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ORIGINAL ARTICLE

# Architectural design concept and guidelines for floating structures for tackling sea level rise impacts on Abu-Qir



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## KEYWORDS

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Architectural design of  
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**Abstract** Previous studies indicate that floating structures developed through the last decades concluding that it's the most sustainable solution against sea level rise (SLR), preferring it to land reclamation approaches regarding sustainability, lifespan, and cost-effectiveness, that Egyptian researches seem to disregard. This paper guides architects and urban planners when designing floating structures by introducing new approach of floating community model and architectural design guidelines for floating structures for tackling SLR impacts on Abu-Qir. To illustrate such approach, this paper initially conducts analysis on Abu-Qir and coastal management solutions practiced as their properties provide the required knowledge for selecting the best mitigation solution for such area. Second, it conducts exploratory analysis to investigate floating structures as a more sustainable and long-term solution. Third, applying conclusions from previous sections of site analysis, mitigation solutions, and floating structures to define a floating community concept model for Abu-Qir. Findings support key arguments that traditional mitigation methods aren't sustainable or long-term solutions. Analysis demonstrate Abu-Qir Bay as the most vulnerable area to SLR. Although floating structures have demonstrated not to be the optimum solution in every case regarding cost-effectiveness and/or site suitability, however upon site analysis, it presents itself as the ideal solution for Abu-Qir bay.

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## 1. Introduction

The primary purpose of this paper is to introduce new approach of floating community model and architectural design guidelines for floating structures for tackling SLR impacts on Abu-Qir. Research and speculation on SLR impacts on coastal areas, small islands and low-lying areas in the world have been growing at a rapid rate. In recent years,

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the study of mitigation solutions regarding tackling the rising seas challenges has dramatically increased. Over the past few years, studies on very large floating structures (VLFS) has been attracting architects, urban and city planners, and civil engineers as it has emerged as an effective solution for tackling the rising seas challenges.

This study is designed to assess two hypotheses: the Nile Delta's coastline will eventually be submerged as design strategies and coastal management practiced only offer unsustainable short-term solutions; and that floating structures may offer the optimum solution for safeguarding Egypt's coastal sovereignty when addressing land subsidence problems. This paper is set out to explore SLR impacts on Abu-Qir, furthermore, this paper highlights probable architectural design strategies and guidelines when designing floating structures for tackling the SLR challenges, to emphasize the absence of global an authorised context regarding their implementation and usage. The objectives of this paper research have been:

- To identify coastal planning strategies and mitigation solutions practiced in most vulnerable sites to SLR and their evaluation in Abu-Qir as Egypt's most vulnerable area.
- To study and analyze different coastal management and adaptation approaches executed around the world for undertaking the SLR impacts in respect to Abu-Qir Bay.
- To introduce a new approach of floating community concept model to function as a future reference for architects and urban planners when designing and planning coastal developments.
- To set architectural design guidelines for developing floating houses for Egypt and the Nile Delta coastline to assess the hypothesis made on floating structures.

This paper well deserves careful analysis on SLR impacts, adaptation approaches, and sustaining the coastal developments of Abu-Qir as it highlights the most vulnerable locations and mitigation approaches practiced. The findings of this paper introduce floating community model and architectural design guidelines for floating structures to demonstrate the benefits of VLFS as the optimum mitigation solution for tackling SLR impacts in some of the most vulnerable areas in the Nile Delta coastline and to offer a future floating structures design reference for Egypt. The more the SLR, the greater the risk on vulnerable and low-lying coastal areas around the world. Therefore, old fashioned and traditional land reclamation solutions practiced by the Egyptian Shore Protection Authority (ESPA) should be abolished and replaced by floating structures wherever possible. The distinct sustainable and flexibility features of floating buildings in settings and environments makes them preferred for their various applications and advantages. If the government applies the recommended method derived from the outcomes of this paper, it will safeguard Egypt's coastal sovereignty for the long-term wherever implementation is possible. Herein this paper, authorities are guided on what should be done to efficiently design and sustain coastal urbanizations in the Nile Delta's most vulnerable locations. The study uncovers critical impacts of SLR on coastal urbanizations of Abu-Qir and offers VLFS as a sustainable long-term adaptation solution that Egyptian researchers seem to disregard. Therefore, a new approach on adapting to SLR concerning Egypt's Nile Delta is explored.

## 2. Literature review

Recent studies conducted by the Intergovernmental Panel on Climate Change [10,11] concerning mega-deltas have shown that the Nile Delta in Egypt is one of the three most vulnerable mega-deltas around the world due to their low-lying coastlines besides the Ganges-Brahmaputra Delta in Bangladesh and India, and the Mekong Delta in Vietnam. The probable one-meter SLR is anticipated to impact around 6.1 million inhabitants of the Nile Delta, while 1.5 m SLR may submerge an area around 22,000 km<sup>2</sup> in the Ganges-Brahmaputra Delta, impacting up to 17 million residents [6].

The Arab Environment Climate Change Report by Tolba & Saab [20] state that about 94% of Egypt's area (over one million km<sup>2</sup>) is desert. With a population approaching a hundred million, most Egyptians only inhabit the Nile valley and the delta which make less than 6% of Egypt's area. The delta is currently withdrawing because of the accelerating erosion lengthways its shoreline. The construction of the High Dam between 1960 and 1970 has blocked great quantity of sediments in Lake Nasser which accounts as the greatest issue for erosion in the Delta.

Submerged coastlines are vital, specially to islands and low-lying areas like the Abu Qir in the Nile Delta's region [7], as it may lead to real sovereignty losses, because of the of sea borders movements. Also, as for risky areas, these losses in land areas may lead into some countries disappearances in case of island countries. The stages of SLR and Consequences [21]:

- Stage 1: SLR.
- Stage 2: Land loss.
- Stage 3: Maritime boundaries movement.
- Stage 4: Potential economic and/or sovereignty loss.

Countries will have to spend a lot of money to tackle this problem, to guarantee minimizing the possible economic and land loss. As that no country could obstruct any of the first two stages, they will have to delay the process form reaching the third stage [21]. Therefore, urban planning and development for any new and existing coastal settlements in any country, specially in Egypt's Mediterranean coastline, cannot be designed for or carried out without incorporating climate change and SLR studies and analysis.

