators, depending on which source is most cost effective at the site (Goreau, 2012). Surely a nice addition to a floating city project.

During its operating life, to perform at its best, a complex system, like the floating city of OCEANIX, requires to be frequently checked by qualified personnel. Fatigue and corrosion should be monitored and limited by applying the right material or protections. Connectors, one of the most delicate components of the whole build, should withstand the interconnection forces (between platforms, with the seabed, with the coastline, …) and motions for a very long time. Additionally, they must allow simple detachment between platforms for maintenance purposes or when the design of the floating community is about to be changed (Ko, 2015).

A floating city can perform at its peak level only through proper and regular maintenance. Performances are also influenced by the choice of materials. Of course, bamboo and wood are aesthetically pleasing and can reflect the local architecture (for example considering the Korean urban fabric, from which OCEANIX Busan's prototype will expand). But how effective are these materials in close maritime proximity? How secure are bamboo and wood really? Safety is probably one of the primary considerations in the design of a floating community. Safety means to provide a stable floating structure and a comfortable living space where people can move around without danger. In order to guarantee the reliability of the floating structure, it is best to safeguard the floating community from environmental dangers like high waves, storms and hurricanes. A breakwater structure around the floating community (or underwater Biorock structures in the project of OCEANIX), for instance, would reduce most wave actions. Additionally, if it is possible, moving the floating community to a more secure area would be another way to avoid powerful hurricanes or other environmental dangers. But for this to be a possibility, it must be possible to anticipate both the risks and the development of those risks. The effort would be ineffective if the floating city is transferred to a location where the hurricane would eventually land (Ko, 2015). Regarding the materials chosen in the UN project, as already mentioned, due to its high elasticity value, bamboo offers a reliable resource against strong movements, such as winds and earthquakes (Chin, 2021). A floating city, by its nature, is safe from earth movements in and of itself, but it still usually needs a connection to the land for transportation; connections that can be damaged. But, of course, this depends on the design. In offshore installations, connections to the cost are absent, however earthquakes can still cause tsunamis. Additionally, if bamboo and wood are used as two of the main building materials in a floating structure, they may be exposed to severe degrading conditions brought on by mechanical loads, corrosive saline environments and wood-degrading organisms. As a result, they require protections in the form of physical barriers, to resist mechanical forces, and special treatments and maintenance against aggressive biological organisms.

The choice of bamboo is appreciated also for its effectiveness as an insulting material. According to research, in fact, engineered bamboo composites have good thermal insulation performances, though they are a little less effective than traditional wood-based ones. Thus, adopting bamboo-based shear walls in light-frame buildings is a concrete possibility (Wang et al., 2018). Bamboo can be used also for acoustical purposes. Experts have reported that bamboo fiber materials, made especially with the Betung variant, have sound-absorbing qualities comparable to those of glass wool, considered a good sound absorber. Betung bamboo, also known as giant bamboo (*dendrocalamus asper*), is frequently planted in Southeast Asia. It can grow anywhere from lowlands to highlands (2000 meters), and it is distinguished from other types of bamboo by its larger diameter. Particleboards made with this type of bamboo have shown potential for further development as building materials, for acoustical uses, particularly at higher frequencies, where their acoustical properties are found to be comparable to those of wood and other naturally isolating composites, and for new installations in wood-frame construction, like wall sheathing and subflooring (Karlinasari et al., 2012). But, after serving its construction purpose, bamboo has been discovered to have also other uses. Researchers have, in fact, developed a new technique for creating highly insulating and environmentally friendly biomass materials from waste bamboo. By chemically treating disposed bamboo with special additives, like small amount of phenol, hydrochloric acid and leather shavings, researchers have obtained semi-liquefied bamboo (SLB), which, cross linked with gelatin, would be used to prepare aerogel. This functional new material not only has good thermal and acoustic insulation qualities, but, more importantly, provides a new way to replace traditional synthetic foam in decorations, particularly on outdoor construction sites, while remaining completely biodegradable and non-volatile (Pu et al., 2021).

This demonstrates how the choice of a material must also be made in light of possible future applications, following the end of its predetermined purpose. Society is often well prepared for initial life cycle stages, involving the production and introduction of new products and technologies into the market, while this is frequently not the case when it is time for those products, or product components, to be phased out. Construction-related activities, including demolition, have a significant negative impact on the environment due to their extensive use of natural resources. They also put significant amounts of waste in landfills and emit greenhouse gases. The American Environmental Protection Agency (EPA) estimates that a typical 13,300 square foot (about 1235 square meters) commercial demolition project produces more than 155 pounds (about 70 kilograms) per square foot, or more than 2 million pounds, of waste; building-related projects alone in the U.S. are thought to produce 164 million tons of construction and demolition materials annually (EPA, 2009). Hence, end-of-life product management is a crucial element in product life cycle management, especially considering valuable and delicate materials that are involved in the creation of a sustainable floating city. Having a pro-active, in-depth strategy to manage the life cycle of products, technologies and associate materials is essential. The monitoring of the end-of-life status for any component of a product, especially for those that cannot be easily replaced or substituted, needs also to be continuous and accurate. Businesses should think about whether a particular product still makes sense in the context of their current product portfolio. Does the product still generate enough revenue to cover the cost of upkeep? Does the business have a more effective solution at hand? This are all valuable questions to keep in mind while managing a complex scenario like that of a floating city. OCEANIX itself has stated that their platforms will be designed to allow easy maintenance and disassembly at their end of life (*Oceanix.com*, 2022). The superior advantages of mobility and flexibility, which come with floating installations' modular design, can also be very helpful for final disassembles. Where necessary, other than being expanded and grouped with other floating structures, floating facilities can be removed if they become outdated, towed or sunk as artificial reefs (Adnan, 2020). When it comes to showcasing the efficacy of this technology, Japan for instance has been a clear leader thanks to the numerous floating dormitories and plant barges that have been constructed in the country before being towed and installed in other jurisdictions (Wang & Wang, 2015). Utility plants can also benefit from the mobility of floating structures. It has been exploited since the second half of the 20th century for industrial purposes. These facilities can be built in one place and then towed to the site to be installed as a permanent facility, or they can be moored and towed once more to another site as needed (Adnan, 2020).

4.1.3 City's Perspective

Once fully developed, OCEANIX City will be able to host up to 10,000 inhabitants across 75 hectares (*Oceanix.com*, 2022), presenting the world with a model that will be an example of how millions of people are likely to live during the rest of the 21st century. However, this development won't happen right away; instead, it will be the product of a process which will require quite some time. The final stage of the process, which is to start constructing the entire floating city, in fact, could only begin after a successful experimentation of the first phase, where the viability of the entire operation will be confirmed. And only in the end, a sustainable and self-sufficient offshore floating installation will be the result of this entire project, which started just with the transformation a coastal house into a floating house (Adnan, 2020).

Ko defines "dynamic geography" as "the freedom of moving inside the floating community with one's own house as an individual" or even as the "moving away from the community with a group of inhabitants". This concept is very important for the spatial layout of a floating community. Additionally, he lists four different configurations that could result in a floating city, only two of which are suitable for maximum dynamic geography (Ko, 2015).

- The island-type configuration consists in several individual floating platforms, connected to each other through bridges and jetties. Even though this method makes it easier to detach the platforms, allowing each island to move around with maximum freedom, the stability of the same island is often influenced by forces and loads of nearby ones. Due to bridges and jetties acting as hinged connections, in fact, loads and forces on one floating platform can act as eccentric loads on other platforms.
- The branch-type configuration is similar to the previous one, except that, instead of using bridges and jetties, the platforms are now directly connected to one another. In this way, because the connected platforms will essentially act as one single structure, the eccentric forces on the adjacent platform will be less impactful. However, the denser layout makes it harder to move one platform away from the group. In addition, in order to fit together, the floating platforms must all have the same shape. This method also grants higher degrees of freedom.
- The composite-type configuration allows for the connection of semi-large platforms, similar to the previous methods, but in such a way that they form a single larger platform. In this way, not only it is now more difficult for the platforms to be disconnected from one

another, but they also must typically move as a single structure if moved to a different location. The fact that numerous connections are required to keep the platforms connected is also another drawback of this configuration.

- The single large platform type is similar to the previous, but without connections, due to the installation of a single massive platform (Ko, 2015).

Due to higher versatility and ease of configuration, the first two type are the most suitable options for the design of a floating community. In fact, as already stated numerous times, the core design of OCEANIX City will be based on the modular branch-type configuration. By adopting this type of layout the project will benefit from an easier management of shape and size, compared to larger floating structures, and an easier progressive expansion. Growth, in fact, can be achieved simply gradually adding more platforms to the outer side of the existing floating community. Instead, expanding a large floating structure would be much more challenging. Of course, by increasing in size a large installation, adding another equally large platform next to the current one, the capacity of a floating community can be effectively doubled. However, this is no longer considered gradual growth, therefore any investment in such an expansion must be carefully considered. Another choice would be to build connections, such as bridges or jetties, to join smaller platforms to the main platform. But in this way, because of the heavy eccentric forces and loads from the large floating structure, the sea keeping stability of the smaller platforms is less favorable. Small rotations and movements of the large structure will result in large rotations and movements of the smaller units (Ko, 2015).

The modular nature of OCEANIX City makes it simple to control and experiment with scale. The size of the project depends on the needs of the population and the relation that the project itself has with the surrounding environment. By being scalable, the city could organically transform and adapt over time as the demand to live in it grows, starting from a single platform up to an entire floating metropolis.

As already shown, the smallest unit of the city is its "neighborhood" (illustrated in *Figure 30*), able to house up to 300 residents over a surface of around 2 hectares. The platform will be able to float as it is anchored (not permanently) to the seabed. Each unit will accommodate countless mixed-use buildings, all less than 20 meters in high, both to improve community cohesion and withstand possible extreme weather conditions. Flexible, buoyant skirts will then accommodate food production, boat docks, windbreaks and gathering spaces while being connected directly to water (*Oceanix.com*, 2022).

FIGURE 30: Design of a single neighborhood platform unit as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The next step involves the clustering of six neighborhoods in a hexagonal form, around a central harbor, forming a "village" (illustrated in *Figure 31*). The geometric shape was designed considering nature and the ability of bees to use as few resources as possible thanks to hexagonal honeycomb cells. The village will span over an area of 12.2 hectares and will be able to house up to 1650 residents. The inner harbor will be used as a social hub, with commercial and recreational structures located around, sheltered from the wind (*Oceanix.com*, 2022).

