Seasteading Implementation Plan

Final Concept Report

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1. Introduction

Floating cities have been proposed by designers, researchers and organizations all over the world as a solution to the expected effects of climate change and land scarcity, or as a way to create opportunities for societal and political change. While the number of visions and designs for floating cities is impressive, the actual implementation to date remains limited to small-scale demonstration projects.

The Seasteading Institute is now working on the first part of the implementation phase, by preparing a business case for development of the first seastead. For this process, five important subjects have been identified as current priorities:

- future inhabitants' desires and requirements;
- location (suitability);
- growth and development process;
- images of the first seastead (concept design);
- costs (financial estimate of the concept design);

DeltaSync was invited to join this process and to think about the development strategy, to make a contemporary concept design and a rough cost calculation of this first seastead. The report will serve as the starting point for the development of the first seastead. It also gives an overview on which research needs to be addressed before this development can start.

This report is focused on the feasibility of the first step of the seastead, which can serve as a concept for the end goals of a seaworthy floating city. To be able to offer this, a design concept and development strategy is needed that on one hand is financially feasible and on the other hand is able to change locations in the event that the initial location is no longer suitable. To increase the feasibility, the focus for the first step will be on a design concept situated in protected waters. Because of this, the dimensions of the floating platform will be smaller than a design for the high seas. The ideal situation would be that platforms can exist without a breakwater. When moved to the high seas, the platforms should be able to survive, but be less attractive to live on from a comfort point of view. For example, moving to the high seas could be a short-term solution during a hurricane, after which the platform would be moved back into protected waters. In the best case, the floating structures could be enclosed within a breakwater to make them suitable for the high seas.

In chapter 2, the (internal) objectives are analyzed and the options not interesting for this case are eliminated. Chapter 3 describes the (external) influences from the environment, like climate and waves. Chapter 4 discusses how these objectives and characteristics shaped the design. Here, a first-draft design proposal is also given. Chapter 5 details ecological opportunities and how these could serve the implementation of a seastead. In chapter 6, the feasibility of the design proposition is described, followed by chapter 7 on growth strategy, chapter 8 on future possibilities of growth dynamics, and finally the conclusions and recommendations.

2. Design objectives

This chapter elaborates on the design objectives. The six most important objectives are: movability, dynamic geography, growth, seakeeping, safety, and water experience. For each objective, the pros and cons will be discussed, including how the objective will influence the design of the floating city. After the discussion of objectives, a prioritization of the six objectives is made, and the options that are feasible will be eliminated.

2.1. Movability

The most important ambition of The Seasteading Institute is to guarantee political freedom, and thus enable experimentation with alternative social systems. This aspect is directly linked to the ability to move a floating community when a specific location is no longer suitable because of political interference. The most important design qualities in terms of movability are the speed, safety, and convenience of the movement. The different possibilities to move a floating structure are directly linked to the size. A large structure has a relatively simple mooring system and can be moved quickly. Smaller scale floating structures have more connections between the city elements and with the ocean floor. The expected frequency of movements is infrequent, if at all. However, in some regions it would be a large benefit to be able to move away from hurricanes or cyclones.

Table 1.1 provides an overview of methods that can be applied for moving a floating city. If the structures are only moved occasionally (e.g. once in ten years or less) the self-propelled option would not be cost effective. To achieve the ability to move away from a hurricane, the option of disassembly is also not viable because it would cost too much time to disassemble. The two most suitable options are towing the floating district away and moving the floating district by semi-submersible ships. Both methods can be used to transport large and small structures, but the semi-submersible ship can also transport smaller structures over high seas. The Blue Marlin, for example, has a deck space of 63 m × 178.2 m (207 ft × 584.6 ft) and a deck area of 11,227 m2 (120,850 sq ft).[1] The largest semi-submersible ship is the Dockwise Vanguard (Boskalis) which is 70 x 275 m and suitable for extremely heavy loads.

Table 2.1 Options for Movability

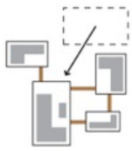
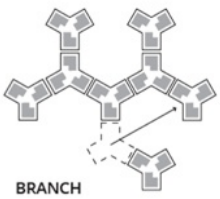
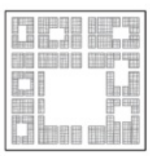
TYPE	DESCRIPTION	PROS	CONS
 SELF-PROPELLED	Ultimate movability is gained by integrating a seastead with or building it on a ship – the most suitable option if city is often relocated.	- Easy to move - Can be moved quickly - With large structures, a simple mooring system	- Large propulsion system - needed for occasional transport - High maintenance costs.
 TOWED	Seastead platform(s) are designed in such a way that they are easy to move using a tugboat or other external device that can generate propulsion.	- Easy to move - Can be moved quickly	- External device needed for transport. - Design should be suitable for towing. - For travelling high seas, only large structures possible.
 SEMI-SUBMERSIBLE SHIP	Seastead is transported by a semi-submersible ship.	- Can be moved quickly - Least design restrictions. - Freeboard can be lower, allowing better water experience - A large variety of platform sizes can be transported. - Allows smaller scale structures to be transported over high seas. - The total structure stays intact.	- External device needed for transport - Large number of ships needed when there is a large number of small platforms. - Mainly suitable for large structures. - Size of floating platforms is restricted to the size of the ship (but ship size is very large) -Structure must be strong enough to be lifted out of the water.
 DISASSEMBLED	Seastead is designed in such a way that it can be disassembled and transported using containers.	- Transport can be fast. - Transport can be to any given location.	- Preparation for transport takes a long time. - Inhabitants must be transported separately.

2.2. Dynamic geography

In addition to granting maximum freedom for its inhabitants from the political point of view, a seastead can enable greater freedom at a city level, on the community level, or individual level. This can be achieved by possibilities for moving inside the seastead with one's own house as an individual, or even moving away from the community with a group of inhabitants. The Seasteading Institute refers to this as 'dynamic geography'. Preferably, this would be enabled on as fine-grained a scale as possible, allowing movability all the way down to the size of a single autonomous house.

Table 2.2 shows different spatial configurations of floating cities that are evaluated for their ability to achieve dynamic geography. The two most suitable options are the islands and the branch. Both structures consist of a small amount of houses. Where the islands are connected by bridges or jetties, the branches are connected using a hinged connection. Because of this, both structures can be disconnected easily. The islands can be used by only one person, a family, and in the case of the branches structure, a small number of families. This gives people the ability to move to another location.

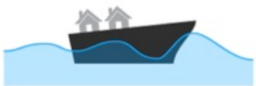
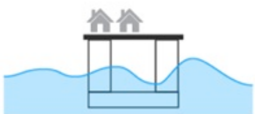
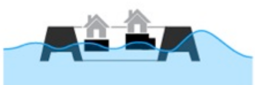
Table 2.2 Options for Dynamic Geography

TYPE	DESCRIPTION	PROS	CONS
 ISLANDS	Every building is located on its own platform (or hull). This enables maximum freedom of movement. Structures are connected with hinged joints.	- Optimal dynamic geography.	- Large number of connections. - Large number of moorings is needed. - Large swell.
 BRANCH	The floating structures consist of several houses or other buildings. The structures can be connected with hinged or rigid joints.	- Easy to move away. - Less swell than 'islands'.	- No possibility to move a single house - Structures need to be uniform to be able to fit together. - Large number of mooring constructions are needed
 COMPOSITE STRUCTURE	Semi large structures are connected to each other until they form one larger structure. Connections are rigid.	- Fewer moorings needed. - Little swell.	- Not easy to disconnect - When rearranging, adjacent structures also need to be moved.
 SINGLE LARGE STRUCTURE	Using a large structure such as a (cruise)ship or oil platform as one unit.	- Fewer moorings needed. - Little swell.	- Rearrangement not possible.

2.3. Seakeeping

Seakeeping consists of two levels: the ability to survive severe sea conditions in a protected bay and to be able to adapt for survival on the high seas. Major issues on the high seas are water depth, large (rogue) waves and (tropical) storms. These factors present challenges for mooring, wave breaking and comfort. Table 2.3 presents the options that are available for seakeeping. The cruise ship and the submerged option are not suitable for achieving a high level of comfort for the citizens. The ship experiences too much swell, whereas the submerged has no direct fresh air or sunlight. Therefore the most suitable options are the oilrig and the breakwater structure.

