FATİH SULTAN MEHMET VAKIF ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ
MİMARLIK ANABİLİM DALI
MİMARLIK (İNGİLİZCE) PROGRAMI

ADAPTIVE REUSE OF OFFSHORE OIL AND GAS PLATFORMS FOR SUSTAINABLE FLOATING CITIES

YÜKSEK LİSANS TEZİ

GÜLNİHAL BARBAROSOĞLU

İSTANBUL, 2022

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GÜLNİHAL BARBAROSOĞLU
(200202005)

Danışman
(Dr. Öğr. Üyesi Hakkı Can Özkan)

İSTANBUL, 2022

FATİH SULTAN MEHMET VAKIF ÜNİVERSİTESİ
TEZ ONAY FORMU

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LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ MÜDÜRLÜĞÜNE

Mimarlık Anabilim Dalı Mimarlık (İngilizce) Tezli Yüksek Lisans programı 200202005 numaralı öğrencisi Gülnihal BARBAROSOĞLU'nun hazırladığı "Adaptive Reuse as a Foundation For Sustainable Built Environment" konulu Yüksek Lisans tezi ile ilgili Tez Savunma Sınavı, 14/12/2022 Çarşamba günü saat 10:30'da yapılmış, sorulara alınan cevaplar sonunda adayın tezinin **Kabulüne Oy Birliği** ile karar verilmiştir.

Tez adı değişikliği yapılması halinde: Tez adının "Adaptive Reuse of Offshore Oil and Gas Platforms For Sustainable Floating Cities" şeklinde değiştirilmesi uygundur.

	Jüri Üyesi	**Karar**
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ETHICAL DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Gülnihal Barbarosoğlu

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Gülnihal Barbarosoğlu

YÜZEN SÜRDÜRÜLEBİLİR ŞEHİRLER İÇİN AÇIK DENİZ PETROL VE DOĞALGAZ PLATFORMLARININ YENİDEN İŞLEVLENDİRİLMESİ

Gülnihal Barbarosoğlu

ÖZET

Bu tezde yeniden işlevlendirme metoduna dair literatür taraması yapılmış, yeniden işlevlendirmenin kullanım alanları, tarihçesi, yararları, kategorileri, yeniden işlevlendirmeye dair zorluklar araştırılmıştır. Aynı zamanda, tezde yeniden işlevlendirmenin küresel ısınmanın etkilerini azaltmaya ve sürdürülebilir bir şehir oluşturmaya dair yararları anlatılmıştır. Tezde, yeniden işlevlendirmenin gelecekte su seviyesi artışı tehlikesi için kullanımı araştırılmış, su seviyesi artışından etkilenecek hatta su seviyesi artışı sonucu evsiz kalabilecek popülasyonu, bulunduğu bölgede, yeniden işlevlendirme metodu kullanarak su seviyesinden muhafaza etmenin yolları, nitel yöntemler kullanılarak araştırılmıştır. Bu kapsamda, yeniden işlevlendirmenin kullanım olanaklarına geniş bir perspektiften bakılarak, petrol ve doğalgaz platformlarının yeniden işlevlendirilmesi üzerine inceleme yapılmış, petrol ve doğalgaz platformlarının, yüzer yapıların yeniden kullanılabilirliği araştırılmıştır. Petrol ve doğalgaz platformlarının enerji üretim süreci bittikten sonra geçirdiği süreç ve devreden çıkma süreçleri anlatılmıştır. Tezde yüzer strüktürlere, yüzen şehirlere ve petrol ve doğalgaz platformlarının yeniden kullanıldığı çalışmalara yer verilmiştir. Yapılan araştırmalar neticesinde, yeniden işlevlendirme metodunun doğalgaz ve petrol platformlarına uygulanabileceği, fakat bu yapının sürdürülebilir, kendine yetecek şekilde bir şehir gibi tasarlanması gerektiği kanısına varılmıştır.

Anahtar kelimeler: yeniden işlevlendirme, küresel ısınma, sürdürülebilirlik, su seviyesi artışı, petrol ve doğalgaz platformu, yüzer strüktür.

ADAPTIVE REUSE OF OFFSHORE OIL AND GAS PLATFORMS FOR SUSTAINABLE FLOATING CITIES

Gülnihal Barbarosoğlu

ABSTRACT

This study reviewed the history, categories, benefits, and difficulties of adaptive reuse. Hence, this study explained the benefits of adaptive reuse in decreasing the effects of global warming and the role of adaptive reuse in building a sustainable environment. Furthermore, the study explored the future use of adaptive reuse for sea level rise (SLR). Thus, the study explored adaptive reuse to protect people vulnerable to SLR and even at the risk of homelessness without relocation with qualitative methods. Meanwhile, the scope of adaptive reuse is examined from a broad perspective. Therefore, adaptive reuse of oil and gas structures and floating structures are examined. Postproduction and decommissioning process of oil and gas platforms explained. The thesis explained studies about floating structures, floating cities, and the reuse of oil and gas platforms. As a result, adaptive reuse of oil and gas platforms is suitable. However, this structure must be designed as a sustainable and self-sufficient city.

Keywords: adaptive reuse, global warming, sustainability, sea-level rise, oil and gas platforms, floating structures.

PREFACE

This thesis explores the history, application areas, and benefits of adaptive reuse. It proposes adaptive reuse as a sustainable solution to fight against global warming and climate change. It focuses on implementing adaptive reuse in sea structures and oil and gas platforms to mitigate sea level rise in low-lying and coastal areas. Finally, the study finds that the potential benefits of adaptive reuse in sea structures are not limited to mitigating the risks of sea level rise but also include preventing urbanization and population density in coastal areas. Although there are significant studies about adaptive reuse, there has yet to be any study about using adaptive reuse for climate change. Adaptively reusing oil and gas platforms and other sea structures can transform the future built environment for a more sustainable and resilient state.

November, 2022 Gülnihal Barbarosoğlu

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SYMBOLS

cm : centimeters

km : kilometers

m : meters

mm : millimeters

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ABBREVIATIONS

ARO:	Adaptive Reuse Ordinance
ARP:	Adaptive Reuse Potentiality
BIG:	Bjarke Ingels Group
e.g.:	Exempli gratia
EF:	Ecological Footprint
GGE:	Green Gas Emissions
HDI:	Human Development Index
HVAC:	Heating Ventilation and Air Conditioning
ICOMOS:	International Council on Monuments and Sites
IM:	Interface Management System
IPCC:	Intergovernmental Panel on Climate Change
LA:	Los Angeles
NASA:	National Aeronautics and Space Administration
OECD:	Organization for Economic Co-operation and Development
OOGP:	Offshore Oil and Gas Platforms
SLR:	Sea Level Rise
UK:	The United Kingdom
UN:	United Nations
UNEP:	United Nations Environment Programme
US:	The United States
VLFS:	Very Large Floating Structures

INTRODUCTION

The population has increased gradually since the industrial revolution. The population growth resulted in urban sprawl. The global increase in urbanization resulted in new coastal settlements. New facilities, trade, and transportation routes established in coastal areas attracted more internal migrants and immigrants. Currently, 90% of the population resides in coastal areas. The population density in coastal areas caused land scarcity and infrastructure damage.

Industrialization not only grew the population and changed the urban fabric but also increased the green gas emission. Green gas emission is a significant contributor to global warming. Sea level rise, a consequence of global warming, threatens coastal cities that accommodate a large portion of the population. Unfortunately, the current forecasts indicate that millions of people may eventually become environmental refugees due to catastrophic results of sea level rise, even if green gas emissions decrease. The built environment significantly affects the environment and society's well-being. The construction industry consumes 40% of the global energy and is a prime contributor to green gas emissions. The construction industry is responsible for implementing more sustainable approaches than conventional developments.

Sustainability is an environmental approach to meeting the current population's needs and impacting future generations positively. New sustainable city design approaches, especially for coastal areas, tackling climate change must be incorporated before it is too late. Land scarcity caused by global urbanization and climate change encouraged architects to design sea cities. Some governments attempted to build artificial lands in water to control population growth. Regardless of each city's different characteristics and dynamism, population distribution in different sustainable and self-sufficient floating cities was perceived to be an ideal solution to tackle the scarcity of land and resources. However, the design, construction, and operation of sustainable and self-sufficient floating cities are risky, complex, time-consuming, and require a significant capital investment. Implementing adaptive reuse approaches in existing floating structures is an interim solution toward learning and building sustainable floating cities. The interim adaptive reuse solution is sustainable, shorter-duration, and less costly to test and improve future floating city concepts.

Adaptive reuse is the practice of using an existing structure with a purpose different than its original intent. It has been implemented since the beginning of human civilization, consciously and unconsciously. Improved sustainability with an extended structural life cycle, decreased carbon emission, and increased energy efficiency are among the most popular goals driving the current adaptive reuse implementations. In addition to the environmental benefits, social and economic gains are typically realized in adaptive reuse implementations. The existing structure's type, status, and future intent determine the most suitable adaptive reuse approach. Coastal cities at risk of sea level rise can implement adaptive reuse in existing floating structures, such as decommissioned offshore oil and gas platforms, for residential purposes. Currently, over 100 offshore oil and gas platforms are decommissioned every year. Only the Gulf of Mexico has approximately 4000 platforms to decommission in the 21st century. Private and public sectors explore practical solutions to reuse existing floating structures to contribute to sustainability by extending the structure's life cycle and converting them into habitable spaces. Several researchers recognize the reuse of floating structures as a feasible solution to mitigate the potential impacts of sea level rise.

This study aims to provide an interim step to building sustainable and self-sufficient floating cities to mitigate sea level rise risks in coastal cities. The study proposes an adaptive reuse approach to convert decommissioned offshore oil and gas platforms into floating settlements. The study reviews adaptive reuse literature, including its history, applications, and categories. Important considerations and implementation challenges of adaptive reuse are outlined in the study. The need for floating settlements is analyzed from urbanization and climate change perspectives. Implementing adaptive reuse in floating offshore oil and gas platforms will help timely mitigate the potential impacts of sea level rise in coastal cities and test sustainable and self-sufficient floating city concepts less costly and in a shorter time.

Aim of the Thesis

This study reviews adaptive reuse's history, application areas, and benefits. It aims to propose adaptive reuse as a sustainable solution to fight against global warming, climate change, and population growth. It mainly focuses on implementing adaptive reuse in existing sea structures and oil and gas platforms near coastal areas to mitigate the high risk of sea level rise. The study aims to provide a sustainable interim solution for rising sea levels by implementing adaptive reuse in existing floating structures.

Scope and Limitation of the Thesis

This study reviewed the history, application areas, and benefits of adaptive reuse. It proposed adaptive reuse as a sustainable solution to fight against global warming and climate change. It mainly focused on implementing adaptive reuse in existing sea structures and oil and gas platforms near coastal areas to mitigate the high risk of sea level rise. The study analyzed floating structures and city designs to select the most efficient design for SLR. The floating cities, Marine City, Triton City, Plan for Tokyo, Floating City Ijmeer, Lilypad, ClubStead, The Seasteading Implementation Concept, Green Float Tallinn, Oceanix Busan, Next Tokyo 2045 selected in the case study all focused on resolving existing problems in the built environment by proposing an alternative living. Marine City, Triton City, and Plan for Tokyo are designed for a growing urban population and a city resilient to natural disasters. Floating City Ijmeer, Lilypad, Green Float Tallinn, Oceanix Busan, and Next Tokyo 2045 were selected because they were designed for SLR. ClubStead and The Seasteading Implementation Plan were selected because they propose an alternative autonomous community in the sea. The floating structures selected for the study were Baram-8, Seaventures Hotel and Resort, and The Rig Extreme Park adaptively reused and proposed a new approach for existing activities by implementing adaptive reuse. The floating city and structure designs were evaluated according to the LEED for Homes Design and Construction, LEED for

Neighborhood Development, and LEED for Cities and Communities, Floating structure analysis of El-Shihy and Ezquiaga and DeltaSync's floating city objectives.

Methodology

This study was conducted in 3 steps. In the first step, the adaptive reuse literature was comprehensively reviewed including

- History
- Application areas
- Related concepts
- Potential benefits

In the second step, the need for sustainable floating city and structures explained due to current problems of

- Population growth and urbanism
- Global warming and climate change
- Sea level rise

In the last step a case study was established to implement adaptive reuse as a sustainable solution to fight against the impacts of global warming and climate change, particularly sea level rise. The case study included research and analysis of

- Floating cities that emerged to resolve an existing problem
- Adaptively reused floating structures

The study was concluded including a results part that emphasizes score card of floating cities and structures based on the evaluation method.

Findings

This study proposed an interim solution by using adaptive reuse to design floating structures for population growth, urbanization, global warming, climate change, and especially for sea level rise. This study examined the adaptive reuse method and the role of adaptive reuse in mitigating climate change. The study evaluated floating structures and cities to find a suitable design for environmental and urbanization problems. The evaluation method analyzed floating structures and cities according to their structural, technological, social, and sustainable characteristics. The LEED rating system inspired the evaluation method. This rating system was chosen because it correlates with designing sustainable cities resilient to climate change. Floating cities and structures were evaluated using LEED for Homes Design and Construction, LEED for Neighborhood Development, and LEED for Cities and Communities, floating structure analysis of El-Shihy and Ezquiaga and DeltaSync's floating city objectives. The evaluation consisted of categories of construction feasibility and process, impact on marine ecology, modularity of design, production of energy, food, and water, adaptive reuse of materials, structure, and building, and resilience to environmental conditions that have been assigned to evaluate and find the best design. Each characteristic scored from 1 being the highest and 0 being the lowest. According to the evaluation, the highest score belongs to Floating City Ijmeer due to the tremendous variety in sustainability and social variety characteristics. The highest score in floating structures belongs to Seaventures Dive Rig, with a score of 23. The adaptively reused structure has a high score due to sustainability, transportation, and adaptive reuse. The structure's only disadvantage was that it was designed for temporary lodging. Therefore, it does not provide matching options for energy, food, water production, and design range as Floating City Ijmeer.

On the other hand, the lowest scores belong to the first floating city example, Marine City. Based on the evaluations, adaptively reused structures show strength in environmental protection and feasibility. Therefore, the highest score would belong to a project designed with adaptive reuse concordant with sustainability principles and has a great variety of social options. This study proposed an interim solution using adaptive reuse to design floating structures for population growth, urbanization, global warming, climate change, and especially sea level rise.

CHAPTER ONE

1. ADAPTIVE REUSE

1.1. HISTORY OF ADAPTIVE REUSE

Adaptive reuse is a practice of using an existing building differently than its intended purpose. It has been implemented since the foundation of human civilization (Mohamed, Boyle, Yang, & Tangari, 2017). Adaptation has been a common method in urgent conditions that requires fast decision making and prompt action (Wong, 2016). For instance, the adaptation process is widely used during wars and revolutions. Temples were refurbished for different functions during wars. For example, the Parthenon Temple was converted into a treasury, church, mosque, and museum in the premodern era (Images 1.1 and 1.2).

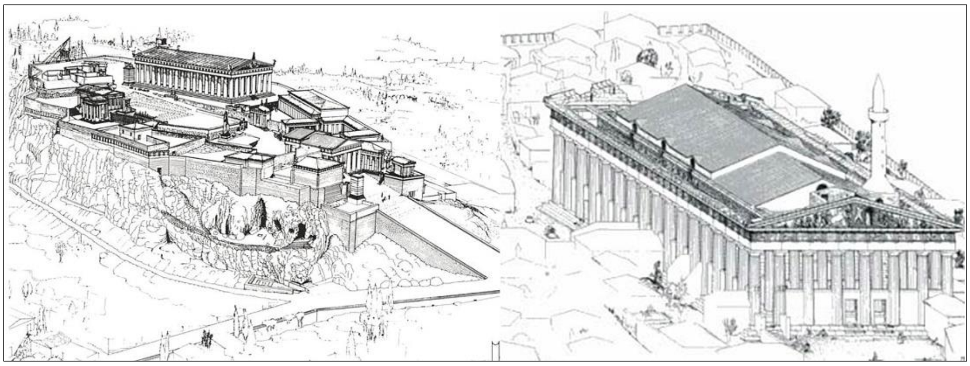


Image 1.1: Parthenon as a temple and a mosque (Neils, 2005).

Image 1.2: Parthenon restoration in 2004 by Shields (Al-Ghamdi, 2011).

However, adaptation was not practiced for preservation but for necessities and economic reasons in the premodern era (Mohamed, Boyle, Yang, & Tangari, 2017). Therefore, buildings' appearance changed, and their functions adjusted to meet the shifting needs of people and society (Cantell, 2005). For example, places of worship (e.g., church) adapted for defense headquarters, industrial facilities, workshops, and other functions by the military in the French Revolution. Adapting place of worship into defense facilities without heritage preservation has been a dramatic example of the adaptation history (Plevoets & Van Cleempoel, 2013). Protection of historical and existing buildings has been disregarded until Viollet le Duc's preservation theories. In the 19th century, Viollet le Duc defined adaptation as a method of building preservation that finds a new use for the building (Plevoets & Van Cleempoel, 2011). After the 19th century, historical and architectural layers of buildings gained prominence and the conservation process accelerated. Buildings' architectural style and era became more significant (Wong, 2016).

The built and work environments changed rapidly with the Industrial Revolution. Factories, large workshop areas with various machinery opened in city centers. Young people from rural areas migrated to city centers to earn money. This shift continued until the beginning of the 20th century. Some buildings became nonfunctional and obsolete due to the technological advancements in the 20th century. Some industries declined and factories were abandoned. Abandoned factories were demolished or remained outmoded. Vacant industrial buildings stayed closed and unused until the emergence of adaptive reuse methods. Industrial heritage preservation gained ground after World War II in the United Kingdom (UK). In the 1950s, a preservation committee called The International Institute for Conservation of Historic and Artistic Works was established to conserve industrial buildings and projects in the UK (Cantell, 2005).

North America and Europe started to use adaptive reuse for sustainable urban development and smart growth, and to remove the economic and social burden created by vacant buildings (De Sousa, 2003; Stas, 2007). In fact, adaptive reuse brought back old, abandoned industrial buildings of the 19th and 20th centuries to life with new functions by upgrading their functions, comfort, and safety standards in the United States (Eyüce & Eyüce, 2010). During the 1960s, the preservation movement progressed in the US. In that period, transportation and material costs were high due to high fuel costs. These circumstances pushed developers into searching for alternatives to new construction. As a result, adaptive reuse became a preferable method for mitigating the impact of the scarcity of resources. Growing environmental concerns in the 1960s also drove professionals to reuse vacant industrial buildings (Cantell, 2005). Some city regeneration plans incorporated adaptive reuse for sustainable city development in the 1960s (Bullen & Love, Structural Survey, 2009). At the beginning of the 1960s, adaptive reuse was used in SoHo in New York City for rejuvenation. In 1964 The Ghirardelli Chocolate factory was converted into a retail center in San Francisco. The Ghirardelli Chocolate factory was the first successful adaptive reuse of an industrial building (Hein & Houck, 2008) (Image 1.3).

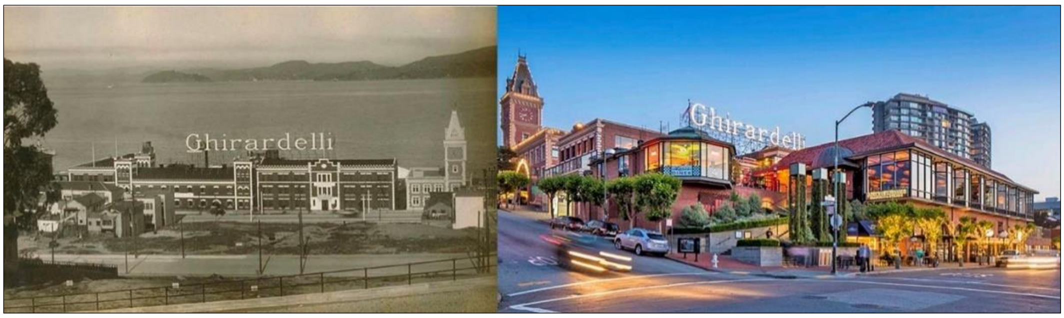


Image 1.3: Ghirardelli before and after adaptive reuse (Johnson, 2021).