FIGURE 31: Design of a single village as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

The final scale is created combining six villages in the same hexagonal array, creating a large sheltered central city harbor in the middle. This plans to be the city's hub for cultural, recreative and commercial activities, hosting also other smaller secondary floating structures, connected by shared modes of transport (*Oceanix.com*, 2022). When observing the project at a city scale, in fact, it is important to underline also what is in between the platforms. Breakwaters, for example, designed to resist and dampen the wave-action, will be installed to shield the floating community from powerful waves (Ko, 2015). Additional wave-breaking outpost will be present around and throughout the city, allowing for additional energy or food production while providing recreation, art and performance destinations for residents. As mentioned before, the "city" (illustrated in *Figure 32*) will be able to house up to 10,000 resident across 75 hectares, maintaining a strong sense of community and identity (*Oceanix.com*, 2022).

FIGURE 32: Design of a single city as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

This final configuration of the UN design envisions to expand the installation reaching a city scale of about 1.3 kilometers in diameter (*Oceanix.com*, 2022), but nothing prevents it from being scaled down to smaller dimensions or, on the other hand, scaled even further to get an even bigger size, able to accommodate millions of residents. Several options and configurations are possible tanks to one of the concepts on which OCEANIX has invested the most: scalability. With this idea, illustrated in *Figure 33*, the city scale of the project can be seen as only the first step towards further expansions.

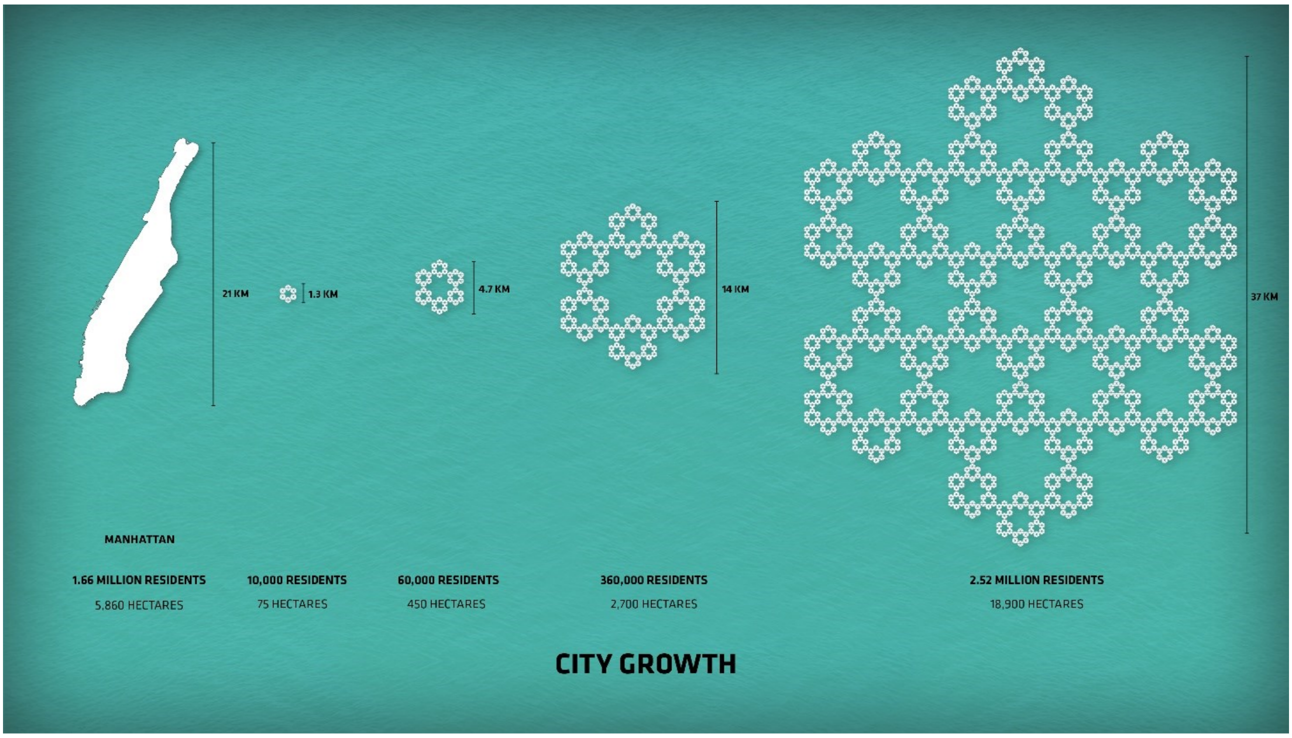

FIGURE 33: Concept of scalable growth as envisioned for the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

4.1.3.1 Mobility in the OCEANIX project

In recent years, urban mobility has been one of the most significant and difficult issues to address. High traffic demands contribute to congestion and traffic buildups in infrastructure networks, which lower mobility efficiency in many major urban centers around the world. Everyday billions of travelers waste a significant amount of time in traffic, regardless of their mode of transportation or distance traveled. This results in a damage to both the economy and the environment. To address these congestion issues, many major urban cities around the world provide centralized mass public transit systems in the form of underground subways, above ground trams, buses and even boats (Amilcar et al., 2010). Historically, cities like Venice, Rotterdam, or other Dutch cities, have, in fact, used urban water systems intensively for transportation. This shows how, in addition to floating urbanization, urban surface water could be promoted to be a means of water-based public transportation. In particular, up until the 19th century, water was the primary means of transportation in the Netherlands. Unfortunately many canals were filled in due to hygienic issues and water pollution, favoring at that time other infrastructures like train systems and logistics. However, despite this, the main water infrastructure remains still in place, as well as in other cities. This makes it possible to use once more the water system for water-based urban transportation (De Graaf, 2012).

Mobility is a key component of global sustainability and has a big impact on the quality of life in cities. At its most basic level, urban mobility is about getting people from one place to another.

However, that is not all it encompasses; it also covers how people move around in urban areas for both work and leisure pursuits like dining out, shopping and visiting cultural attractions. Urban mobility is also about how these modes are spatially arranged in a built environment. And this applies to any urban center, from the smallest town to the futuristic floating metropolis. Transport is crucial in every urban reality, even in a project like OCEANIX City. People and goods, in fact, need to move outside and throughout the floating city.

However, when dealing with a floating environment, things frequently become more challenging. A floating platform is, in fact, not the only element that is necessary to realize a floating city. In order for the floating community to perform well in all circumstances and to set itself apart as a city, there are a number of structures and services that are necessary, and, among these, the ones related to urban mobility, transport and logistics are undoubtedly some of the most crucial.

Floating cities, due to their completely different nature compared to regular urban centers, in fact, require new infrastructures and transportation systems in order to accommodate their inhabitants. One way to support transportation in a floating city could be to use the same network, infrastructures and modes of transportation that are typically used in regular urban and mobility plans on the mainland, but, instead, setting them on the water. In fact, as some experts have envisioned, it is likely that creating new transportation systems will result in an improvement because they would better meet the unique demands of these floating environments (Vreugdenhil, 2015). Unfortunately it is not possible to predict in advance which choice will be the best for a floating environment.

Floating cities that host tens of thousands of inhabitants or more, which support a modern Western lifestyle, in fact, do not exist yet and it will probably take some time before such floating cities begin to appear all over the world. Furthermore, how the transportation systems will operate in such cities is unknown. Of course, this will affect the research methodology. Because current floating settlements are too small and do not provide enough comfort for the Western modern lifestyle, gathering data about transportation in floating cities is difficult and analyzing the current situation is not sufficient (Vreugdenhil, 2015). For this reason, further research and developing studies are needed. OCEANIX City is a special subject because, despite the lack of concrete information and case studies about floating cities, it is suggested as one of the first pioneering models capable of introducing urbanization in a new light to humanity.

As part of its plans for the floating community, the OCEANIX company envisions to offer residents new infrastructures and transportation systems that are centered on the concept of "shared mobility" (illustrated in *Figure 34*). Autonomous delivery robots, shared small electric vehicles, bikes and pedestrians will, in fact, grant an integrated, mixed and productive community, replacing all fuel-based cars, reducing carbon emissions and promoting human relations and a healthy lifestyle (Oceanix.com, 2022).

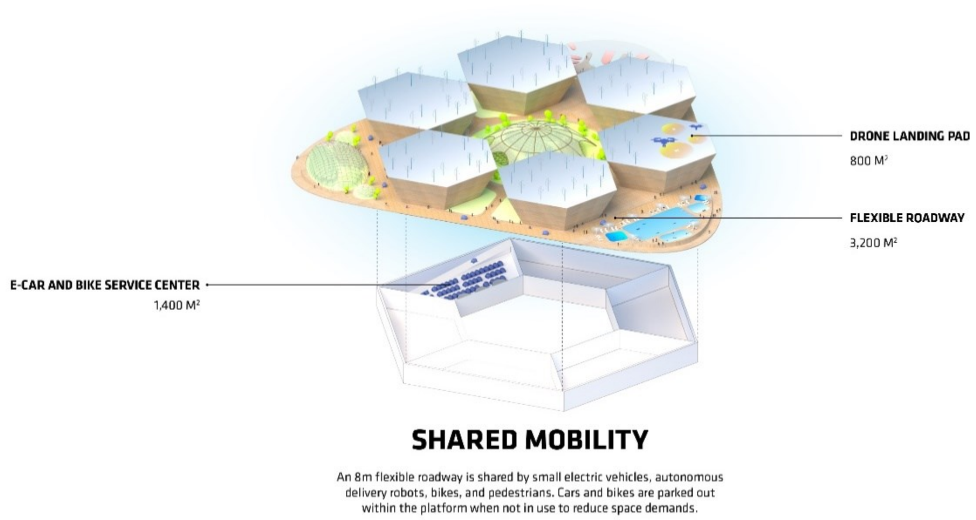

FIGURE 34: Platform shared mobility as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

In line with one of the base criteria which every floating community should respect (Ko, 2015), OCEANIX City envisions also to adopt a circular shaped configuration of the platform layouts in order to efficiently fit behind a breakwater structure, while providing a shared closed-loop surface network for slow mobility (Oceanix.com, 2022), as illustrated in *Figure 35*.

