Futuristic Cities "Aqua Cities"

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***Abstract*—**In the past century, living in cities inside the water or beneath it, was an idea only used by film makers in Hollywood to create some interesting science fiction movies. In this century and with the challenges the world is facing, the idea became more and more appealing to architects as a solution to many of their immediate and future problems. To these architects, these cities are expected to be smart, liveable, sustainable and resilient, four concepts any city now strives to achieve. This indicates the importance of such a city and the possibilities it can offer. In addition, the concept of building a complete city in the water, an "Aqua City" as the research calls it, is very inspiring and has its own aesthetical values. Thus this paper tries to explore the idea of an aqua city and to illustrate its relation with the aforementioned four concepts and their principles.

***Keywords*—**Aqua Cities, Cities of the Future, Livability, Resiliency, Sustainability, Smart Cities.

I. Introduction

ALTHOUGH technology was introduced into all areas of life in answer to current and future economic, social, and environmental problems. However, as a result people managed to alter the world´s climate in a way that it has become a threat to human civilization [1]. Many coastal cities are slowly sinking into the water due to the climate change and the rise in sea-level it caused [2]. For example, the edges of Dubai´s most famous holiday resort, the artificial palm island, have already been eroded by floods. Therefore, architects, with futuristic architectural visions, tried to overcome the ongoing global warming with all its damaging consequences through new and unconventional architecture. One of these contemporary futuristic concepts invented by revolutionary architects and designers are "Aqua Cities", an innovative and imaginative solution to the future environmental problems [1]. It is also a new trend that aims at using the ocean/sea space, an approach that can result in the human populations' settlement of the oceans [3], especially since land became more and more limited in some countries.

II. Historical Background

Until recently, only marine biologists and underwater archaeologists were the main parties interested to live underwater, since to biologists, to be there, is the only way to understand what's really happening in the oceanic environment. As for archaeologists, they could resurrect sunken ships or search for lost artefacts. However, lately some architects began to see underwater living as a solution for preserving human kind in case of an apocalyptic catastrophe, a newer version of Noah's ark [4]. On the other hand, major oil companies were the main parties interested in developing water floating platform technology. Most of their platforms have been piercing the ocean surface while resting on the ocean floor. However, lately, the oil companies have started to use free-floating platforms, which do not need to be bottom supported; where the platform can float freely but stays in position by resisting the effects of wind and waves [3]. However, the oil company's platforms were not the only floating systems that appeared. Table (1) will illustrate the different types of floating systems found nowadays.

TABLE I
Current Floating Structures
By: Researcher Source: (Watanabe, E., etal: 2004)

Current Floating Structures		
Type	**Name**	**Picture**
Floating Bridges	*Nordhordland Floating Bridge, Norway*	
Floating Entertainment Facilities	*Floating Restaurant in Yokohoma, Japan*	
Floating Storage Facilities	*Kamigoto Floating Oil Storage Base, Nagasaki Prefecture, Japan*	
Floating Emergency Bases	*Emergency Rescue Base ,In Tokyo Bay*	
Floating Plants	Studies are already underway to use floating structures for wind farms.	
Floating docks, piers, berths and container terminals	*Floating Pier at Ujina, Japan*	

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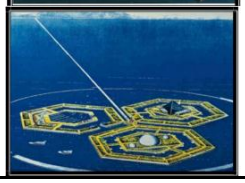
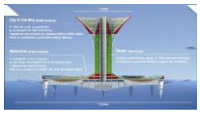
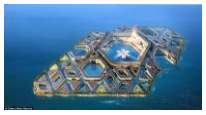
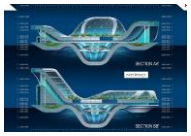
Floating Airports and Mobile Offshore Base	*Mega-Float in Tokyo Bay, Japan (Photo courtesy of SRCJ)*	
Floating Cities	*Osaka Focus B by Japanese Society of Steel Construction*	