Adaptive reuse practices started to apply, more consciously, after the rise in oil prices and conservation theories. In the 1970s, high fuel, transportation, and material costs changed construction facilities in the United States. Developers implemented adaptive reuse due to oil, transportation, and material prices (Kersting, 2006). In 1973 the Industrial Archeology Society was established. The Industrial Archeology Society accelerated preservation and conservation facilities worldwide (Zhang, 2007). Urban renewal plans with adaptive reuse continued in the 1970s. The urban renewal process consisted of conserving heritage buildings and refurbishing abandoned buildings (Cantell, 2005). Lower Downtown of Denver started implementing adaptive reuse to adapt industrial buildings into office buildings in the 1970s. In 1975 the state of Maryland established a heritage preservation tax program to encourage adapting historic buildings and preserving heritage values (Hein & Houck, 2008). Conservation activities accelerated in the 1980s in France. The Industrial Council on Monuments and Sites (ICOMOS) signed an agreement to encourage industrial heritage conservation worldwide to accelerate adaptive reuse and conservation of historical buildings (Zhang, 2007).

Adaptive reuse started to gain ground and was implemented in different regions, in the 1990s. China paid attention to the urban development of industrial heritage and adaptive reuse to conserve historic industrial buildings in the 1990s (Wang & Nan, 2007). Concurrently, Toronto started to regenerate industrial buildings and sites with adaptive reuse (Wilson, 2010). In England and France, adaptive reuse was implemented to rehabilitate landmarks in the early 1990s. Gare d’Orsay station in Paris (Image 1.4) and Tate Modern Museum in London (Image 1.5) were transformed with adaptive reuse (Hein & Houck, 2008).

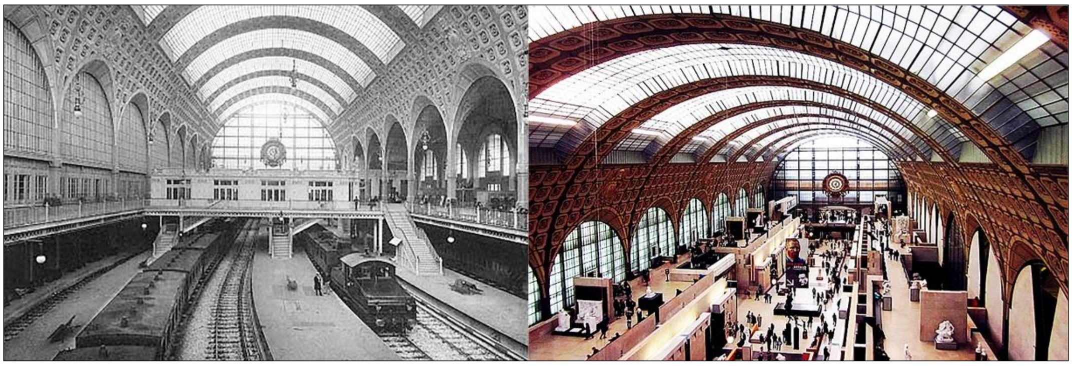


Image 1.4: Gare d'Orsay Station after adaptive reuse (Richman-Abdou, 2019).

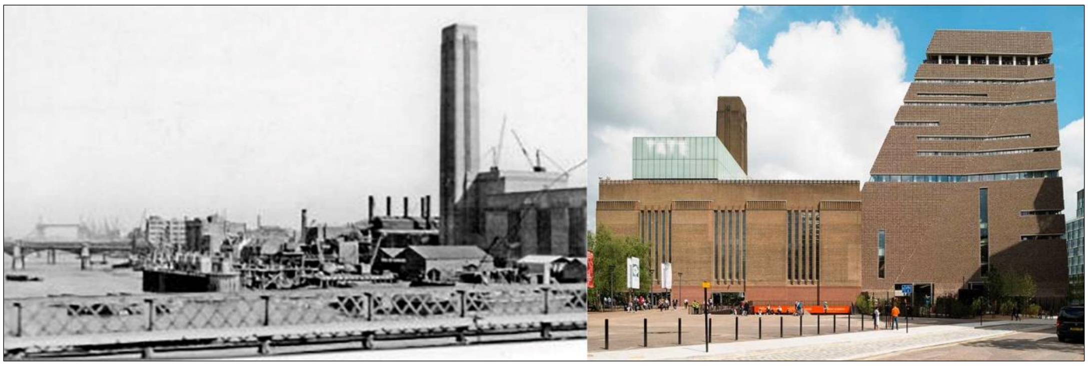


Image 1.5: Tate Modern (Tabak & Sirel, 2022; Frearson, 2016).

Meanwhile, adaptive reuse was implemented in some regions in the US and Canada for infill development, neighborhood revitalization, and reduced urban sprawl (Bullen, 2007). The US introduced adaptive reuse city ordinance programs to achieve revitalization in the 1990s. Some of the adaptive reuse city plans implemented in the US were from Arizona, Massachusetts, Los Angeles, and Charlotte, North Carolina. These regions in the US implemented adaptive reuse with the main goal of revitalizing cities and contributing to sustainability conditions (Bullen & Love, 2009). They changed building codes to encourage developers to implement adaptive reuse. For example, the State of Arizona established a city ordinance code to encourage adaptive reuse in 1995. In 1998 Massachusetts governor established legislation to encourage developers to clean brownfields to rejuvenate the landscape. In 1999, Los Angeles city implemented an adaptive reuse ordinance plan to adapt industrial and non-residential buildings in the downtown. The ordinance encouraged developers to transform old buildings into new structures through adaptive reuse. A suburb of Los Angeles, Downtown Culver City, rejuvenated with adaptive reuse (Young, 2008; Bullen & Love, 2009).

In time, adaptive reuse became more prevalent in city plans to improve sustainability by expanding the building life cycle, decreasing carbon emissions, and increasing energy efficiency (Yung & Chan, 2012). In the beginning of the 21st century, Canada implemented adaptive reuse to rehabilitate historic and old buildings. The Canadian government achieved economic growth and preservation by adaptation (Shipley, Utz, & Parsons, 2006). Industrial buildings in Toronto were reused for infill policy (Wilson, 2010).

Australia focused on adaptive reuse for sustainable development, heritage conversion, regeneration, and renovations (Bullen & Love, 2010). In 2001, North Carolina Mills were adapted into offices, shops, retail, and houses in Charlotte. In 2003, Los Angeles adaptive reuse ordinance (ARO) expanded across the city to solve the housing shortage. The ARO helped revitalize the neighborhood with adaptive reuse (Cantell, 2005). Some regions in North Africa implemented adaptive reuse in historic buildings in 2003 (Langston, 2008). Adaptive reuse has almost been used worldwide since 2007.

For example, Sanaa, Yemen, adopted the reuse process in housing in 2008 to preserve the historical fabric and world heritage (Haidar & Talib, 2015). The Australian government established the Carbon Pollution Reduction Scheme for a more sustainable environment in 2010. The legislation encouraged developers to use buildings for adaptation (Yung & Chan, 2012). Australia focused on rehabilitation and adaptation of existing structures and aimed to rejuvenate and renew building stock by 2020 (Wilkinson, James, & Reed, 2009). Adaptive reuse has gradually become more popular by promising benefits related to economic development, urban revitalization, and authenticity (Fisher-Gewirtzman, 2016) (Figure 1.1).

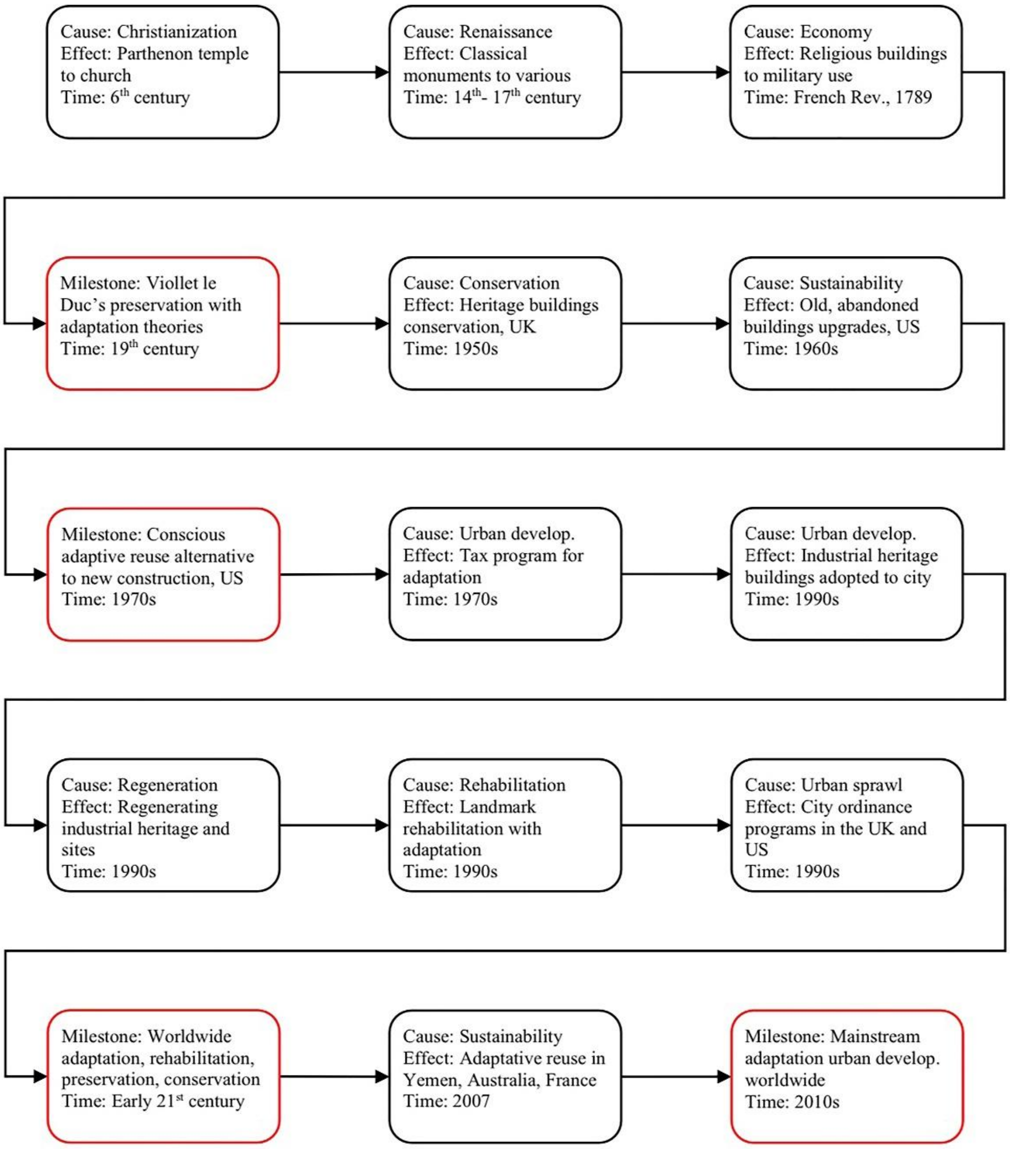


Figure 1.1: History of adaptive reuse drawn by author.

1.2. CATEGORIES OF ADAPTIVE REUSE

Adaptive reuse covers multiple approaches for different building types and requirements (Hein & Houck, 2008). Buildings constructed in the past represent aesthetic, culture, and nonrenewable resources (Shipley, Utz, & Parsons, 2006). Each building deserves protection as their existence contributes to a collective urban memory (Cantell, 2005). Protection of existing buildings and preservation of urban memory urges a method called adaptive reuse. Refunctioning an existing building through alterations falls under the scope of adaptive reuse (Plevoets & Van Cleempoel, 2011). Adaptive reuse helps existing buildings and structures meet current needs when the building's previous function is not needed. Changes made through adaptive reuse maintain the building's compliance with the code requirements (Cantell, 2005; Hein & Houck, 2008; Langston, 2008; Eyüce & Eyüce, 2010).

Current adaptive reuse methods are advanced versions of Chusids' urban ore theory (1993). According to Chusid (1993), misused, obsolete buildings approaching potential demolition are a mine of raw materials for new projects (Chusid, 1993). Assigning new functions to existing buildings through adaptive reuse is much more effective and sustainable than extracting raw materials from buildings in the demolition stages (Langston, 2011). However, changes made to improve a building's function can be challenging for designers. For instance, new building functions may require additional structures or space. Developers can build new structures or extensions if the existing structure cannot accommodate new functions. In that case, the design team may expand the existing structure by extensions or new buildings. Expansions and alterations operate according to the design. First, the design team establishes a plan for adjustments and then apply alterations (Eyüce & Eyüce, 2010). The design team must always consider local codes and regulations to achieve a successful adaptive reuse process (Langston, Wong, Hui, & Shen, 2008). Adaptive reuse through extensions and additions must consider the condition and context of the existing building. The surroundings and local environment must also be investigated in advance when planning an adaptive reuse project (Kersting, 2006).

Adaptive reuse categories consist of retrofitting, remodeling, refurbishment, conservation, adaptation, reworking, rehabilitation, and upgrading (Cantell, 2005). Adaptive reuse has different applications, such as scarring, layering, and display (Kersting, 2006). Building type, design flexibility, building age, function, obsolescence level, current building condition, durability, multi-functionality, disassembly, client expectations, current building requirements, and regulations are among the factors that determine the most feasible adaptive reuse method and application (Bullen & Love, 2010; Conejos, Langston, & Smith, Enhancing sustainability through designing for adaptive reuse from the outset: A comparison of adaptSTAR and Adaptive Reuse Potential (ARP) models, 2015). Building typology, technical infrastructure, and architecture are also considered when determining the most ideal adaptive reuse approach (Plevoets & Van Cleempoel, 2011). Some adaptive reuse categories, such as preservation, and restoration, do not require change (Bullen, 2007). On the other hand, refurbishment, retrofitting, and renovation may require changes in interior space and building services (Langston, 2008).

Rehabilitation is an adaptive reuse approach that analyzes vacant and abandoned buildings with regards to their conditions, defection, stability, and safety. Identifying appropriate resources and materials is within the scope of rehabilitation. It is essential that vacant buildings are considered for rehabilitation from an adaptive reuse perspective (Cantell, 2005).

Restoration is an adaptive reuse approach that falls under rehabilitation. Restoration projects aim to turn existing buildings into their original form. It mainly applies to historically significant buildings (Bullen, 2007; Hein & Houck, 2008). Restoration projects often complete behind schedule and over budget (Hein & Houck, 2008). Planning, scheduling, and cost estimating efforts are crucial in the pre-design phase (Ijla & Broström, 2015).

Renovation is an adaptive reuse approach, similar to restoration. However, its application area is not limited to building rehabilitation. Renovation minimizes building obsolescence by upgrading building’s technology and standards (Ijla & Broström, 2015).

Preservation and conservation are an ideal adaptive reuse approach for historical buildings when a strict historic preservation law applies (Bullen & Love, 2010). It is important to analyze buildings beforehand to preserve the building heritage and architectural style (Bullen & Love, 2009).

The preservation community and government officials assess the adaptive reuse process when the building is considered cultural heritage (Bullen & Love, 2011). Historical buildings can implement adaptive reuse through different approaches. In the absence of strict regulations for preservation, the building adaptation process is determined based on the building's desired function (Bullen & Love, 2010). Some building sections can be kept intact in the adaptation process while some extensions are added to meet the desired design. Such additions may increase the cost and reduce the efficiency of the adaptation process (Bullen & Love, 2011). Preserving historic buildings through adaptive reuse may also include upgrading and regenerating buildings (Bullen & Love, 2010). Foundation inspection, mechanical inspection, and material inspection for safety are typical and common prior to adaptive reuse implementations in historical buildings (Hein & Houck, 2008).

Adaptive reuse of historic and old buildings requires thorough examination of architectural patterns and attributes before buildings implement the adaptive reuse process. Designers explores various memory lanes while examining adaptive reuse applicability of historical buildings (Wong, 2016).

Refurbishment is a popular method for functional changes. Refurbishment rearranges building equipment and conditions and improves building operation and appearance (Bullen & Love, 2011). Buildings and structures can be refurbished and repaired through adaptive reuse. The refurbishment method converts, and upgrades misused buildings (Langston, 2008). Redecoration and reconstruction are among different categories of the refurbishment method (Langston, Wong, Hui, & Shen, 2008). When a client demands mild changes in building services and appearance, the design team may change interior design with redecoration. Except for conservation and preservation projects, rehabilitation of building and equipment maintenance are included in refurbishment processes (Bullen & Love, 2011). Refurbishment process may result in adding extra space in historical or heritage buildings according to the preservation laws. Designers must always consider the heritage value when adding extra space is necessary in refurbishment of historical buildings (Kersting, 2006; Hein & Houck, 2008). Mechanical equipment in existing buildings become outdated due to rapid technological advancements. Buildings can become obsolete when mechanical equipment are outdated or misused. In that case, developers can use the refurbishment process to upgrade buildings with new equipment (Langston, 2008). The performance of obsolete buildings implementing adaptive reuse to upgrade their equipment is expected to increase significantly (Aigwi, et al., 2019).

Remodeling and retrofitting are ideal adaptive reuse approaches when the building cannot meet expected conditions but requires new, bigger spaces and advanced technologies. Remodeling adjusts and makes additions to the space when necessary. Retrofitting renews and adapts building equipment in accordance with the current technology. Keeping up with advanced technologies in a building is not easy. Existing equipment are at risk of being outmoded by new technology. Therefore, buildings must be upgraded to avoid service complications and instabilities (Bullen & Love, 2011) (Figure 1.2).

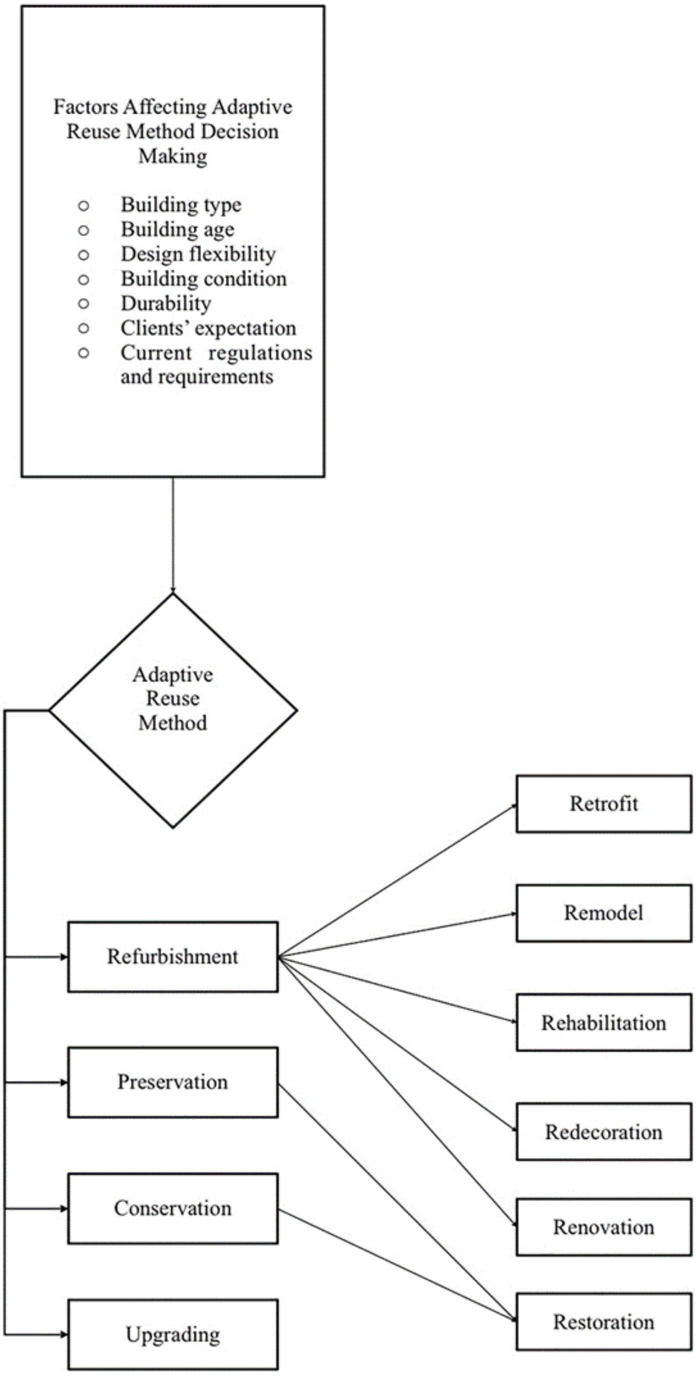


Figure 1.2: Categories of adaptive reuse drawn by author.