Tolba & Saab [20] suggest that Egypt rely heavily on traditional land reclamation solutions especially in the Nile Delta's region where low-lying lands are being submerged gradually by SLR impacts. Architects, urban and city planners shift to land reclamation solutions to decrease the pressure on the current heavily busy zones and underground areas. Wang & Tay [25] state that by implementing fill materials from the seabed, mountains, as well as deep subsurface excavations, and construction wreckages, architects and urban planners are capable to make rather an enormous and respected area from the sea. Wang et al. [26] state that although land reclamation solutions can offer an unexpansive one, however, they only serve as temporary solutions, as they are unsustainable to coral reefs, and not cost-effective in areas with large depth.

Distinguished researchers [2,3,13,18] propose that future SLR impacts must be undertaken over an official adaptation. As stated by Suzuki et al. [19], the demand on different architectural and urban planning floating applications like floating

piers, floating hotels, floating fuel storage facilities, floating stadiums, floating bridges, floating airports, as well as floating cities have generated wide-ranging research studies throughout the last decades. Floating structures has advanced noticeably through the last decades and now we have several innovative approaches planned to increase the stability, advance the mooring systems, and structural integrity of floating structures. As Tsaltas et al. [21] state that floating structures do not work in every case, but it could still be a practical answer in some cases for conservation of fragile ecosystems, protecting in and offshore strategic economic activities, safeguarding borders and habitats.

### 3. Research methodology

To achieve the objectives mentioned earlier, the study conducts three researches using state-of-the-art data on SLR, architectural and urban planning mitigation solutions, and VLFS research.

#### 3.1. Qualitative assessment on SLR impacts and adaptation approaches practiced

This section conducts site analysis on Abu-Qir and coastal planning and management approaches practiced as their properties provide the required knowledge for selecting the best mitigation solution for such area to test the hypothesis that the Nile Delta coastline will eventually be submerged where land reclamation approaches and other mitigation solutions practiced only offer short-term solutions.

Nevertheless, as a result of such approach, this paper has encountered some limitations which require considering. The Lack of long-term national analytical SLR scenarios, and regarding the assessments [10,11], this paper tracks Egypt's National Strategy for Adaptation to Climate Change and Disaster Risk Reduction [9]. It's mostly founded on worldwide climate estimates which are approved upon by the Copenhagen Accord 2009 [22] which states that temperature will increase by 2 °C maximum by the end of the 21st century. This paper applies parameters for SLR estimates (0.5 m, 1, 1.5, 2 m scenarios) by the end of the 21st century too.

Furthermore, this section conducts an evaluation design matrix on ten mitigation solutions to generate the overall evaluation of their features. Analysis included ten different adaptation solutions analyzed, solutions included: building seawalls, raising roads, building storm-water pumps, upgrading sewage systems, using beaches as barriers, creating natural infrastructure, slowing land sink-age, managed retreat, elevating houses, and VLFS. Mitigation solutions are analyzed through six variables in detail which are: descriptions, costs, durability, constructing time, lifespans, and their environmental impacts to conclude their overall evaluations which tests the hypothesis that floating structures developments may offer the optimum solution for such Abu-Qir.

#### 3.2. Exploratory analysis on floating structures

This section conducts analysis on floating structures to explore if it may offer the optimum solution regarding Abu-Qir against SLR impacts. This section conducts exploratory analysis to investigate floating structures as a more sustainable and

long-term solution for Egypt. Therefore, it analyzes floating structures by investigating their definition, applications, advantages, analysis, technological advancement, environment, and design considerations for floating body, mooring systems, breakwaters, and design. These analyses will provide the sufficient information on VLFS for Egypt's Nile Delta.

#### 3.3. Concept development on floating structures

This section applies the conclusions of the previous sections of site analysis, mitigation solutions, and floating structures to define a floating community concept model and architectural design guidelines for Egypt. This section generates project's outline, design, project characteristics, superstructure, mobility, feasibility, floating structures design approach, siting, local bathymetry, tides, and waves, structure and stability, platform size, mooring system, platform formations and modular assembly, expanding dynamics and growth strategy, pathways and wave attenuators, materials for a floating community concept for Abu-Qir.

Since there is no systematic floating structures investigation has been considered in Egypt regarding tackling SLR impacts in the Nile Delta since the government still rely on old fashioned and traditional land reclamation solutions, local guides for planning floating structures were not found. Generally, there is an absence of global authorised context regarding their implementation and usage. Therefore, basic design project standards for the floatation devices were adapted from the British Columbia Float Home Standards [1]. The guidelines and principles for achieving a sustainable floating community concept for Egypt is based on McDonough & Braungart [15], while the archetypal structural design outline adapted from Suzuki et al. [19] is set as shown in Fig. 1 to create a realistic concept for the Nile Delta.

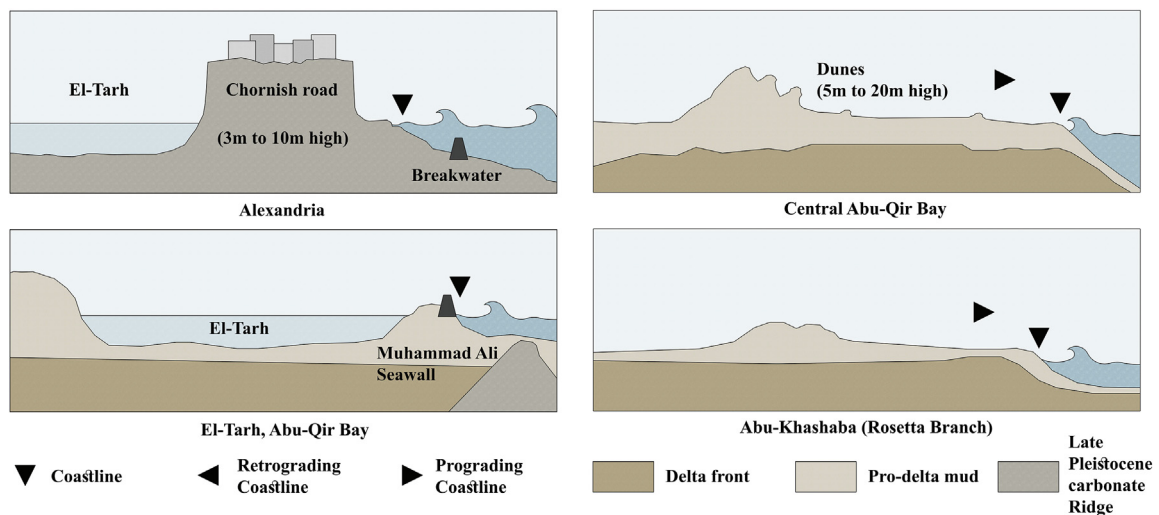
## 4. Case study analysis: Abu-Qir

#### 4.1. SLR impacts on Abu-Qir

While there is an obvious negative impact on the Nile Delta coastline due to SLR, However, it's rather hard to measure such impacts with the available data on the accurate demographics based on the SLR scenarios, social and biophysical vulnerabilities. Nevertheless, densely populated areas like Alexandria would be highly impacted when related to lower densely populated regions.