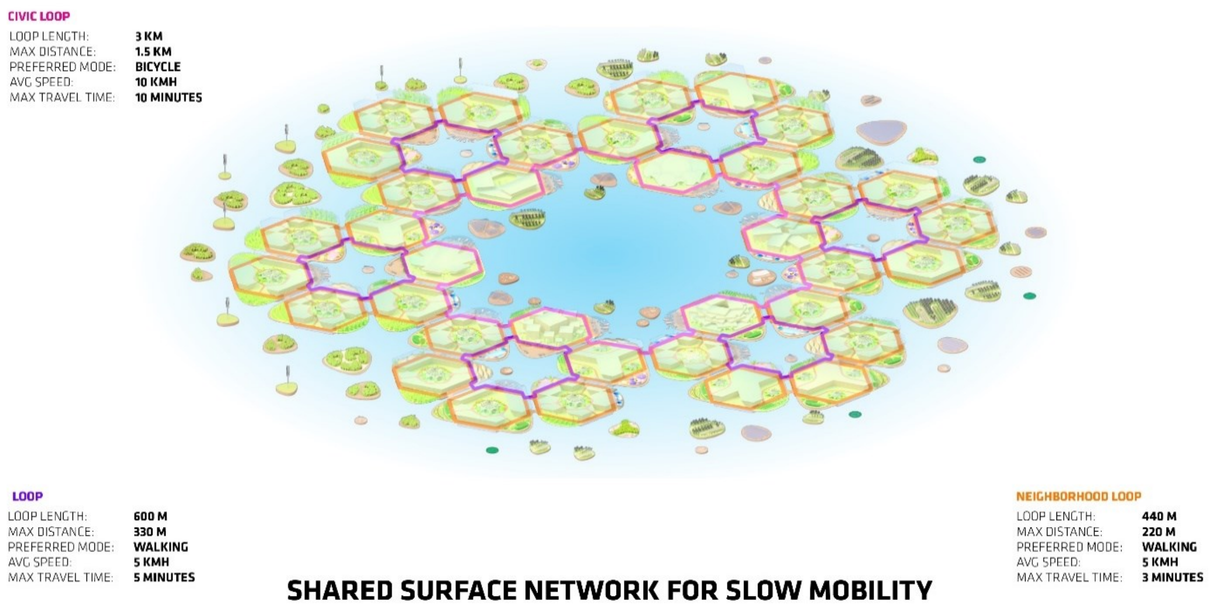

FIGURE 35: City circular shared surface network as envisioned in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Six specialized villages will create destination and unique landmarks, drawing people from across the city (Oceanix.com, 2022). Residents and tourists will move around using one of three preferred routes, each designed to allow fast time travel, while still being able to connect all points of interest of the build, such as cultural and athletic hubs, clinics and health centers, commercial areas, school and learning centers.

This design is in line with the concept of “urban densification”, an important strategy that can be useful to both floating and coastal cities as a way to increase land availability, making more efficient use of space and other resources. As cities become denser and distances become smaller, in fact, transportation of goods and people requires less energy. Additionally, it improves a city's walkability and raises the competitivity of public transportation. The population's reliance on cars will decrease, and more sustainable form of transportation will be more likely used (De Graaf, 2012). Density is also one of the main aspects which constitute the so called “15-minutes city”. Introduced for the first time in 2016 by Carlos Moreno as a framework for combating greenhouse gas emissions, the 15-minutes city concept aims to create dense and connected socially and functionally mixed self-sufficient neighborhoods with the essential functions of living, working, commerce, healthcare, education and entertainment by decentralizing urban functions and services. After the pandemic, this compact design gained enormous popularity, to the point where it was used as a re-urbanization model in a number of political campaigns, including that of Paris mayor Anne Hidalgo in 2020. However, this concept has also been under fire, accused of being a physical determinist idea that disregards the needs of various social groups, biodiversity, energy efficiency, clean energy sources, culture and heritage (Khavarian-Garmsir et al., 2023). Hence, further research on this innovative concept and its future applications to floating environments need to be performed.

Once fully developed and expanded to its maximum potential, OCEANIX City can be viewed as a sort of cluster of 15-minute floating cities. People and goods, in fact, will be able to take advantage of several forms of shared and multimodal mobility to move through different medias, such as land, water and even air (as illustrated in *Figure 36*), in a human-scale urban design. The floating city will be constructed redesigning public spaces based on human needs and characteristics, for the benefit of citizens rather than cars. Additionally, local infrastructures will also encourage active modes, such as walking and biking, so that residents can fulfill their daily needs within a 15-minute walking or cycling distance.

FIGURE 36: Modes of transport envisioned for the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Once the city expands over the boundary of a simple city, as the demand for housing grows, bigger infrastructures needs to be implemented to include also more substantial public transports in the floating city. A typical city has a surface area of at least 100 square kilometers. Examples of cities in Europe are in the range of 105 square kilometers (Paris), about 200 square kilometers (Amsterdam) or almost 900 square kilometers (Berlin). Thus, simply walking or riding a bike on these environments would take too long to get anywhere in the community. Therefore, the expanded design of a future floating city must include public transportations and dedicated infrastructures. To cope with these challenges, the floating platforms must also be built to withstand the dynamic loads of traffic on the surface or, if internal spaces are available, perhaps even within the floating platform. In fact, as the surface of the floating city is quite constrained and mainly intended for buildings and service infrastructure, there will be a possible space shortage for secondary uses, like parking lots or e-car and bike service centers. Building inside the platforms could be the solution (Ko, 2015).

4.1.4 Regional Perspective

Planning must take into account the territory's needs for formal, functional, physical and social organization. When developing a plan, even before the project is actually created, a comprehensive range of factors present in the study area, including politics, the economy, the environment, the culture and the heritage of the community, in addition to the specific design and creation of the project, must be taken into account. This is how a "plan" differs from an "urban project". Because of this, when designing a floating city, choosing the ideal location for the installation is just as important as designing and building the city itself. To develop a plan, the knowledge about the area, the future possibilities, the needs of the population and the environment are essential for determining the direction that the transformation will take. And maritime nations and coastal cities are prime candidates.

Cities in coastal areas are constantly changing. Driven by every year more oppressing social and physical challenges, they are constantly adapting to new realities and creating new opportunities at the same time. With rising living standards, population growth and the threat posed by sea level rise, coastal cities have turned into stakeholders of a more feasible strategy, that of urbanizing on the sea. With the vast majority of the largest cities in the world situated in areas that are susceptible to flooding, in fact, there are almost no instances where oceanward expansion might not be advantageous. New York, Jakarta, Rotterdam, San Francisco: these are just a few of the cities that have shown interest in the floating urbanization strategy.

Of course, some places are more suitable than others and there could be a variety of reasons why one territory would be preferred over another. For example, choosing the right place for a floating city could be a matter of social interest and public perspective. It may seem obvious, but it is clear that people who have lived in close proximity to water for a long time, like many East Asian or Polynesian communities, will be more accustomed to this new idea than people who currently live in “drier” cities like New York or San Francisco. Or, once again, the future location of a floating city may depend on money and finances. Building a floating city doesn’t come cheap and, as a result, developed nations may be more inclined than poorer countries to develop this idea.

It is also a matter of governance. Suppose that a government has created, financed and acquired a floating city. For some reason, it needs to move near another government's coastline for a while. Which country will it then be a part of? It will be a country within a country. Politics could therefore affect the future location of a floating city. Additionally, the environment itself may have an impact on this choice. In contrast to a smaller floating community, which would be best suited to be located within protected waters with a calm environment, a larger floating city would be able to survive in more violent conditions.

From a safety perspective, it is, indeed, generally favorable to stay away from hazardous phenomena like hurricanes and cyclones. The location where a floating city is to be built should thus be chosen where such phenomena either never happened or only happened occasionally, like once every few hundred years. Or else, one might even suggest moving the installation. However, even in extremely dangerous circumstances, this should be the last option. In fact, moving such massive structures a few kilometers from its original location will surely be more difficult than it sounds. Moving the entire floating community will even get more challenging as it gets bigger and more connections and platforms are involved. Therefore, the design of the floating city must be such that it can withstand common severe conditions, in order to keep the frequency of its movement as low as possible (Ko, 2015).

Valuating how the floating community will interact with its surroundings and nearby existing urban realities will be also a huge necessity and will help planners choose the best location for a floating city. “If you think from a social perspective and you put people offshore, you somehow need to connect them to the people on land otherwise it will turn into an empty community”. This was one of the remarks put forward by David Foster during an interview attended by Marc Collins, Founder and CEO of OCEANIX (*FLOATING CITIES: Real Estate for a Warming World?*, 2020). Although this comment, brought up during the discussion about the relationship between ocean-based cities and land-based cities, has not received a clear response by Collins, it is beyond dispute that the compatibility of these two realities is crucial to the accomplishment of both developments. Some experts believe that offshore floating cities can already be built on open oceans with current resources and technologies, however, several case studies have given sufficient proof to claim that a floating community's success may be somewhat more dependent on its connection to the coastline (Adnan, 2020). This idea is reflected in the plans of Busan, which together with UN-Habitat and OCEANIX, is directly taking part in the development of the world’s first sustainable floating city prototype: OCEANIX Busan. This installation, designed to be in the future an organic expansion of the urban fabric of the Korean port city (as illustrated in a possible render in *Figure*

37), will be to all intents and purposes an integrated part of the coastal city, with the sole distinction that it will be floating.

FIGURE 37: Rendered aerial view of the port of Busan after the final phases of the project (OCEANIX/BIG-Bjarke Ingels Group).

But how can society move from the present to a time when there will be cities on the water and billions of people inhabiting the oceans? No doubt, this is not a simple question. Although it will be the end goal, at first, nations won't be able to construct a floating city that is entirely self-sufficient (Adnan, 2020). Cities on the land did not emerge in one day. They were initially small villages that, over the course of many centuries, evolved into cities. Similarly, the first floating neighborhoods and small cities won't be built on the sea either. As part of the strategy for land-based adaptive urban development, it is more likely that they will be built as an expansion of current coastal cities (De Graaf, 2012), just like OCEANIX is planning to do with the Korean city of Busan. By starting close to the shore, through supply chains, transportation networks and social interactions, the floating city will organically establish close relations with its terrestrial counterpart (Adnan, 2020). As a result, the growth of the floating city will initially depend on its population and on resources that are found on the nearby mainland (Ko, 2015). Over time, the ocean-based city will grow and manage a more self-sustaining economy, while, ideally, keeping persistent the social networks that currently exist between sea and land. It takes time to bring about any kind of change; it cannot be done overnight (Adnan, 2020). As the floating city grows, it will also be able to withstand a more hostile environment, like the open sea (Ko, 2015), while being able to house all of its own resources and facilities. Only at this point, it would be completely self-sufficient.

Given these assertions, it should be clear that effective communication between the floating community and the mainland will be crucial to the growth of both realities. Various media can be used to accomplish this. Being the most versatile and flexible mode of transportation between the mainland and offshore installations, and vice versa, a floating city will be heavily reliant on water traffic. As already stated, in fact, traveling by boats and ferries will be convenient even within the floating city itself, providing means to reduce the need for logistic infrastructures and land transportation. Ports will be required, but mainly for the import of goods, as a floating city won't have much mass fabricated items to export to other locations (Ko, 2015).