1.3. BENEFITS OF ADAPTIVE REUSE

Adaptive reuse offers many environmental, social, and economic benefits by utilizing obsolete, nonfunctional, abandoned, old, historic buildings, structures, and fields. Abandoned buildings often and indirectly disrupts social life and employment in the area. Vacant and abandoned buildings are likely to become a place for criminals and they eventually increase the crime rate in the community. On the other hand, adaptive reuse can help reduce the crime rate and increase employment by giving a function to vacant buildings. Adaptive reuse efforts ideally prioritize vacant and abandoned buildings (Cantell, 2005).

Building functions are expected to change from one era to another from a design perspective (Wong, 2016). Adaptive reuse provides a dialogue between different eras. Adaptive reuse integrates different timelines by incorporating different materials and styles. The mixture of different materials is mainly seen in adaptive reuse applications that include extensions and additions to historical and old buildings (Kersting, 2006).

Adaptive reuse is also a green alternative to demolition and reconstruction. Some buildings can be prevented from being demolished if adaptive reuse is applied as a rehabilitation method (Tan, Shen, & Langston, 2014). Environmental burden caused by demolishment can be substantially decreased by adaptive reuse (Bullen & Love, 2010). Reclaiming existing buildings through adaptive reuse protects the building’s embodied energy (Wang & Nan, 2007).

Prevention of demolition with adaptive reuse minimizes transportation and energy consumption. It reduces construction waste and decreases scarcity of resources (Wang & Nan, 2007). It mitigates safety risks due to heavy construction activities in the neighborhood (Cantell, 2005). Alternating to demolition projects by adaptive reuse can decrease pressure on landfills, reduce carbon emissions, and significantly contribute to the environment (Wang & Nan, 2007). These environmental benefits of adaptive reuse make it a useful sustainability tool that can help fight climate change (Tan, Shen, & Langston, 2014). Othman and Elsaay (2018) grouped benefits of adaptive reuse by sustainable development type (Table 1.1).

Table 1.1: Benefits of adaptive reuse (Othman & Elsaay, 2018).

Pillars of sustainable development	Benefits of adaptive reuse
Environmental	Environmental enhancement
Economic	Economic development
	Increased cost effectiveness
Social	Cultural continuity, identity, and sense of place
	Better aesthetic appearance to the environment
	Heritage conservation
Environmental & Economic	Reduced use of resources, energy, and emissions
	Stimulated vacant neighborhoods
	Recovery of energy embodied in buildings
Economic & Social	Expanded building life cycle
	Increased productivity and involvement of local communities
Social & Environmental	Decreased consumption of land and urbanism
	Revitalized and upgraded heritage districts
	Increased technical and architectural innovation

Adaptive reuse principles can function as a reliable process to achieve sustainable development (Tan, Shen, & Langston, 2014). Adaptive reuse contributes to sustainable development by reclaiming existing, old, and historical buildings. Recycled buildings, revitalized neighborhoods, and controlled urban sprawl are among the common benefits of adaptive reuse that relate to sustainability (Zhang, 2007). In fact, adaptive reuse implementation on a large scale provides urban regeneration (Langston & Shen, 2007). Additional expected benefits of adaptive reuse include but are not limited to lower construction cost, increase energy efficiency, enhanced environmental protection, improve social regeneration, and up-to-date buildings (Haidar & Talib, 2015; Ijla & Broström, 2015). Updated buildings increase the building stock and renews the existing building stock (Kersting, 2006; Langston & Shen, 2007). Using the existing building stock as an alternative to new construction contributes to the sustainable growth (Wang & Nan, 2007). Bullen and Love (2011) identified benefits and barriers in adaptive reuse method (Table 1.2).

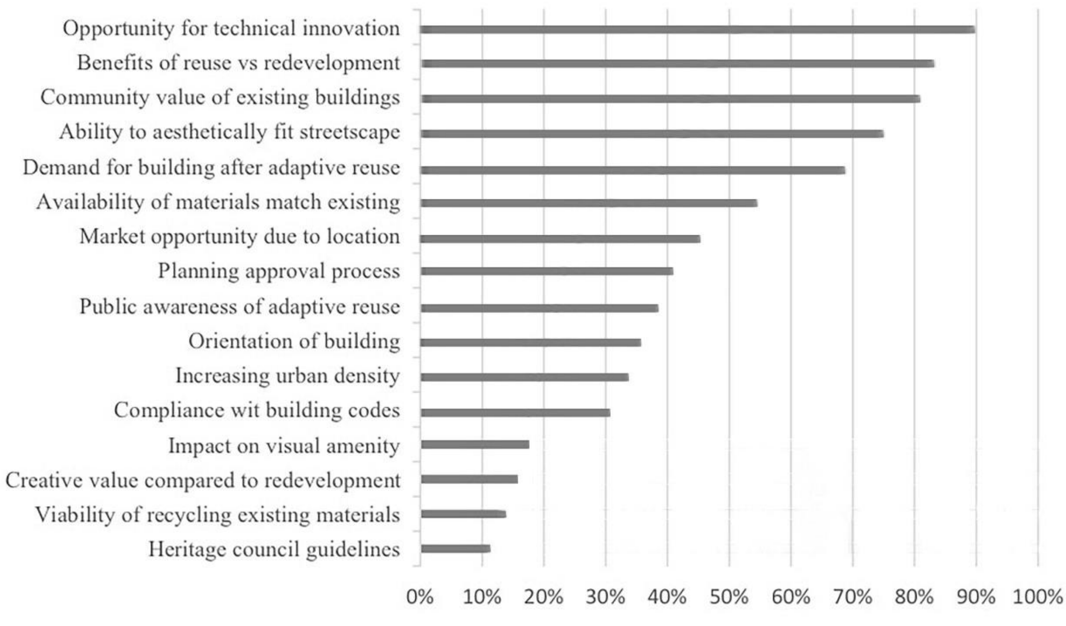
Table 1.2: Benefits and barriers in adaptive reuse (Bullen & Love, 2011).

Benefits	Barriers
Reduced material, transport, and energy consumption	Bad conditions of external fabric and finishes

Reduced material waste	Increased rental rate in reused buildings
Increased energy efficiency	Limiting regulations and restrictions
Improved building functionality	Building complexity
Reduced disruption	Lack of skilled tradesmen
Reduce negative environmental and social impact	Limiting building layout
Positive changing in patterns	Strict health and safety requirements
Increased potential for multi-purpose use	Increased economic uncertainty
Availability of financial incentives	Low construction quality

These easy to realize benefits help adaptive reuse become a mainstream method and encourage more governments to implement adaptive reuse methods (Haidar & Talib, 2015; Ijla & Broström, 2015). In fact, different regions implemented adaptive reuse for city regeneration and sustainable development (Eyüce & Eyüce, 2010). For instance, some governments implemented adaptation reuse methods by sustainable development legislation. The Los Angeles Ordinance is an example of government legislations that encourage sustainable development by adaptive reuse (Young, 2008). Adaptive reuse of existing buildings help maintains the community's social life and work environment (Bullen & Love, 2010) (Table 1.3).

Table 1.3: Benefits of adaptive reuse (Bullen & Love, 2011).



With all these benefits considered, adaptive reuse has almost become a norm to protect and maintain social and environmental attributes of the society (Bullen & Love, 2010). However, some practitioners in the industry are cautious toward implementing adaptive reuse despite its potential and realized benefits. For example, Koolhaas, a well-known architect, claims that adaptive reuse and preservation can form historical amnesia. He states that adaptive reuse can become a dangerous epidemic for our cities (Fisher-Gewirtzman, 2016). In contrast, planned extension and additions made through a formal adaptive reuse process can contribute positively to the urban fabric (Zhang, 2007). Overall, adaptive reuse is an economic, social, and sustainable alternative to develop and maintain communities (Bullen, 2007).

1.4. PLANNING IN ADAPTIVE REUSE

Each adaptive reuse approach such as rehabilitation, renovation, revitalization, and restoration require a detailed decision-making process (Wilson, 2010). Each approach requires a different level of attentiveness and planning (Hein & Houck, 2008). The design team evaluates different adaptive reuse approaches in the pre-design phase (Langston, Wong, Hui, & Shen, 2008). Each adaptive reuse approach includes various complex steps involving different parties, from the pre-design phase to project close-out. Adaptive reuse projects can cover different scopes that can be carried out by different contractors, and consultants (Fisher-Gewirtzman, 2016). The versatile scope of adaptive reuse projects requires a formal committee of interdisciplinary people (Bullen & Love, 2009).

Uncertainties related to lack of information about existing buildings can make adaptive reuse implementation more complex than initially perceived. The potential complexity of adaptive reuse implementations is often intimidating and can result in bias against the process. Risk mitigation in adaptive reuse projects is crucial, and it requires a comprehensive planning. Communication and coordination must be flawless and project cost, schedule, quality, and risk management plans must be complete and accessible to achieve a successful adaptive reuse project. Quantity survey and cost estimate are among the first reports that must be generated in adaptive reuse projects (Fisher-Gewirtzman, 2016). Deficiencies and potential changes in existing buildings are identified through adaptive reuse evaluations. The evaluation can be done using different methods. Some evaluation methods identify changes, record, monitor, and track adaptive reuse projects throughout the lifecycle. Comprehensive evaluation methods deploy a sophisticated management system to track adaptive reuse project progress in various components and scopes. Interface Management System (IM) is an example of sophisticated management systems that can track adaptive reuse implementation progress (Eray & Sanchez, 2019). Langston's Adaptive Reuse Potentiality (ARP) method evaluates applicability of adaptive reuse in buildings from a product life cycle perspective. The ARP method assigns adaptive reuse applicability ranks to the building in terms of physical, economic, functional, technological, social, legal, and political aspects. This method aims to help decision-makers optimize their expectations when implementing adaptive reuse (Langston, 2012). The ARP method usually measures the applicability of adaptive reuse in percent where higher percentages indicate a greater likelihood of successful adaptive reuse implementation. For example, project stakeholders may find it risky to implement adaptive reuse when the ARP score is lower than 20%. Several factors affect the success of adaptive reuse implementation. Structural integrity, foundation, climate, and design complexity are among the most influential factors in successful adaptive reuse projects. Each of these factors is likely to influence the success by 15% to 20%. Measuring adaptive reuse applicability score of a building using these influential factors is another adaptive reuse evaluation method (Conejos, Langston, & Smith, 2011).

1.5. DIFFICULTIES IN ADAPTIVE REUSE

Old, and historical buildings may contain components with harmful materials such as, asbestos, lead-based paint, and heavy metals. These harmful materials were commonly used in old buildings for equipment protection and fire resistance purposes. Adaptive reuse projects involving structure improvements and equipment upgrades consider the potential exposure to harmful materials (Siddiqi & Thomas, 2006). Developers must remove existing components containing hazardous materials or apply solutions for unsafe conditions to comply with health and safety requirements. However, removing hazardous components is not easy due to limited access or excessive extra work. Pipe insulations and ductwork containing hazardous materials are among difficult to remove materials in adaptive reuse projects (Cantell, 2005). Contamination in building components due to hazardous materials can leak into buildings and even building sites (Shipley, Utz, & Parsons, 2006). Inaccessibility to hazardous materials and unforeseen contamination increase the cost, complexity, and overall risks in adaptive reuse projects (Cantell, 2005). Developers avoid implementing adaptive reuse in old buildings where the risk of contamination and unforeseen conditions is high (Shipley, Utz, & Parsons, 2006).

Lack of as-built documentation such as blueprints of existing buildings is another factor that can significantly disrupt the design phase in adaptive reuse projects. Architects, structural engineers, and consultants measure and evaluate the existing building in the absence of as-built documents. The result of the comprehensive evaluation outlines the status of the existing building and identifies necessary modifications. Construction activities in adaptive reuse projects can be more challenging than usual when the evaluation suggests modifications in structure, foundation, and roof (Hein & Houck, 2008). Existing buildings with as-built documentation still require site surveys as the building status can be different than the conditions indicated in the as-built documents (Cantell, 2005). Measuring building integrity through site surveys is expected to prevent unexpected costs in adaptive reuse projects (Siddiqi & Thomas, 2006).

Historical, old, abandoned, existing buildings may require additional space for equipment upgrades, capacity improvements, and functional changes. Design for additions or extensions to existing buildings can be a challenging process in adaptive reuse projects. Meeting preservation law requirements and maintaining the existing structure are among the difficulties encountered in adaptive reuse projects involving additions and extensions (Table 1.4).

Table 1.4: Challenges and benefits in adaptive reuse (Bullen & Love, 2011).

Challenges in Adaptive reuse	Benefits in Adaptive reuse
Hazardous materials	Authenticity
Structural degradation	Increasing building life cycle
Site contamination	Economic feasibility
Spatial complexity	Protecting collective memory
Lack of as-built documents	Protecting building embedded energy
Functional change	Reduce crime rate
Problems in mechanical equipment	Increase employment
Regulations	Reduce construction waste
Market conditions	Reduce energy consumption

Each project comes with uncertainties that can evolve into problems. Problems faced in adaptive reuse projects are usually caused by the building status and obsolescence levels that are not identified until the construction phase. Degradation related to the existing building's infrastructure, foundation, and mechanical systems are usually the problems that are rarely identified prior to the construction phase in adaptive reuse projects. The uncertainties and known challenges can cause investors to avoid implementing adaptive reuse despite its benefits. The feasibility of adaptive reuse projects depends on project's schedule, market conditions, construction cost, capital cost, and regulations. Considering the factors influencing the feasibility, risks and challenges must be carefully analyzed for a successful adaptive reuse project (Kiley, 2004). When the project feasibility is not assessed properly, developers tend to choose demolition and reconstruction over adaptive reuse for higher profits even if it increases the risk of damaging the built environment and heritage (Wang & Nan, 2007).

Adaptive reuse can apply to most existing buildings for different desired functions. However, the desired outcome determines the number of challenges that the design and construction teams must overcome. For instance, designers must preserve the existing building's style and decorations to maintain the specific era that the design reflects. Interior design and functional changes must avoid resulting in dramatic deviations from the original building. Adaptive reuse projects implemented in heritage buildings may limit the designer’s creativity and constrain the design perspective (Bullen, 2007).

Functional changes in adaptive reuse projects are typical. However, potential changes in the building’s function must be carefully reviewed to avoid problems related to code compliance (Shipley, Utz, & Parsons, 2006). In case, functional changes in an adaptive reuse project require compliance with different codes, the cost of extra effort can be significant. These cost considerations must be reviewed in the pre-design phase (Langston & Shen, 2007).

Large scale implementation of adaptive reuse projects may pose social difficulties when the community standards are ignored. Los Angeles Ordinance plan was relatively an unsuccessful example of large scale adaptive reuse implementations. Los Angeles Ordinance plan aimed urban regeneration. However, it resulted in displacement and gentrification of under-privileged people due to lack of social considerations (Fisher-Gewirtzman, 2016). Adaptive reuse must be implemented in a considerate way that respects and recognizes the social value the buildings carry for local people (Langston & Shen, 2007).

CHAPTER TWO

2. ADAPTIVE REUSE OF FLOATING STRUCTURES

Cities come across with several problems as they grow and shape through years. Population growth and urbanism is among one of the challenges in cities. High population density urged architects to design new types of cities to resolve the population problem. Started in the 1960s with Buckminster Fuller and Kiyonari Kikutake designing novel cities for existing problems continues. Climate change, sea level rise (SLR) and sustainability are among the current challenges for cities. SLR predictions causes a stress for cities with high population and low-lying areas. Adapting cities for current and future environmental problems are crucial. European countries invest in infrastructure for coping with SLR. However, these investments will submerge to water in high acceleration of SLR. Cities can be adapted and designed for SLR by examining past examples and concept of floating structures and floating cities. Past examples and floating cities designed to mitigate with land scarcity and high population can enlighten perspective in designing for SLR.

2.1. THE NEED FOR FLOATING STRUCTURES AND CITIES

2.1.1. Population Growth and Urbanism

The world population has changed rapidly since the industrial revolution in the 18th century. People from all ages moved from rural areas to cities to work in factories or find other jobs. Technological developments in the manufacturing industry in the 18th and 19th centuries caused sprawl in urban cities. In addition to the industrial developments, population growth also contributed significantly to the sprawl in urban areas (Berg & Hudson, 1992).

The high rate of urbanization has increased globally since the 19th century (Davis, 1955). People moving from rural areas to urban centers due to economic reasons caused a shift in urban demography. Changes in middle and upper classes reshaped the urban fabric (Kiley, 2004). The rise of automobiles caused industrial plants to move from city centers to suburbs (Wilson, 2010). Decentralization of people and jobs contributed to the sprawl in urban areas (Stas, 2007). The shift in industrial locations resulted in vacant industrial buildings, machinery, workshops, mills, factories, and warehouses. Vacant buildings were eventually neglected and became a concern of hazardous conditions in neighborhoods (Cantell, 2005; Haidar & Talib, 2015). In the absence of regulations and restrictions, buildings were reused and repurposed without considering cultural heritage (Wong, 2016). Urban sprawl also negatively affected health services, traffic, pollution, and life quality in urban centers (Stas, 2007). Some metropolises experienced increased coastal settlements with the increase in suburban population. Migration to coastal settlements with new facilities and structures increased the sprawl (Dafforn, et al., 2015). Since the 1950s, a significant urban population growth has occurred especially in the coastal cities that provide higher trade and transportation accessibility (Nicholls, 2011). Currently, 60% of the population resides in cities, and 90% of it is concentrated in coastal areas (Lim, 2021). Growing and concentrated population in the coastal areas has resulted in land scarcity and damaged infrastructure (Nicholls, 2011). Rapid changes in the built environment caused by overpopulation and urban sprawl damaged the surrounding and the environment (Cantell, 2005).

Growing suburban areas, obsolete, abandoned, and underutilized buildings in city centers have created a need to revitalize neighborhoods. Urban planners and policymakers developed urban revitalization plans in response to urban sprawl. The revitalization plans are often referred to as new urbanism, sustainable urban development, or smart growth (Stas, 2007). Smart growth policy is a strategy that was initially implemented in Los Angeles. The policy aims to create a denser city with mixed use buildings with stores, restaurants, apartments, and condos within a walking distance (Young, 2008). Smart growth policy also promotes reuse of heritage buildings to help control urban sprawl (Shipley, Utz, & Parsons, 2006). In fact, adaptive reuse in blighted areas is an ideal approach to overcome urban sprawl (Young, 2008). Growing urbanization resulting in land scarcity urged architects to design new cities that aim to fulfill the growing population needs by creating land, infrastructure, and supply in water (Serra, 2018).

As urban sprawl and migration to coastal areas increase, coastal land cannot meet the demand (Dafforn, et al., 2015). Even though the world is rich in terms of land and water, only 8% of the world is currently habitable for humans. As a result, the population concentrates in limited areas. Rapid population growth crowds already dense areas day by day and most coastal areas are already overpopulated. Developed countries do not have new lands to accommodate population shift (Bolonkin, 2010). Governments often attempt to claim land from water and build artificial land and infrastructure to control population growth. While each city has different characteristics, flexibility, dynamism and needs, distributing high population onto different artificial structures in water such as sea and ocean is considered an ideal solution (Dafforn, et al., 2015) because oceans remain underutilized and cover 71% of the world's surface (Bolonkin, 2010). In fact, governments and architects explore options to design settlements on water to tackle with population, land deficiency and scarcity of resources (Lin Z. , 2007; Trang, 2022).

2.1.2. Sustainability

Sustainability was first defined as an environmental approach to fulfill the population's need without impacting the future generations negatively (World Commission on Environment and Development, 1987). Quality of life and ecological footprint (EF) aspects were added into the scope of sustainability in 2008. The United Nations assesses the quality of life using the measure called human development index (HDI). The HDI measures the quality of life in terms of health, education, and income. The EF measures the area of biologically productive land and the amount of water needed to generate the resources consumed by the population. The EF classifies the resources in terms of food, energy, goods, and services. The land and sea used in absorbing the waste of population is also measured by the EF (Gibberd, 2015). The EF is a useful concept that aims stopping unnecessary consumption and promotes implementing a sustainable life by both governments and the society.