In 2019, the Egyptian population have reached 98.572 million according to the Central Authority for Mobilization and Statistics (CAPMAS). The residents of the Nile Delta littoral areas are assessed to be around 13.30 million, which accounts for 13.5% of Egypt's population. The Nile Delta accounts for the highest population density when compared to the neighbouring vast areas of Sinai, the western and eastern deserts. The most densely populated governorates are Dakahleya, Beheira, and Alexandria when compared to the governorates of Kafr El-Sheikh, Damietta, and Port Said.

Previous studies which assessed SLR impacts have identified the Nile Delta region to be the most vulnerable location to SLR in Egypt and one of the most vulnerable in the world [10,11]. While further studies which are assessed through tide gauges that are mounted in Alexandria, Abu-Qir, Rosetta,



**Fig. 1** Cross sections for vulnerable coastal areas analyzed along Abu-Qir Bay showing adaptation approaches practiced and main topographic characteristics that influence flood levels of and permanent inundation of lowlands which are caused by SLR impacts and strong storm events (Illustration courtesy of Ahmed El-Shihy).

Burullus, Damietta, and Port Said identify Abu-Qir region to be the most vulnerable location to SLR in the Nile Delta and in Egypt. This section conducts site analysis on Abu-Qir and coastal management solutions practiced as their properties provide the required knowledge for selecting the best mitigation solution for such areas and test the hypothesis that VLFS may offer the optimum solution for such vulnerable sites in the Nile Delta.

Large ports are situated lengthways the Nile Delta coastline. Ports in Alexandria like El-Dekhiela harbor, the eastern and western harbors and Abu-Qir Bay are the biggest and most jammed ports in Egypt. Such ports are sheltered by breakwaters and levees [7]. Some fishing docks are situated nearby several fish landing facilities like Abu-Qir Bay and Burullus lagoon.

The design of harbors, barriers and harbor facilities considers high waves, floods, and storm activities, to safeguard people, buildings, and infrastructures from SLR impacts. Nevertheless, such protection approaches must be strengthened to sustain such ports in the future.

#### 4.2. Adaptation approaches practiced in Abu-Qir

Coastal adaptation approaches are natural high topographies like sand dunes or artificial barriers like seawalls, levees, and breakwaters are employed in the Nile Delta's coastline. A stone ridge of around +4 m over the mean sea level is one of eight coastal ridges which expand from Abu-Qir Bay to the Arab's Bay, around 100 km west of Abu-Qir Bay [5]. Therefore, the majority of Alexandria's shoreline, a section of such ridge, is rather safeguarded from the anticipated SLR, excluding the lowland zones of Lake Maryut, Mandara (Fig. 1) as well as the southeastern depression. Nevertheless, areas exposed to disruption or any gaps in the ridge are defenceless to SLR. Abu-Qir bay has a 1.2 km stretched seawall which was constructed in 1830 and recognized as Mohamed Aly's Seawall (Fig. 1). Such seawall is 3.5 m over the mean sea level to prevent the probable SLR and high wave [5].

Artificial structures such as revetments, jetties, groins, detached breakwaters, seawalls, and land reclamation, are constructed by ESPA lengthways the Nile Delta coastline have multifunctional purposes, which involve either erosion management, or controlling shore variations and sediment accumulation at the harbor's entries, river distributaries, bays, and inlets. The materials practiced for constructing such structures are sandstones, basalt mounds, and concrete for either creating dolos or blocks.

Apart from the disastrous impacts of such traditional methods like ruining the aquatic environment and coral reefs, such traditional solutions like land reclamation method is functional only where water depth is shallow (max. 15–20 m) [26]. In a situation where water depth is more than the 20 m, henceforth the seabed would be very soft and as a result, land reclamation solutions are no longer cost effective or even reasonable [21]. However, the unexpected price of land reclamation makes it understandable why such solution may look very attractive for the ESPA. Egypt's vast landscape consist of desert, therefore the price of sand for land reclamation makes it such an easy decision. Not only its cost that makes it practiced in Egypt, but also being rapid, easy, and doesn't requiring high technology.

#### 4.3. Adaptation approaches

Table 1 above conducts an evaluation design matrix on ten mitigation solutions to generate the overall evaluation of their features. Analysis included ten different adaptation solutions analyzed which are: building seawalls, raising roads, building storm-water pumps, upgrading sewage systems, using beaches as barriers, creating natural infrastructure, slowing land sink-age, managed retreat, elevating houses, and VLFS. Mitigation solutions are analyzed through six variables in detail which are: descriptions, costs, durability, constructing time, lifespans, and their environmental impacts which conclude that floating structures could offer the best possible solution against SLR.

**Table 1** Evaluation design matrix for different types and characteristics of mitigation solutions against SLR impacts where their impact factors conclude the potential of each.

Type	Description	Cost	Durability	Construction time	Lifespan	Positive environmental impact	Impact %
Seawalls	They are built on the coast. They decrease flooding from both tides and storms.	VH	M	M-H	L	L	32.5
Raising roads	Elevating roads above sea level may help drain water and decrease tidal floods.	VH	H	H	M	M	42.5
Building storm-water pumps	Pumps could speed up the course of removing water from the roads by vacuuming up flood waters and discharging it back into the sea/ocean.	VH	H	H	M-H	M	42.5
Upgrading sewage systems	Whereas saltwater is corrosive, it could disturb tanks and push sewage to spew out, which outcomes in a smelly problem and other possible health hazards.	H	M	M-L	M-H	M	45
Using beaches as barriers	Beaches and dunes could function as a natural wall that decreases the effect of storm surges plus shielding them from erosion.	H	M	L-M	L	L	37.5
Creating natural infrastructure	Natural structures like barrier islands, oyster, coral reefs, mangroves, seagrass, and salt marshes could be united with built infrastructure, to function as seawalls, to shield from storm surges.	M-H	H	M-H	L-M	H	52.5
Slowing land sink-age	Towns could decrease land sink-age by preventing additional groundwater pumping plus introducing pilot schemes to reverse such land sink-age.	H	M	H	M-H	H	37.5
Managed retreat	Relocation.	H	–	–	–	–	–
Elevating houses	Elevating houses over flood levels by using two meters high wooden stands or concrete blocks.	M	M	M	M-H	L	50
VLFS	Artificial floating islands.	M	VH	M-H	H	VH	72.5

H: High; VH: Very High; A: Moderate; L: Low; VL: Very Low.