III. Aqua City Definition And Types

As aforementioned, many different types of structures have been built in the sea as floating platforms in order to expand the living space or for functional uses. It started with small structures as illustrated and ended with architects designing offshore floating cities to absorb urban expansion in the years to come, which will be referred to in the research as the "Aqua City" [3]. By 2020, it is expected to establish the first Aqua-Floating City, with significant political autonomy [5]. To the research, an "Aqua City" is the city where its residents live and work permanently on a floating or underwater structure, on offshore shallow waters or on open-ocean in deep water. The city can be fixated in a certain place or free to move and travels like a ship or a submarine with different promising visions and constructive plans to deal with multiple scenarios [1]. Developed from these visions, the "Aqua city" will be classified into three main types; a floating city, a submersed city and a semi- submersed city, illustrated in table (2).

TABLE II
The Different Types Of An Aqua City
By: Researcher Source: Variable

The Different Types of an Aqua City			
	Floating Aqua City (Above Water City)	**Submersed Aqua City** (Beneath Water City)	**Semi-Submersed Aqua City** (Above & Beneath Water City)
Definition	A Semisubmersible platform designed to house residents [5] mainly above water surface. It is best to be placed near shore in the calm, shallow waters found within territorial seas and bays; however, it can be set in deep water on the open ocean. It can also be fixed in one place or move like a ship.	A totally submerged construction designed to house residents mainly under water surface. However, in some types, it can have platforms above surface with some services. It is best to place it in deep water on the open ocean and to be fixed in one place although it can be movable like a submarine or ship as well.	A Semisubmersible construction designed to house residents above and beneath water surface. It is best to place it in deep water on the open ocean and to move like a ship although it can be found in calm, shallow waters found within territorial seas and be fixed in one place as well.
Example	**Floating Ecotopia City (Green Float)**	**The Floating City**	**Lilypad,City**
			
			
	Floating ecotopia or green float is a series of floating islands where residents live and work in its eco skyscraper cities. They can also easily get to open space, gardens and the beach above its platform. The islands are connected together and can form a country [6].	The floating city is a submerged construction designed to sustain residential, commercial and cultural facilities, mainly under water surface. However, it has a platform above surface that contains a series of canals, boats and submarines [7] and some services and entertaining spaces; such as farms and stadium [8].	Lilypad is an autonomous semisubmersible floating city, providing room for up to 50,000 citizens. [1]. It is built so its residents can live and work above and beneath see level.

IV. Advantages & Disadvantages Of An Aqua City

An Aqua City has many advantages. As urban development grows in land-scarce countries or countries with long coastlines, resorting to aqua city to decrease the existing load on heavily-used land is the best solution [9], since it creates additional spaces for new cities to ease the over-population. Furthermore, living in water is a reasonable solution to the dilemma of environmental collapse since to some experts, it will be less expensive and easier to accomplish than building in space [4]. Aqua city also provides a testing ground for new water, energy and floating technology solutions [10]. It provides freshwater produced using condensation of precipitation or desalinization and energy developed from sunlight by using solar panels and from wind by using wind turbines [4], [5]. In addition, its design can allow it the flexibility to move around the world as submarines or ships or position itself offshore as a fixed structure [3], providing movability, dynamic geography, water experience and sea keeping [5]. The city that will be constructed offshore or in bays will be easier for its citizens to travel to and from the existing land-city and acquire goods and services when needed [11]. Moreover, fresh seafood is easy to deliver from the bottom of the ocean [4]. However, most of the aqua cities are self-sufficient and can also use the Blue Revolution technology which allows for remediating the environment and high technology food production ways [5]. Finally, one of the main advantages of an aqua city is being a smart, sustainable, livable and resilient city, which will be discussed in the coming section.