The construction industry tends to prefer demolition and reconstruction projects over the alternatives due to higher profits. Rapid urbanization with many demolition and reconstruction projects adversely impacts the sustainability of the built environment. The sustainability of the built environment significantly affects the society's well-being. Demolition of old and obsolete buildings damages the environment by causing air, water, and noise pollution. High energy, water, and material consumption in demolition and reconstruction projects increase green gas emissions (GGE) (Plevoets & Van Cleempoel, 2011). According to the Intergovernmental Panel on Climate Change (IPCC), the construction industry consumes 40% of the global energy and it is a significant contributor of the GGE. The environment is likely to suffer significantly if the construction industry does not replace the conventional methods with greener alternatives. Considering the amount of GGE contribution, it is the construction industry’s responsibility to adopt sustainability to minimize GGE. The construction industry must constantly explore more sustainable, viable, and feasible approaches. There are several approaches to optimize project feasibility and environmental impact. Increasing the building life cycle can reduce the negative environmental impact (Wilkinson, James, & Reed, 2009). Mechanical equipment upgrade and structural maintenance are among the practices that increases the average building life cycle and prevents building demolition (Bullen, 2007). Increased building life cycle directly contributes to sustainability by minimized construction waste (Aigwi, et al., 2019). Using existing buildings as a source of material can reduce waste (Plevoets & Van Cleempoel, 2011). Recycling existing buildings contributes to the sustainable built environment. Adaptive reuse approaches such as upgrading, refurbishment, and renovation partially recycle existing buildings. These approaches are very beneficial to the built environment in terms of sustainability, economy, and quality of life (Siddiqi & Thomas, 2006). New urban strategies aim to implement adaptive reuse approaches to achieve sustainable development. Local governments revive and revitalize cities through adaptive reuse to provide affordable housing sustainably. Considering the advancements in construction technologies and the society’s needs, adaptive reuse is much more beneficial and sustainable for the future than conventional construction methods (Bullen, 2007).

2.1.3. Global Warming and Climate Change

Greenhouse gas emission has increased globally after the industrial revolution and has contributed to global warming significantly (Caire, 2007). Global warming has attracted more attention as a matter of concern since Broeckers' scientific publication in 1975 (Broecker, 1975). A cycle of events such as climate change, extreme weather conditions, drought, water scarcity, epidemics, change in sea acidity, and rise in sea levels are among the major consequences of global warming (Caire, 2007; Biermann & Boas, 2010; Nicholls & Cazenave, 2010).

The emergence of human-induced climate change since the 1980s has also created meteorological and geophysical threats for coastal lines (Nicholls, 2011). People living in coastal cities are at risk of having to leave their homes and eventually become refugees due to the impacts of climate change (Biermann & Boas, 2010). In 1951, the UN defined refugees as people who fear returning to their homes due to their race, religion, or political views. Considering the definition was formed in a post-war atmosphere, the UN accepted refugee status only when the conditions were a direct result of war-like events. The refugee status failed to consider the results of natural hazards caused by climate change (El-Hinnawi, 1985). In 1985, the UN expanded the definition of refugee by adding environmental refugees as a new category. People who are forced to leave their homes as a result of environmental disruptions are considered to be environmental refugees as defined by the UN’s environment program (Biermann & Boas, 2010). Environmental refugees are categorized in three groups. The first group consists of people who leave their homes temporarily due to natural hazards such as cyclones, and earthquakes. The second group consists of people who leave their homes permanently due to human-made structures such as wells and artificial lakes. Lastly, people who leave their homes as a result of resource scarcity and search for better life falls within the third group of environmental refugees. Environmental refugees may settle in other regions within their countries or abroad. Displacement of refugees is likely to result in socioeconomic and cultural issues that can negatively affect the quality of life in the areas where environmental refugees migrate to, especially where robust adaptation plans do not exist (El-Hinnawi, 1985). Modifying existing abandoned structures can resolve the environmental refugee problem in the future.

Acceleration in the impact of climate change has forced governments to develop mitigation and adaptation plans to tackle climate change (Nicholls, 2011). These mitigation and adaptation plans include but are not limited to better management of transportation, healthcare, water resources, and coastal defense (Lowe, et al., 2009). Nicholls (2011) identified climate adaptation approaches for different environmental conditions (Table 2.1). Analyzing climate adaptation approaches are essential to design SLR resilient cities.

Table 2.1: Adaptation approaches for climate change (Nicholls, 2011).

Natural System Effect		Possible Interacting Factors: Climate	Possible Interacting Factors: Non-climate	Possible Adaptation Approaches
Inundation & flooding	Surge	Wave/storm climate, erosion, sediment supply	Sediment supply, flood management, erosion, land reclamation	Dikes, surge barriers, closure dams, dune construction, building codes, flood-proof buildings, land-use planning, hazard mapping, flood warnings
	Backwater Effect	Runoff	Catchment management, land use	
Wetland loss		CO_2 fertilization, sediment supply, migration space	Sediment supply, land reclamation, migration space	Nourishment, sediment management, land-use planning, managed realignment, forbid hard defense
Erosion		Sediment supply, wave/storm climate	Sediment supply	Coast defenses, seawall, land claim, nourishment, building setbacks
Saltwater Intrusion	Surface Water	Runoff	Catchment management, land use	Saltwater intrusion barrier, change water extraction
	Groundwater	Rainfall	Land use, aquifer use	Freshwater injection, change water extraction
Impeded drainage & high-water tables		Rainfall, runoff	Land use, aquifer use, catchment	Drainage systems, polders, change land use, land use

	management	planning, hazard delineation

Canada, The United Kingdom (UK), Germany, and France are among the countries that are early developers of climate change plans (OECD, 2019). In addition, some governments within the body of the United Nations (UN) have formed an agreement against climate change. The main focus of the agreement is to mitigate the impacts of climate change by reducing greenhouse gas emissions (United Nations, 2015). Current environmental policies aim to adapt to the impacts of climate change that differ from one region to another. As a result, some governments have taken specific actions based on their local needs (Nicholls, 2011). The results of climate change are well known while the long-term pace of climate change is uncertain (OECD, 2019). More urgent and global policies must be implemented to tackle climate change in a broader spectrum before its impacts become unrecoverable (Nicholls, 2011). Mitigating effects of climate change include but not limited to using floating structures. El-Shiy and Ezquiaga (2019) developed a evaluation desig matrix for mitigation solution of floating structures toward SLR. Table 2.2 explains decriptors in floating structure analysis.

Table 2.2: Descriptors used in floating structure analysis (El-Shihy & Ezquiaga, 2019).

Aspect	Very High	High	Modertae-High	Moderate	Moderate-Low	Low	Very Low
Cost	C7	C6	C5	C4	C3	C2	C1
Durability	D7	D6	D5	D4	D3	D2	D1
Construction Time	T7	T6	T5	T4	T3	T2	T1
Lifespan	L7	L6	L5	L4	L3	L2	L1
Poitive Environmental Impact	E7	E6	E5	E4	E3	E2	E1

Table 2.3 evaluates cost, durability, time, lifespan and positive environmnetal impact of each floating structure to confirm most feasible floating structure towards environmental and urban problems.

Table 2.3: Floating structure analysis (El-Shihy & Ezquiaga, 2019).

Type	Description	Cost	Durability	Construction time	Lifespan	Positive environmental	Impact
Seawalls	Built on coast decrease flooding of tides and storms	C7	D4	T5	L1	E4	2.5
Storm barriers	Built on coast prevents flood and spring tide	C7	D6	T6	L6	E4	2.5
Storm-water pumps	Removes flood water from roads	C7	D4	T6	L5	E4	2.5
Dams	Prevents flooding by retaining water	C6	D4	T6	L4	E2	5
Raising roads	Drain water and decrease flood	C7	D6	T6	L4	E4	2.5
Sand nourishment	Reduce storm damage	C6	D2	T3	L2	E2	7.5
Upgrading sewage system	Prevents flood in low elevations	C6	D4	T4	L5	E4	5
Land reclamation	Creating new land from river, sea, ocean, lake	C6	D6	T5	L6	E2	7.5
Natural infrastructure	Natural structure like barrier island, oyster, coral reefs	C5	D4	T5	L5	E6	2.5
Flood proofing buildings	Hold back flood water	C4	D6	T6	L5	E4	7.5
Showing land sinkage	Preventing additional ground water pumping	C6	D4	T6	L6	E6	7.5
Planned retreat	Relocation	C6	N/A	N/A	N/A	N/A	N/A
Elevating houses	Elevating houses over flood level	C4	D4	T4	L4	E2	0
Very large floating structures (VLFS)	Creating artificial floating islands	C4	D7	T5	L6	E7	2.5
Adaptive reuse of rigs	Reusing oil and gas rigs to create a platform for lost land	C4	D7	T5	L6	E7	3

2.1.4. Sea Level Rise (SLR)

The sea level rise (SLR) caused by global warming and climate change puts lands at risk globally. SLR creates risk of submergence and floods (Nicholls & Cazenave, 2010). The current forecasts indicate that SLR is likely to continue even if greenhouse gas emission decreases (Nicholls, 2011; Haasnoot, et al., 2020). Unfortunately, floods often significantly damage structures, urban life, people, and coastal areas in general. Considering the potential damages, life on a land with flood risk can become challenging, people living in areas with flood risk may have to evacuate their homes (Lim, 2021). Floods and submergence make coastal land particularly vulnerable. People living in highly populated coastal areas can become homeless and landless due to SLR caused by climate change (Nicholls & Cazenave, 2010). The map shown in image 2.1 represents cities at risk of sea-level rise, dark purple conveying regions with extreme risk.

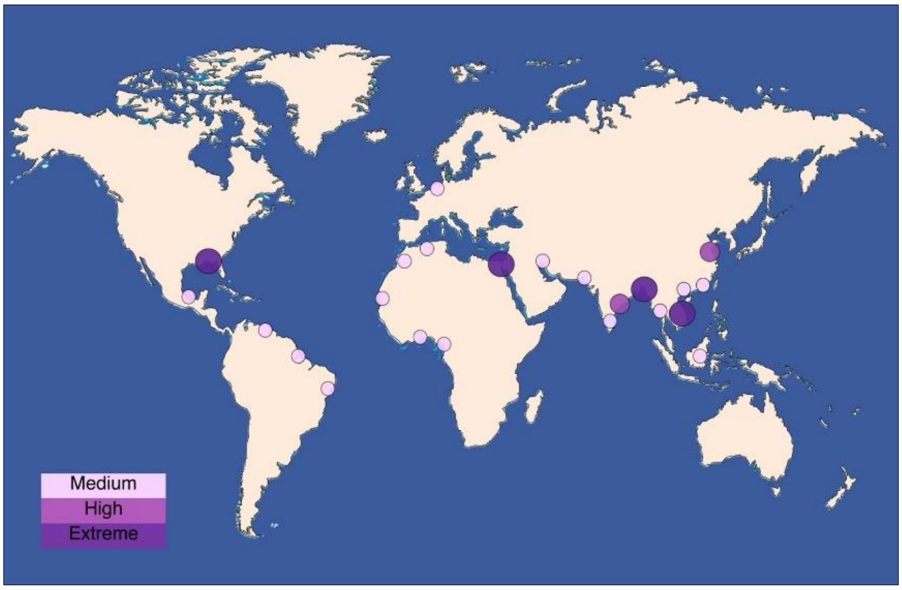


Image 2.1: Sea-level rise map (Nicholls, 2011).

Living in coastal areas may become impossible if potential hazard scenarios and necessary preventive actions are not taken in the near future (Haasnoot, et al., 2020).

The U.S. Global Change Program found that SLR has been 23 cm from the 1880s to 2019. The program also indicated that SLR is expected to be 30 cm from 2019 to

2050. NASA calculated SLR to be about 10 cm from 1993 to 2022. In fact, SLR can be somewhere between 65 cm and 110 cm by 2100 depending on the high greenhouse gas emission and ice sheet melting (Haasnoot, et al., 2020; Trang, 2022). The sea level change map published by NASA in 2021 indicates that SLR will have a greater global impact within 30 years (Taherkhani, et al., 2020) (Image 2.2).

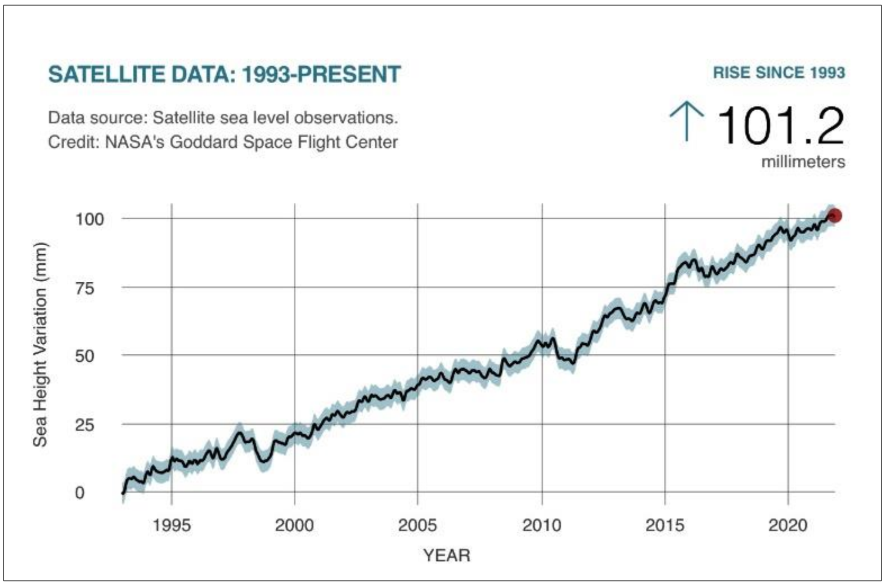


Image 2.2: SLR since 1993 (NASA, 2020).

Some SLR predictions made for 2100 based on greenhouse gas emissions vary from 25 cm to 2 meters (OECD, 2019). SLR probability and impact prediction vary greatly due to uncertainties in calculations (Lowe, et al., 2009) and nonuniform occurrences in different regions (Met Office, 2021). In fact, SLR can exceed 5 meters in the Netherlands by the end of the 21st century (Olsthoorn, van der Werff, Bouwer , & Huitema, 2008). The findings of several organizations and researchers indicate that SLR has increased exponentially and the impact of SLR in the near future can be greater than it has ever been in history. According to Halluli (2018) population at risk of sea level rise includes millions of people in 2030 (Image 2.3).

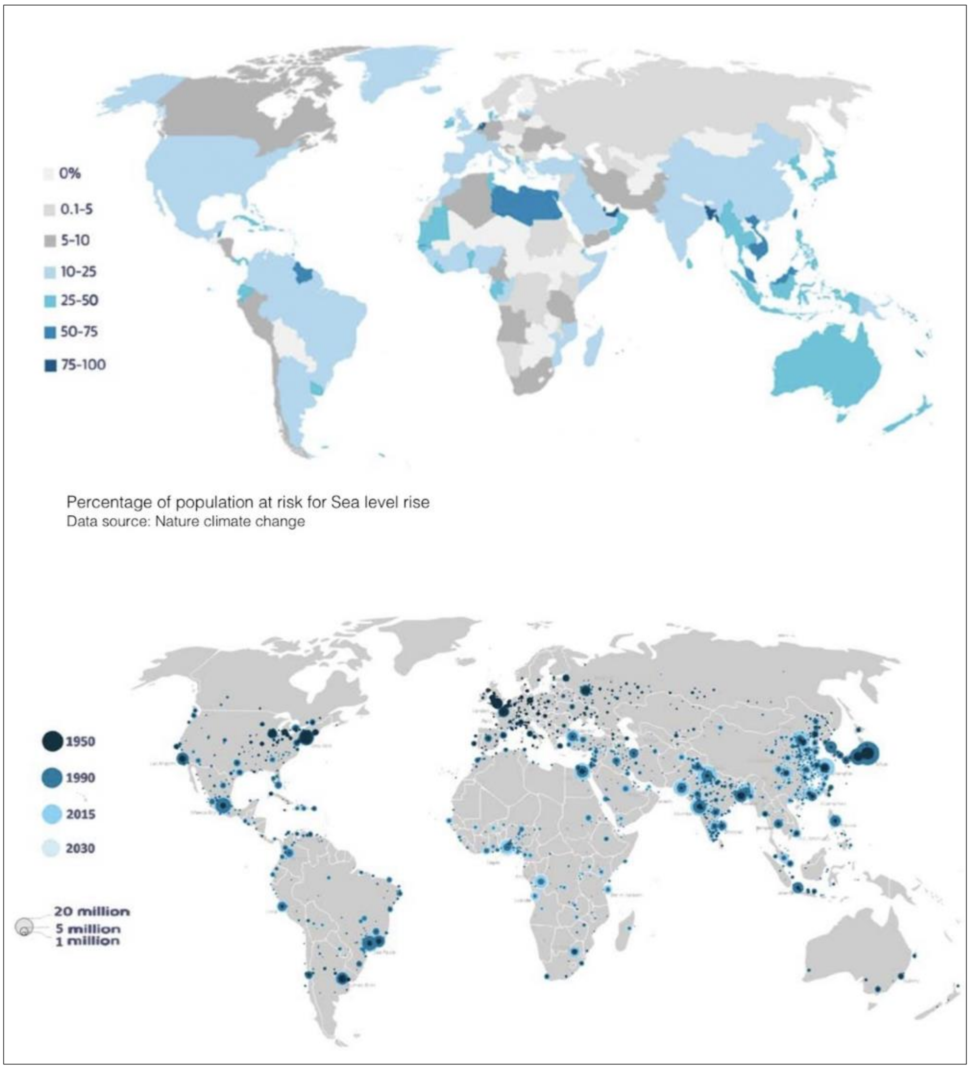


Image 2.3: Population at risk of SLR (Halluli, 2018).

Acceleration in SLR is likely to result in more frequent and stronger floods. These floods may be catastrophic as they can displace millions of people by the end of the 21st century (Hinkel, et al., 2014; Taherkhani, et al., 2020); Taherkhani et al., 2020). Mississippi, Nile, Ganges Brahmaputra, and Chao Phraya rivers are especially likely to experience more floods that may cause locals to move to new areas in the west, which may eventually cause urban sprawl. Some of the displaced people may eventually become environmental refugees (El-Hinnawi, 1985; Hinkel, et al., 2014). Global flood planning is crucial and inevitable as floods become more frequent and destructive (Nicholls, 2011).

The SLR estimates prove the risks of submerging lands in low lying countries such as Singapore, Japan, and China are unavoidable (Lim, 2021). SLR already threatens about 20 million people living in coastal areas (Nicholls, 2011). In addition, low lying coastal areas with the risk of SLR correspond to 10% of the world population. These areas induce but are not limited to New York, Tokyo, Jakarta, Ho Chi Minh City, Rio de Janeiro, Manila, Lagos, Dhaka, London, Amsterdam, and Rotterdam. These areas are only about 10 meters above the sea level, and they are primary metropolitan areas for food logistics and housing (Haasnoot, et al., 2019) (Figure 2.1).