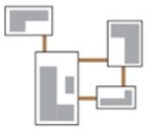
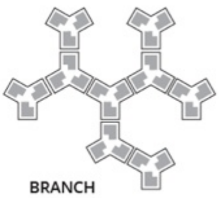
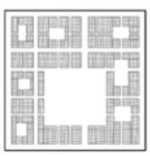
Table 2.3 Options for Seakeeping

TYPE	DESCRIPTION	PROS	CONS
 SHIP	Ships are a proven concept and large vessels are especially suitable for the high seas because of their shape and size. Wave attenuation is integrated into the ship itself. The structures are very responsive to waves and can experience a large amount of swell.	- Integrated wave protection.	- Wave attenuation only functions when ship is in motion. - Not optimal shape to create a city with public space, connections etc.
 RAISED PLATFORM	A raised platform like an oilrig or an air container type of structure minimizes the surface that is in contact with the water's surface and thus minimizes the force of the waves.	- Integrated breakwater. - Minimum contact with water surface reduces wave impact and wave influence.	- Only suitable for large structures
 BREAKWATER	An external structure is constructed to serve as a breakwater, and behind this the city can take any shape.	- Large design freedom. - Breakwater could be integrated with other systems or functions. - Creates calm water behind structure that could be used for aquaculture, recreation etc.	- External structure needs additional mooring solutions. - Is not able to withstand every wave type, which would result in swell behind it under some circumstances.
 SUBMERGED	When the structure is submerged, the impact of waves is minimized. The force of waves decreased exponentially with the depth.	- Suitable for almost every location.	- Providing enough daylight would be a challenge. - Inhabitants need oxygen. - No contact with outside climate could also cause mental discomfort.

2.4. Water experience

Water experience in the seastead can be subdivided into visual experience and physical experience. The first experience is primarily concerned with residents' ability to see the water. The second experience includes swimming, sailing, diving, aquaculture, and perhaps even surfing. Living in a neighborhood close to the water would be preferable to living on an oilrig or a cruise ship, where the connection to the water is only visual, and at a distance. Table 2.4 presents various options to create a water experience. Only the large platform is not suitable. In all other options, the smaller the platform the better the water experience. The island and branch options have the best water experience because the distance to the water is the smallest and all houses have direct contact with the water.

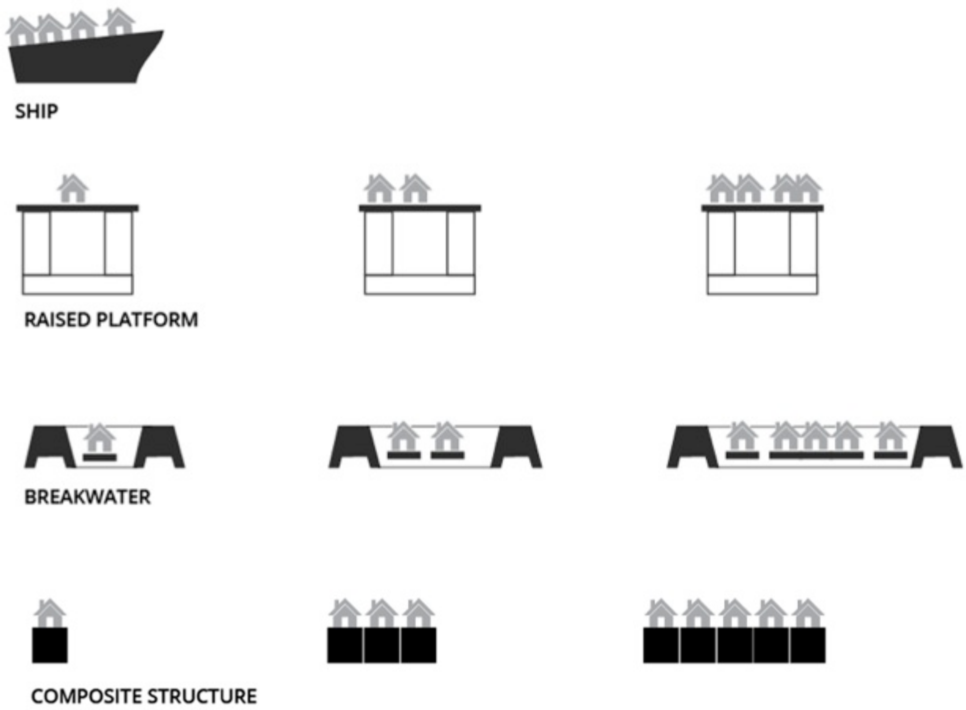
Table 2.4 Options for Water Experience

TYPE	DESCRIPTION	PROS	CONS
 ISLANDS	Every building is located on its own platform (or hull). This enables maximum freedom of movement. Structures are connected with hinged joints.	- Maximum water experience.	- Less stability. - Needs protection by breakwater, which may obstruct ocean view.
 BRANCH	The floating structures exist from several houses or other buildings. The structures can be connected with hinged or rigid joints.	- Very good water experience. - Intermediate stability.	- Needs protection by breakwater, which may obstruct ocean view.
 BAY	Semi-large structures are connected to each other until they form one larger structure. Connections are rigid.	- Nice bay-like experience. - Very stable.	- Many different platform types. - Many rigid connections needed.
 PLATFORM	Using a large structure as a (cruise)ship or oil platform as one unit.	- Building shapes not limited by platform - Very stable	- Little water experience, except from the edges. - Even the edge has less optimal water experience, because exposed to waves.

2.5. Growth development

Looking at the previous sections, roughly two types of structures can be distinguished: large structures developed at once and modular structures that grow gradually. Table 2.5 provides an overview of the options. The 'ship' or 'raised platform' structures need to be constructed and financed at once and are difficult to expand. Smaller structures, which may be protected by a breakwater or combined to one large structure, allow for much more gradual growth. For a gradual strategy, a modular system consisting of smaller parts is more suitable than large structures that are constructed at once.

Table 2.5 Growth Development



2.6. Safety

A major requirement that is connected to all objectives discussed in this chapter is securing the safety of the inhabitants. This aspect will have a strong influence on the design decisions. Safety means on one hand providing a reliable floating structure and a living environment where people can safely move around and enjoy their life. It is equally important to protect the floating city from environmental hazards like large waves, storms, and even hurricanes. Therefore it is important to be able to move away fast enough to avoid a hurricane. More information about this can be found in chapter 3.5 Climate.

2.7. Prioritization of objectives and influence on the design

Conclusions on the relative importance of the aforementioned objectives were determined during the design and research process of this study. The most important objectives were identified as movability and seakeeping, especially in terms of safety. The dynamic geography, water experience and growth development are less important. How dynamic geography could work in future situations is discussed in chapter 8. Because the size of the platform has to be estimated in order to make the design and calculate the feasibility, a first selection on size is made using the objectives. For movability in normal conditions, any size can be towed, whereas transporting in rough waters can only be achieved with larger platforms. The semi-submersible ships can move very large-scale oil platforms, but the maximum size is limited to that the size of the semi-submersible.

The dynamic geography is mainly influenced by the number of people living on the platform and agreeing to move. A smaller size platform is easier to move around in a city than a large one. From the point of view of seakeeping the size greatly depends on the significant wave characteristics a region. The smaller the platform size, the more swell. On the other hand, if the platform is too large, hog and sag can occur, which will lead to extra investments in order to strengthen the construction. The water experience will be maximized if the platforms are small in size and low in height. Small platforms are also more favorable for growth development; smaller platforms require smaller investments than larger ones. From the point of view of movability the next location is important to take into consideration. While future seasteading communities are envisioned to withstand the high seas, the first communities in The Floating City Project will start out in more protected waters, and will only be in higher seas occasionally and for short periods of time, such as when moving or fleeing hurricanes (figure 2.1).

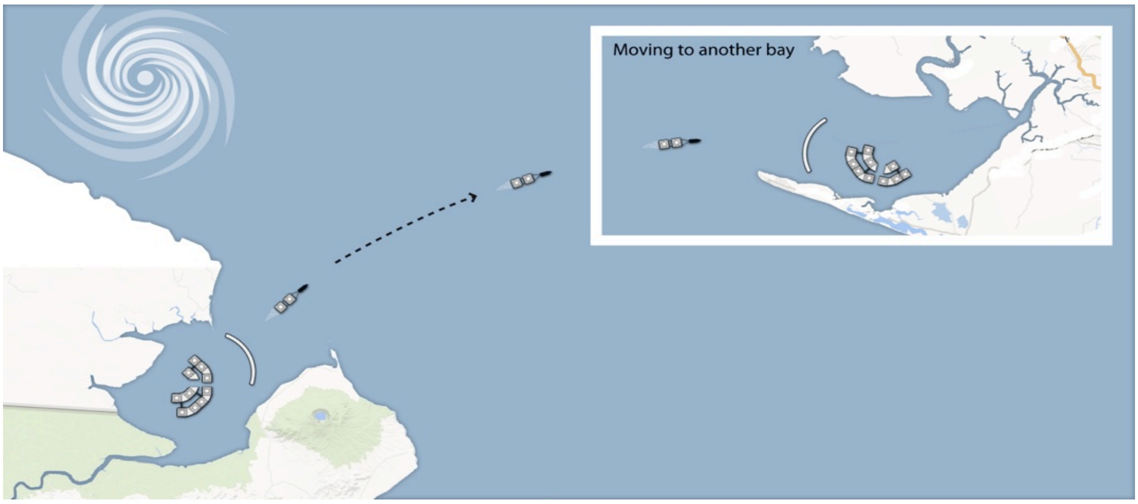


Figure 2.1 Moving from one bay to another

From the analysis in this chapter, a first selection of possibilities is made (figure 2.2). For occasional movability, the options of semi-submersibles and towed platforms remain interesting options. Because the large structures like a ship or oilrig are not interesting from the point of view of water experience, comfort, dynamic geography and growth strategy, these options are excluded. Because of this, only the breakwater option remains for the seakeeping. The small islands are also not suitable for seakeeping, because even with a breakwater comfort would be compromised. The remaining options can be summarized as a branch-like structure that can be composed into one larger structure or can be placed behind a breakwater. Modular components of a branch like city could be towed or moved with a semi-submersible ship.