As for its disadvantages, one of Aqua City greatest challenges is transnational law since it can support populations large enough to create a new state in itself [3]. In addition, crucial needs such as emergency evacuation systems and

environmental controls, used for air supply and humidity, use technological advances that will need high maintenance and observation to avoid their failure. Also cooking underwater, although possible, will be prevented because of the smells it produce, since fumes are felt stronger in static air, unless special technology is found to contradict its effect [4]. Other factors that present challenges are mooring, wave breaking, comfort and **costs** of the city, which depend greatly on the sea depth, the large waves, tides, winds and storms [5]. The city must also be guarded against disasters especially hurricanes, since if not protected well it can lead to total loss of the city. In addition, a submersed city will face another challenges such as scalding volcanic fluids, ravaging storms and bone-crushing pressures [12]. Thus, it is most likely to build no deeper than 1,000ft (300m), since the pressures at such depths will require building very thick walls in addition to excessive periods of decompression for citizens who needs to return to the surface. However, currently, people who stay in laboratories under the water did not experience any ill effects from staying below the surface for around 60 days. It is believed that living up to six months would be feasible [4]. Finally, one of the main disadvantages of an aqua city is the high costs of some of its visions, which will be discussed later on [5].

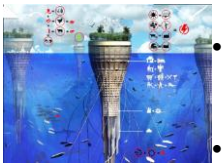
V. Four Main Aspects To An Aqua City

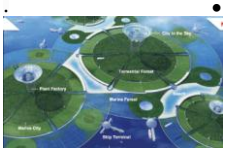
Sustainability followed by livability than resiliency approaches have replaced the old belief in technology and smart approach only, with its careless consumption of energy and resources, while creating a city [1]. Nowadays, usually the term "livable city" includes sustainability and resiliency as well, three essential aspects while developing a city; in addition to advanced technological appropriation. This part will illustrate that an aqua city is developed putting all these four aspects in consideration. According to some architects, the temporary or permanent living on the sea can be peaceful, profitable and also luxurious [5]. Since an aqua city uses digital technology and computer controlled systems which can produce various benefits: such as the availability of new services to citizens and commuters, and thus improving the quality of life and developing a smart city [1], [13]. This is considered an answer to the main aim of a livable city, which is improving the quality of life for the city's residents [14].

On the other hand, sustainability is always related to the ability of the city to be maintained and to sustain itself and its resources for many coming centuries for the future generations and residents [14]. And, sustainability of an aqua city is related to an approach that is mainly conscious about the energy, water and ecologically of the city [15]. Again, using smart technology in aqua cities can reduce energy and water consumption, hence contributing to CO_2 emissions reductions [11]. Harnessing wave action or using solar panels are great sustainable future options used in aqua cities as renewable energy techniques [4], [15]. As for water, enough water could be collected from condensation of precipitation or desalinization, as previously mentioned, to meet the citizens' needs [5]. Additional sustainable characteristics can include recycled and relocatable usage, installation of self-supporting plant, wastewater treatment technology and waste treatment plans [10], [16].

As for resiliency, it is the ability of the city to develop within 100-year context, providing its citizens with basic needs in face of its changing circumstances, opportunities and limitations [14]. Aqua city in itself is an answer to the changing needs that resulted due to the unavailability of usable land in urban area and sea level rise, offering an attractive alternative solution for new land inside the sea [15], [9]. Resiliency is also achieved in an aqua city through using the modular system and connected platforms designs to accommodate ongoing increase of its population. In addition, aqua city structure is designed to comply with serviceability and safety requirements for a service life of 100 years or more [15], [5], [8]. Moreover, it uses smart technology to smooth the peaks' demands on energy, water and transportation systems of the city and thus improve its resiliency [11]. Finally a collection of essential principles must be addressed in order to develop an integrated smart, sustainable, livable, and resilient city [14]**.** In the following table, these principles will be used to further validate that an aqua city sustain in itself the four aforementioned aspects, through using and analyzing multiple case studies.