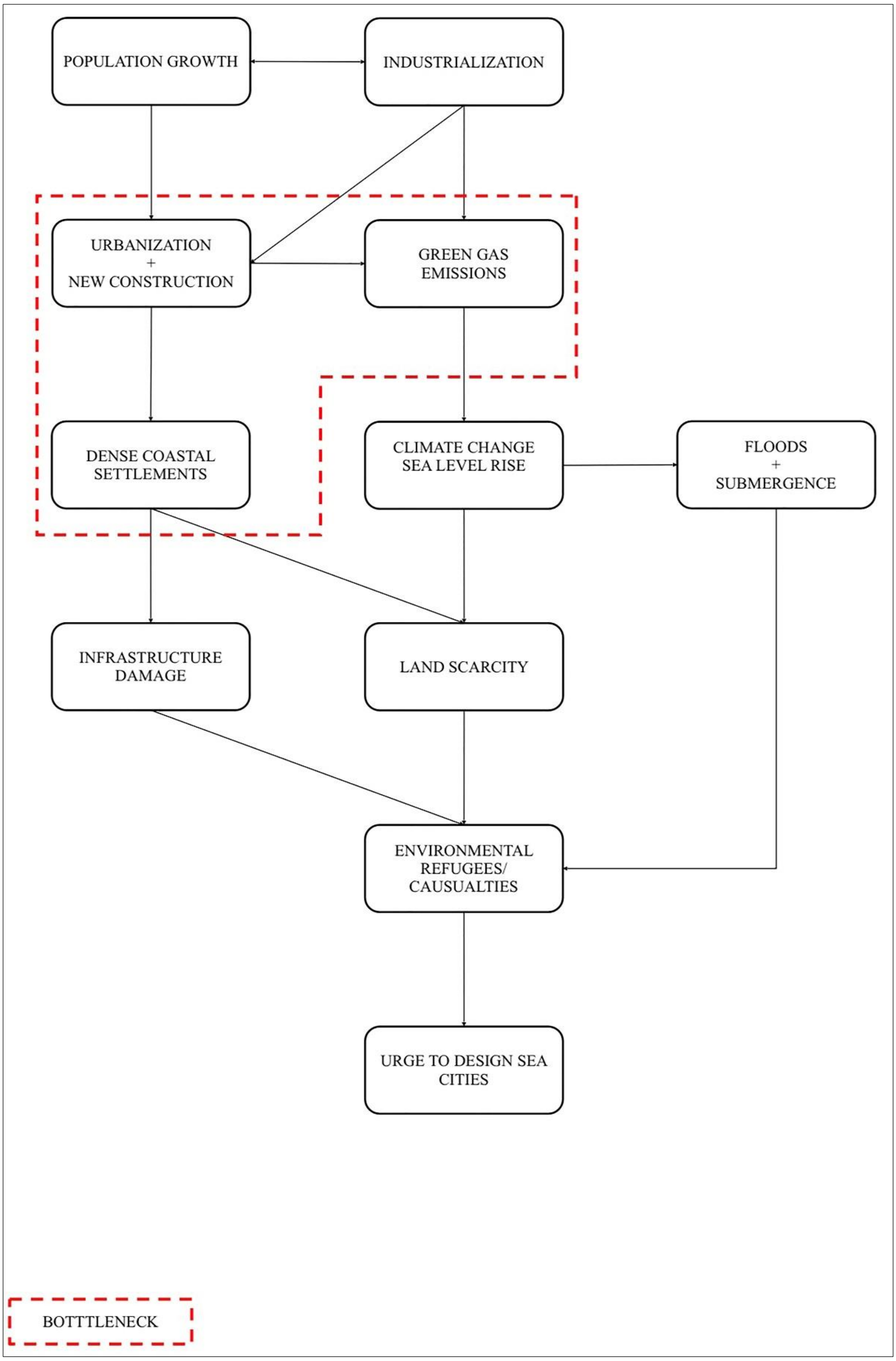


Figure 2.1: Cause and effect chain need for sea settlements drawn by author.

Increasing SLR forces governments to build protective structures. Government and environmental policies aim to build structures to mitigate floods in coastal areas. However, these protective structures are for mitigation purposes only and do not promise eliminating the risks related to SLR (El-Shihy, 2019; Haasnoot, et al., 2019). In fact, the Dutch Directorate-General for Public Works, and Water Management ('Rijkswaterstaat') indicates that it may become necessary to abandon some parts of The Netherlands due to SLR which is likely to submerge a portion of the Netherlands (Essink, 1999; Olsthoorn, van der Werff, Bouwer , & Huitema, 2008). Coastal cities with great risk of SLR must urgently incorporate new city design approaches (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010; Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013).

Flexible and floating islands are considered to be among the actions to mitigate potential flood and submergence risks due to SLR (Flikkema & Waals, 2019). While people living in areas with SLR risks consider owning floating houses and housing boats (Lin, 2008), designers explore ways to build floating cities to overcome SLR risks (Wang B. T., 2019). Cities at risk of SLR can reuse existing artificial structures for dwelling purposes (Image 2.4).

Image 2.4: Floating Houses in Ijburg (Archdaily, 2011).

2.2. FLOATING STRUCTURES

Floating structures are of several types. Offshore oil and gas platforms (OOGPs), wind turbines, energy storage facilities, and aqua farms are among floating structures (Gudmestad, Sparby, & Stead, 1993; Dafforn, et al., 2015) that are artificially built on open seas, lakes, and gulfs (Sadeghi, 2008). Floating structures are designed with durable characteristics and complex specialties to avoid being vulnerable to strong loads of storms, winds, and waves (Gudmestad, Sparby, & Stead, 1993; Sadeghi, 2008). The life span of floating structures is determined by their functions. For example, OOGPs can have a useful life from 20 to 40 years (Gudmestad, Sparby, & Stead, 1993). OOGPs designed for ease of assembly and disassembly can be appropriate for reuse after their useful lives (Velenturf, 2020) (Image 2.5).

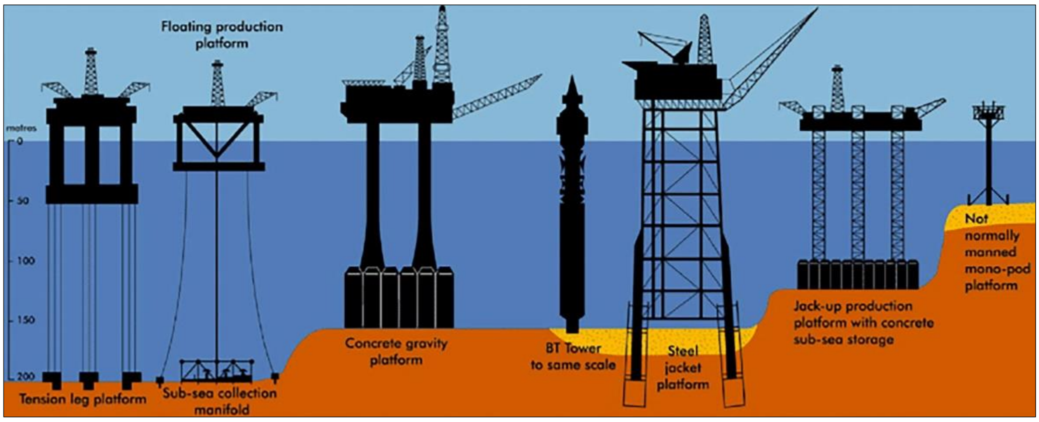


Image 2.5: Floating structures (Ayadi & Ali, 2013).

Environmental conditions, number of wetlands, rivers and land deficiency can push locals to build settlements on water even without incorporating planning and design. Cambodia, Thailand, Vietnam, Hong Kong, and Benin are among low lying countries where floating houses and villages are a part of local architecture even though they lack proper design considerations (Trang, 2022). Ijburg district of Amsterdam, on the other hand, is a neighborhood composed of floating structures that were designed specifically to combat SLR (Lin, 2008).

Floating structures have been well-recognized by several researchers as a solution to combat SLR (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010; Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013; Cubukcuoglu, Chatzikonstantinou, Tasgetiren, Sariyildiz, & Ke-Pan, 2016; Lim, 2021). Seasteading Institute evaluates suitability of designing a floating community in French Polynesia (Gelles, 2017). Coast of California is an example of ideal locations for floating structures that can have autonomous life in terms of sustainability (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010). Gulf of Fonseca is another example of coastal areas where innovation and autonomy can be synthesized by a floating structure design (Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013). Izmir, a coastal city of Turkey, is also one of the locations that attracted researchers' attention for designing floating settlements (Cubukcuoglu, Chatzikonstantinou, Tasgetiren, Sariyildiz, & Ke-Pan, 2016). In a border spectrum compared to individual researchers, the European Commission researched the design of water settlements through a research program called the Ocean of Tomorrow. The program included several projects such as TROPOS, H2OCEAN, and MERMAID (CORDIS, 2014; CORDIS, 2015; CORDIS, 2015). The main goal of the program is to solve population overgrowth on coastal areas by proposing water settlements with floating structures that are sustainable, self-dependent, eco-friendly, and multi-purpose. The program explored tropical and subtropical regions of the Mediterranean area as feasible locations (European Commission, 2015; Papandroulakis, Thomsen, Mintenbeck, Mayorga, & Brito, 2017). Similar to the European Commission, Dutch and Canadian governments investigate designing floating structures to mitigate risks related to population overgrowth and potential submergence due to SLR (Lin et al., 2008). Most of these research projects chose to design floating settlements without reusing existing offshore structures (Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013; Papandroulakis, Thomsen, Mintenbeck, Mayorga, & Brito, 2017).

2.2.1. Floating Cities

Atomic bombing of Japan emerged metabolism movement in 1945. Metabolists explored different approaches to design solutions for catastrophes, natural disasters, growing population, and land scarcity. Metabolist architects considered design and technology to be an organic component of living and growing society (Harris, 2014). Metabolist architects had a design vision of incorporating advanced technologies into establishing habitats in the sky and on the ocean. Floating cities have been studied and designed by several researchers since the early metabolism movement in the 1950s (Schalk, 2014). The Marine City (Kikutake, 1958), Plan for Tokyo (Tange, 1960), and Triton City (Fuller, 1960) floating city designs particularly aimed for solving problems related to urbanism, growing population and land scarcity from metabolism perspective. The Marine City project design is composed of modular tower capsules that establish a mega sea structure to overcome society’s problems due to land limitations and unstable policies (Lin, 2007) (Image 2.6).

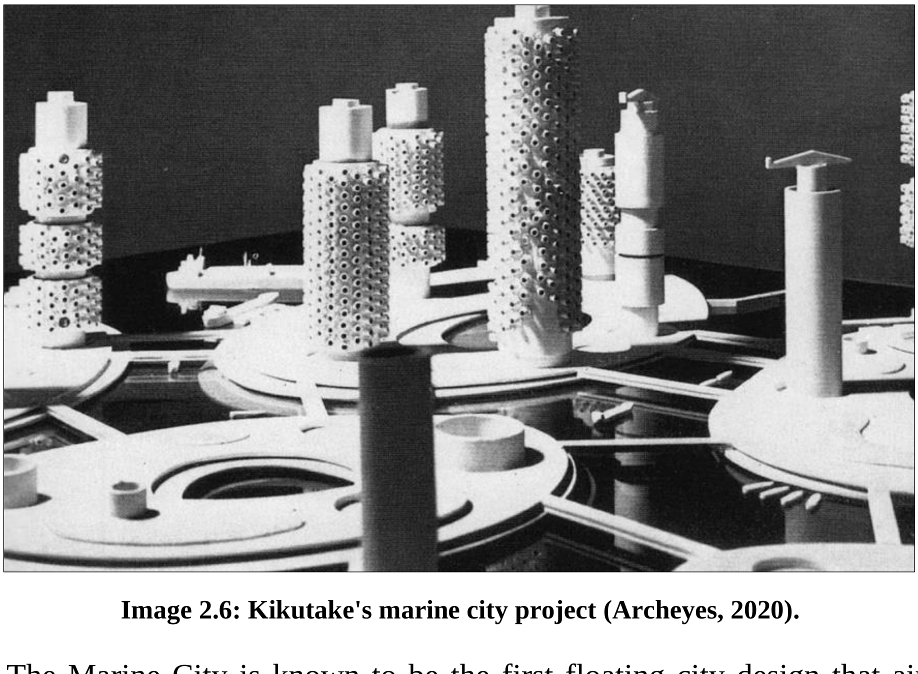


Image 2.6: Kikutake's marine city project (Archeyes, 2020).

The Marine City is known to be the first floating city design that aimed to solve urban sprawl (Archeyes, 2020). Plan for Tokyo project design covered the bay between the Tokyo and Chiba regions of Japan. It was composed of commercial facilities and offices connected to highways and it aimed to accommodate population growth with the consideration of urban regeneration (Lin, 2008; Archeyes, 2020) (Image 2.7).

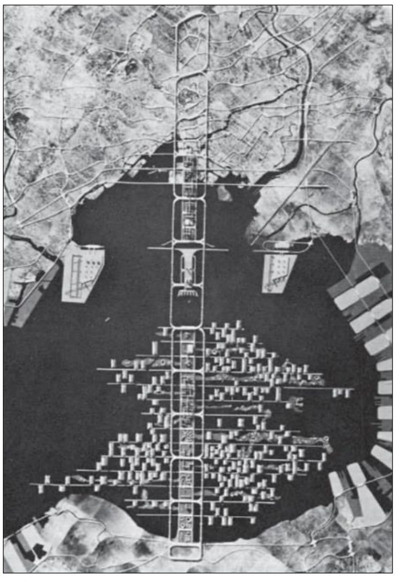


Image 2.7: Tange's plan for Tokyo (Lin, 2008).

The Triton City project had a tetrahedron-shaped design to provide optimum space and structural strength. The design aimed to maximize self-sufficiency and durability against tsunamis. The Triton City design proposed bridges connecting the artificial island to the mainland and it also contained underwater sea farms (Archeyes, 2020). Floating cities designed in the early metabolism movement often could not proceed into the construction phase due to administrative and bureaucratic problems (Image 2.8).

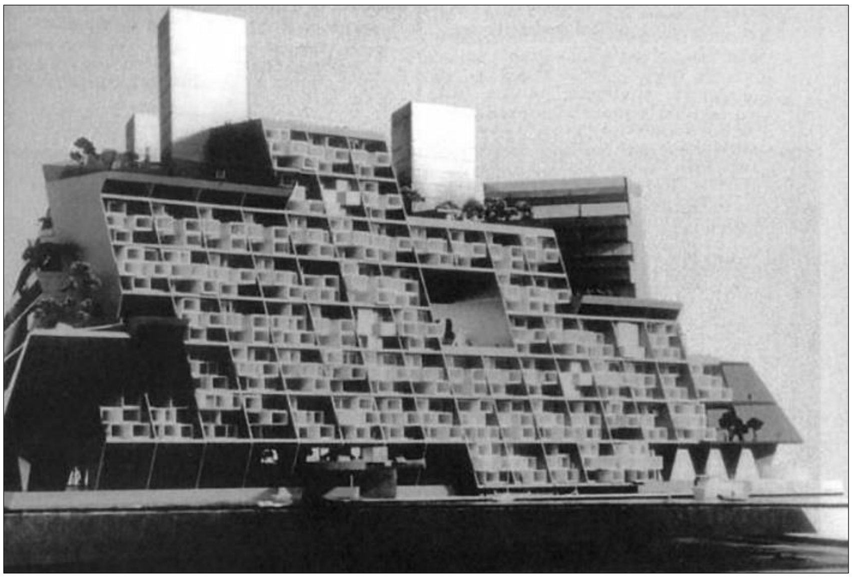


Image 2.8: Buckminster Fuller's Triton City project (Wang B. T., 2019).

Research interest in floating city designs continued even after the early years of the metabolism movement. The number of floating city designs has increased with raising awareness and concerns with regards to SLR. Floating city designs have gained more popularity especially after the early 2000s. Floating City Ijmeer (Graaf, Fremouw, Van Bueren, Czapiewska, & Kuijper, 2006), Green Float Tallinn (Blue21; Shimizu Corporation, 2020), and Lilypad (Callebaut, 2014) were designed to accommodate people affected by SLR. Floating City Ijmeer was designed for the Rhine Delta, The Netherlands. The main goal of the project was to remediate the regional housing, economic and ecological vulnerabilities to increasing population, climate change and high urbanization by a self-sustaining floating city (Graaf, Fremouw, Van Bueren, Czapiewska, & Kuijper, 2006) (Image 2.9).

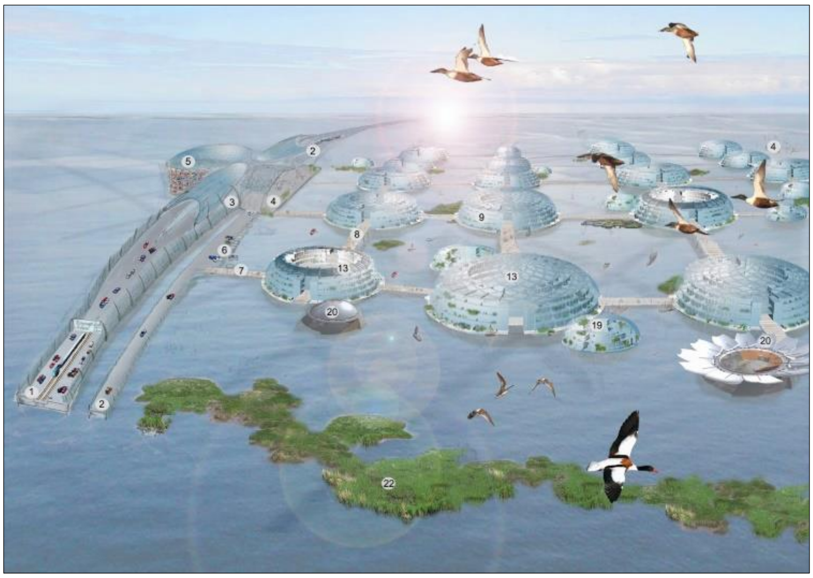


Image 2.9: Ijmeer (DeltaSync, 2013).

Green Float Tallinn was designed in a collaboration between Japanese and Dutch corporations. The project proposes an environmentally-friendly, and self-sufficient floating city that is adaptable to SLR and expected to connect Estonia and Finland through a tunnel (Blue21; Shimizu Corporation, 2020) (Image 2.10).

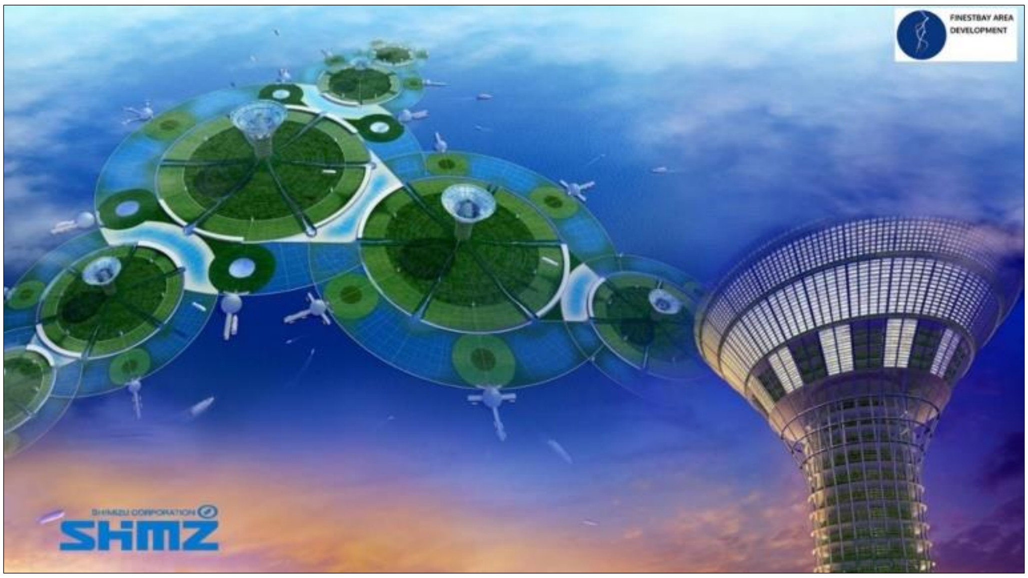


Image 2.10: Green Float Tallinn (Blue21; Shimizu Corporation, 2020).

The Lilypad project proposed a conceptual design of a floating city that is modular and self-sufficient. The project aimed to accommodate environmental refugees due to SLR. Lilypad, also known as Ecopolis, incorporating sustainability, renewable energy and air quality principles is expected to accommodate up to 50.000 environmental refugees in 2100 (Callebaut, 2014) (Image 2.11).