Furthermore, "physical" connections to the mainland, such as mooring structures or other service infrastructure, will be crucial. The future will provide means to create both large city state in the middle of the ocean and smaller outposts of overcrowded cities close to the coast. In both scenarios, the floating installation must nonetheless remain connected to the mainland for both transportation and import/export purposes. It won’t be very practical to only have access to air and/or sea transportation to and from the floating city. Therefore, it would be advantageous to have also land infrastructure to connect the floating city, particularly if in the case of an extension of a nearby urban coastal area. When the floating city will, in fact, be designed as an expansion to an already-existing city close to the coast, with a relatively small distance between the two urban centers, infrastructures like floating highways, floating bridges and even regular bridges, could be used to connect the two locations. However, the construction of conventional bridges will be less preferable in the case of an independent floating city far from the coastline. Traditional bridges are capable of crossing great distances, but they are constrained by factors like deep water (the pillars of the bridge can occasionally become impossible to construct or will be very expensive with the increasing water depth), brittle seabed soil, frequency of earthquakes and many more. The type of bridge that will be used to connect the mainland is thus situational to the location and boundary conditions of the floating city (Ko, 2015).

Floating bridges, on the other hand, are subject to displacements brought on by wind, waves and currents, just as the floating city is. Additionally, the floating bridge strength and stability would be impacted by the movements and loads of the floating city itself, and vice versa. Due to the floating bridge's length, a small displacement at one end will cause a larger displacement at the other end, just like a whip does. A conventional bridge, however, is a rigid structure anchored to the seabed, thus experiencing minor if not null displacements due to wind, waves and currents actions (except for earthquakes), functioning like a mooring structure for the floating city, limiting its displacements. Simply, what kind of connection is best for the floating city determines whether to use a floating bridge or a traditional bridge (Ko, 2015).

4.1.4.1 Focus on OCEANIX Busan

Busan, with its over 3.4 million inhabitants, is the second most populous city in South Korea, after Seoul. Located on the southeastern tip of the Korean peninsula (as illustrated in *Figure 38*), thanks to the gentle tides and a deep harbor, the city has grown into the largest container handling port in the Republic of Korea and the sixth busiest in the world. It is also home to the biggest industrial complex in the "Southeast Economic Region" of Korea. Considered as the economic, cultural and educational center of southeastern South Korea, Busan is thus surely one of the most important coastal cities of this century, making it an optimal choice for the development of the world's first sustainable floating city prototype ("*Busan*", 2023).

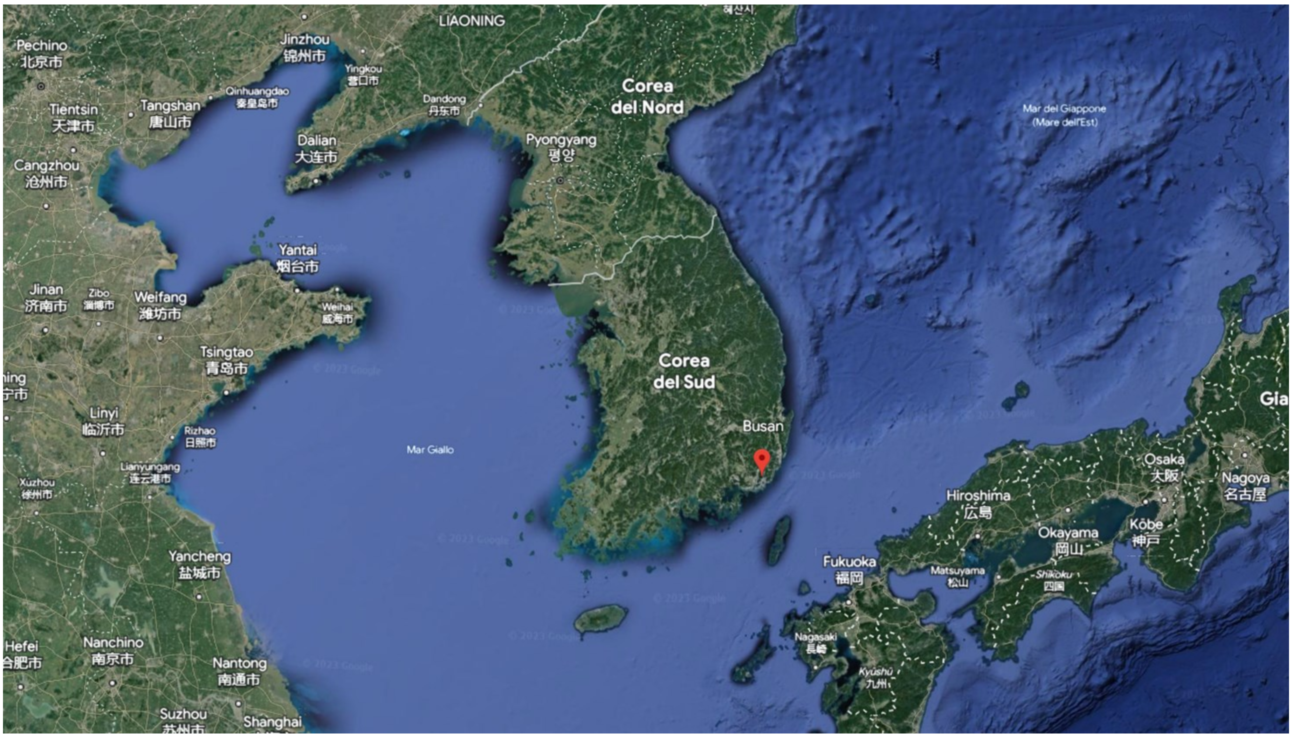

FIGURE 38: Satellite image of South Korea, with a focus on the metropolitan city of Busan (Source: https://earth.google.com/web/).

Results shows how Korea's average annual temperature has followed the global path caused by climate change, with a positive trend that has even accelerated over the past 50 years. In fact, every decade from 1981 to 2010 the change rate was estimated to be about 0.4 °C, but between 2001 and 2010 it increased to 0.5 °C, more than two times the value of 0.23 °C estimated between 1954 and 1999. Moreover, according to a Korean Meteorological Administration report, the average temperature is estimated to further increase, with values of 1.7 to 4.4°C higher between 2071 and 2100 compared to those of the 1980s and early 2000s, depending on greenhouse emissions. Higher temperatures and longer heat waves days could also bring more extreme weather events such as typhoons and torrential storms, threatening especially the waterfront of the Korean peninsula, where the city of Busan is located (*Korea Meteorological Administration*, 2023). Additional results shows also how the sea level has increased from about 60 centimeters in 1966 to about 74 centimeters in 2015 and, according to the climate outlook of the Busan Climate Network, how the sea level is projected to rise by more than 70 centimeters in 2100, seriously affecting the coastal areas (Yang et al., 2022).

In light of the aforementioned challenges, the city of Busan, together with UN-Habitat and OCEANIX, is directly taking part in the development of an adaptable maritime city in response to climate change. The three involved parties, in fact, signed on 18 November 2021 a historic agreement to build the world's first prototype of a sustainable floating city (Busan Metropolitan City et al., 2021), after the intent to build it together with a host city was unveiled to the public in April 2019. The final design of the installation was then unveiled 3 years later, on 26 April 2022, during the Second UN Roundtable on Sustainable Floating Cities held at the UN headquarters in New York. There, UN-Habitat, the Korean city of Busan and OCEANIX, together with a team formed by the world's best designers, architects, engineers and sustainability experts, successfully proposed their first prototype of a floating maritime city, OCEANIX Busan (Busan Metropolitan City et al., 2022).

The mayor of the metropolitan city of Busan, Park Heong-joon, was one amongst the first to state the city's commitment to face sea level rise and its devastating effect on the coast. "With the complex changes facing coastal cities, we need a new vision where it is possible for people, nature and technology to co-exist. There is no better place than Busan to take the first step towards sustainable human settlements on the ocean, proudly built by Korea for the world" he said (Busan Metropolitan City et al., 2021). The mayor plans to turn the Korean city into a green smart city by launching an ambitious campaign and also promoting it for World Expo 2030 (Busan Metropolitan City et al., 2022).

"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. We look forward to developing nature-based solutions through the floating city concept, and Busan is the ideal choice to deploy the prototype," said the Executive Director of UN-Habitat, Maimunah Mohd Sharif, emphasizing the fact that the battle against climate change will be fought firstly in cities and urban settlements. UN-Habitat, founded in 1978 and today based in Nairobi (Kenya), is the United Nations Human Settlements Programme. It works in over 90 countries promoting environmentally and socially sustainable urbanization and, following its vision of achieving "a better quality of life for all in an urbanizing world”, it plans to induce positive changes in cities and human settlements through knowledge, policy advice, technical assistance and collaborative action (Busan Metropolitan City et al., 2021).

“Sea level rise is a formidable threat, but sustainable floating infrastructure can help solve this looming catastrophe. We are excited to make history with Busan and UN-Habitat in ushering in humanity’s next frontier,” said the co-founders of OCEANIX, Itai Madamombe and Marc Collins Chen, stressing that to maintain the uniqueness of the country the prototype will be design as an organic extension of the local Korean urban structure maintaining the social, cultural and economic aspects of the country’s heritage. OCEANIX is a blue tech company, recently founded in 2018, that focus on designing floating urban settlements, with particular care towards the sustainable lifestyle of their residents (Busan Metropolitan City et al., 2021).

FIGURE 39: Rendered aerial view of the tree initial platforms of OCEANIX Busan (OCEANIX/BIG-Bjarke Ingels Group).

OCEANIX Busan (illustrated as a possible future render in *Figure 39*) is a pioneering floating city project, that, using the words of the company, will represent “the world’s first prototype of a resilient and sustainable floating community”, as the goal is in fact not only to design a city that can effectively withstand the effect of climate change and adapt to sea level rise, but also to design a city that will be able to supply autonomously food, energy and fresh water, in line with the UN Sustainable Development Goals, helping endangered coastal cities and island nations to carve their future with sustainable innovations (*Oceanix.com*, 2022).

"OCEANIX's modular maritime neighborhood will be a prototype for sustainable and resilient cities" said Bjarke Ingels, creative director and founder of BIG (Bjarke Ingels Group), one of the lead architects of the project, together with SAMOO (Samsung). "As our first manifestation of this new form of waterborne urbanism, OCEANIX Busan will expand the city's unique character and culture from dry land into the water around it. We believe OCEANIX's floating platforms can be developed at scale to serve as the foundations for future resilient communities in the most vulnerable coastal locations on the frontlines of climate change" (Busan Metropolitan City et al., 2022).