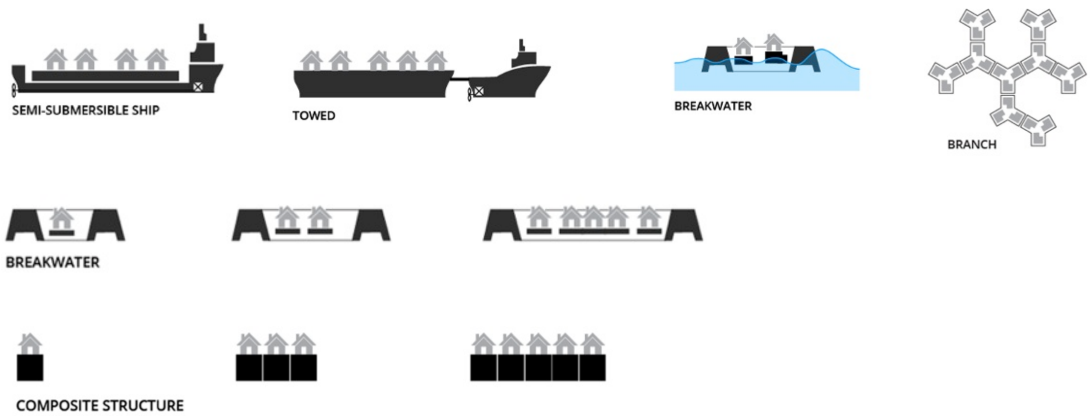


Figure 2.2 First selection of possibilities based on the objectives

3. Local conditions

It is unavoidable that the design of a seastead will be affected by local conditions. For example the wave conditions will determine the dimensions of the floating structure and breakwaters. The depth of the ocean floor (bathymetry) will affect the dimensions and costs of mooring systems and whether such systems are more cost effective than station keeping facilities. At the same time, the local characteristics that the seastead has to deal with should not be regarded as fixed values. The seastead should be able to relocate and deal with many possible scenarios. It should at least be able to be moved to another bay with approximately the same conditions. It should be able to survive less attractive wave conditions during storms and temporary relocation in case of hurricanes. In the ideal situation it should be able to handle the high seas with or without additional protection (figure 3.1).

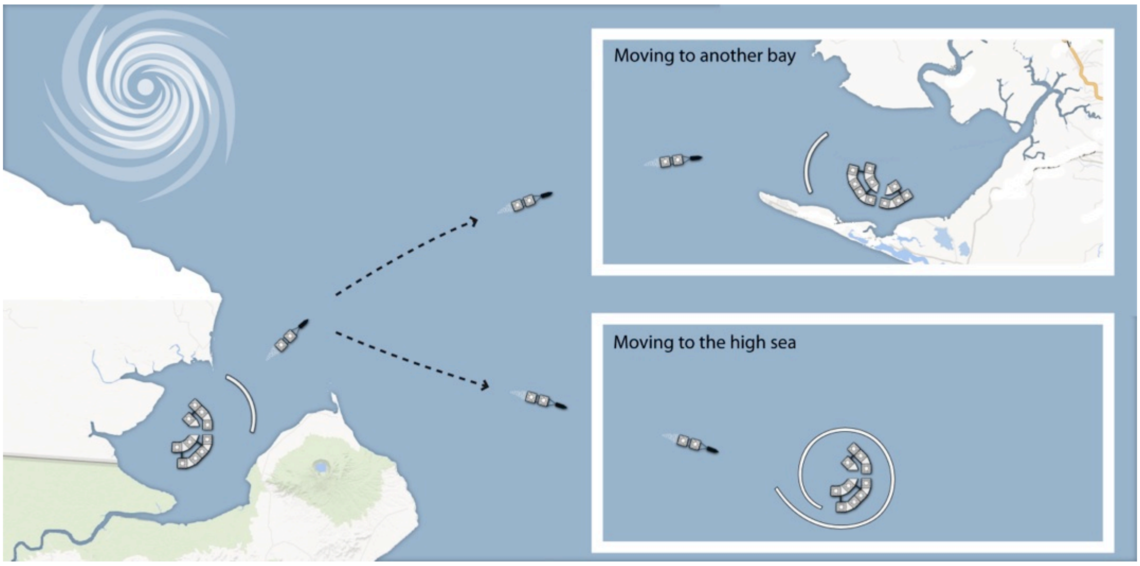


Figure 3.1 Scenarios of relocation

In order to successfully develop a growth strategy for The Seasteading Institute, an inventory of local conditions and their effects on the design have been drawn up. The conditions were subdivided into those that are of structural influence and those that affect the design in terms of energy and resource, as illustrated in figures 3.2 and 3.3.

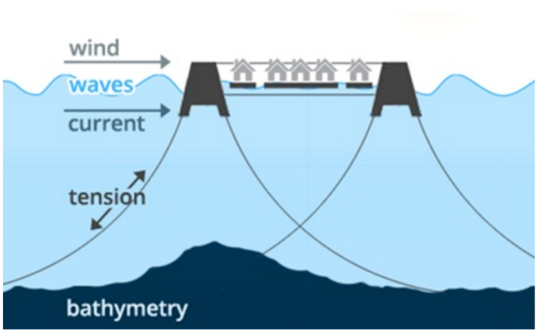


Figure 3.2 Structural aspects

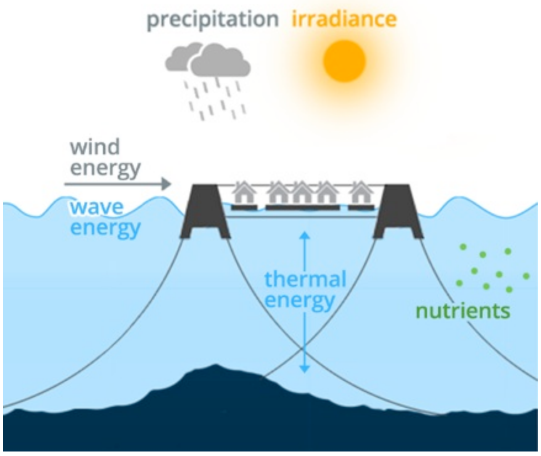


Figure 3.3 Energy and resources

3.1. Bathymetry

The depth of the ocean floor will affect the dimensions, type of material and costs of the mooring systems. Chains attached to anchors are the most common choice for shallow water up to 100 m.

Different material compositions are applied depending on soil properties, strength due to currents, differences in tides, how often the structure will need to be moved and so on. Seamounts and ridges may provide good locations for the seastead because they decrease the depth and for this the length of the anchoring system. In relatively shallow water, bathymetry also affects waves. Typically the depth of a wave is equal to half the wavelength, which means that a 200m long wave will tend to get shorter and higher if the depth is smaller than 100 meters. When the wave approaches to the coast, more and more energy is pushed upward and the wave becomes steeper and less stable until it breaks, at wave height greater than 80 percent of the water depth.[2]

3.2. Tides and currents

The local currents and tides determine the water forces on the submerged part of the seastead. A counterforce needs to be present in order to keep the seastead at the same position, either by mooring it or by propelling it. This means that the mooring system will also have to deal with these forces. The equation used to calculate this is shown in appendix 1.

In some locations ocean currents can get quite high. For example the Gulf Stream can reach ocean current surface speeds of 2.5 meter per second. At an ocean current speed of 2.0 m/s the pressure on the structure amounts to 2.0 kPa (kN/m²).[3] This amount of pressure compares to a category 3 hurricane with wind speeds of around 60 m/s (107 knots). Ocean current speeds of 1.0 m/s compare to wind speeds of 30 m/s (58 knots): a wind force of 11 on the Beaufort scale. Such speeds may even be encountered close to continents, as is illustrated in figure 3.4. In storm conditions it is likely that the structure will deal with currents and wind that have the same direction. This means that high water pressure and wind pressure can occur simultaneously.