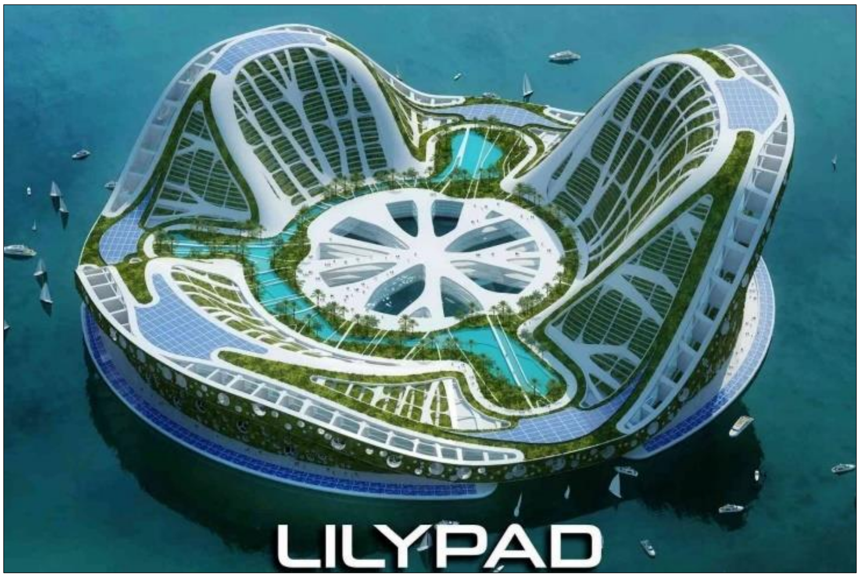


Image 2.11: Lilypad (Callebaut, 2014).

Next Tokyo project proposed a floating megacity design that is resilient to earthquakes, typhoons, and SLR. The design was composed of hexagonal infrastructure rings and a mile-high tower to be constructed in the Tokyo Bay. The top priorities and considerations of the design were stable food supply, renewable energy resources, improved environmental conditions, safety, and a habitat adaptable to climate change. The project was estimated to accommodate a half million people who live in coastal regions and are at risk of becoming environmental refugees by 2045 (Malott, et al., 2015) (Image 2.12).

Image 2.12: Next Tokyo (Malott, et al., 2015).

The Seasteading Implementation Plan proposed a floating city design to mitigate SLR risks (Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013). The design was composed of self-sufficient modular units in the Gulf of Fonseca between El Salvador, Honduras, and Nicaragua (Lim, 2021). The design of Seasteading prioritized resident requirements and desires, location, population growth and expansion strategy, and feasibility (Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013) (Image 2.13).

Image 2.13: Seasteading Implementation Plan (DeltaSync, 2013).

Governmental organizations have tested ocean colonization by utilizing oceans to establish artificial habitats (Bolonkin, 2010). The United Nations (UN) currently plans on designing a self-sufficient floating city in Busan, South Korea. The floating city is named Oceanix Busan and it is expected to provide solutions to societies displaced due to climate change, population growth and land scarcity. The project is expected to have a capacity to accommodate up to 10.000 people who may eventually become environmental refugees if stayed in their current residences (Wang B. T., 2019; UN Habitat, 2022) (Image 2.14).

Image 2.14: BIG's Oceanix project (Wang B. T., 2019).

Functions of floating cities are key factors determining the design (Lim, 2021). Structure, location, accommodation capacity, type (i.e., fixed or mobile), self-sufficiency in terms of energy, food and water supplies are among the key factors that determine the design (DeltaSync, 2013). A fixed floating city is designed to be constructed in a safe area where it can remain for a long time with high durability to waves. The mainland and the fixed floating city are connected through infrastructures such as bridges and tunnels. A mobile floating city is designed to move elsewhere in case of severe climatic conditions such as storms (Lim, 2021). In case a mobile floating city needs to move faster, it can be towed by semi-submersible ships (Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013; DeltaSync, 2013). Mobile cities must be designed for self-sufficiency to support sustainable detachment from the mainland (Lim, 2021). Design for self-sufficiency is encouraged for both fixed and mobile floating cities (DeltaSync, 2013). Self-sufficient floating cities are required to provide resource and energy supply, and access to clean food and water. Food can be produced in aquaculture and hydroponics in a closed ecosystem. Energy can be generated in forms of biofuel by recycling waste. Energy generation in open seas is limitless as it spans from wind energy, wave energy to thermal energy (Lim, 2021). Floating cities are expected to have a symbiotic relationship with their mainlands. Floating cities can supply food to the mainland. The mainland can provide energy to the floating city in case it is not self-sufficient (Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013; DeltaSync, 2013).

Self-sufficient floating city concept has inspired unusual governing ideas such as autonomy. The autonomous floating community concept is referred to as seaborne leisure colonies (Halluli, 2018). The Seasteading Institute supported autonomous self-sufficient floating cities with Seasteading and ClubStead floating city designs. The designs proposed permanent and habitable sea structures are independent and are within the jurisdiction of any other country (DeltaSync, 2013). Although ship-like structures are often not recommended in floating city concepts, Freedom Ship design proposed a floating community including a 25-story structure where people can live, work, have vacations, and retire while constantly moving around the world (Wang B. T., 2019) (Image 2.15).

Image 2.15: Freedom Ship (Freedom Cruise Line International, 2021).

2.2.2. Sustainability of Floating Cities

It is challenging to meet the needs of a floating city. There are several elements to consider when addressing the needs. Location of the floating city and its connection to the land defines the necessary supply chain process. The floating city's food might occasionally be provided from the land. Floating cities must be designed and engineered for self-sufficiency. Resources like food, water, energy, and waste must function as inputs and outputs of a closed loop system. The framework called the Blue Revolution system relies on these self-sufficiency principles (Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013; DeltaSync, 2013). The system proposes reusing the land waste to produce food and biofuel for floating cities. The nutrition waste obtained from the land is used to fertilize algae that is used in biofuel production. Aquaponics support fresh vegetable production while aquaculture helps fish production. Rainwater storage is the main method for supplying clean water (Lim, 2021). The greywater output of the land is used for washing machines and toilets in floating cities. The wastewater generated in floating cities can be used back for algae as a nutrient resource. These cyclic operations establish a self-sufficient closed-loop system for floating cities (DeltaSync, 2013).

2.3. A PROPOSAL FOR ADAPTIVE REUSE OF FLOATING STRUCTURES

Adaptive reuse is often associated with reusing structures on the land. However, it can be implemented in other environments if the conditions are feasible. For example, floating structures such as offshore and artificial structures in water can implement adaptive reuse to overcome future problems. Majority of floating structures are oil rigs, gas rigs, ships, and coastal defenses. Oil and gas rigs are relocated offshore after decommissioning for recycling and demolition, and other floating vessels are demolished after their product life-cycle ends. Although adaptive reuse land implementation has been relatively well established, its implementation in floating structures has not been common until recently. Owners in the oil and gas industry usually move floating structures ashore and dismantle them for recycling. Reuse and repurpose of oil and gas rigs is a relatively new concept. Reuse and repurpose concepts in the oil and gas industry are used almost synonymously with the adaptive reuse concept (Velenturf, 2020). For example, repurpose of floating structures aims functional changes similar to adaptive reuse implementations (Lakhal, Khan, & Islam, 2008). Both repurpose of floating structures and adaptive reuse of buildings evaluates the existing components and transforms them into a better state. However, repurpose of floating structures does not usually examine structures from an architectural perspective as comprehensive as adaptive reuse does (Velenturf, 2020). Recently, several countries repurposed and redesigned their oil and gas rigs after decommissioning. Even though, adaptive reuse considerations in floating structures are relatively new, the oil and gas industry are expected to incorporate more architectural transformation when repurposing rigs (Velenturf, 2020). The existing Adaptive Reuse Potentiality methods used in the construction industry are likely to apply the oil and gas industry. These methods should be used in determining the feasibility and practicality of implementing adaptive reuse in oil and gas rigs prior to the decommissioning phase.

2.3.1. Offshore Oil and Gas Platforms (OOGPs)

The usage of prominent fossil fuels (i.e., oil and gas) goes back to the Iron age in Europe and 347 CE in China. Mining and surface sweeping operations were the only way of extracting oil and gas until the 1850s. Unsophisticated methods of extraction limited the use of oil and gas (Craig, Gerali, MacAulay, & Sorkhabi, 2018). After many attempts of drilling wells for resource extraction, the first commercially successful oil well drilling was initiated in 1859 (Khalifeh & Saasen, 2020). It brought rapid technological advancements in oil refinery and production sectors and increased the oil usage in the 1860s. While shale and coal were used, along with oil, to generate energy for the industry, these resources could not fulfill the increased demand in the 1900s. Oil extraction and usage began to shape world dynamics in terms of economy and military power. Oil extraction became even more crucial as oil was an important military supply in the first world war. The influence of oil extraction and usage on the war, pushed countries to accelerate their oil explorations even after the war. Great Britain drilled about eleven oil wells from 1918 to 1922. The inefficiency in cable drilling tools and insufficiency of oil extracted from land resulted in offshore oil and gas explorations in the 1960s (Craig, Gerali, MacAulay, & Sorkhabi, 2018). Increased fossil fuel demand in the 20th century accelerated governments' oil explorations in different locations. As soon as some gas was explored in water, fossil fuel research was expanded to offshore locations in open seas (Sadeghi, 2008). Currently, Most OOGPs are located in the North Sea, the Middle East and the Gulf of Mexico that have very rich oil and gas reservoirs. The estimated number of OOGPs in the North Sea, the Middle East, and the Gulf of Mexico are 1000, 700, and 4000, respectively (Lakhal, Khan, & Islam, 2008).

Very large floating structures (i.e., OOGPs) are designed for high functionality and durability so they can bear aggressive environmental conditions such as hurricanes and storms. Top design priorities of OOGPs are flexibility, mobility, portability, and ability to operate in supreme water depth. In general OOGPs work as an artificial island and they can be completely floating or have supports from the bottom of the sea (Khalifeh & Saasen, 2020). OOGPs can also be categorized as mobile or fixed structures. Water depth and other geotechnical conditions determine the OOGP type that is most feasible to a specific location. Mobile OOGP is composed of semi-submersible platforms. Fixed OOGPs are usually designed for shallow waters where the structure can be attached to the seafloor by steel supports. Template (jacket) platform, tower platform, tension leg platform, and gravity platform are different types of fixed OOGPs. Template (jacket) OOGPs consist of tubular steel and are very commonly used in gulfs such as the Persian Gulf and the Gulf of Mexico. Tower OOGP is the most flexible fixed OOGP type. Tension leg OOGP design allows operations that can be as deep as 7,000 feet (roughly 2135 meters). Gravity OOGPs use their mass to sustain their locations without being attached to the seafloor (Sadeghi, 2008).

OOGP design is not the first phase of exploration and operations. OOGPs typically go through five phases that are complex and multi-disciplinary. These phases are development, production, closure, decommissioning, and post-closure. Oil exploration starts with seismic surveys that send seismic waves to the seafloor to identify potential oil and gas reservoirs. After a reservoir is identified as feasible in terms of ease and cost of operations, drilling phase starts. Depending on the depth, the drilling phase may take up to four years and it eventually initiates the production phase. Feasible production capacity determined by dept, reservoir, and the OOGP design, the life cycle of the operation can be up to forty years (Lakhal, Khan, & Islam, 2008). At the end of the production phase, the OOGP is shut down for closure and decommissioning phases that needs to be conducted carefully to avoid damaging the marine ecosystem (Lim, 2021). Damaged rocks and exterminated marine colonies once living on OOGP are common results of these phases. Decommissioning phase of OOGPs is often complex due to the size, weight, and complexity of the structure, and it consists of government approvals, removal, disposal, and reuse of structures. OOGPs can be completely removed, partially removed, toppled, or left in place based on the decision made in the decommissioning phase (Lakhal, Khan, & Islam, 2008). Decommissioning procedures differ from one region to another. Environmental impacts are assessed based on site-specific characteristics and protocols. These procedures and protocols promote safety as the top priority. The decision made during decommissioning determines the timeline of the phase. Removal of OOGPs requires comprehensive inspection of components from seafloor to the sea surface (Bureau of Safety and Environmental Enforcement, 2020). Complete removal of OOGPs often endangers marine ecosystems (Lim, 2021). Removed materials can be disposed of or used as an artificial reef site (Bureau of Safety and Environmental Enforcement, 2020) (Figure 2.2).

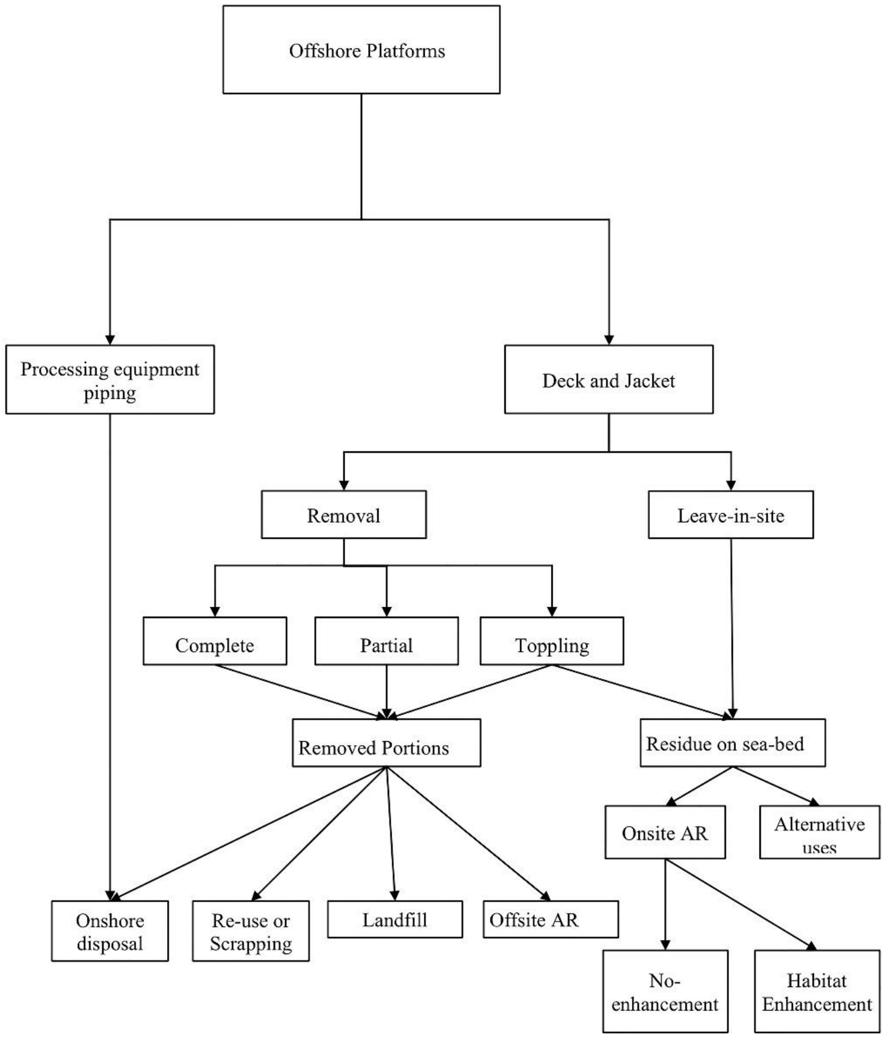


Figure 2.2: Decommissioning of oil platforms (Lakhal, Khan, & Islam, 2008).

It is estimated that over a hundred OOGPs are decommissioned annually. The Gulf of Mexico alone has approximately 4000 OOGPs that are going to be decommissioned within this century. Governments have been exploring practical solutions to reuse and repurpose decommissioned OOGPs (Lakhal, Khan, & Islam, 2008). Considering economic and environmental impacts of OOGP decommissioning and SLR risks in coastal areas due to climate change, potential reuse of OOGPs should be evaluated at early phases.

2.3.2. Adaptive Reuse of OOGPs

Durability attributes of OOGP designs are advantageous for reusing purposes. Hotels, tourism facilities, and artificial reefs are among the most common potential reuse of OOGPs (Schulze, Erdner, Grimes, Holstein, & Miglietta, 2020). OOGPs can also be reused as liquid natural gas (LNG) terminals, aquamarine facilities (Lakhal, Khan, & Islam, 2008; Cheng, Tan, Song, Liu, & Wang, 2017), prisons, carbon sequestration centers, renewable energy generators, and sea cities (Lakhal, Khan, & Islam, 2008). Reusing OOGPs minimizes the cost of disassembly and risks of endangering the marine ecosystem. In general, the industry is divided into two points of view, one of which supports reusing OOGPs as artificial reefs to restore marine ecosystems, and the other leans towards reusing OOGPs as multi-purpose structures. Artificial reefs aim to mimic the features of natural reefs to attract unique fish and sea animals and provide a habitat for them. The cost of reusing OOGPs as artificial reefs to protect vulnerable marine fauna from predators is significantly less than the cost of disassembly (Schulze, Erdner, Grimes, Holstein, & Miglietta, 2020). On the other hand, the cost of reusing OOGPs as multi-purpose structures varies depending on the design intent and desired function. In fact, some countries such as the US and Saudi Arabia evaluate options of reusing OOGPs for both ecological and tourism purposes (Barandy & Designboom, 2021).

An OOGP called Baram-8 was constructed in 1968 in Malaysia. Unfortunately, it collapsed in 1975, and then it was reused into an artificial reef in 2004 in an attempt to restore the marine ecosystem. Researchers detected large groups of different fishes and marine species on and around the structure in 2005 (Awang, 2013). Northern Gulf of Mexico houses over 4000 artificial reefs composed of OOGP legs that remained in place after decommissioning (Image 2.16).

Image 2.16: Baram-8 (Awang, 2013).

Most of the artificial reefs in the area were established as a part of a reuse program called Rigs to Reef. The program has aimed to restore negative environmental impacts of OOGPs and has been successfully applied in the Gulf of Mexico since 1988. Some researchers indicate that it is worth investigating how artificial reefs impact invasive species and the commercial fishery (Schulze, Erdner, Grimes, Holstein, & Miglietta, 2020). Dol (2018) designed a self-sustainable mariculture farm that proposed reusing an OOGP at the post-production phase. The design aimed to help restore the damages given to the marine ecosystem and minimize decommissioning costs (Dol, 2018). Markham's Triangle is an offshore marine conservation zone (MCZ) located in the Southern North Sea near the eastern coastline of England. Markham's Triangle is close to several gas platforms, including the British Gas Company Centrica's platform. Centrica's decommissioned gas platform sustains marine life by attracting seals to eat sand eels. Several decommissioned OOGPs nearby marine conservation zones supply and help sustain marine life (Pearce, 2018; Lim, 2021).

Malaysia reused an abandoned OOGP near Mabul Island as diving rig and resort. The resort owned and operated by the private sector contains a 25-room hotel and diving school offering a unique experience (Lim, 2021) (Image 2.17).

Image 2.17: Seaventures dive rig and resort (Seaventuresdive, 2018).

ClubStead floating hotel and resort project incorporated a design that reused OOGP. The project was proposed to be used in California, USA (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010) (Image 2.18).

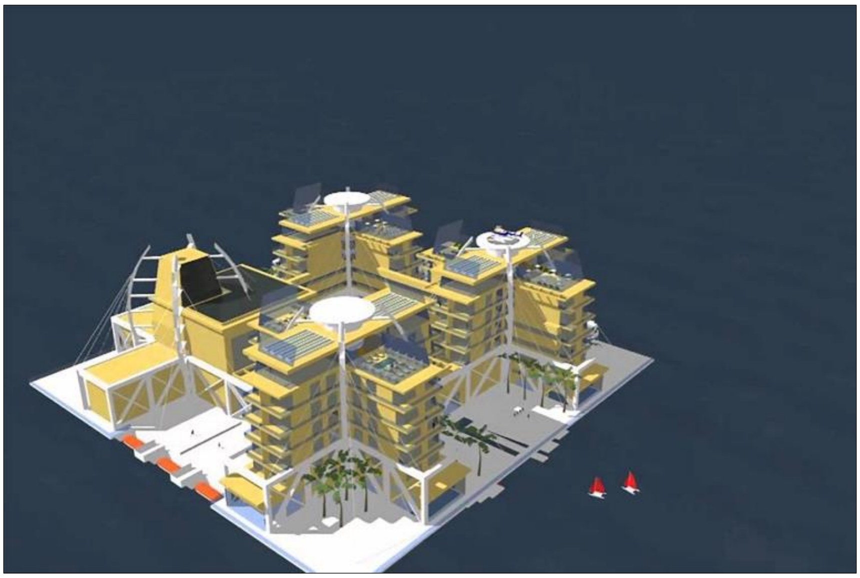


Image 2.18: Clubstead (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010).