## 5. Research on VLFS

This section conducts analysis on floating structures to explore if it may offer the optimum solution regarding Abu-Qir. This section conducts exploratory analysis to investigate floating structures as a more sustainable and long-term solution for Egypt. Therefore, it analyzes floating structures by investigating their applications, advantages, types, environment, mooring systems, breakwaters, drifts, and design. These analyses would provide the sufficient information on VLFS for Egypt's Nile Delta.

Future SLR problems to coastlines must be undertaken over an official adaptation (namely fixed baselines or outer limits) [8,21]. Some are permitted as recognized adaptation could be through the disposition of the VLFS as a future approach not just hypothetically. Other natural phenomena's other than SLR exist like soil erosion, delta appearances, annually melted ice from the oceans, which make modifications to the shorelines, therefore highlighting the issue of portable or movable borderlines is essential to define a countries sea borders [8,21].

### 5.1. Advantages of floating structures

Where floating building method don't look like working with every case, but it still could be a practical answer in some cases, however, such approach have more benefits over the old and

traditional land reclamation solution in terms of space creation in the following aspects [19,26]:

- They're cost effective where the water depth is considerably big. Although in the case of Egypt it's different, but the price of imported sand for the usage of land reclamation in some areas has increased remarkably and a time could arrive where sand might not be even obtainable from neighbouring countries.
- Ecological friendly for the conservation of fragile ecosystems where they neither harm the maritime eco-system, nor do they silt-up deep ports or disturb the tides and sea waves.
- They are uncomplicated and fast to assemble. Different elements and components could be manufactured at different dockyards and then transported to the location to be assembled and thus sea-area could be exploited quickly.
- They could be easily disassembled or totally withdrawn if the sea space is required in the future as well as being able of expanding where they acquire modular forms.
- The facilities and the structure of the VLFS are protected to avoid harmful seismic shocks where their bases are fundamentally isolated.
- They do not suffer from a settlement gap because of the reclaimed soil consolidation.

- They have constant situations in consideration to the water surface and consequently, this enable small ships and vessels to come along to be used as docks and ports.
- Their position in seaside waters offer an attractive form in the water, making them an appropriate fit for future developments related to leisure, activities and water sport events.
- Protecting strategic economic in and offshore actions.
- Safeguarding borders and habitats like in the situations in which the submerged area was highly important and unacceptable.

### 5.2. Main types of VLFS

VLFS are simply an artificial man-made island-like platform that acts as a floating land on water. VLFS give the impression of huge panels resting on the water surface. They could be roughly characterised into two types, semisubmersible and pontoon.

The Semi-submersible type floating structures have an elevated platform above the sea level and that occurs due to the column tubes. It's very suitable in case of deploying it in high sea levels areas with big and unexpected waves impact on the floating building and at the same time sustaining a constant buoyancy force. Therefore, they can decrease the wave made movements, therefore installed in areas such as high-seas that have big waves. In the case of the floating oil drilling platforms which are made for drilling and producing oil and gas are perfect cases of the semi-submersible-type VLFSs. When connected to the seabed via vertical tethers with extremely high pretension like an extra buoyancy for the structure, they are called tension-leg platforms [26].

The Pontoon type floating structures rests on sea surface like a giant plate floating on water. It is designed to be deployed in calm waters like bays, inlets, lagoons, lakes or harbors, and adjacent to the coastlines. Large pontoon-type floating structures are called Mega-Floats by the Japanese engineers. Generally, these Mega-Floats are referred to VLFS where at least one of its sides have length more than 60 m [26].

Main components of VLFS are [26]:

- The very large pontoon floating structure.
- Mooring facility to make the floating structure in stay in position.
- An access bridge or floating passageway to reach the floating structure from the coast.
- The breakwater (it is frequently required if wave heights reaches more than 4 m) to decrease the wave forces which is affecting the floating structure).

### 5.3. Mooring systems

The mooring system guarantees that the VLFS stay in location so that the facilities mounted on the VLFS constantly work, also avoiding any drifting of the VLFS caused by the dangerous sea situations and storms. In a case where VLFS drift away, such VLFS could not only lead to possible harm to the adjacent facilities, but it also could lead to a possible loss of human lives, for example if a collision with boats or ships

occurs. The station system of the mega-floating structure could be categorized into two main approaches [25]:

- The chain/cable.
- The tension leg methods.
- The pier/quay wall.
- The pile-type dolphins-foreguide with rubber fender system.

The movements of the Mega-floating structures turn out to be big where the dimension of mooring line is relatively elongated [27,28]. Particularly in the case of deep seas, the tension leg system is implemented where the pretension is enforced to the mooring line in pursuance of preventing any motion occurrence. In a similar station keeping system, it is very hard to control the horizontal movements well and frequently the mooring lines encounter some substantial tension forces [23,25,27].

The rubber fender-dolphin method is extremely efficient in controlling the horizontal dislocation that may occur in the mega-floating structure. As the big size rubber fenders can endure significant dislocations up to roughly one-third of their spans, whereas a substantial quantity of the kinetic energy of the mega-floating structure could be absorbed. The mooring system was initially implemented in Kamigoto and Shirashima islands in Japan for two floating oil storage project bases [19]. It has been implemented later in floating piers, floating terminals, floating exhibition halls, floating emergency bases, and floating bridges [23–25].

## 6. Floating community concept model

This section conducts a floating community model of floating interconnecting platforms for an expandable floating community to establish architectural design guidelines for developing floating houses for Egypt. Abu-Qir Bay didn't only seem as the most vulnerable areas when addressing SLR, but also the ideal location for floating structures regarding its depth (18.5–22) [12] and being in protected waters. Although the Manzala Lake which lies on the eastern side of Damietta's distributary is in high risk to SLR, however its situation is not as critical as the situation in Abu-Qir Bay as well as its shallow water makes floating structures appear not to be cost effective solution for such site.