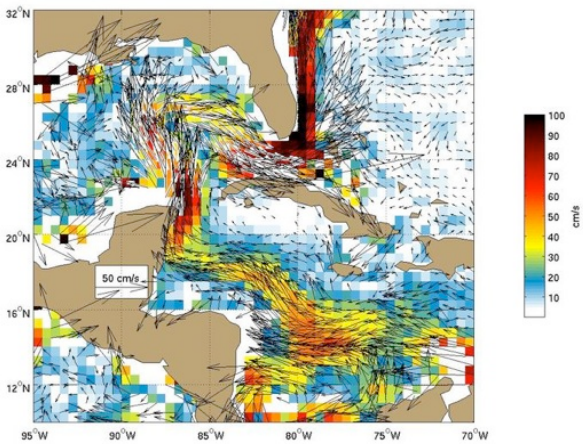


Figure 3.4 Ocean Currents[4]

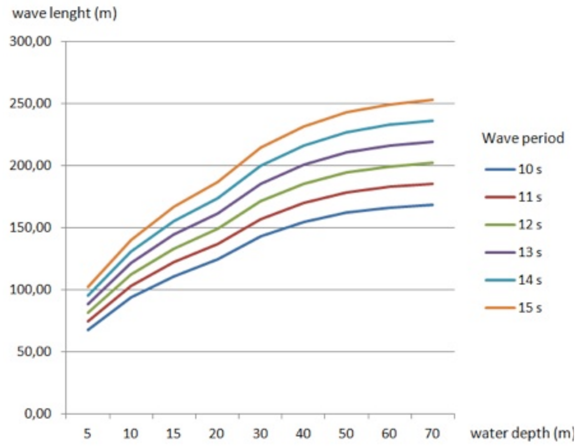


Figure 3.5 Variation in wavelength of wave with period 15s.

3.3. Waves

The main characteristics of a wave are the period, the wave height, and the wavelength. Wave period is the time it takes for successive waves to pass the same point in seconds. Long period waves (T>14 s) have more energy, a flatter profile in deep water and they create taller waves when entering shallower water but decrease in length (fig. 3.5 and 3.6). Wavelengths can be classified in short (□ <100 m), average (100< □ <200 m) and long waves (□ >200m); wave heights are classified in low (H<2 m), moderate (2<H< 4 m) and high waves (H>4 m). Wavelength and height are related to the wave period. The wavelength was calculated using Hunt's method. This allows calculating the wavelength of known period waves in any water depth, with an accuracy of 0.1 percent. The equation for wavelength can be found in appendix 1.

Wave characteristics are important to know, because they affect the size of the platform, as explained in chapter 4. The wave characteristics for the selected locations will likely be a lot more favourable than the high seas conditions, since preferable areas for the first phase of the seastead will be bays or gulfs.

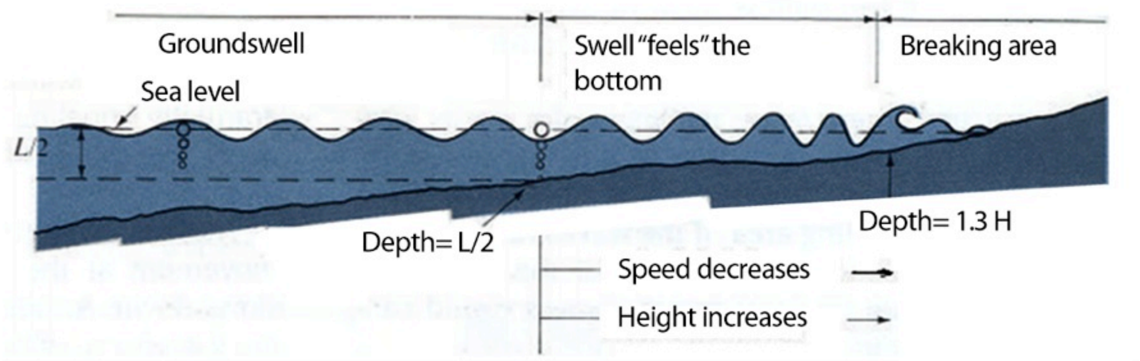


Figure 3.6 Behavior of a wave that approaches the coast[5]

3.4. Wind

Wind blowing on the water is responsible for wave formation. The size of the wave depends on the strength and duration of the wind, in conjunction with water depth. Large waves formed in open seas will continue travelling for long distances after winds have already stopped. During their travel those waves will be influenced by tides and wind from other directions, but also from the shape of shorelines. For this reason it is important to know data on wind speed and directions for the specific locations. In a bay, for example, wind waves (surface waves that occur on the free surface of sea, as result from the wind blowing over a vast stretch of fluid surface) could be predicted knowing the fetch and the wind speed. This will allow wave protection to be applied specifically in the areas where they are needed.

3.5. Climate

The general climate conditions, such as precipitation, humidity, wind and solar radiation are relevant for the construction and detailing of the buildings. High humidity will be inherent to water surface locations. This means that the structures are to be built with consideration for moisture.

In addition, particular climate zones may see more heavy storms such as cyclones and hurricanes. Cyclones are smaller and less intense than hurricanes and therefore less of an issue. Some of the potential areas for future seasteads are in hurricane prone zones (figure 3.7). According to NASA's Earth Observatory, "Globally, about 80 tropical cyclones occur annually, one-third of which achieve hurricane status. The most active area is the western Pacific Ocean, which contains a wide expanse of warm ocean water. In contrast, the Atlantic Ocean averages about ten storms annually, of which six reach hurricane status"[6].

The intensity of a hurricane can be measured using the Saffir-Simpson hurricane scale (appendix 2). A hurricane's destructive winds and rains can extend outward from 40 km to more than 240 km. The force of a tropical storm can extend up to 500 km from the eye of the hurricane.[7] Once a hurricane has formed is can be tracked and its path predicted for 3-5 days in advance.[8] It is informative to consider a worst-case scenario of a category five hurricane, allowing for planning only 24 hours in advance. In this time all platforms would need to be disconnected, one or more tugboats would need to arrive on short notice and the platforms would need to be placed in formation to be tugged away. A tugboat can reach a speed up to 12 knots, but in the case of heavy currents, 6 knots (11 km / hour) is used. This would mean that getting away from a hurricane's destructive winds would take 22 hours, leaving 2 hours for other tasks. To get away from the tropical storm force zone requires another 24 hours.

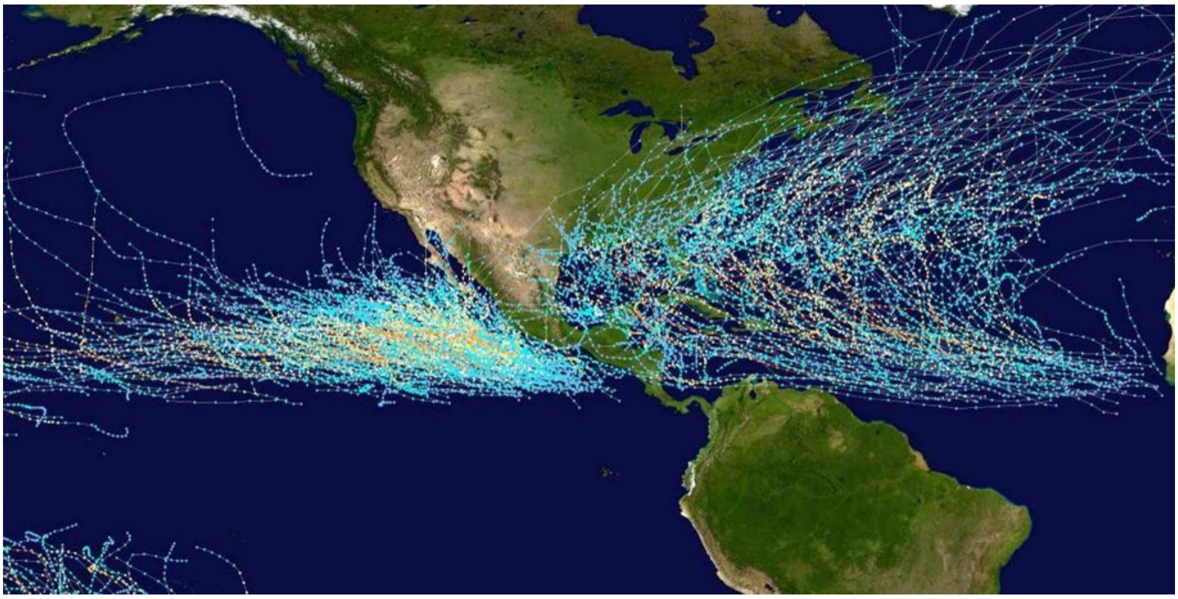


Figure 3.7 Tropical cyclone tracks, from 1985 – 2005 color is linked to the Saffir-Simpson hurricane scale.