Saudi Arabia announced plans to reuse a decommissioned OOGP as a multi-purpose structure in Arabian Gulf. The OOGP is about 40 km from the shore. The conceptual design proposes a 150.000 square-meter sustainable tourism facility that contains theme parks, hotels and restaurants. The construction of the facility is planned to be complete by 2025 (Barandy & Designboom, 2021) (Image 2.19).

Image 2.19: The Rig (Barandy & Designboom, 2021).

Lim (2021) designed floating settlements that proposed reusing semi-submersible OOGPs as multi-purpose structures containing fish farms, restaurants, crematories, and housing. Top goals and priorities of the design were decreased ecological footprint in food and energy production, user expectations, feasibility, safety, and habitat for climate change (Lim, 2021) (Image 2.20).

Image 2.20: Superbarge Settlements (Lim, 2021).

Several studies proposed reusing OOGPs as artificial reefs and multi-purpose structures. However, reusing OOGPs as a city base remains relatively unexplored despite their adaptable and flexible design (Lim, 2021). After the oil and gas production ends and the OOGP is decommissioned, the structure can adapt to city conditions. The structure can be relocated closer to the coastline when it is feasible (Gudmestad, Sparby, & Stead, 1993). Cities and regions that are at risk of SLR and close to OOGPs can reuse these structures as city bases (Schulze, Erdner, Grimes, Holstein, & Miglietta, 2020). Each OOGP has its own limitations and distinguishing characteristics that may have positive or negative impact on its suitability to be reused as a floating city base. Mobile OOGPs can be challenging to reuse as floating city bases, but they can still be reused as a component of a sea settlement (Lim, 2021). Fixed OOGPs, on the other hand, are more advantageous to reuse as city bases. Especially semi-submersible fixed OOGPs' flexibility, structural integrity, and durability in severe weather conditions make them more suitable than other types of OOGP with regards to reusing them as floating city bases (Chandrasekaran, 2017). In general, semi-submersible OOGPs are engineered to maximize the tensile strength and durability to tidal motions occurring due to storms and wave motions, so they can adapt and remain unaffected by severe weather conditions (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010).

Cruise ships have also been evaluated for reusing as a floating city settlement to mitigate the negative impacts of SLR in coastal areas. In theory, they can be considered as an alternative to OOGPs due to their flexibility and potential for space reconfiguration. However, in practice, they are fragile in nature and insatiable with regards to severe weather conditions (Lim, 2021; DeltaSync, 2013). They are not as durable as OOGPs in reacting to sea motions (Lim, 2021). Contrary to OOGPs, cruise ships' horizontal and vertical motions are determined by surrounding environmental conditions (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010).

Large floating structures reused as artificial islands can be attached to existing cities through infrastructure and allow existing cities to expand strategically in terms of sustainability (Dafforn, et al., 2015). However, a reused OOGP as a city base is not the only requirement of designing floating settlements. There are several other requirements such as safety, structural integrity of dwelling units, functionality of settlement, supply-chain adequacy in terms of food and energy, and potential for further strategic growth (DeltaSync, 2013; Czapiewska, Roeffen, Dal Bo Zanon, & de Graaf, 2013).

2.3.2.1. Sustainability of OOGPs

Oil and gas rigs are decommissioned after the production is over. Some decommissioned rigs are abandoned, while few of them are removed for recycling (Velenturf, 2020). Complete removal is often unfeasible due to limited recycling opportunities. A limited number of materials, such as metals, cabling, and plastics, can be recycled and the rest of the structure is moved to landfills after the decommissioning phase. Decommissioning of rigs with limited recycling creates environmental risks especially on the marine environment (Lim, 2021). Some big petroleum corporations try to promote reuse and recycle methods for decommissioned rigs. Durability and structural strength of oil and gas rigs make them great candidates for material reuse and repurposing (Velenturf, 2020). Reuse and repurpose of decommissioned oil and gas platforms contribute to sustainability by extending the service life of the structure. Transforming decommissioned oil and gas platforms into sustainable habitats is possible by implementing adaptive reuse approaches. The Rigs-to-Reefs program applied in several countries aims to implement adaptive reuse in decommissioned oil and gas platforms to create a sustainable marine ecosystem and reverse environmental damage. The program cleans the decommissioned platform by removing toxic substances and uses the platform's components to form reefs and coral-like structures in water. The artificial reef created by adaptive reuse implementation provides a shelter to marine organisms and help grow symbiotic fauna and flora (Schulze, Erdner, Grimes, Holstein, & Miglietta, 2020).

CHAPTER THREE

3. COMPARISON OF NOVEL FLOATING CITIES AND FLOATING CITIES WITH ADAPTIVE REUSE

Floating cities can be an important element for designing against climate change and SLR. It is crucial to design a feasible, functional, comfortable, sustainable, and self-dependent floating city. Therefore, the case study examines floating city and structure designs from Metabolist architecture to contemporary floating city and structure designs to find most suitable option (Harris, 2014).

3.1. EXAMINATION METHODOLOGY AND CLASSIFICATION

The purpose of the examination method is to determine strengths and weakness of floating designs and decide the most suitable design for SLR. The examination method focuses on economic, sustainable and comfort standards of floating cities and structures. Each factor consists of several elements for analyzing floating structures and cities. Economical factor measure structures feasibility, resource optimization, support on regional economy and multi-functionality of the structure. Self-sufficiency, environmental effect, and adaptive reuse of the structure indicates sustainability score. Comfort standards based on social variety, transportation, safety, and connection with land. Each of the information about floating city and structures collected according to journal articles, reports, and architectural websites. Each of the designs evaluated and scored according to mentioned criteria of economical, sustainable and comfort standards (Table 3.1).

Table 3.1: Evaluation parameters.

Factor Categories	Parameters	Maximum Score
Economic Factor 1	Feasibility	5
Economic Factor 2	Multi-function	5
Economic Factor 3	Adaptive reuse or recycle	5
Sustainability Factor 1	Self-sufficiency	5
Sustainability Factor 2	Effect on surrounding environment	5
Sustainability Factor 3	Adaptive reuse of the existing structure	5

Comfort Factor 1	Social variety	5
Comfort Factor 2	Transportation	5
Comfort Factor 3	Safety	5

Each factor divided into different categories to evaluate floating cities and structures throughly (Table 3.2, Table 3.3, Table 3.4).

Table 3.2: Economic parameters.

Economic Parameter Subcategories			
Feasibility	Supporting regional economy	Optimizing resources	Multi-functionality
Low cost	Investment on tourism	Recycle/reuse	Educational
Investment toward extreme conditions	Investment on infrastructure	Upcycle	Retail
Low impact materials	Protecting environment	Limited material usage	Commercial
Fast construction process	Adaptability to climate change	Modular design	Residential
Long building life span	Creating jobs	Waste recycle	Institutional

Table 3.3: Sustainability parameters.

Sustainability Parameter Subcategories			
Renewable energy	Production systems	Environmental effect	Adaptive reuse
Wave energy	Water	Low carbon footprint	Material
Wind power	Food	Restoring marine ecosystem	Existing building
Solar energy	Fish	No waste policy	Structure
Bioenergy	Algae	Decreasing urban population	Field
Geothermal energy	Waste	Solving urban sprawl	Heritage building

Table 3.4: Comfort parameters.

Comfort Parameter Subcategories			
Safety	Transportation	Social variety	Land connection
Ventilation system	Ferry	Restaurant	Bridge
Resistance to SLR	Helicopter	Cafe	Elevator
Resistance to floods	Car	Parks	Pathway

Resistance to seismic movement	Bike	Shopping center	Road
Resistance to tsunami	Subway	Lounge	Floating platforms

The structures will be analyzed of total score of 60, affinity towards total score indicates suitability of the structure according to score board. Analyzing factors are inspired by LEED score card and transformed according to case study subjects in the results chapter. Different characteristics of floating cities and structures and their feautures explained throughly from table 3.5 to table 3.17. Projects are ordered chronologically, and advancement levels increase as the list goes on.

3.1.1. Marine City Concept Project

Marine City was the first example of an artificial floating city (Image 3.1). Kikutake designed Marine City to solve urban problems, seasonal floods, and unstable policies. Kikutake believed the land was the foundation of the current urban problems. Therefore, he designed an urban archetype in the sea to replace land. The design consisted of horizontal and vertical prefabricated cylinder capsules (Pernice, 2022). Prefabricated cylinder capsules can be removed and refurbished when they wear out (Harris, 2014). Kikutake integrated existing technology and his functional perspective into the design (Pernice, 2022). Marine City was the first floating urban design addressing urban, environmental, and political problems. However, it did not address fulfilling people's needs, spatial needs, social needs, and accessibility to the outside world (Table 3.5).

Table 3.5: Marine City Details.

Factors	Details
Design Date	1958
Architect	Kiyonori Kikutake
Function	Floating industrial circular city
Purpose	Solving urban sprawl and vulnerability to earthquakes and political instability
Technology	Sustainable, clean, safe, earthquake prone floating city with 1.000.000 square meters area
Budget	-
Population	50.000 residents
Location	Tokyo, Japan

Structure Design	Six cylindrical concrete towers for dwelling and one tower for control located on floating platforms
Social Variety	Industrial facilities, residential units
Reuse	

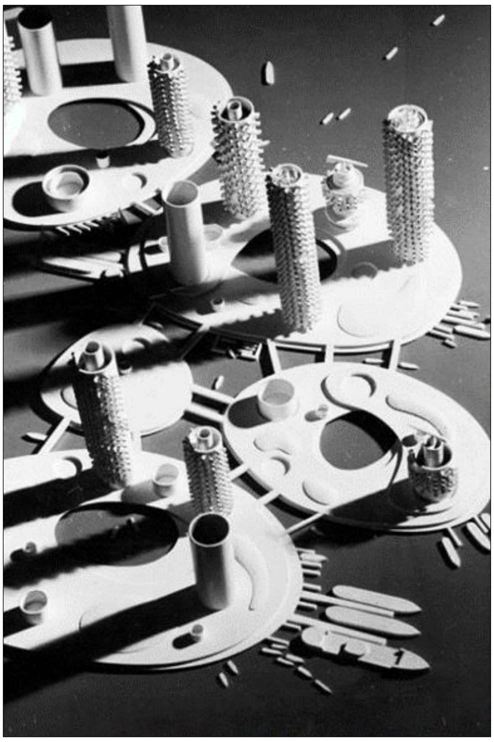


Image 3.1: Marine City (Archeyes, 2020).

3.1.2. Triton City Project

Triton City was a floating city designed for the deep waters of existing ports (Image 3.2). The city design incorporated technologies of supertankers and oil derricks. The city is divided into neighborhoods. Each neighborhood consisted of a single building for waste and services. Triton City distributed community services according to population density. Triton City was a comprehensive design that fulfills social, recreational, entertainment, and educational needs with access to the mainland. Buckminster Fuller designed an economical floating city resistant to tsunamis that addressed the various needs of people. Unlike other floating cities, Triton City was not designed to solve existing problems. Instead, it was designed to explore outside living in the sea (Kaji-O'Grady & Raisbeck, 2005) (Table 3.6).

Table 3.6: Triton City Details.

Factors	Details
Design Date	1958
Architect	Richard Buckminster Fuller
Function	Floating city
Purpose	Providing private outside living resistant to tsunamis and flooding
Technology	Floating city that consists of tetrahedral modules
Budget	$35.850.000 per neighborhood
Population	100.000 residents
Location	Chesapeake Shore, Triton City
Structure Design	Anchored offshore floating city that connected to mainland with bridges
Social Variety	Retail, Residences, Shopping center, School, Church, Commercial, Hospital
Reuse	

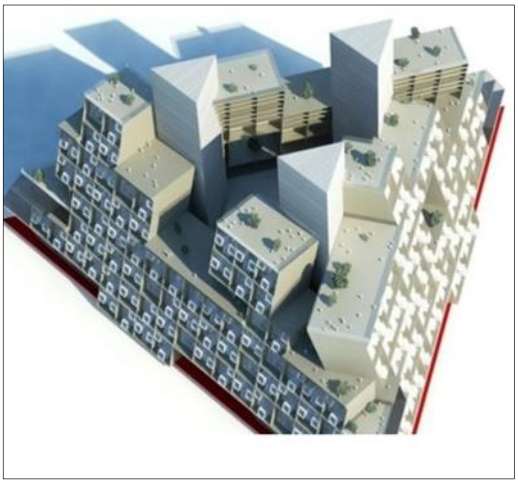


Image 3.2: Triton City (Wang B. T., 2019).

3.1.3. Plan For Tokyo Toward a Structural Reorganization

Tange believed Tokyo was in a state of paralysis and confusion due to its high population density. Therefore he designed an economical floating city to transform Tokyo according to the current needs of the people. Tange designed a mobile framework as a city to expand the city and create a transportation network system. He called this open system made of hierarchical programs. Tange proposed a floating city and a transportation network system that could take the burden of Tokyo (Image 3.3). However, his design did not comprehensively fulfill social, educational, and recreational needs (Lin Z. J., 2007) (Table 3.7).

Table 3.7: Plan for Tokyo Details.

Factors	Details
Design Date	1960
Architect	Kenzo Tange
Function	Floating city and highway network
Purpose	Solve land scarcity and dense urbanization
Technology	Linear megastructure with highways and subways expanding over Tokyo Bay
Budget	-
Population	5.000.000 residents
Location	Tokyo, Japan
Structure Design	Floating megastructure on linear axis and transit system over Tokyo Bay
Social Variety	Public spaces, Office units, Residences, Parking lots, Transportation networks, Elevators
Reuse	-

Image 3.3: Plan for Tokyo (Lin, 2008).

3.1.4. Baram-8 Adaptive Reuse of Oil Rig to Artificial Reef

Baram-8 is an artificial reef project created by reusing oil rig leg and jacket (Image 3.4). Baram-8 is an essential project for restoring the marine environment. In addition, Baram-8 shows an example of the adaptive reuse of an oil rig for ecology. Overall, the project is a sustainable adaptive reuse design (Awang, 2013) (Table 3.8).

Table 3.8: Baram-8 Details.

Factors	Details
Design Date	2004
Architect	-
Function	Artificial reef
Purpose	Restore marine ecosystem
Technology	Former collapsed oil rig converted to artificial reef
Budget	-
Population	-
Location	Tanjung Baram, Miri, Malaysia
Structure Design	Former collapsed oil rig salvaged and converted to an artificial reef with rigs to reef program.
Social Variety	-
Reuse	Adaptive reuse of collapsed oil rig to artificial reef

Image 3.4: Baram-8 (Awang, 2013).

3.1.5. Floating City Ijmeer Concept Design

Floating City Ijmeer is a self-dependent city with different concepts of urban and ecological development, technology, sustainability, transportation, tourism, and economy in the Rhine Delta, Netherlands (Image 3.5). The design consists of a highway bridge to connect the city with the mainland, a metro station, parking facilities, a dock, floating pathways, living clusters, and courtyards. Clusters designed in spherical shapes to provide optimal surface and volume. Floating City Ijmeer is the first self-dependent city design. The design is comprehensive in various categories. However, sustainability and self-sufficiency could have been explained in more depth. (Graaf, Fremouw, Van Bueren, Czapiewska, & Kuijper, 2006) (Table 3.9).

Table 3.9: Ijmeer Details.

Factors	Details
Design Date	2006
Architect	DeltaSync
Function	Floating city and Highway bridge
Purpose	Self-supporting floating city for SLR and urbanization
Technology	Floating island reusing/recycling/upcycling resources with closed loop cycle system
Budget	-
Population	10.000 residents
Location	Amsterdam-Almere area, Netherlands
Structure Design	Floating city consists of multiple circular platforms connected with floating pathways
Social Variety	Residences, Subway, Dock, Pathways, Bridge
	Self-sufficient water, food, energy production system
Reuse	Adaptive reuse of collapsed oil rig to artificial reef

Image 3.5: Ijmeer (Graaf, Fremouw, Van Bueren, Czapiewska, & Kuijper, 2006).

3.1.6. Seaventures Adaptive Reuse of Oil Rig to Dive Rig

Seaventures Dive Rig and Resort is the first hotel converted from an oil rig (Image 3.6). The design is an example of the adaptive reuse of an oil rig. Designers added air ventilation and a water filtration system in the design process to create a sufficient resort. The dive rig is located at sea with access to the sea through an elevator. The dive rig is a novel example to show that oil rigs can be converted into any desirable function with adaptive reuse (Zawawi, Liew, & Na, 2012) (Table 3.10).

Table 3.10: Seaventures Dive Rig and Resort Details.

Factors	Details
Design Date	2007
Architect	-
Function	Dive Platform and Resort
Purpose	Tourism facility
Technology	Former oil rig with air ventilation and water filtration system
Budget	-
Population	50 people
Location	Celebes Sea, Borneo, Malaysia
Structure	Former oil rig turned into a resort and dive rig. 17 meters deep rig

Design	equipped with air ventilation and clear water system
Social Variety	Rooms, Classroom/conference room, Restaurant, Café, Games room, Lounge, Transportation with boats, Elevator to sea, House reef in sea, Diving experiences
Reuse	Adaptive reuse of decommissioned oil rig to diving resort

Image 3.6: Seaventures Dive Rig and Resort (Seaventuresdive, 2018).

3.1.7. Lilypad/Ecopolis

Lilypad is a floating city designed for climate change for climate refugees (Image 3.7). The city is designed as half aquatic and half terrestrial, developing its fauna and flora around a lagoon that collects and purifies water. The city has three zones dedicated to working, shops, and entertainment. The city is auto-sufficient, producing energy from renewable sources and recycling CO2 and waste with aquaculture fields and biotic corridors (Callebaut, 2014). Lilypad is a groundbreaking design proposing and explaining auto-sufficiency in detail (Table 3.11).

Table 3.11: Lilypad Details.

Factors	Details
Design Date	2008
Architect	Vincent Callebaut

Function	Floating city
Purpose	Housing ecological refugees
Technology	Artificial lagoon, Mobile, resilient, self-sufficient, sustainable floating city with 500.000 square meters area
Budget	-
Population	50.000 residents
Location	Monaco
Structure Design	Lily like floating city covered with titanium dioxide surrounded by three marinas and mountains
Social Variety	Entertainment, Offices, Residences, Shops, Suspended gardens, Streets, and alleyways
Reuse	-

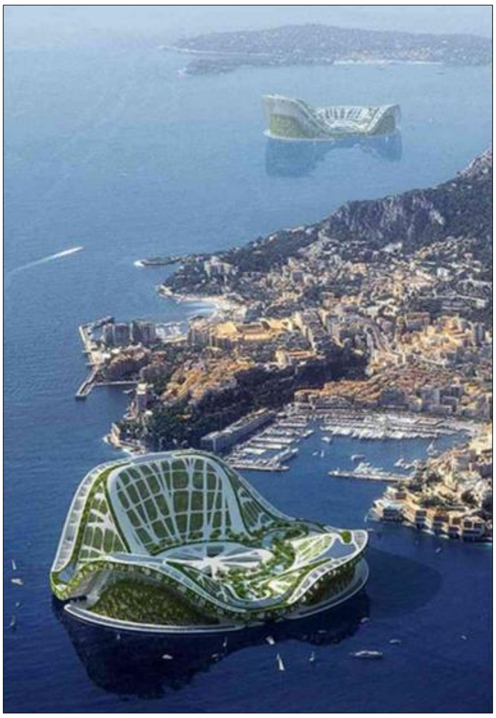


Image 3.7: Lilypad (Callebaut, 2014).

3.1.8. ClubStead

ClubStead is a concept design founded on semisubmersible hull technology. ClubStead is designed to explore living in the sea in a politically autonomous community (Image 3.8). ClubStead is a permanent living facility consisting of commercial, residential, and touristic facilities with a sewage treatment center and safety and maintenance spaces. Passenger comfort and passenger safety shaped the structure's design. The buildings stand on top of a deck supported by a main truss and cable system. Structural integrity and reaction towards relative motions are well thought and reflected in the design. However, recreational facilities, and food production are not mentioned in the design (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010) (Table 3.12).

Table 3.12: ClubStead Details.