This section applies previous conclusions of site analysis, adaptation solutions, and floating structures to define a floating community concept model for Abu-Qir Bay to analyze each feature. This section generates project's outline, design, project characteristics, superstructure, mobility, feasibility, floating structures design approach, sitting, local bathymetry, tides, and waves, structure and stability, platform size, mooring system, platform formations and modular assembly, expanding dynamics and growth strategy, pathways and wave attenuators, materials.

### 6.1. Floating structures design approach

The most significant objectives concluded for any site are portability, dynamic geography, development, survival/durability, security, and water life. If such features are to be integrated with energy and food production in any design, the result will be a fully self-independent community from

the outside. The main objective here was to sustain Egypt’s coastal sovereignty while offering a self-sufficient platform to compensate for the submerged areas instead of retrieving it by old-fashioned and traditional land reclamation solutions.

6.2. *Sitting*

Although the surrounding environment [17], the public demands, and the government officials [14] define the project development and boundaries regarding building on water, nevertheless, VLFS also plays a role in choosing the most suitable site as it may not offer the optimum solution in any site. Therefore, site analysis is crucial for any site to create genuine, practical, and suitable conclusions regarding the appropriate mitigation solution for each area.

Floating structures must be designed to be able to survive not only in protected waters, but also in open waters if relocating is needed, however that would be unusual like in short-term situations such as in natural disasters. Modular platforms could help in expansion strategies, movability in case of emergencies, and creating ordered formations, especially since findings demonstrate that harbors appear to create traffic chaos. Findings demonstrate the practicality and uncomplexity of VLFS as it could be assembled/disassembled easily or totally withdrawn if their location is required in the future as well as being able of expanding where they acquire modular forms

[26]. They demonstrate to offer different elements and components could be manufactured at different dockyards and then transported to the location to be assembled and thus sea-area could be exploited quickly.

6.3. *Local bathymetry, tides, and waves*

VLFS are ecological friendly for the conservation of fragile ecosystems where they neither harm the maritime eco-system, nor do they silt-up deep ports or disturb the tides and sea waves, however, some criteria should be taken into consideration for bathymetry, tides and currents, and wave properties (Table 2) where their properties and impacts on designing floating structures are set. Findings support the argument that traditional land reclamation methods are not a practical long-term solution apart from its various disadvantages on the ecosystem. The findings provide support for the key arguments that VLFS are more sustainable as it offers a cost-effective solution where there is a big water depth in terms of space creation and preserving the marine ecosystem [26]. They are planned to be ecologically friendly as they don’t disturb sea currents or silt-up the deep harbors of Abu-Qir and the Nile Delta in general. Also, they could easily be detached or expanded as well as not getting affected by seismic shockwaves as they are characteristically remotely based. However, such solution may does not seem to be practical in every case, nev-

**Table 2** Properties and impacts of bathymetry, tides and currents, and waves on the floating structures design (Illustration courtesy of Ahmed El-Shihy).

Factors	Properties	Impact on floating structures Design
Local bathymetry	0–10 m depth within 10 km from the shoreline [26].	Mooring system dimensioning will be considered an average depth 20 m [26].
Tides and currents	Cycle of tides is on average 2.5 m/day (2 cycles per day). Current speed from 6.0 to 6.3 s [19].	The difference in height considered a mean tide of 1 m as highest wave is around 2 m. Total = 2 m circa [19].
Waves	Naturally, waves heights are equivalent to half the wavelength, therefore a 200 m long wave is relatively smaller than a 100 m long wave. Usually, when waves of higher than 80 percent of the water depth advance towards shorelines, more energy is generated, and waves gets steeper and unsteady till they break [19].	Wave properties data are essential to get, as they have influence the platform dimensions. Wave properties for a certain site is always preferable in bays or inlets than of open waters situations [25].
Wave Behaviour (own illustration).		
Wave motion on structure stress of various platform sizes (own illustration).		

ertheless, VLFS may offer a practical solution for further areas when the sea level rises even more.

6.4. Structure and stability

The long-term structural stability is one of the greatest challenging objectives (Fig. 2). Initially, the floating structure must be appropriate for the sea-site. Facilities and the structure of the VLFS should be protected to avoid harmful seismic shocks where their bases are fundamentally isolated. They do not suffer from a settlement gap because of the reclaimed soil consolidation. They have constant situations regarding water surface, hence, this enable small ships and vessels to come along to be used as docks and ports. VLFS also demonstrate to protect strategic economic in and off-shore actions as well as safeguarding borders and habitats like in the situations in which the submerged area was highly important and unacceptable.

6.5. Platform size

Platform size is subjected to social needs, functionality, site properties and further aspects such as financial and structural boundaries. The optimal size of the platforms is subjected to a lot of matters, where some could be accurately measured where some others could stay hypothetical. Findings show that optimum platform size varies between 45 and 75 m for structural stability and safety purposes [19]. Herein the platform size of 50 m a side was set for interconnecting characteristics as demonstrated in Fig. 3. Platform to wave-induced motion at various platform sizes and stress outcome on structure see Table 2.

6.6. Mooring system

Findings from site analysis and mooring system research conclude that the dolphin system to be the most suitable for