3.6. Precipitation

Fresh water is a necessity for human survival and needs to be available at all times. Being dependent on supply from imports has risks. At the start of the development dependency is unavoidable, but as soon as the seastead reaches a certain size, it becomes an interesting option to locally produce fresh water. There are two options: water desalination and rainwater harvesting, both of which may contribute to sufficient and commercially feasible water supply. The calculation model determined that rainwater is likely to be sufficient for most applications in the site selected for this feasibility study.

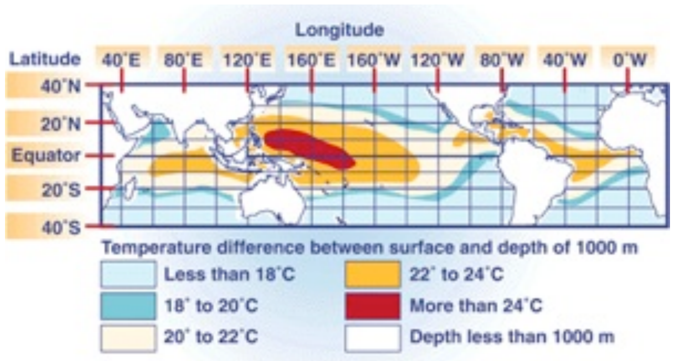


Figure 3.8 Interesting zones for OTEC: wikimedia.org/wikipedia/commons/e/e7/Temperaturunterschiede_Ozeane.png

3.7. Ocean energy production

Depending on the local conditions, a combination of renewable energy systems may be chosen. Currently, several small-scale commercial floating wind farms have been realized. Most of the designs use offshore platform technology, for example the Hywind system that features a turbine mounted on a floating pole with a 100-meter deep draft similar to a spar.[9] Costs of offshore wind facilities are substantially higher than their on-shore counterpart and will depend on the water depth and wave conditions. However, in the seasteading project there may be ample opportunities to combine wind turbines with other functions, such as breakwaters. This may bring prices down to the level of on-shore wind energy and could prove to be one of the most cost-effective renewable energy sources.

Ocean Thermal Energy Conversion (OTEC) uses the temperature difference between deep and shallow ocean water to produce electricity and, as a byproduct, desalinated fresh water. The feasibility depends on the temperature difference, which is relatively high in tropical areas (as illustrated in figure 2.8). No commercial facilities have yet been realized. Other energy producing options could be solar cells, algae biofuel and osmotic power.

3.8. Nutrients

Worldwide, a vast amount of nutrients are discharged into the oceans. These nutrients can be used to produce food or algae. Part of the supply may be recycled from human waste, which at the same time would prevent pollution of the environment. Figure 2.9 shows the level of chlorophyll, which is an indicator for the nutrient concentration. The largest concentrations occur at the edge of continental shelves where the currents cause upwelling.

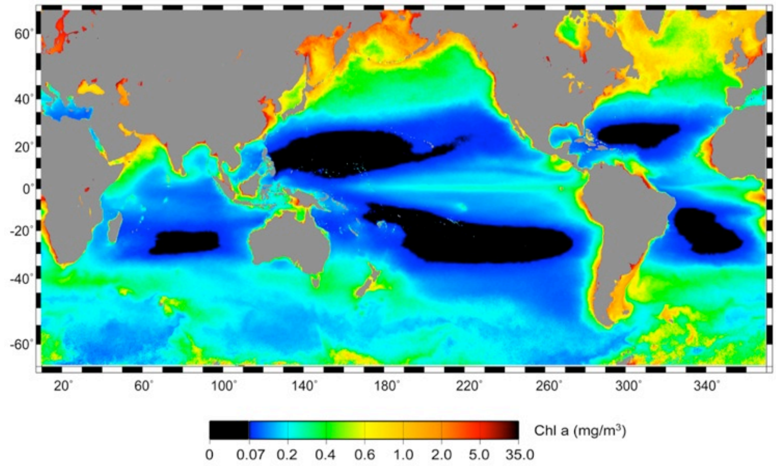


Figure 3.9 Level of chlorophyll Source: http://www.vos.noaa.gov/MWL/apr_08/Images/globe1big.jpg

3.9. Conclusions

Each of the aspects discussed in this chapter are listed in table 3.1, with corresponding influence on design. Bathymetry, waves, tides and winds were found to be the most important aspects that influence the most critical elements of the seastead. Consequently, the mooring system and the platforms will be the major focus for the design. The energy and resources overview will be mainly used for the calculation model.

Table 3.1 Overview conditions

	Local conditions	Influence on design
1) Structural	**Local bathymetry**	mooring system dimensions
	Tides and currents	structure and mooring system dimensions
	Waves	platform dimensions
		breakwater dimensions
		mooring system
	Wind and tropical storms	structures and mooring system dimensions
		time needed to escape, 240 km max from destructive hurricane force, 500 max from tropical storm force
	Climate	building design and construction (sun/rain control)
2) Energy & Resources	**Precipitation**	water treatment & storage facilities
	Nutrient upwelling	food production opportunities
	Solar radiance	energy production opportunities
	Wave energy	energy production opportunities
	Ocean thermal energy	energy production opportunities
	Wind energy	energy production opportunities

3.10. Characteristics of a specific location

To be able to provide a more realistic design, the location characteristics described in chapter 3 have been examined for one specific location. The Seasteading Institute conducted a large-scale selection process for suitable countries. Locations were analyzed on criteria ranging from the political situation in nearby nations, piracy, climate, the presence of protected waters, among others. The Institute instructed us to focus on the Gulf of Fonseca for this investigation.

To narrow our focus, we selected a location in Honduran waters for our study of the design and cost estimation. Honduras has jurisdiction over the North East part of the Gulf of Fonseca, including the Bays of S. Lorenzo, Chismuyo, Choluteca delta and part of the Bay De La Union. Large parts of the coastal area consist of wetlands (light green zones), including swamps and areas with mangroves vegetation (figure 3.10).

Figure 3.10 Location of the Gulf of Fonseca and map including EEZ.

Input for the design

Our selected location in Honduras is marked with a star in figure 3.10. This location could be an interesting option because of protected bay area and the proximity of the Choluteca airport, which could be reached by car in less than an hour (45 km). The existence of effluents from shrimp farms (currently a cause of eutrophication and hypoxic conditions), could provide nutrients for algae farming. In table 3.2 the local conditions have been summarized and linked to the design. Because no data on waves was available, two buoy points (figure 3.11) close to the bay have been used as input. In appendix 3 a full description of the analyzed input data is given.

Table 3.2 Local conditions structural influence

	Characteristics	Influence on the design
Local bathymetry	0 to 10 m depth within 10 km from the coastline.	Mooring system dimensioning will take into account an average depth 5 m.
Tides and currents	Cycle of tides is on average 2.5m/day (2 cycles per day). Current speed 0 to 20cm/second.	The variation is height considers a mean tide of 2.5m +4m (highest wave). Total = 7m circa
Waves	Significant height: 0.5-2m*. 1 out of 100: 3.3m and in storm 4m10. Yearly average: Wave period** Data based on wave forecast Average wave period 12-14s. Wave length*** at 10m depth 115m**** Swell direction SSW	

Wind and tropical storms	Within 100 km radius a few severe storm tracks were registered, which occurred every 10 years. In 2005 tropical storm Adrian passed through the Gulf.

*Based on NWW3 model predictions since 2006 (values every 3 hours). The wave model does not forecast surf and wind right at the shore so we have chosen the optimum grid node based on what we know about Punta Mango. Here the best grid node is 23 km away (14 miles). Swell heights are open water values from NWW3. Coastal wave heights will generally be less. No swell: 1.3%, 0.5-1.3m waves: 71%, 1.3-2m waves: 26%, 2-3m waves: 1.5%, >3m waves: 0.1%.
**Historic data on wave period was not found. Weather data forecast from October 9 - 20 at Punta Mango show an average wave period of 16s (varying from 13s to 19s). Green alert by Honduran authorities predicted a tropical storm with wave period of 12-14s in October 2011.
*** Historic data on wavelength were not found. If period values between 12-14 seconds are chosen, waves length will vary between 190-240m at the inlet of the Gulf (sea floor depth of 40m) and 100-130m at 10 km circa from the coast (sea floor depth of 10m)
***Based on NWW3 model predictions since 2007 (values every 3 hours). The wave model does not forecast wind or surf waves right at the coastline so we have chosen the best grid node based on what we know about Corinto. The best grid node is 21 km away (13 miles). Swell heights are open water values from NWW3. Coastal wave heights will generally be less, especially if the break does not have unobstructed exposure to the open ocean.

Figure 3.11 Buoy points

4. Design

In this chapter the objectives discussed in chapter 2 and the characteristics of a specific location of chapter 3 are applied to the design of the floating structure and real estate. First of all, an estimation of the optimal platform size is made. Then, considerations on the most suitable materials will be made and finally, a structural concept and the design of the real estate will be outlined.