Factors	Details
Design Date	2010
Architect	The Seasteading Institute
Function	Offshore floating platform
Purpose	Politically autonomous community
Technology	Semisubmersible technology with fresh water generating-recycling, sewage treatment and diesel engines solar panels
Budget	$114.333.000
Population	200 residents and 70 people for staff
Location	Coast of California
Structure Design	Large floating semi-submersible structure with footings and cantilevered buildings supported with cable system corrosion resistant structure
Social Variety	Hotel rooms, Headquarters, Restaurants, Spa, Fitness area, Casino, Community space, Retail, Terraces, Boat landing, Helipads, Lifeboats
Reuse	-

Image 3.8: ClubStead (Aubault, Roddier, Roddier, Friedman, & Gramlich, 2010).

3.1.9. The Seasteading Implementation Concept Plan

The main design objectives were mobility, dynamic geography, growth, seakeeping, safety, and water experience. The city comprises housing, offices, hotels, streets, green and public spaces, and private open space in 50m to 50m dimensioned platforms (Image 3.9). Apartments, villas, terraced house blocks, offices, and hotels are among the building typologies. Square and pentagonal-shaped platforms are chosen for high dimensional stability. The city is built upon a blue revolution concept. The output of one system becomes an input for another in the blue revolution concept. The city provides food production with aquaponics and aquaculture. Rainwater harvesting and desalination of seawater provide freshwater. Solar panels and diesel generators provide energy production in the city. The city plan provides a self-sufficient, sustainable living in the sea. The seasteading Implementation Plan proposes a novel sustainable self-sufficinet floating city design in detail (DeltaSync, 2013) (Table 3.13).

Table 3.13: Seasteading Details.

Factors	Details
Design Date	2013
Architect	DeltaSync and The Seasteading Institute
Function	Floating City
Purpose	Sustainable, autonomous floating city
Technology	Politically autonomous floating city durable to climate change, and land scarcity
Budget	€1,100/m²
Population	225 people per platform
Location	Gulf of Fonseca, Honduras
Structure Design	Self-sufficient floating city producing energy, fuel and nutrients from water and waste. Floating city made of 50 m x 50 m platforms. Platforms can transport with semi-submersible ships
Social Variety	Residences, Villas, Offices, Hotel, Restaurant, Community space, Helipads, Port, School/Community center, Self-sufficient water, food, energy production system
Reuse	-

Image 3.9: The Seasteading (DeltaSync, 2013).

3.1.10. Green Float Tallinn

Green Float Tallinn is a floating city and tunnel project between Helsinki and Tallinn (Image 3.10). The city has a circular shape with three layers of breakwaters to protect it from rising sea levels. The city is aimed to meet the United Nations 17 Sustainable Development Goals by not generating any waste. The floating city design offers many benefits to the environment and society. However, it does not cover design, sustainability, and safety in detail (Blue21; Shimizu Corporation, 2020) (Table 3.14).

Table 3.14: Green Float Tallinn Details.

Factors	Details
Design Date	2016-2024
Architect	Finest Bay Area Development, Shimizu Corporation and Blue21
Function	Floating island and tunnels
Purpose	Sustainable floating island adaptable to SLR
Technology	Floating island reusing/recycling/upcycling resources with closed loop cycle system
Budget	-
Population	50.000 residents
Location	Baltic Sea between Tallinn city in Estonia and Helsinki in Finland
Structure	Floating island will have the shape of three circular layers with sea

Design	depth of 2,5 m-50m and surface size of 1,2 km by 2,5 km
Social Variety	Residences, School, Offices, Self-sufficient water, food, energy production system
Reuse	-

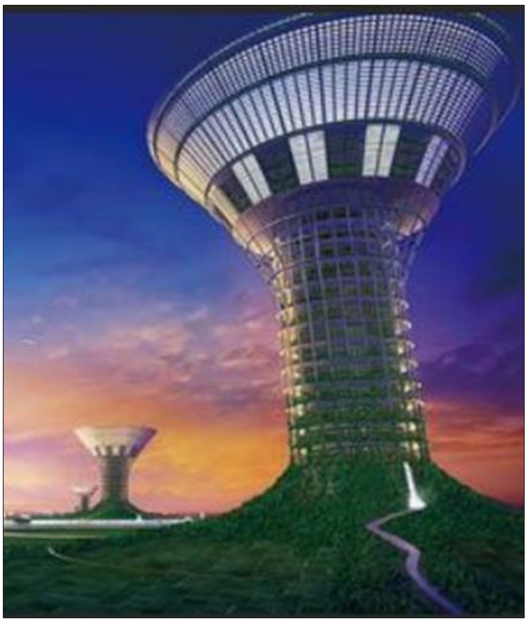


Image 3.10: Green Float Tallinn (Blue21; Shimizu Corporation, 2020).

3.1.11. The Rig Extreme Park

Saudi Arabia aims to reuse oil rigs for amusement parks and resorts. The project is the first example of the adaptive reuse of an offshore oil platform (Image 3.11). The project consists of three hotels, eleven restaurants, an amusement park, a dock, a helipad, a ferry, a cruise, and a yacht (Stouhi, 2021) (Table 3.15).

Table 3.15: The Rig Details.

Factors	Details
Design Date	-
Architect	Foster + Partners
Function	Extreme floating park and resorts
Purpose	Tourism facility
Technology	150,000 square meter amusement park and resort built on offshore oil platforms
Budget	$187 million
Population	50.000 residents

Location	Saudi Arabia
Structure Design	Floating oil rig
Social Variety	Three hotels, Eleven restaurants, Amusement Park, Extreme sports, Ferry, Yacht, Cruise, Helipad
Reuse	Adaptive reuse of oil rigs

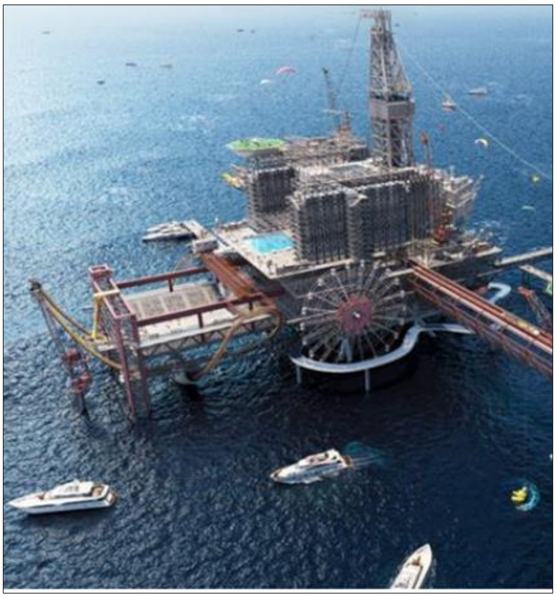


Image 3.11: The Rig (Barandy & Designboom, 2021).

3.1.12. Oceanix Busan

Oceanix Busan is expected to be the first prototype of a sustainable, resilient floating community in Busan (Image 3.12). The community consists of three different functioning platforms. The lodging platform consists of tourism and retail-based activities with communal terraces, greenhouse amenities, and harbor-view guestrooms. The research platform comprises a research center with a temperature-controlled atrium and a forest for food production. The living platform consists of sustainable circular living with a backyard (Oceanix, 2022) (Table 3.16).

Table 3.16: Oceanix Busan Details.

Factors	Details
Design Date	2023-
Architect	BIG
Function	Floating city
Purpose	Floating city resistant to SLR and floods
Technology	Sustainable, self-sufficient floating city consist of modular ecological hubs
Budget	-
Population	12.000 residents
Location	Busan, South Korea
Structure Design	Sustainable floating city made of different function ecological lodges with maximum five story 20 meters height
Social Variety	Residence, Offices, Restaurants, Cafes, Terraces, Winter garden, Research hub
Reuse	-

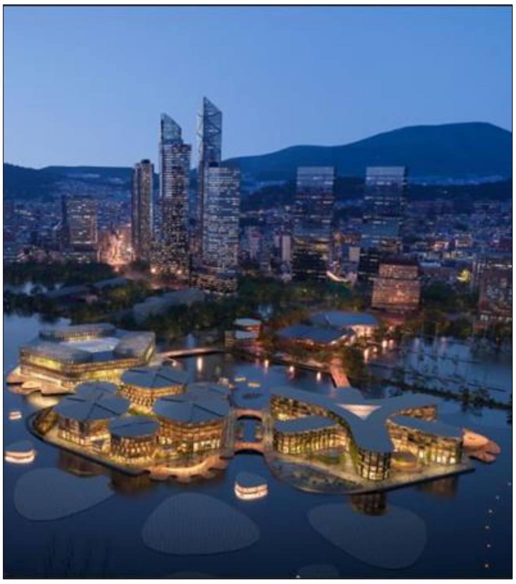


Image 3.12: Oceanix Busan (UN Habitat, 2022).

3.1.13. Next Tokyo 2045

Next Tokyo is aimed to be resilient to climate change, earthquakes, and typhoons in Tokyo Bay. The design creates a linear district by protecting Tokyo Bay and creating a new city with transit lines. The city consists of hexagonal rings ranging from 150 to 1500 meters and a residential Sky Mile Tower (Image 3.13). In addition, the city will produce energy from renewable sources. Next Tokyo is designed to transform existing coastal megacities to be more resilient toward climate change (Malott, et al., 2015) (Table 3.17).

Table 3.17: Next Tokyo 2045 Details.

Factors	Details
Design Date	-
Architect	Kohn Pedersen Fox Associates
Function	Floating city
Purpose	Floating city resistant to SLR, seismic movement, typhoon
Technology	Floating city with mile high tower and hexagonal rings around the skyscraper
Budget	-
Population	555.000 people
Location	Tokyo Bay, Japan
Structure Design	14,800,377 square feet sustainable mega city built with coastal defense infrastructure protecting coastal zone surrounding Tokyo Bay
Social Variety	Residence, Offices, Retail, Cafes, Sky lobby, Dock, Elevator
Reuse	-

Image 3.13: Next Tokyo 2045 (Malott, et al., 2015).

RESULTS

The charts above explain adaptively floating structures and cities based on their architectural, technological, social, and sustainable characteristics. Past floating city designs were selected as a reference for adaptively reused sustainable floating cities resilient for SLR in the future. Floating cities and adaptively floating structures and their design concept evaluation were conducted according to the information gathered from the charts above. The LEED rating system, floating structure analysis of El-Shihy and Ezquiaga and DeltaSync's floating city objectives inspired the evaluation method. The LEED rating system examines buildings' health, efficiency, feasibility, and lower carbon emissions. LEED for Homes Design and Construction, LEED for Neighborhood Development, and LEED for Cities and Communities was chosen because it correlates with designing sustainable cities resilient to climate change (USGBC, 2016). Floating structure analysis of El-Shihy and Ezquiaga (2019) selected to evaluate floating structures in terms of durability, feasibility, and environmental impact. Finally, DeltaSync's floating city objectives used for evaluating social varieties and self sufficiency (DeltaSync, 2013). Categories of construction feasibility and process, impact on marine ecology, modularity of design, production of energy, food, and water, adaptive reuse of materials, structure, and building, and resilience to environmental conditions have been assigned to evaluate and find the best design. A score of 1 indicates the highest score, a score of 0 indicates the lowest score, and no score indicates there is no information available about the feature. Floating cities written in left side of the table and adaptively floating stuctures located on the right side of the table painted with gray (Table 4.1).

Table 3.18: Floating City and Structure Design Concept Evaluation.

Floating Cities/Structures	Marine City	Triton City	Plan for Tokyo	Floating City Ijmeer	Lilypad	ClubStead	Seastading Implementation Plan	Green Float Tallinn	Next Tokyo	Oceanix Busan	Baram8	The Rig	Seaventures Dive Rig
Low cost	-	-	-	-	-	-	-	-	-	-	1	1	1
Investment toward extreme conditions	1	1	1	1	1	0	1	1	1	1	0	0	0
Low impact materials	0	0	0	0	0	0	0	0	0	1	1	1	1
Fast construction process	-	-	-	-	-	-	-	-	-	-	1	1	1
Long building life span	-	-	-	-	-	-	-	-	-	-	1	1	1
Investment on tourism	0	1	0	1	1	1	1	0	0	1	0	1	1
Investment on infrastructure	1	1	1	1	1	1	1	1	1	1	0	0	0
Protecting environment	0	0	0	1	0	0	0	0	0	0	1	0	1
Adaptability to climate change	1	1	0	1	1	1	1	1	1	1	0	0	0
Creating jobs	0	1	0	1	1	1	1	0	0	1	0	1	1
Recycle/reuse	0	0	0	1	1	1	1	0	0	0	1	1	1
Upcycle	0	0	0	0	0	0	0	0	0	0	0	1	1
Limited material usage	-	-	0	-	-	-	1	-	-	1	1	1	1
Modular design	1	0	0	1	1	0	1	1	0	1	0	0	0
Waste recycle	0	0	0	1	1	0	1	1	-	1	0	-	0
Educational	0	1	0	0	0	0	1	1	-	1	0	0	0
Retail	0	1	0	0	1	1	-	0	1	1	0	1	1
Commercial	1	1	1	1	1	1	1	1	1	1	0	1	0
Residential	1	1	1	1	1	0	1	1	1	1	0	0	0
Institutional	0	1	0	0	0	0	-	0	0	1	0	0	0

Wave energy	0	0	0	1	-	-	1	-	-	-	0	-	0
Wind power	0	0	0	-	-	-	-	-	-	-	0	-	0
Solar energy	0	0	0	-	-	-	-	-	-	-	0	-	0
Bioenergy	0	0	0	-	-	-	-	-	-	-	0	-	0
Geothermal energy	0	0	0	-	-	-	-	-	-	-	0	-	0
Water production	0	0	0	1	1	1	1	1	-	1	0	-	0
Food production	0	0	0	1	1	-	1	1	-	1	0	-	0
Fish production	0	0	0	-	-	-	-	-	-	-	0	-	0
Algae production	0	0	0	-	-	-	-						
Waste production	0	0	0	1	1	-	1	1	-	-	0	-	0
Low carbon footprint	-	-	-	-	-	-	-	-	-	1	1	1	1
Restoring marine ecosystem	-	-	-	-	-	-	-	-	-	1	1	-	1
No waste policy	-	-	-	1	0	-	1	-	-	-	1	-	0
Decreasing urban population	1	-	1	1	1	-	-	-	-	-	0	-	0
Solving urban sprawl	1	-	1	1	1	1	1	-	-	-	0	-	0
Adaptive reuse (material)	0	0	0	-	0	-	-	-	-	-	1	1	1
Adaptive reuse (existing building)	0	0	0	-	0	-	-	-	-	-	1	-	1
Adaptive reuse (structure)	0	0	0	-	0	-	-	-	-	-	1	1	1
Adaptive reuse (field)	0	0	0	-	0	-	-	-	-	-	-	-	0
Adaptive reuse (heritage building)	0	0	0	-	0	-	-	-	-	-	-	-	0
Ventilation system	0	0	0	-	0	1	-	-	-	-	0	-	1
Resistance to SLR	1	1	-	1	1	-	1	1	1	1	0	-	-
Resistance to floods	1	1	-	-	1	-	1	1	1	1	0	-	-
Resistance to seismic movement	1	-	-	-	-	-	-	-	1	-	0	-	-
Resistance to	1	1	-	0	-	-	-	-	0	-	0	-	-

tsunami													
Ferry	0	1	1	1	-	-	1	-	1	-	0	1	1
Helicopter	0	1	0	1	-	1	1	-	0	-	0	1	1
Car	0	0	1	1	-	-	-	-	0	0	0	-	0
Bike	-	-	-	1	-	-	-	-	0	0	0	-	0
Subway	0	0	1	1	-	-	-	-	0	0	0	-	0
Restaurant	0	0	0	1	1	1	1	-	1	1	0	1	1
Cafe	0	1	0	0	-	0	1	-	0	1	0	1	1
Parks	0	0	0	0	1	0	1	-	0	1	0	1	0
Shopping center	0	1	0	0	0	-	0	-	0	-	0	1	0
Lounge	0	1	0	1	-	1	1	-	0	1	0	1	1
Bridge	0	1	0	1	0	-	0	-	0	-	0	-	0
Elevator	0	0	1	0	0	-	0	-	1	-	0	-	1
Pathway	0	0	0	1	0	-	1	1	0	-	0	-	0
Road	0	0	1	1	0	-	0	1	0	-	0	-	0
Floating platforms	1	0	1	1	0	-	0	-	0	1	0	-	0

Floating cities: Marine City (1958), Triton City (1958), Plan for Tokyo (1960), Floating City Ijmeer (2006), Lilypad (2008), ClubStead (2010), The Seasteading Implementation Concept Plan (2013), Green Float Tallinn (2016), Oceanix Busan (2023), Next Tokyo 2045 and adaptively floating structures: Baram-8 (2004), Seaventures Dive Rig (2007), and The Rig evaluated according to economical, sustainability and comfort parameters. These parameters selected to design an efficient city both for the environment and the residents. Floating city and adaptively floating structures analyzed to understand the needs and requirements of a floating city. Implementing adaptive reuse on decommissioned oil and gas rigs that already existed on sea offers more sustainable living in terms of preserving structures' life cycle. Implementing adaptive reuse on an already existing offshore oil and gas platforms can be an interim solution for rising sea levels, population growth or other current problems in urgent times. The study conducted a comparison of floating city and adaptively floating structure designs to identify essential requirements for a city. A score card produced according to the evaluation method. According to evaluations adaptively reused structures also showed strength in environmental protection and feasibility these aspects show the interrelation between sustainability and economic feasibility (Table 4.2).

Table 3.19: Total score based on comfortability, sustainability, and economy.

Project Name	Score
Marine City	13
Triton City	19
Plan for Tokyo	12
Baram8	13
Floating City Ijmeer	30
Seaventures Dive Rig	23
Lilypad	20
ClubStead	13
Seasteading Implementation Plan	27
Green Float Tallinn	15
The Rig	21
Next Tokyo	12
Oceanix Busan	25

According to the evaluations the highest score of 30 belongs to Floating City Ijmeer. Floating City Ijmeer (2006) scored due to its self-sufficient system, no-waste policy, social variety, and design approach. The highest score in floating structures belongs to Seaventures Dive Rig (2007). The adaptively reused hotel has a score of 23. Sustainability, adaptive reuse, positive impact on the environment, transportation, and social functions enabled a high score. The structure's only disadvantage was that it was designed for temporary lodging. Therefore it does not provide matching options for energy, food, water production, and design range.

On the other hand, the lowest scores belong to the first floating city examples of Metabolist architects. Plan for Tokyo (1960) and Marine City (1958) projects are an example of floating cities to solve urbanization designed with the sustainability principles of the past. Marine City and Plan for Tokyo could not attain the meets of a contemporary city in terms of energy, water, food production, social functions, transportation, and environmental impact. Sustainability, self-sufficiency, and environmental impact establish the focal objectives of the evaluation method. Adaptively reuse of offshore oil platforms can offer an alternative to conventional construction as seen in Seaventures Dive Rig, Baram8 and The Rig. These adaptive reuse projects show advantages in economy and sustainability by protecting structures' life cycle and help to restore marine ecology by reserving sea creatures in structures’ legs. However, The Rig and Seaventures Dive Rig designed as a temporarily lodge area for touristic attraction. They lack of self sufficiency, sustainable closed loop system. Hence, they do not meet the needs of a sustainable floating city for sea level rise. However, offshore oil and gas platforms are adaptable for different multi-purpose use. OOGPs can be a valuable asset for rising sea levels when equipped with right tools and design method. According to evaluations an OOGP integrated with novel floating city principles like Lilypad, Floating City Ijmeer or Seasteading Institute Implementation Plan would achieve the highest score and can be an alternative living for SLR. The evaluation methods aimed to find the most suitable design for sustainable floating city for future. Global warming, climate change, SLR, and urban sprawl cause severe problems for cities. Cities need to be resilient towards these issues. However, current conventional construction methods have yet to solve existing problems. The study explained and implemented adaptive reuse as a sustainable method to resolve existing issues in the built environment. The study used and compared past floating city designs with adaptively reused structures to understand the needs for a floating city and aimed to use floating structures particularly OOGPs to design a sustainable floating city in urgent times for existing problems. The study aimed to provide an interim solution for SLR and urban sprawl, global warming, and climate change.

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