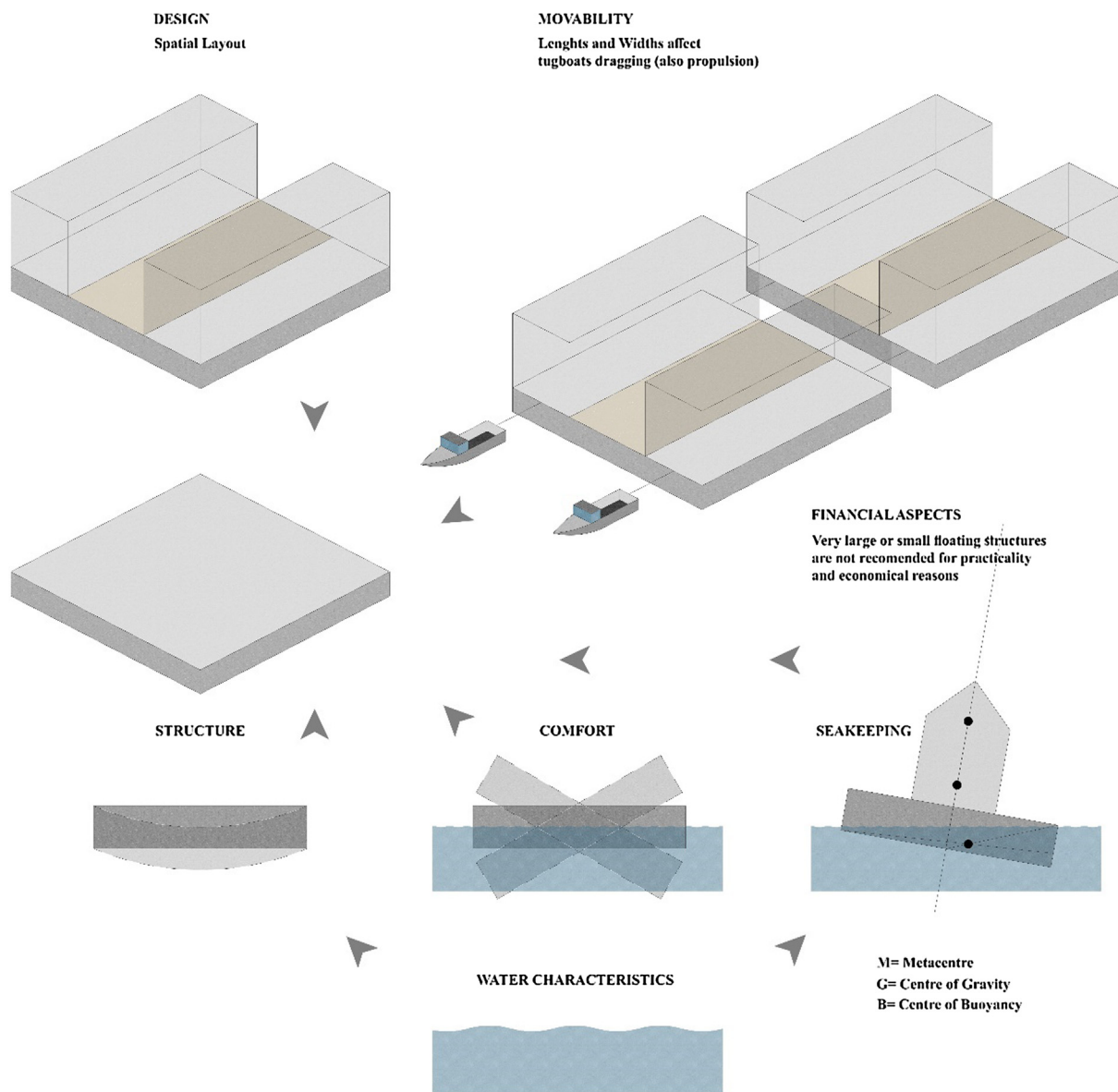
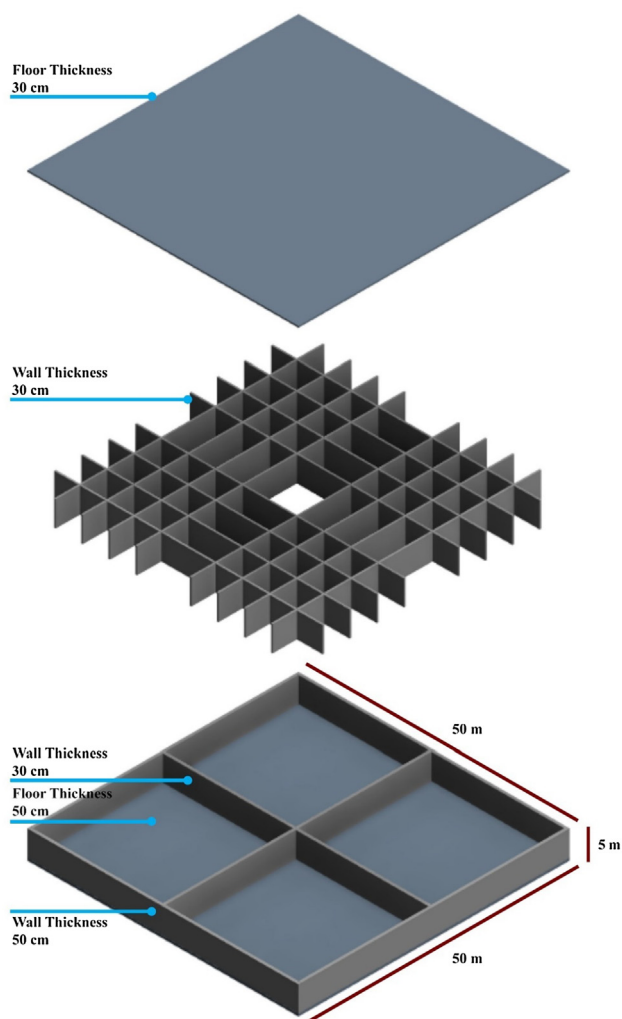


Fig. 2 Factors influencing the size of VLFS platform (Illustration courtesy of Ahmed El-Shihy).



**Fig. 3** Foundation structure of the floating platform (Illustration courtesy of Ahmed El-Shihy).

Egypt's Nile Delta coasts since such mooring system is best implemented where there are no docks, or any coastline attached structure so that the floating structure could stay in position.

#### 6.7. Platform formations and modular assembly

Modular structural interconnected modules have a blend of several positive matters. Since the project is aimed for the protected water of Abu-Qir Bay, so integrating breakwater which surrounds the community was not required for expansions as demonstrated in Table 3. However, breakwater was offered in case of relocating to deep seas is required as the floating community must be designed to be able to survive not only in protected waters, but also in open waters where that would be infrequently and only short-term in natural disasters situations.

Two floating models were designed, pentagonal and squared modules (Table 3) have offered some more organic freedom of design. The hexagonal and square design platform designs have offered the overall perfect combination solution, where it offered a straight-roads achievement, a reliable and more durable solution, as well as being able to continue

growing while only using the hexagonal modules while the squared modules can only expand in linear way.

#### 6.8. Expanding dynamics and growth strategy

Characteristics of Abu-Qir Bay in terms of its protected water, population, water depth (18.5–22), and wave properties makes VLFS as the optimum solution for such area. Being in protected waters means shielding from high waves as well as being able to expand since it won't be bounded by the breakwater. Therefore, modular platforms would be the way to expand and being nearby the coasts helps in emergency cases and transporting goods and people in and out (Table 3). Although Lake Manzala in Damietta is in protected water and have better wave properties in comparison to Abu-Qir Bay, however water depth is extremely shallow (1.2–1.5 m) and its population makes floating structures solution appear not to be cost effective approach for such site.