TABLE III
The Application Of The Integrated City Principles On Various Aqua Cities
By: Researcher Source: Variable

The Application of the Integrated City Principles on various Aqua Cities		
Essential Principles	**Project**	**Application**
Enhancing the residence quality of Life	**The Floating City Project** 	• It provides economic opportunities [11]. • It is a zero-carbon city. • It is an energy-efficient and self-sufficient city [7].
Comprehensive land use and green areas & improved environmental quality	**Lilypad City** 	• Each floating city is designed to sustain around 50,000 citizens. • The man-made landscape in it creates a diverse environment for its citizens. • It is a zero emission city [17].
Efficiency and reservation of resource use	**Water-Scraper** 	• This city produces its own electricity using wind, wave and solar power. • It also produces its own food through hydroponic techniques, farming and aquaculture. • The structure uses a set of squid-like tentacles which generate kinetic energy [18].
Satisfying social needs	**Floating Island**	• Great excitement filled the residents living off the

& supporting historical preservation and cities aesthetics		Han River in Seoul, South Korea for the world's largest floating island. • With its entertainment complex, the Viva is drawing crowds en masse [19]. • It provides its own sense of beauty.
Conducting a waste & pollution control management plan	**Floating Ecotopia City** 	• It manages waste through a waste control plan. • Energy is generated from renewable sources which decrease pollution [6].
Providing livable streets and traffic	**The Floating City**  	• The city is connected above water by submarines and a series of canals with eco-friendly boats, providing most of the transportation system. • The city will be filled with electric cars, preventing pollution in the underwater sections [7].
Sustainable and resilient infrastructure and systems	**The Ark** 	• It is a bioclimatic structure with independent life-support system. • Open layout to accommodate different functions over time and allows resiliency of the city. • It uses solar cell & wind turbine, while enough daylight enters through the transparent roof [15].
Economic development plans	**The Floating City Project** 	• It provides new job opportunities and uses international waters which allow for worldwide recruitment of top talent, entrepreneurs and investment capital. • The ocean offers radical possibilities for some of the boldest economic dreams through the new technology it uses. • The oceans are the superhighway of trade with seastead inside of it [11].

VI. Additional Aspects To Aqua City

A. Costs, Structure & Economics

According to some people, aqua city technology is not expensive and can be afforded by most countries of the world [3]. However, to the majority, the costs of engineering some designs, that can withstand the ocean's elements; wind, waves and corrosive seawater and at the same time remain comfortable enough to live on permanently in sea, are high [5]. Until now, there are two types of huge floating structures (VLFSs) that are being used; the semisubmersible-type and the pontoon-type. The semi-submersible type is raised above the water surface using ballast structural elements or column tubes, in addition to using breakwaters which makes it suitable to deploy in high seas and open-ocean with its large waves [8]. However, according to DeltaSync, the costs of a breakwater are very expensive [5]. Floating oil drilling platforms are great examples of semi-submersible-type. On the other hand, pontoon-type lies on the water surface like a huge plate floating on sea. Pontoon-type floating systems are suitable for use in only calm, shallow waters near the shoreline [8], which makes it less expensive to engineer compared with structures engineered for the open ocean [11].

Moreover, some architects consider it best to create the city using small structures that could be added or taken away to develop a living space for as many citizens as needed [4]. This can help in the resiliency of the city especially to accommodate the growing population. However, constructing the city in this way using small structures provides less stability in harsh waters, and requires extra engineering requirements for moorings and connections. On the other hand, larger platforms are certainly more stable, but more expensive due to the need to brace it by a taller costly internal structure [5].

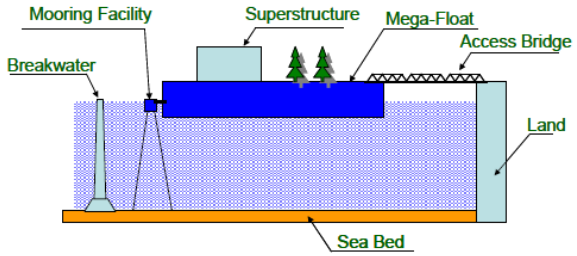


Fig.1 The components of a mega float system which is a large pontoon system Source: (Watanabe, E., etal: 2004)