Located in the calm and sheltered waters of the Korean port city, OCEANIX Busan is conceived as a natural expansion of the local urban structure, extending and transforming it in an organic way to maintain those aspects that make the country unique, such as its urban art village, celebratory events and cultural heritage. Similarly, every future OCEANIX City projects, starting with the Busan prototype, will be characterized by a site-specific architecture, responsive to social, political, environmental and economic aspects of each location. Spanning a total of around 6 hectares across the interconnected neighborhoods, the initial modular design will comprise 3 hexagonal platforms (as illustrated in *Figure 40*), which will be able to initially accommodate a community of 12,000 people, but it has the potential to expand to over 20 platforms and accommodate around 100,000 people (*Oceanix.com*, 2022).

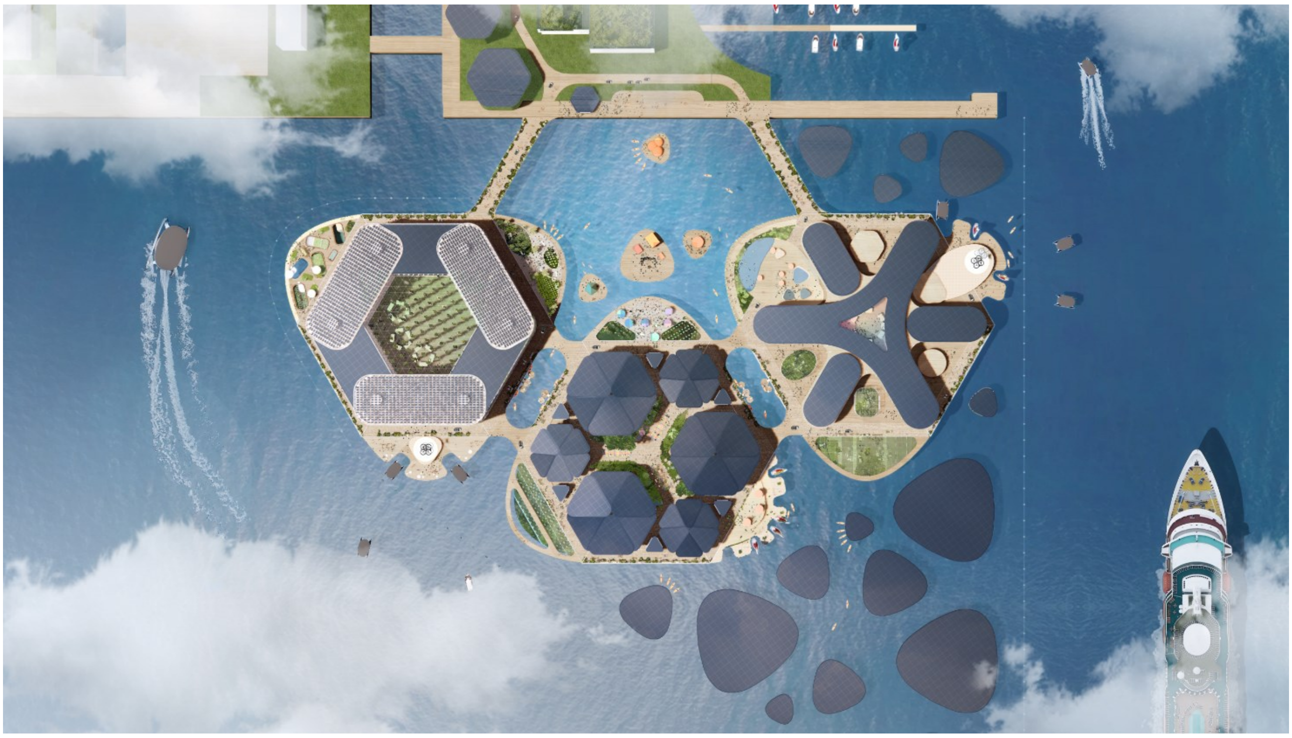

FIGURE 40: Aerial view of the tree initial platforms of OCEANIX Busan (OCEANIX/BIG-Bjarke Ingels Group).

The floating platforms, each able to accommodate thousands of square meters of mixed-use services, will maintain their connection with communities on land via link-span bridges connecting the port and framing the sheltered blue lagoon holding floating recreation, art and performance outposts. OCEANIX Busan is envisioned to feel both like home for residents and an incredible destination for visitors who want a taste of a sustainable lifestyle. On each platform residents and tourists will, in fact, gather, work and play in an activated public environment, characterized by low-rise buildings, made by sustainable materials and defined by their soft lines and shaded terraces, which embrace the comfort of indoor-outdoor spaces, helping to activate the network of vibrant public spaces. By being modular, the city would also organically transform and adapt over time as the demand to live in it grows, while at the same time making it easier to maintain the correct resource allocation as platforms get added, as once the initial phase is operative, it will become possible to monitor useful parameters as energy demand, space requirements and food production requirements. Furthermore, additional wave-breaking outpost will be present around and throughout the city, allowing for additional energy or food production while providing recreation, art and performance destinations for residents (*Oceanix.com*, 2022).

4.2 “SOCIAL” CONSIDERATIONS

Coastal cities are facing unique demographic, environmental, economic, social and spatial challenges. Pressured, in fact, by every year more intense impacts of climate change, like sea level rise and more severe flooding, as well as an increasing demand for land space along the coast, due to rapid urban population growth, maritime urban realities are trying to come up with new ideas, concepts and revolutionary projects. Some of these cities are adopting mitigative solutions to reduce the effects of sea level rise, other are exploring more creative ideas to adapt to these challenges, learning to live alongside them, in direct contact with water.

But do people really want to live on the water? When picturing the probable drawbacks of a floating city, public’s perception frequently centers on the expenses, the resources and the necessary technology and technical elements required to build and sustain such ingenious project. However, as it was already highlighted in this thesis, the failure of a floating community will likely not be a technological issue. Current modern technology and technical elements, available on the global market, offer enough alternatives to support the construction of a floating city. If not, their future iterations will probably be able to do so. Architects and engineers already know how to build floating structures on the water. However, floating cities are not only a matter of technical feasibility and technology. Although, in fact, the idea of a floating city may seem reasonable from the perspective of a city, it would not succeed if people did not want to live there. Living on the water requires a very different mental state: humans are by default social beings who prefer to live together as a community, so the different lifestyle and social behaviors, which derive from living in a separated floating installation, need to be carefully analyzed to correctly design a project that can socially serve both citizens and visitors, combining increased prosperity for everyone with a desirable lifestyle. The social component of the whole project is likely a factor that can easily hinder its success, thus it has to be clearly studied to understand if it can be one of the issues preventing the idea of a fully self-sufficient floating community from becoming a reality.

However, historically, people appeared to be very interested in living nearby water bodies, like the sea, rivers or lakes. The very concept of a floating city and community, which lives in close contact with water, isn't new. Examples of floating homes can be seen all around the world, in form of traditional houseboats in Amsterdam, or as floating villages in China and South America (De Graaf, 2012). More recently, this natural predilection does not seem to have diminished, both as a consequence of the well-known benefits of having direct access to water, as well as the threat posed by climate change, which seems to have renewed interest worldwide in the concept of sustainable urban water-based communities. A market study, carried out by a Dutch marketing consultancy, for instance, have found that about one third of the country's citizens think that living in a floating home could be a "serious option" in the future. In the Netherlands, in fact, even in the midst of the country's current housing crisis, the market for floating homes has suffered less than that for regular homes (De Graaf, 2012).

This is probably due to the many advantages that the idea of "living on the water" has for the population. First of all, it can give residents a sense of freedom and can open up a wide range of water recreation opportunities. Hence, when developing a new floating community, it is important to present enough water experience for its proper development. In OCEANIX City (as illustrated in a possible render in *Figure 41*), for example, platforms with low edges will allow residents direct access to water, providing both visual and physical water experience (*Oceanix.com*, 2022).

FIGURE 41: Rendered view of the village's harbor during daytime in the OCEANIX City project (OCEANIX/BIG-Bjarke Ingels Group).

Physical experience is about activities on the water like swimming, sailing, diving and everything else that relates to the use of the water as a means of transportation, leisure and residency, while visual experience is simply about being able to see the water. Visual water experience, in fact, is important especially for people to actually realize they live in floating communities. For instance, if a floating community was founded on a single and large platform, residents of the center of the platform would not even be aware that they were living on water (Ko, 2015). Hence, the layout of OCEANIX City has been designed choosing relatively smaller and modular platforms, as a way to easily experience the marine environment due to the open and flexible configuration.

Adding on social considerations of the project, OCEANIX City will offer residents the chance to actively participate in the production of their city's food, energy and water. Doing so, floating urbanization will allow citizens and neighborhoods to manage their own utilities, producing resources, increasing their participation and awareness and reducing their dependence from realities that are still dependent on fossil fuels. In land-based cities, in fact, citizens can often find extremely challenging to contribute to sustainable development. People must visit supermarkets to buy food and, to move, connecting directly or indirectly to fossil fuel networks is required. Because of the way today's cities are constructed, a sizeable portion of the population has no choice but to drive to work. Even if people want to act sustainably, the current way cities are designed do not offer the right environment for them to do so (De Graaf, 2012). In OCEANIX City instead, people can participate much more in energy and food production and water supply. Both resident and visitors can conveniently use shared water based sustainable modes of transport to go to work, to move in and throughout the city harbor, or to move to or from the nearest coast. This will not only have a positive impact on the environment but will also strengthen citizens' independence and increase their influence in the floating society, in comparison to their counterparts in land-based cities. The level of education and access to technical information will be higher than ever, and citizens will be more prepared than ever to take on such a role (De Graaf, 2012).

Valuating how the floating community will interact with its surroundings and nearby existing urban realities will be also a huge necessity and will help planners choose the best location for a floating city. For instance, since floating cities are mainly projected to be located in coastal regions, often characterized by persistently high temperatures and humidity, these conditions will have an impact on the satisfaction of both resident and visitors. The happiness and wellbeing of people will therefore be one of the major challenges for the future floating cities, also in relation to the surrounding environment (Umar, 2020). "If you think from a social perspective and you put people offshore, you somehow need to connect them to the people on land otherwise it will turn into an empty community". This was one of the remarks put forward by David Foster during an interview attended by Marc Collins, Founder and CEO of OCEANIX (*FLOATING CITIES: Real Estate for a Warming World?*, 2020). Although this comment, brought up during the discussion about the relationship between ocean-based cities and land-based cities, has not received a clear response by Collins, it is beyond dispute that the compatibility of these two realities is crucial to the accomplishment of both developments.