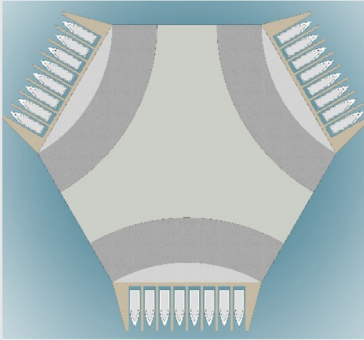
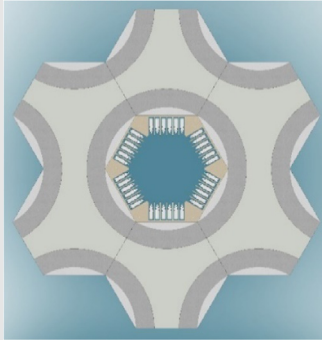
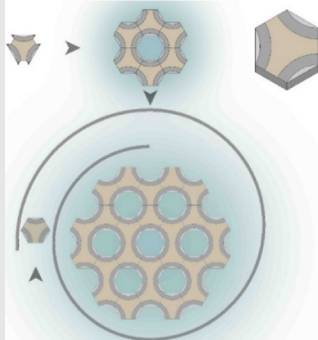
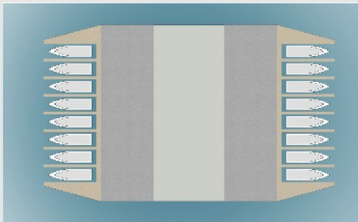
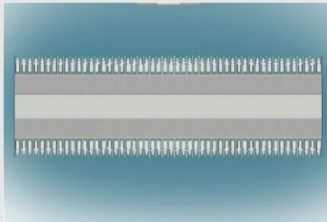
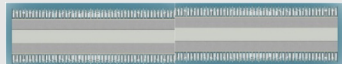
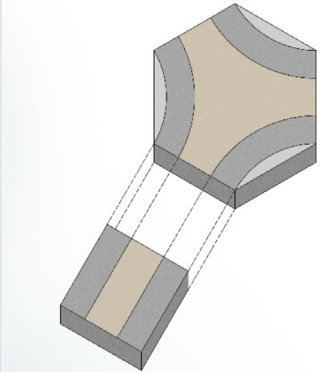
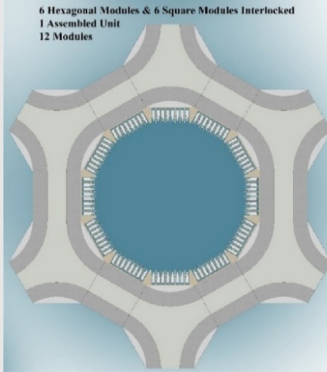
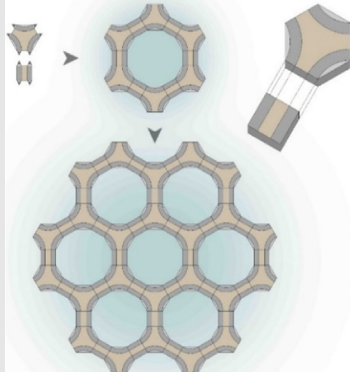
#### 6.9. Pathways and wave attenuators

Pathways are frequently attached to the floating building to the coastline and especially that in urbanized areas are generally very well attached to the neighbouring traffic system. Pathways of floatation ability are required for the gap space from coast to the floating community as it requires mooring to the seabed. Global common safety procedures require floating buildings to have emergency vehicles routes to the location and close to the building.

#### 6.10. Materials

The selected materials (concrete, steel, and composite materials) are analyzed in terms of maintenance, cost, weight, and stability. The analysis shows that concrete is the optimum selection in terms of maintenance, cost, and stability [15]. However, steel is better only in terms of weight, while showing superiority over composites regarding its cost. Nevertheless, composites have emerged a great material in terms of maintenance and weight, however, it could be only implemented in high budget projects (possibly by the private sector). Concrete is regularly practiced in marine developments, like in underwater tunnels, offshore and subsea facilities. Some marine projects have practiced underwater concrete which have since existed over than 50 years [16]. Although regarding durability and stability concrete has high-pressure strength, nevertheless it has low-tensile one. The biggest disadvantage in using concrete is the steel reinforced which is implanted inside the concrete structure to offer a better tensile strength, although such material could rust. Thus, the appropriate concrete coating thickness is required to preserve the steel is unaffected. Such process has great impact on concrete structures weights. Lately, further supporting elements are implemented like fibers, for instance the Engineered Cementitious Composite (ECC) and the Fiber-reinforced concrete (FRC). In platforms, implementing non-corrosive materials may offer huge progresses regarding resilience, mass and usage. On the other hand, composites have emerged a great material in terms of maintenance and weight, however, it could be implemented in high budget projects which will be mainly by the private sector.

**Table 3** Units Assembly Proposals of both Modules showing the harbor, wave attenuators, and master-plan options proposed (Illustrations courtesy of Ahmed El-Shihy).

Platform model	Platforms assembled to one unit (district/neighborhood)	Unites united assembled to one great unit (city-scale)
 <p data-bbox="156 649 459 676">One hexagonal floating platform</p> <p data-bbox="156 727 405 755">Hosting 480–600 residents.</p>	 <p data-bbox="579 649 906 702">Six hexagonal models assembled to create a district/neighborhood.</p> <p data-bbox="579 727 847 755">Hosting 2880–3600 residents.</p>	 <p data-bbox="941 649 1460 755">Master-Plan 'B' showing the independency of the hexagonal platform from the square one, also showing the breakwater around the united platforms. Hosting 11,520–14,400 residents.</p>
 <p data-bbox="156 989 438 1017">One squared floating platform</p> <p data-bbox="156 1042 405 1070">Hosting 256–320 residents.</p>	 <p data-bbox="579 989 906 1064">Five squared models assembled to create a district/neighborhood. Dependable.</p>	 <p data-bbox="941 989 1460 1064">Squared model doesn't need a specific platform number to create a city-scale. Dependable.</p>
 <p data-bbox="156 1457 550 1542">Hexagonal and squared platforms interlocking together for further expansion as a dynamic growth strategy.</p> <p data-bbox="156 1542 167 1564">–</p>	 <p data-bbox="579 1457 922 1542">Six hexagonal models and Five squared models assembled to create a district/neighborhood. Hosting 4416–5520 residents.</p>	 <p data-bbox="941 1457 1460 1510">Master-Plan 'A' where hexagonal and square platforms are assembled together.</p> <p data-bbox="941 1542 1244 1564">Hosting 19,200–24,000 residents.</p>

**7. Architectural design guidelines for building on water in the Nile Delta**

Architectural design of floating structures against SLR impacts rely on various aspects, such as the existing infrastructure, capitals, expertise, data and the level of reasonable distribution of resources. The results of this paper suggest the following architectural design guidelines when designing floating structures in the Nile Delta:

- The findings demonstrate that the most significant objectives for any site are portability, dynamic geography, development, survival/durability, security, and water life. If such features are to be integrated with energy and food production in any design, the result will be a fully self-independent community from the outside.
- Floating structures must be designed to be able to survive not only in protected waters, but also in open waters if relocating is needed, however that would be unusual like in short-term situations such as in natural disasters.