4.1. Estimation of platform size

The ideal size of individual platforms will depend on many factors, some of which can be precisely determined while others remain speculative. The relevant factors that have been included in this study are illustrated in figure 4.1:

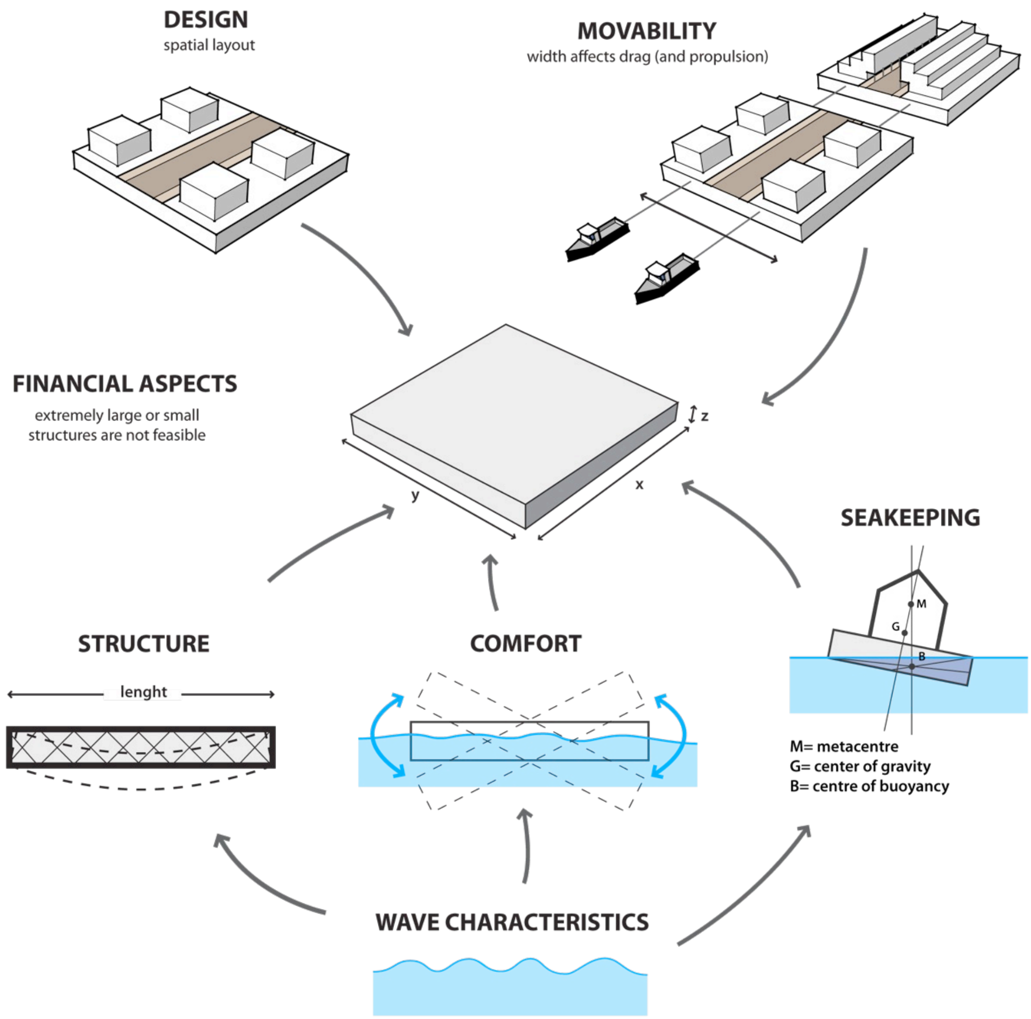


Figure 4.1. Factors that influence the optimal size of a floating platform

Movability

It is important to be able to relocate the seastead, in case of emergency or if a new location is required. Whether this is a feasible option will depend on several factors: **Connections**: the type and number of mooring connections and interconnections between platforms; **Resistance**: The hull resistance to water during transportation; **Type of transportation**: e.g. semi-submersible, tugboat, etc.

Connections, both to the ocean floor and in between different platforms are vital to the feasibility of a seasteading community. Mooring connections will keep the community stationary. In between the platforms there will be several types of connections: structural connections, utility connections and bridges. In order to enable emergency relocation, these connections not only need to be strong and flexible, but also easily disconnected. These parameters will affect the costs. Opting for smaller platforms means that an exponentially greater number of platforms are required for the same amount of space, which will increase the number of connections. This is illustrated in figure 4.2, which assumes a population of 225 people and 100 m^2 platform space per person. It follows that for a platform size of 50 by 50 meters, a total of 9 platforms are required. At least 8 connections are required to connect all 9 platforms (but additional connections may improve the strength and dimensional stability of the cluster). When the platform size becomes smaller than about 25 x 25 m the number of connections grows rapidly. Connections between floating structures are often complex and at smaller sizes may become a substantial part of the overall costs. Additionally, a large number of connections may adversely affect the ability to relocate the seasteading community in case of emergency.

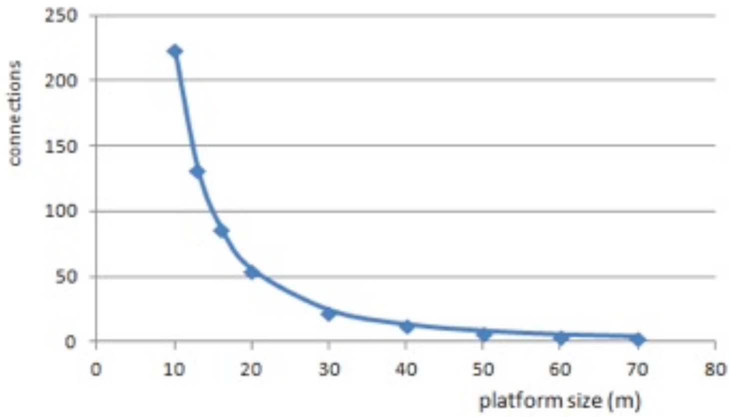


Figure 4.2 Relation between the amount of connections and platform size.

Whether movability is feasible will also depend on the amount of resistance in the water. When platforms are towed during relocation, the shape of the hull will affect the amount of resistance and thus the amount of power that is required for propulsion. A larger platform requires greater structural height and a larger part of this height will be submerged, resulting in increased draft. This means that increasing the size of the platform will exponentially increase the resistance (and the required propulsion power). Propulsion is one of the main challenges for larger vessels[11].

While the seastead under transportation is likely to travel at a lower velocity, will have a different shape and will be propelled by smaller engines (of tugboats), this comparison does indicate that the width of the platform will have a large impact on movability. A more detailed calculation is required in order to determine the maximum platform size for a given towing speed and tugboat engine capacity.

The last factor that influences movability is the required type of transportation. The ability to move away during a hurricane is one of the issues that is considered, as discussed in chapter 2. It is for this reason that the floating structure should be able to move away quickly and the mode of transportation should be one that is available at any given time. The option of the semi-submersible ship is not feasible, because the risk that it will not arrive on time is quite large. An integrated propulsion system is expensive, especially if it is only used as an emergency system. This likely limits the options to a towed form of transportation, such as local (tug-)boats. These boats could potentially also be used for the transportation of people and supplies.

Seakeeping, comfort and structural aspects

The definition of 'seakeeping' is somewhat ambiguous. It can be used either to denote dynamic response of a vessel to wind and wave conditions or a measurement of a vessel's performance in the environment (sea state) it operates in. In this study a distinction is made between 1) safety, which includes adequate strength, stability and buoyancy for given design conditions, and 2) comfort, which focuses on deformations, motion and acceleration arising from interaction with waves and wind. Both objectives are influenced by the size of the platform. Generally, larger and heavier platforms will have lower motions compared to small or light platforms, because the relative size and energy of the waves will be lower.

Stability is a measure of the platform's resistance to tilting. When waves or other forces tilt the platform, the center of buoyancy moves to the direction of the tilt, because this side now displaces more water. The upward buoyant force will counteract the tilting motion and in combination with the downward weight of the platform, it rotates back to its equilibrium. The distance between the forces of buoyancy and gravity is referred to as the *righting arm*. A larger platform has more resistance to tilting, because more water needs to be displaced in order to tilt the platform. Very small platforms with a high center of gravity are not an option because of the high risk of negative stability. Large platforms with a low center of gravity, on the other hand, also have some points of attention. In this situation the righting arm will be very large, which means that the platform will rapidly return to the upright position. This is referred to as a 'stiff' vessel. While this condition reduces the risk of deck immersion, it will result in larger forces in the structure and higher accelerations that may cause motion sickness.

As described in the Seasteading Engineering Report (Hoogendoorn, 2011), a structure that is less than half a wavelength in size will tend to mostly follow that wave; if the structure is more than twice the wavelength, its response will tend toward zero. This is illustrated in figure 4.3. It is also indicated in the report that where waves with length of over 100 m are concerned, a huge platform would be needed in order to minimize wave-induced motion for all types of waves. Furthermore, such a structure will be exposed to extreme forces due to sagging and hogging. In order to deal with such forces, the structural height may need to be increased, which will have dramatic effects on financial feasibility and practical usability.