Luckily, living on the water provides the advantage of offering a variety of options for a flexible way of life. In a floating city, locations and residence can be sold separately, hence it is possible for its citizens to relocate with their home to a different floating urban area or neighborhood within the same city if, for example, they have found a new job. Or alternately, citizens can decide to stay in the same place, if their family grows for instance, selling their home and buying a bigger one in the same location. Therefore, by providing a much more dynamic way of life, floating urbanization may be appealing to many people (De Graaf, 2012).

Building a floating city is a process that will require not only money and resources, but also time. According to literature reviewed, the optimal approach seems to be to initially setting up a small coastal floating environment, gradually implementing floating structures in a marine environment close to a land-based coastal urban area, before expanding it as the demand to live in it grows. Only slowing focusing on minor units, increasing their number as demand for housing rises, will ultimately led to a future floating city. Then, by waiting and observing how people will respond to the first phase, evaluating if the floating residences will properly integrate into their daily life, it will be possible to determine whether the design and the process are successful (Adnan, 2020). In fact, especially when there is a small-scale project, after people have moved in, lived there for a while and then give feedback on their living experience, the level of satisfaction of the residents can be truly accurately measured. Of course, such projects would not only be expensive but also risky if the citizens provide unfavorable feedbacks (Umar, 2020); but if this first phase turns out to be successful, with citizens accepting this floating way of leaving, the next phase, which involves the creation of a real floating city, could be started even after few years (Adnan, 2020). Once created, this new city will require floating platforms able to compete with inland urban areas. To do so, floating cities must be designed to serve their citizens and visitors, combining increased prosperity for everyone with a desirable lifestyle (Riffat et al., 2016). Platforms needs to accommodate numerous single-family homes and apartments, as well as crucial social services as schools, community centers, medical facilities and more (Adnan, 2020). In future cites, people should be able to satisfy their basic needs and access essential public goods. Future cities should be also places where various products can be found in enough quantity and their utility enjoyed, but also locations where aspirations, goals and other intangible aspects of life are fulfilled, bringing contentment and happiness and improving the chances of both individual and societal wellbeing. Prosperity shouldn't be absent, reserved for a selected few or only experienced in specific areas of the city (Riffat et al., 2016). And this also applies to floating cities. Floating community requires the same infrastructures, opportunities and social structure as any other community on land would need. The only physical difference would be that this community will be on the water (Adnan, 2020).

Additionally, a new sustainability paradigm is required, one that provides stronger incentives for reducing consumption, conserving energy and protecting the environment while also raising levels of public wellbeing (Riffat et al., 2016). In the OCEANIX City, residents and visitors, will gather, work and play in an activated public realm. Additionally, diverse building terraces, designed to be site specific and responsive to the social, political, environmental and economic aspects of each location (as illustrated in *Figure 42*), will provide indoor-outdoor living and encourage socializing with neighbors (*Oceanix.com*, 2022).

FIGURE 42: Rendered view of the different site-specific neighborhood boardwalks envisioned for the OCEANIX City project. Top left: African, top right: Southeast Asian, bottom left: Middle Eastern, bottom right: Northern European (OCEANIX/BIG-Bjarke Ingels Group).

Future floating cities should be socially diverse environments where social and economic activities coexist and where neighborhoods serve as the focal point for communities. Urban areas, both on land and on water, must be developed or adapted to enable their residents to be socioeconomically creative and productive. Recent development give reasons for optimism that these problems can be solved (Riffat et al., 2016).

5. CRITICAL READING AND WAY FORWARD

With rising sea level and increasing population growth threatening every day more delicate maritime urban realities, experts from around the world are mobilizing with new ideas, investing in new and revolutionary projects, building ingenious infrastructures. Among these stands out the revolutionary idea of taking advantage of the unused water surface to develop floating urbanization. But are floating communities and floating cities really the right solution to address these challenges?

Upon reviewing the most recent sources it can be concluded that, at this point in time, OCEANIX City remains just a concept, without any practical sign of its actual implementation in a real-life case scenario, at least from what has been shown to the public until now. No bricks have been laid so far. Except for certain statements and press releases which envision South Korea as the location for the first iteration of this trailblazing project, the lack of further information is often limiting the view of its full potential. Government bodies of the metropolitan port city of Busan, together with the United Nations, have stated their commitment and expressed their support for this project, however, nothing has been done in the open as of yet. Moreover, adding to the already large pile of uncertainties surrounding the OCEANIX floating city project, are the qualitative and often limited information and data currently available to the public, related mainly on the overall design and layout of the floating community, but often without a clear understanding of their background and context of origin. From these doubts stand out, for instance, certain decision-making criteria that have led to particular design choices, materials or specific quantities needed for the correct sizing of technologies in OCEANIX City. Where do those daily 30 kWh per capita, for example, estimated to meet the energy demand in the project, come from? Comparing this value with the EU standardized energy consumption scheme, for instance, accounts do not add up. In each of its living platforms, OCEANIX plans to allocate about 8500 square meters of building footprints and house about 300 people. But this means that, with about 385 kWh per square meter per year, each building will be far below the minimum energy efficiency class (G). Surely not a good energy score for an installation that claims to be efficient and sustainable. Therefore, it is not wrong to assume that there must be something else underneath. Most likely, the daily value of 30 kWh per capita does not only refer to the energy required to reside in each platform, but includes also other aspects, such as the workplaces of the residents and related activities, or even additional factors linked to the energy consumption present in other platforms, from the electric current used to heat and light plants, up to the one used to power electric transportation. If this is the case, the value used cannot be compared to that used in conventional regulations. This makes additional analysis of this floating project challenging and often without a clear meaning. The same considerations can be done to other aspects. How and why was the daily estimate of 600 liters of water per person made? How did designers and architects determine that each platform could hold at least 300 people? These are all questions that remain without a clear answer. As a result, this project's analysis, addressed in this thesis, remains limited to a qualitative and hypothesis-based approach, often considering the most reasonable option for the type of application among a pool of alternatives, rather than the one that will actually be adopted.

Additional uncertainties, instead, surround the future location of this project. The first prototype of the UN project is set to be built in the sheltered port of Busan. However, what would have happened if the project had been located in another place? What factors would have changed? OCEANIX Busan has been developed to be operative in Korea, but how would it behave elsewhere? The transferability of the project is crucial. The technologies and technical elements allocated in the prototype are designed to satisfy the typical requirements of the East Asian climate, urban fabric and heritage. However, these same technologies would need to be modified if the project were to be moved in a different location, say to more northern regions. If OCEANIX City had found space in a sheltered Norwegian fjord, for example, energy production would need to be adapted to cover a higher demand, due to the heating required to cope with lower temperatures. Other factors like ice blocking the platforms, or snow covering solar panels and vertical axis wind turbines, would need to be considered. Native materials like bamboo, which are envisioned to make up the majority of the buildings in OCEANIX Busan, would not be the best building material to use in non-Asiatic or colder climates; instead, locally sourced materials should be used.

Moreover, in areas where even the most common natural phenomena, such as sea currents, tides or winds, are shielded by the local surrounding landscape, natural or man-made, which can be characterized, for instance, by shallow or constricted bays or by the proximity with high-rise buildings or natural elevations (mountain ranges, hills, cliffs, …), some technologies currently proposed by the OCEANIX project would need to be adjusted and resized accordingly. Local factors may also influence the choice of location. In the instance just mentioned, for example, where both winds and sea currents are constrained, the sun remains one of the only renewable energy sources that can be truly used in a cost-effective way. However, the intermittent nature of solar energy and its nighttime unavailability would become a significant problem if it were the only primary energy source used. This simple example clearly demonstrates how the choice of the location for the whole project is fundamental and not trivial. There are undoubtedly right and wrong places to site a self-sufficient floating installation. For this reason OCEANIX must pay close attention to how its future iterations will interact, respond and create relationships with their future surrounding landscape and ecology. The best course of action may be to approach this using the principles, concepts and way of thinking advocated by ecological urban planning.

Each location's social environment must also be taken into account and examined. While housing 300 people on a single platform might make sense in an urban context like that of Asia, in other realities with different settings and mentality, such as New York or along the coasts of the Mediterranean, where each family is accustomed to have its own separate property, these dense options may not be the right choice. Or else, adopting a plant-based diet for all upcoming OCEANIX installations might not be compatible with the traditions and lifestyles of all coastal communities around the world. Thus, for the project to be successful each floating iteration, starting from the Korean one, will need to be site-specific and responsive to environmental, political, social and economic aspects of each location.

Concerning the location of these floating cities, additional research needs to be done also in respect to their distance from the nearby mainland. When the project is developed to be an organic floating expansion of a coastal urban fabric the challenges that hamper its progress are surely smaller than those related to an offshore project. If connected to the coast, mainland and floating infrastructures could merge creating an integrated system, while if developed in the open sea, infrastructure will be inevitably disconnected. Transport and communication to and from the offshore floating installations also become a crucial aspect to consider. Both residents and visitors would find it simpler to travel between the mainland city and the floating urban area if the floating community were built along the coast, while maintaining the connections between the two distinct, but close, realities. Of course, new infrastructures would have to be built in peripheral areas to link the two environments, such as service stations, external parking or security systems, in a manner similar to how the border areas of historic pedestrian or traffic-restricted urban zones are currently designed in regular cities on land. With this regard, at least based on what has been displayed, it appears that OCEANIX Busan's focus is primarily directed toward interior elements (decentralized technologies, building materials, internal mobility, …) of the build, rather than taking into detailed account its surroundings. It is, in fact, also crucial to understand how the project will affect the local environment and its nearby urban fabric. If the floating community will be located far from the coast, on the other hand, specialized infrastructures will be also especially necessary. Infrastructures like ports, heliports, bridges, power lines, internet cables and so on will be required and adapted to these situations not to ease the transition between the two urban areas, like in the context previously just mentioned, but rather to enable communication and exchange of goods, people and information, that would not have been possible otherwise.