- Findings show that modular platforms could help in expansion strategies, movability in case of emergencies, and creating ordered formations, especially since findings demonstrate that harbors appear to create traffic chaos.
- Design strategy could help achieving self-sufficiency if the design considers integrating sustainable approaches [4,14,17] for achieving natural lightening, ventilation system, waste flow system, and water recycling system in the superstructure design.
- Platform size is subjected to peoples' needs, functionality, site properties and further aspects such as financial and structural boundaries. However, the optimum platform size recommended varies between 45 and 75 m for structural stability and safety purposes.
- The dolphin system to be the most suitable for Egypt's Nile Delta coasts since such mooring system is best implemented where there are no docks, or any coastline attached structure so that the floating structure could stay in position.
- Mooring system dimensioning will be considered an average depth 20 m. The difference in height considered a mean tide of 1 m as highest wave is around 2 m. Total = 2 m circa. Wave properties data are essential to get, as they have influence the platform dimensions. Wave properties for a certain site is always preferable in bays or inlets than of open waters situations.
- Pathways of floatation ability are required for the gap space from coast to the floating community as it requires mooring to the seabed. Global common safety procedures require floating buildings to have emergency vehicles routes to the location and close to the building.
- In platforms, implementing non-corrosive materials may offer huge progresses regarding resilience, mass and usage. Concrete is the optimum selection in terms of maintenance, cost, and stability. Although regarding durability and stability concrete has high-pressure strength, nevertheless it has low-tensile one. The biggest disadvantage in using concrete is the steel reinforced which is implanted inside the concrete structure to offer a better tensile strength, although such material could rust.
- Establishing rules and guidelines for coastal management and integrating the adaptation approaches like floating structures against SLR impacts. Including SLR impacts in the framework of the Environmental Impact Assessment (EIA) as well as the Strategic Impact Assessment (SEA). Establishing restrictions and binding regulations when providing licences for drilling wells for extracting groundwater in littoral areas [7,17].
- Involving floating structure approaches and policies to both climate change and SLR in national development strategies [4,7].
- Improving the public awareness, and scientific research, and building regulations on floating structures for vulnerable areas.
- Improving official capability and capacity for monitoring, creating strategies, and developing early stage cautionary systems.

## 8. Conclusion

This paper supports Abu-Qir bay as the most impacted area in the Nile Delta and in Egypt. Findings support the argument

made on the Nile Delta coastline that it will eventually be submerged and that land reclamation approaches practiced only offer short-term solutions. However, VLFS assessment and site analyses made do not fully support floating structures as the optimum solution in every case in Abu-Qir Bay in terms of cost effectiveness and site suitability. Nevertheless, upon site analysis, floating structures has presented itself to be the best solution for Abu-Qir bay for many reasons but most importantly for its depth, wave properties, being in protected waters, and its connectivity to main land.

The contribution to the papers in this paper are: redefining the means of SLR, analysing practices of various mitigation solutions and updating data concerning SLR impacts on Abu-Qir; developing a new prospective for tackling SLR impacts on the Nile Delta; advancing in the architectural design methodology framework of self-sustaining and expanding floating communities; establishing architectural design guidelines for constructing floating structures for Egypt; and presenting two architectural models of floating interconnecting platforms for an expandable floating community for the Nile Delta. Hence, this study advances our understanding the floating structures for undertaking SLR challenges in Egypt as the most vulnerable locations were high-lightened as well as presenting the required architectural design guidelines and floating concept proposals for future references. The results of this paper should not be generalized in any low-lying coastal area impacted by SLR in Egypt or anywhere. However, in an area with similar site and climate characteristics, wave properties, and the appropriate water depth, floating structures would present itself as the optimum solution especially in terms of cost effectiveness and sustainability like in the case of Abu-Qir Bay. Therefore, the floating community concept per say should not be observed as a precise demonstration for a future floating community module, but somewhat a blend of probable future factors to guide the future seaside area developments in which floating community projects could be well-thought-out rather than the costly land recuperation solution.

Whereas future studies at all scales are needed like from a local to regional scale assessments, however, complications beyond the 21st century must not be disregarded. Developing sustainable coastal management and architectural design strategies are required in Egypt. Coastal planning and management should be enlarged to incorporate all climate impactors in any coastal region. To conclude, any architectural design approach for tackling SLR impacts must consider also other non-climate factors to understand other possible effects and behaviours, particularly regarding human impacts and adaptation objectives, as such issues commonly worsen climate change impacts.

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## Update

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**CORRIGENDUM**

# Corrigendum to “Architectural design concept and guidelines for floating structures for tackling sea level rise impacts on Abu-Qir” [Alex. Eng. J. 58(2) (2019) 507–518]



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The authors regret forgetting to add the main inspiration behind the illustrations created for Table 2, Figs. 2, and 3 in the article. Therefore, initially we would like to caption: “Table 2 (page 513), Fig. 2 (page 514), and Fig. 3 (page 515)” as follows:

**Table 2.** Properties and impacts of bathymetry, tides and currents, and waves on the floating structures design. (Adapted from: DeltaSync (2013)).

**Fig. 2.** Factors influencing the size of VLFS platform. (Adapted from: DeltaSync (2013)).

**Fig. 3.** Foundation structure of the floating platform. (Adapted from: DeltaSync (2013)).

Secondly, the authors would like to reference the report as:

“DeltaSync, Seasteading Implementation Plan. Final Concept Report, 2013. Retrieved from: <http://2oxut21weba5oivlniw6igeb.wpengine.netdna-cdn.com/wp-content/uploads/2015/12/DeltaSync-Final-Concept-Report.pdf>”.

The authors would like to apologise for any inconvenience caused.

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