Whether a size of half the wavelength results in acceptable levels of acceleration (the main cause of motion sickness), will depend on many factors. As described above, the wave response time of the structure will depend on the total mass and distribution of mass in the structure. Secondly, research indicates that altering the shape of the platform may reduce acceleration considerably.[12] Finally, several platforms will need to be connected. This may further reduce negative effects of waves. More research and detailed simulations are needed to further investigate the optimal size, shape and connections.

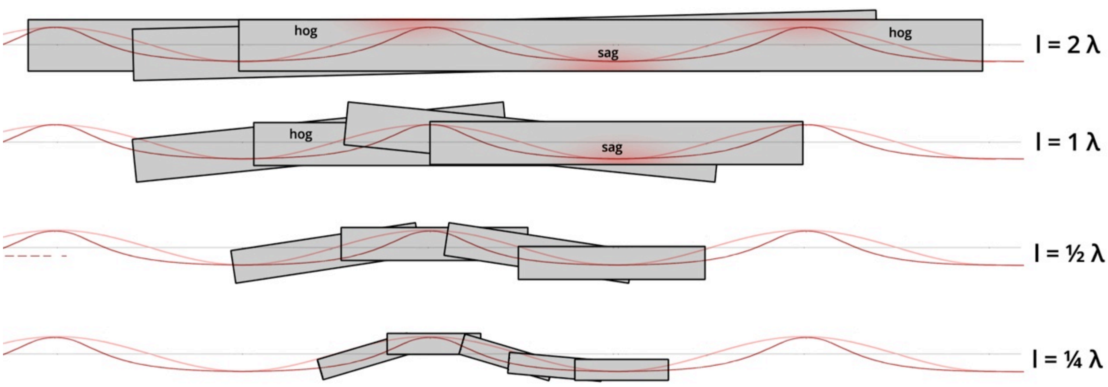


Figure 4.3. Wave-induced motion of a platform at different sizes and resulting stresses in the structure.

Ideal size from a design perspective

The platform is likely to be the most expensive part of the seastead. In order to keep the costs down, the amount of sellable floor space needs to be optimized. A platform width between 40 and 60 m is ideal to fit two rows of houses and leave enough space for roads or access/escape routes. Smaller platforms with a single row of houses would still need a road in order to access the house or provide emergency escape routes. This would make the design less efficient in terms of sellable floor space. This will be further elaborated in section 4.3.

Conclusion

One of the objectives of this project was to come up with a more feasible alternative to large scale floating developments such as cruise ships or semi-submersibles. It was found that from a design perspective 40-60 m platforms, with a mean size of 50 by 50 m, would be ideal. This is also a good size to ensure movability by tugboats. Larger wavelengths may present problems in terms of comfort, but as discussed, it is not structurally feasible to try and deal with this by making extremely large platforms. In order to solve comfort requirements it is advised to do a more detailed study on how interconnected platforms with semi-flexible connections behave under different wave conditions. Although the data on the ideal dimensions of the platform is not yet conclusive, for this design the size of 50 x 50 meter has been chosen as a basic size. More detailed data on local wave characteristics and further research on the structural design is needed to evaluate this assumption. For comparison of the chosen size, the platforms have been compared to other sea vessels in figure 4.4.

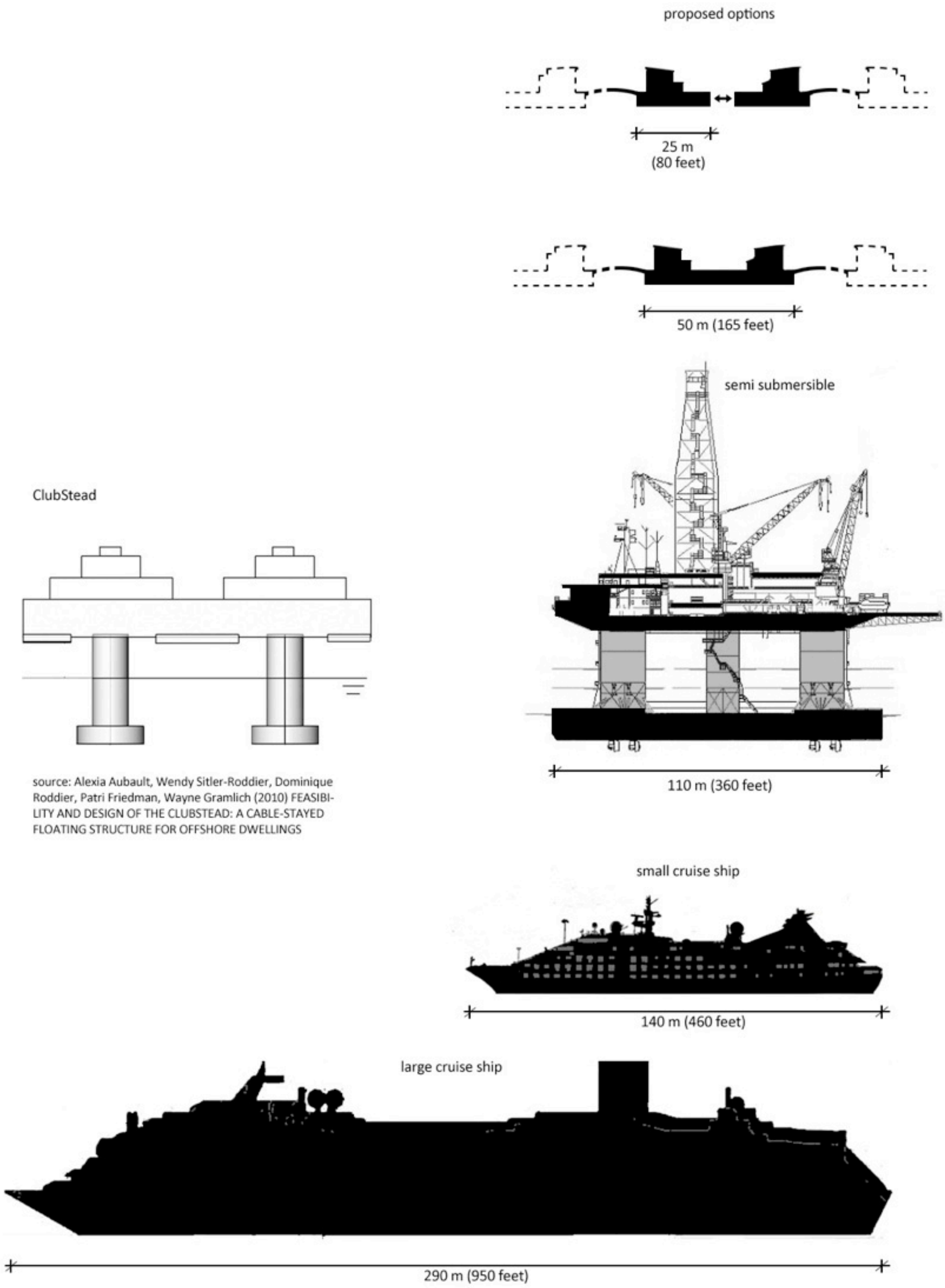


Figure 4.4 Size comparison of floating platform with alternative strategies.

4.2. Platform structure and material

There are three main material options for the platform structure: steel, composites, and concrete. Steel is the most frequently used material in the ship building industry, because it can be easily shaped and curved, has a high tensile strength and is easy to repair or modify. The drawbacks of steel are the high price and high maintenance costs (needs to be repainted on a regular basis in order to prevent corrosion).

Composite materials combine fibers (carbon-, glass-, cellulose, Kevlar, etc.) and a hardened resin (epoxy, polyester, vinyl ester, etc.). Despite their generally high costs, they are increasingly used in high-performance products, such as racing cars, airplanes, tennis rackets and fishing rods. The material is also commonly used in the construction of yachts, sailboats and surfboards, and the use of the material is currently expanding to many other industries. The material does not corrode, is durable, requires hardly any maintenance, is lightweight and can be stronger than steel. The main drawback is the price, which ranges from high to very high, depending on the type of resin and fibers that are used.

Concrete is also frequently used in water-related projects, such as submerged tunnels or offshore facilities. There are examples of submerged concrete that have remained structurally sound for over 50 years. Concrete has high-pressure strength but a rather low tensile strength. The main vulnerability of concrete is the reinforcement steel that is embedded in the concrete to provide tensile strength. This material may corrode. Therefore, a sufficiently thick layer of concrete needs to be applied to make sure the steel is not affected. This has large implications for the weight of concrete structures, and the amount of material that is used. Recently, other types of reinforcements have been used such as fibers (e.g. Fiber-reinforced concrete (FRC) and Engineered Cementitious Composite (ECC)). For floating platforms, using non-corrosive reinforcements would bring great improvements of durability, weight and material use.