Finally, in spite of the high expenses of some designs, the market for an aqua city with residential spaces and some level of political independence is growing especially at crowded industrial cities for the purpose of offshore housing [5], [3]. And with a practical design the city's construction costs can match the market's price point. In addition, aqua cities not only provide new market for residences but also for tourism, business parks, research institutes, aquaculture, and power-plants which provide energy and clean water [11]. Furthermore, aqua city enables more businesses to be commercially feasible on the seas. It promotes mariculture, aqua farming, medical research, "bluegreen energy" technologies, and floating hospitals, which creates jobs and provide prosperity for its citizens [5]. And as aforementioned, aqua city can derive energy from the wind, sun, ocean currents and waves, and food from mariculture and fishing operations which was found cheaper than traditional ways [3]. The extra produced energy or water can be also sold to other cities.

B. Movability & Materials

Movability is an essential aspect to aqua city. It is required so the city can move away from a sudden disaster or travel over the seas for any other reasons. The self-propelled option is not cost effective, if the city moved only once in ten years or less, also the disassembly option is not viable since it would take too much time to disassemble. The best feasible options, until now, are moving the floating district by semi-submersible ships or towing the floating district away. Both ways can be used to move large and small structures [5].

As for materials, architects proposed various materials to use in constructing an aqua city. Until now, the most practical materials used for the aqua city are steel, or concrete or steel-concrete composite [8]. Additional materials are used such as; glass, special cement used underwater, fill materials from seabed, hills, deep underground excavations, construction debris and even fibers made from sea shells [4], [8], [1]. However, concrete, especially concrete pontoons, is always preferred to build the aqua city for its balance of stability, low cost, none required maintenance and the ability to use the pontoon as a living space [5], [10].

C. Safety

Securing the safety of the city and its citizens is a major aspect that can have an enormous influence on the design decisions. Safety measures are divided into two parts; first the ability of the city's structure to survive severe sea conditions in both a protected bay and/or on the high seas. Secondly, the survival of its citizens at ordinary conditions or at times of a disaster [5]. Thus, the safety measures in an aqua city must consider avoiding extreme consequences such as property damage, fatalities or environmental damage. Property damage may occur as a result of a small structural damage, as for fatalities it can occur due to major structural failures such as capsizing, sinking, global structural failure or drift-off [8]. These disasters are mainly a result of environmental hazards such as large waves, storms, or hurricanes. Therefore it is important for the city to be able to move fast enough to avoid the disaster, with a study of the wind and climate [5]. Another important safety requirement, related to personnel safety, is conducting evacuation and rescue plans. An effective safety plan must provide a safe place for citizens to survive on board before safe escape can take place, in addition to a broad risk analysis approach with multiple possible accident scenarios [8]. It is equally important to the safety of the citizens to provide a reliable stable structure for the city and a living environment where citizens can live and enjoy their life safely [5]. This could mean assuring that underwater residence is running smoothly through observing life support systems, air composition levels, temperature and humidity from above at the surface, and pressures [4].

VII. Conclusion

This paper tries to provide a visionary, innovative and revolutionary answer to the expected rise in sea level due to global warming that led to the sinking of the cities in the sea and the scarce in lands to accommodate the growing populations in some countries. In hope that it will cause a debate that leads to a deeper awareness and professional interest in aqua cities between academics and architects, apart from science fiction writers and utopian dreamers. Hence, if the cities should truly be flooded by oceans, people will survive in aqua cities, a city that can travel on all oceans from the equator to the polar-regions in high seas, or stand still on calm offshore water. The aqua city can have three main types; the floating city, the submersed city and the semi- submersed city, which were demonstrated through using examples.

Unlike what many architects think, an aqua city has many more advantages than its disadvantages. And by using various case studies, an aqua city proved that it can sustain a better way of living by being a sustainable, livable and resilient city through being a smart one; the four main aspects required achieving while developing any successful city. Additional important aspects that were discussed in relation to an aqua city to prove its applicability are; costs, structure, economics, movability, materials and safety. Finally, although an aqua city might seem now, in some way, ahead of its time, demonstrating a vision of the future that is thought by some likely to be impossible, it can be very applicable and much needed at the near future.

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