Initially setting up a small coastal floating environment, just like OCEANIX envisions for Busan, and then expanding it as the demand to live in it grows, will give researchers a priceless opportunity to observe how a floating city will develop over time. Additionally, as platforms get gradually added in the floating community, the maintenance of the correct resource allocation will be easier, as, once the initial phase is operative (three platform scenario in OCEANIX Busan, for instance), it will become possible to monitor useful parameters as energy demand, space requirements and food and water production requirements, to then keep in mind while designing the successive platform additions or offshore adaptations. This seems to be the best approach. If one plans to build an entire floating city all at once, the plan will surely fail.
As can be seen from the various real-life case studies and literature reviewed in this work, supported as well as by the viewpoint of several experts, the tools currently available in modern technology are sufficient to construct a workable floating installation. Perhaps not in the near future, however, sooner or later, a floating project, at the scale of the one proposed by the United Nations, will be constructed. In this, OCEANIX accomplishes a fair task by providing information, albeit often qualitatively, about the various technologies that will be used in its projects. But floating cities are not only a matter of technical feasibility and technology. Living on the water requires also a very different mental state, so it is important to pay close attention to how people will perceive things. By understanding how people will react while living on the water, floating communities can be designed to be more accurate and efficient solutions. However, this is something that OCEANIX seems to be lacking: a deeper, more comprehensive and thorough study of the project's social component. This is of course a crucial turning point, as the social behavior is likely a factor that can easily hinder the success of the whole project. Even if creating a floating community might make sense from a city' perspective, it would still fail if residents lacked a desire to settle there. For this reason, while it is fundamental to invest time, money and resources in the creation of a sustainable, efficient and technological environment, is equally important, if not more, to concentrate efforts also on the social component of the project. Humans are by default social beings who prefer to live together as a community, so the isolation that derives from living in a separated floating installation should be further analyzed to understand if it can be one of the issues preventing this idea from becoming a reality.
There are in fact numerous instances of newly planned communities, almost perfect from the point of view of urban design, mobility, provision of basic amenities, efficient use of resources and so on, which have proved unsuccessful because the population refused to stay there, after the second generation, or even during the first one. Others, despite having great plans for the future, ultimately failed to meet their goals and lost the motivation necessary to do so, failing to expand naturally

and in response to the needs of their residents. And these were all regular urban areas, let alone an offshore floating city!

To avoid repeating the same scenario, future cities and floating cities should focus on the participation of the population, key in urban planning. However, from what has been shared so far, at least, it appears that OCEANIX has not yet promoted this aspect at levels deemed sufficient to pique the public's interest. Undoubtedly, society is currently facing, on a global scale, a growing awareness and interest in climate-related issues, with the population appearing to recognize the urgency of taking personal action to address these same challenges. However, communities don't always get involved enough when it comes to showcasing the actual course of action and the options currently available to deal with these issues. One of the primary obstacles that seems to be hindering the development of both the OCEANIX project and other floating installations is, in fact, an apparent "lack of reason". In other words, given that no practical model has yet been developed, demonstrating that such an endeavor can be socially and economically successful, population growth, climate change and sea level rise appear to be not yet a serious enough threat to warrant significant consideration for a floating city. As they already float above the water surface, floating cities can essentially ignore the problems caused by rising sea levels. On top of that, by being modular and mobile they can potentially avoid storms and other extreme events, which will be more frequent as the amount of energy in the atmosphere rises due to global warming. These are aspects on which the scientific community and those who are directly involved in developing these cutting-edge installations should invest on publicizing. Additionally, it is important to raise awareness of the potential use of these same floating communities to address climate-related issues like rising sea levels and more recurrent floodings. Then, it still remains crucial to persuade the population, with convincing and valid arguments, of the effectiveness of the project, so that people won't only participate in this ground-breaking concept by relocating to its floating platforms, but also will view them as their permanent homes in the future. This will likely be the biggest challenge, probably much more than the construction of the floating city itself. In fact, despite the numerous environmental benefits, the idea that there are other alternatives to floating cities being proposed to cope with climate change and sea level rise means that there could be still no sufficient reasons to pursue this approach. When given the choice between a more cost-effective strategy, at least in the short run, with already prior background experience, and an expensive adaptive solution, which has yet to develop a real-world, practical model that can demonstrate its full potential, society seems to view the first option more favorably. Thus, OCEANIX should make reversing this trend a priority.

The actual population behavior is another crucial cue to take into consideration. OCEANIX City envisions to respect the 17 UN Sustainable Development Goals, by being fully sustainable, harvesting clean energy with solar panels, wind turbines and renewable techniques, respecting the environment and the local heritage by using locally sourced recyclable materials and other green solutions, and with all the water used treated and recycled. However, the results could be very different from what is theoretically hypothesized. Who says that residents and visitors will respect these lifestyles? Could it be that the prestige one would get by merely residing in this innovative floating project's is what will draw people in, rather than the sustainability and eco-friendly view of the project itself? It will be pointless to define OCEANIX Busan as "the world's first prototype of a resilient and sustainable floating community" if, once fully operational, its residents won't engage in recycling and waste sorting, will pollute or won't use water and energy in a sustainable way. A portion of the budget should therefore be invested also in raising citizens and visitors awareness and social acceptance about environmental aspects and challenges, through participation, education and involvement.

To facilitate discussion and better enlighten the differences and relations between "new construction" and "regeneration", two different approaches to resilient urbanization, two distinct qualitative graphic matrices have been proposed below. The first matrix, in fact, offers considerations with respect to novel planning, by taking, in particular, the project of OCEANIX City as reference (*Figure 43*), while the second one with respect to a conventional requalification project in a regular coastal urban neighborhood (*Figure 44*). Both will be considered as different alternatives to cope with the problem of sea level rising. Based on the author's experience and literature reviewed, both matrices have been computed highlighting in a qualitative way the degree of need (from most essential to not essential) of the main technologies, chosen among the ones envisioned for the OCEANIX City project, in relation to some aspects that most distinguish the concept of resilience. In other words, each resilience aspect will be valued as more or less essential to each technology for the successful outcome of the relative project (OCEANIX City project or requalification project).

In order to not weight down the visual appeal of the two matrices, each resilience-related factor has been grouped based on their main category: social aspects, output production, settlement form and environmental interactions. Additionally, for the same reason, a complete analysis of all the technologies, subjects of study in previous chapters, has been replaced by a shorter but more precise and selective analysis of the technologies deemed most important by the author's personal experience and reviewed literature. Tidal and wave energy have been grouped under the heading of "blue energy" for example, due to their similar behaviors and fields of application. Other technologies, concerning food production, water management and waste management, have been handled in a similar way, always trying to bring together those technical elements which present analogous characteristics.

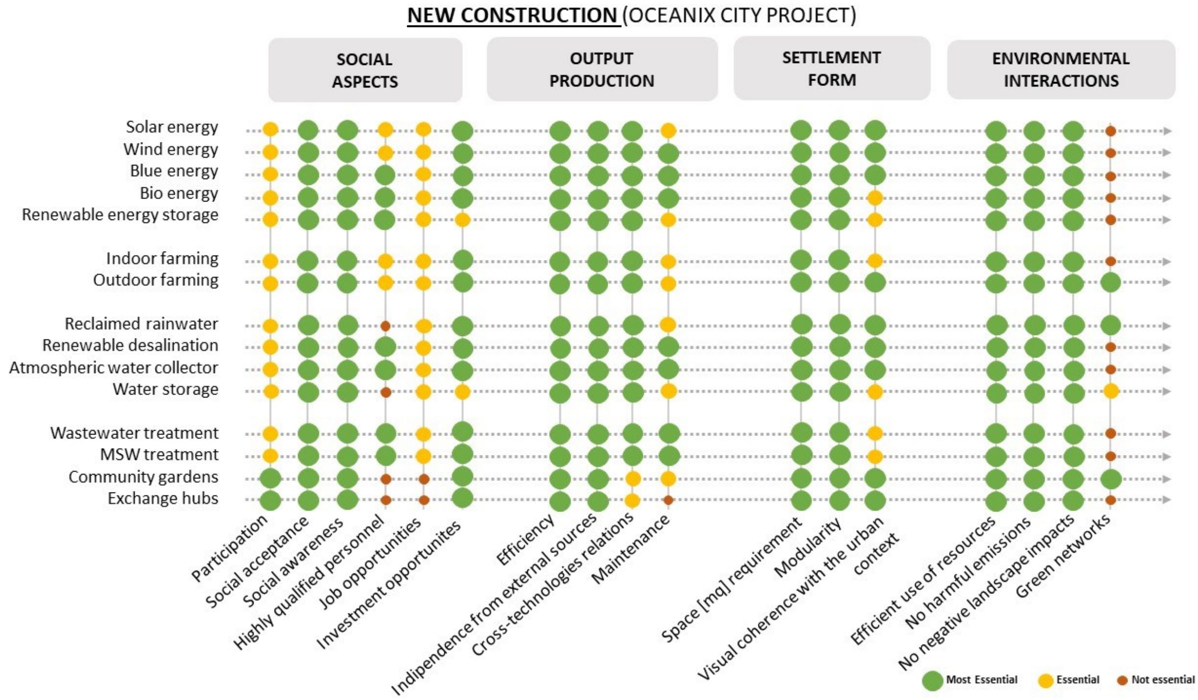

FIGURE 43: Qualitative graphic matrix related to the OCEANIX City project ("new construction").

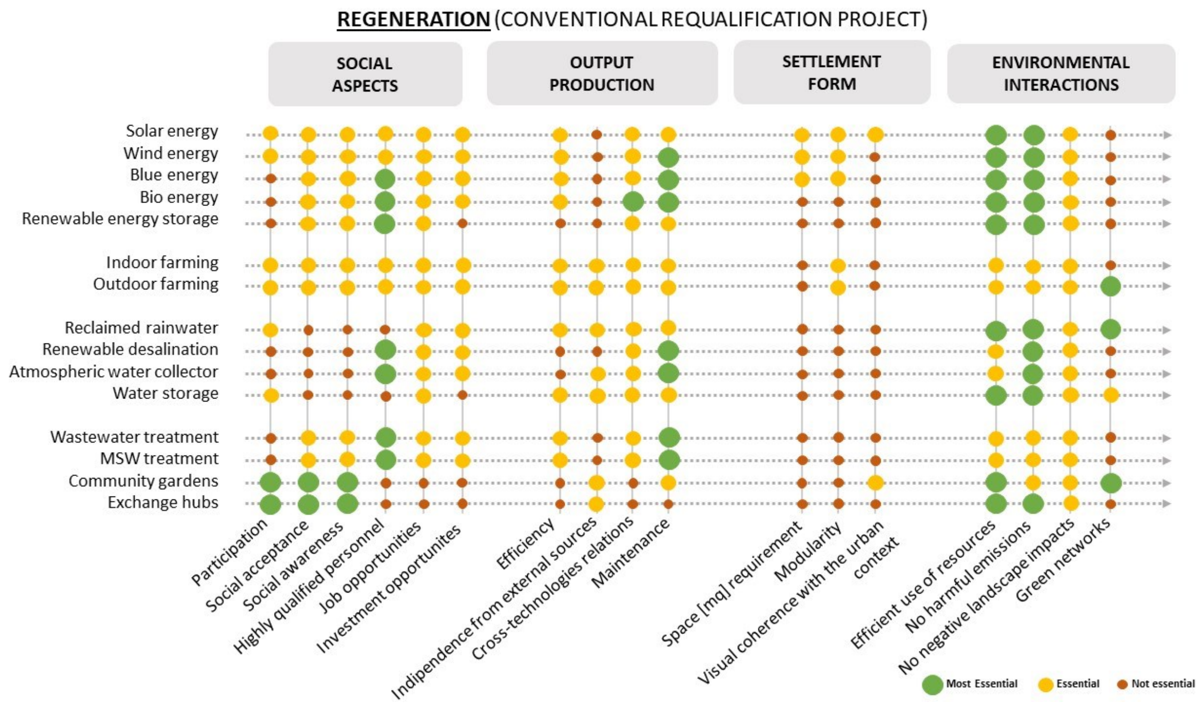

FIGURE 44: Qualitative graphic matrix related to a conventional urban requalification project ("regeneration").

What emerges the most when comparing the two matrices is a quite noticeable difference between the two approaches to resilient urbanization. The new urbanization matrix (related mostly to the

OCEANIX City project), in fact, shows a general greater tendency to view the chosen components of resilient urban management as more relevant. This result (easily deducible from the first figure's preference for the green tone, compared to the second one) is to be considered expected given the inherent differences between the two projects and urbanization approaches. Planning and designing on a blank canvas can, moreover, better favor the development of resilient cities, fostering a consequent greater demand towards typical aspects of it, thus explaining why OCEANIX City, which further aspires to be the first self-sufficient sustainable floating city project, appears to be more attuned and in need with the elements of resilience. The two different approaches simply present different opportunities, so this is neither a positive nor a negative.

Planning a brand-new project from the ground up, in fact, enables better implementation of all those policies intended to achieve a resilient reality, but without having to take into account the likely dated and obsolete environment already present. When building a new project from zero, and OCEANIX City may serve as proof of this, it is likely possible to develop, in an easier way compared to reconversion projects, a system capable of thriving despite increasing challenges and able to respond to unforeseen risks and events, unfavorable changes to society and other negative impacts, preventing or mitigating their effects through resilient development.

On the contrary, instead, regardless of how much it is based on resilience concepts, a regeneration project will always have some connection to the previously built urban structure. The outdated urban fabric could of course be removed, but doing so would result again in a case of new construction. Urban regeneration is the process of modifying and adjusting what already exists in the urban context, improving the overall resilience of the urban area, as well as the well-being of its residents, by strengthening its underlying structures and developing a deeper understanding of the risks that threaten its stability. However, by revitalizing an urban area, whether it's an entire city or just a small neighborhood, designers, architects and engineers have to work on a project that has already been built, therefore they do not have the same creative freedom they would have if they were working on a brand-new construction project. In this case, city planners are, in some shape or form, forced to adjust to the context, without sometimes having to look at the aspects of resilience, because they cannot create a brand-new one. It is, therefore, normal that some aspects are partially overlooked, in light of a compromise between aspects related to resilience and cost-effective measures, between adaptation and mitigation measures or simply because the context itself allows it. For instance, it is not necessary, during the renovation of a new district, to concentrate on the modularity or dimensions of some technologies (wind farms, anaerobic digesters, storages, …) when these are already developed elsewhere, in places where they do not affect the landscape; while the opposite is necessary in a new closed and isolated context like that of OCEANIX City, where everything is viewed as a single large network, in which each element interacts with the others.

By delving even deeper in the two matrices, it is possible to see how social factors play a crucial role in resilient city management. In both urbanization approaches, participation, social acceptance and awareness are fundamental to correctly develop a resilient community; however, in an installation like OCEANIX City, where the success of the whole project depends mostly on the single individual perception, these factors are even more crucial. Only the participation factor, among these, can be deemed rather less needed for the correct development of the two projects, as it is not necessary for the whole population to be directly involved in participating in the technologies under observation, except for community gardens and exchange hubs, i.e. elements that most need a human presence. Some technologies have even lower participation values in a conventional urban neighborhood, due to their reduced interactions with the population, respect to a closed environment like that of a floating city, where, for better or for worse, everything is connected and within the reach of the whole community. It can be noted also how, as technology become more complex, technical and sophisticated (from the advanced knowledge required to manage renewable desalination facilities to the one required to operate biological energy systems for example, and so on), less collective participation and social awareness appear to be required in a traditional regenerative urban project. Despite this, the theory underlying each technology is the same, regardless of how different the two approaches are, so the skills required to manage each technology are also the same. Concerning the creation of workplaces, instead, by developing new urban spaces, both new construction and regenerative urban approaches are able to provide new job opportunities. However, even though it is still crucial, this is not the primary function in either scenarios, thus the evaluation is slightly lower in both matrices. Ultimately, because investment opportunities are usually somewhat always present when new developments take place, in both approaches it can be considered relevant; however in a regenerative project they can be considered less essential compared to a groundbreaking project like that of OCEANIX City, which, on the contrary, has a much higher potential to open up opportunities never seen before.

Then, concerning the output production category, a similar trend can be observed. With the exception of maintenance, which essentially can be valued in a similar way for both the approaches to resilient urbanization, in fact, new construction projects may find production-related aspects to be more relevant, compared to regenerative ones. In particular, given that factors like decentralization, with the consequent independence from external sources, and cross-technologies relations are both essential to reach higher efficiencies in an isolate or off-shore installation, it is not surprising to find a more diffuse green tone in the first matrix in this category also. This is due to the fact that, since they are being constructed from the ground up, projects like OCEANIX City require more efforts and assistance to reach competitive output levels, and thus they are viewed with more regard. They, in fact, cannot generally rely on already existing networks to make up for any deficiencies or shortcomings, compared to regenerative projects that are based on the adaptation of the existing urban structures, buildings and infrastructures; thus, higher levels of production-related investments must be made to achieve conceptually equivalent results.

For a project like OCEANIX City, which is constrained by its own nature, space requirements, modularity and the ability to be visually coherent with the urban context are crucial factors. In fact, whereas on the mainland, large, heavy and cumbersome technologies (from landscape-demanding wind turbines, used to produce clean energy, to big and widespread facilities for example, required to desalinate seawater or treat solid waste and wastewater, and so on) can typically be sited in locations far from the city, reducing their impact on the urban landscape, self-sufficient offshore installations do not have this option. Careful considerations about an intelligent use of space, urban density and mixed-use areas are therefore essential in new constrained projects, including that of OCEANIX City, compared to a more conventional and less limited in space urban development.

Ultimately, regarding the interaction of new construction and regeneration projects with the environment, both of them, if being developed following sustainable resilience principles, appears to provide positive considerations. Aspects like efficient use of resources, creation of harmful emissions and visual appeal are crucial in both approaches. Of course, being proposed as one of the most sustainable project of the United Nations, OCEANIX City considers those aspects with higher degrees of need compared to a conventional urban area. The technologies that will be installed on the floating platforms will, in fact, be designed to be as clean and efficient as possible, being at the same time adaptable to the urban floating context and the surrounding landscape (loud an unpleasant technologies will be hidden inside buildings or under the platforms, solar panels will be placed on the roofs or in external floating production outposts, as well as vertical wind turbine, for example).

6. CONCLUSIONS

The primary purpose of driving this thesis was to shed light on the challenges surrounding the "floating city" concept. This is done gathering and reviewing, on a theoretical basis, technical and planning information coming from case studies of existing and designed floating communities, first and foremost from the OCEANIX City project, which constitutes the core of this work. For this ground-breaking United Nations project, that, for the first time, combines the concept of a fully self-sufficient floating city with the idea of sustainability and carbon neutrality, a resilience assessment on the technological feasibility and environmental sustainability is proposed. Through both reviewed literature and the author's personal background, a special focus has been dedicated toward both the technical and social components accounted in the project, with the aim of providing the necessary resources and tools to form an in-depth judgment about this ground-breaking floating community.

It is fair to say that the significance of a project like OCEANIX City cannot be overstated. Developing floating environments in flood-prone coastal regions could be likely one of the most innovative and adaptive ways to support critical areas, which have far fewer options to deal with sea level rise.

However, this thesis ultimately came to the conclusion that there are a number of interrelated difficulties, from technical to social, from financial to political, which are challenging these floating installations from actually being developed and, especially, from gaining a foothold in the collective ideal. The future development and application of a sustainable floating urban community is still shrouded in a sea of fog, hindered by huge requirements of resources, funding, government intervention and time. These challenges must all be overcome at once if the vision of a floating city is to become a reality. Hence, since no one can foresee when urgent measures to address this wave of climate change will be required, faster research progress should take on greater importance.

Unfortunately, based on what has been presented to the public so far about the UN OCEANIX project, it appears that this trailblazing self-sufficient and sustainable floating city still remains just a concept, with no concrete evidence of its implementation in a real-world situation. Moreover, adding to the already considerable amount of uncertainties surrounding its realization, the lack of further public information is often preventing people from seeing the OCEANIX floating city project's full potential. Until these doubts are clarified and more information are shared it will be difficult to envisions a future in which floating cities, among which OCEANIX City plans to be a first sustainable prototype, will serve as the backdrop to maritime realities and in which floating communities will be the norm all over the world.

However, despite these challenges and uncertainties, both reviewed literature and experts share a positive view at the actual realization of this pioneering project. The author of this same thesis also expresses optimism about the feasibility and construction of the project, at least when taking into account an initial simple yet functional iteration (which will later develop into OCEANIX Busan, for example). Perhaps not in the near future, however, sooner or later, a floating project, at the scale of the one proposed by the United Nations, will be surely constructed.

Failure is, in fact, likely not a technological issue. On one hand, technology and technical elements offer enough alternatives to support the construction of a floating city. It is not science fiction. Architects and engineers already know how to build on the water. On the other hand, the other thing that could hinder the success of the project is the social aspect. Humans are by default social beings who prefer to live together as a community. Thus, even if creating a floating community might make sense from a city' perspective, it would still fail if residents lacked a desire to settle there. It cannot be predicted how a community will adjust to this new way of life on the water. For this reason, it is important to treasure the knowledge and experience coming from already-existing floating communities scattered all round the globe.

Floating cities, of which OCEANIX and the United Nations are two of the organizations most supportive, may not be the solution to all the problems of modern urbanization; however, just considering these projects is already a significant step toward ensuring a viable, sustainable and long-term adaptive alternative to assist vulnerable areas.

The ocean's surface is a massive and mostly untapped resource that has the potential to address negative effects posed by population growth and climate change. This thesis demonstrates that the challenges floating cities are facing can be overcome and that there may be significant benefits as a result. As such floating urbanization should require more consideration.

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