The three basic materials described above are all technically viable for water constructions. In table 4.1 the pros and cons of each material are listed. Concrete is preferred, because it hardly needs maintenance and is the cheapest option, in particular when there is a lot of repetition in the construction. A heavy concrete base will also be very stable, because it has a low center of gravity. Lighter platforms on the other hand have higher center of gravity and therefore they are less stable, especially if real estate structures are added. Except for the price, composites would also be an interesting option, and is a lighter construction that could be used for the real estate as well. Currently, several new systems are being developed and tested. Because not all of the information on these new techniques are yet available, the conventional concrete is chosen for this design and cost estimate.

Table 4.1 Comparison of materials for the platform

	Maintenance	Costs	Weight*	Stability
Concrete	20-50 years	$	600 kg/m^2	very stable
Steel	2-5 years	$$	200 kg/m^2	stable
Composites	20-50 years	$$$($)	70 kg/m^2	less stable

* weight calculations: Hull weight (kg/m2) = Hull thickness (m) * material density (kg/m3). Concrete: 0.25 m * 2400 kg/m3 = 600 kg/m2 ; Steel 0.025 m * 8000 kg/m3 = 200 kg/m2; Composites 0.04 m * 1500 kg/m3 + 0.04 m *

The floating platform will be designed as a hollow box (*caisson)*. Usually, large concrete caissons are compartmentalized with walls, in order to reinforce the structure. Instead of using walls everywhere, a series of ribs can be placed on the floor of the caisson. The ribs will carry the load of the water pressure to the columns, similar to beams that carry the load of a floor. The voids, in between the ribs, may be used for cables and wiring and fitted with insulation material. The main elements of the concrete floating platform are shown in figure 4.5. The dimensioning is based on expert judgement from a specialist on large scale floating structures. Part of the hull thickness provides concrete cover, which is needed to protect of the steel reinforcement in the concrete structure from the saline waters. The sizes shown in the figure are estimations; a thorough calculation would be needed in the next phase, including maritime conditions on selected locations.

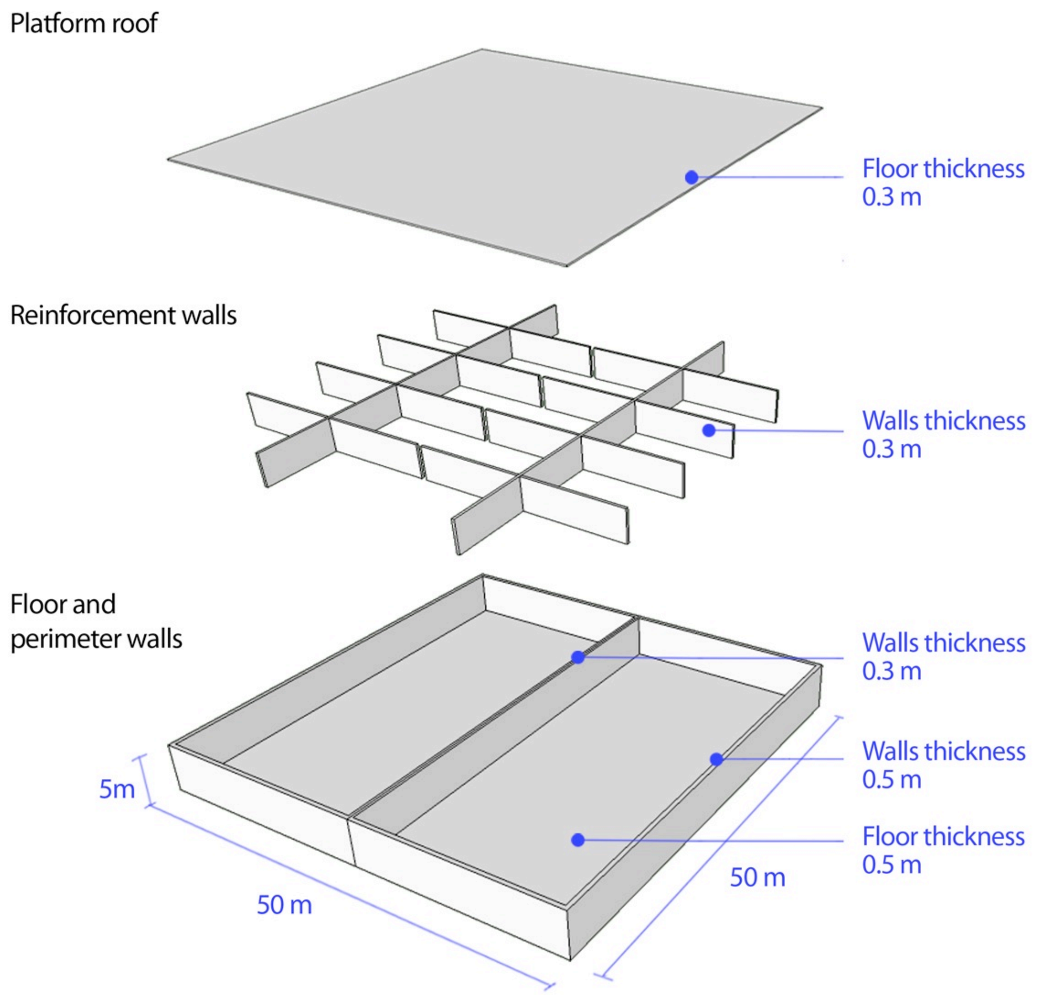


Figure 4.5. Exploded axonometric of the structural elements of the platform and assumptions of dimensions.

4.3. Buildings on the platform

In this section the platform size is evaluated from the point of view of the real estate. This is done to understand how different functions and building typologies can be accommodated on it. The functions include:

- buildings for housing, offices and hotel
- streets
- green and public space
- private open space

Buildings and open space need to be integrated in 50 m x 50 m platforms. Sections combining multiple functions on the basic platform were made, showing design options for housing, offices and hotels. The street width varies between 7 to 10 meters in order to keep enough distance between two facing households. The building depth is usually not larger than 12 meters in order to facilitate natural ventilation, fundamental for the comfort in hot-humid climates.

Housing

Three different housing typologies were studied for the square platform. The first typology includes 3-floor apartment blocks with large terraces oriented towards the water. On the platform, two of those buildings are constructed and the space between them (7m to 10m circa) is used for the street and the public green space. The edges of the platform include private open spaces owned by apartments on the ground floor. Facades on the street can include arcades that provide covered public space and protect inhabitants during rains. Ground floor space can be used for apartments, small offices and shops. Such buildings on one platform are suitable for approximately 30 inhabitants.

The second housing typology includes detached houses (villas) with private gardens. This typology has a very low density, from one to six houses. When two or more houses are built on one platform a street to access them is necessary.

A solution that allows achieving higher density with houses is to build two blocks with 3-floor terraced houses or 2-floor houses on top of shops/offices. The section for those building typologies includes a street in the middle and two rows of houses with private gardens facing the water. The density is equal to roughly 30 inhabitants per platform.

Offices

An option for a large office building is also included in the design exploration. The footprint of the building includes a covered courtyard in the center. Streets and green spaces are built around the office building, which can be used by a large company or shared among more offices.

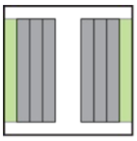
Hotel

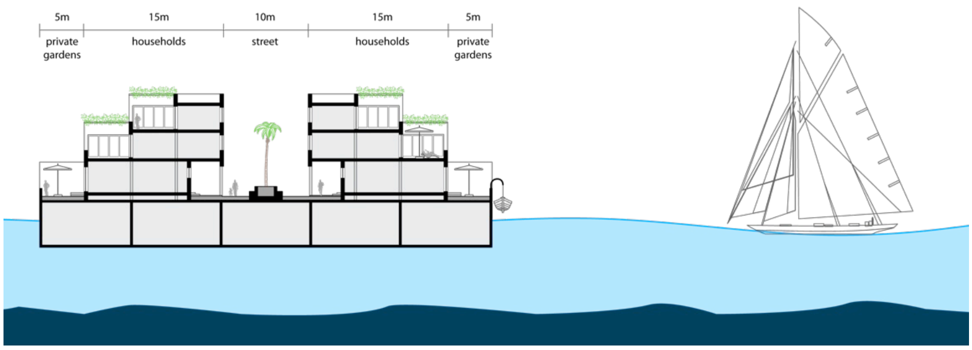
The building, dimensioned for 50 guests, has a gross floor area of about 2000 m^2. If the hotel is designed on multiple floors, space on the platform is available for a large swimming pool and/or other facilities. Attention should be given to the balance of all those elements that share the platform.

Preliminary designs for all of these functions are included in table 4.2.

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

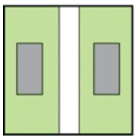
FUNCTION
Apartments block

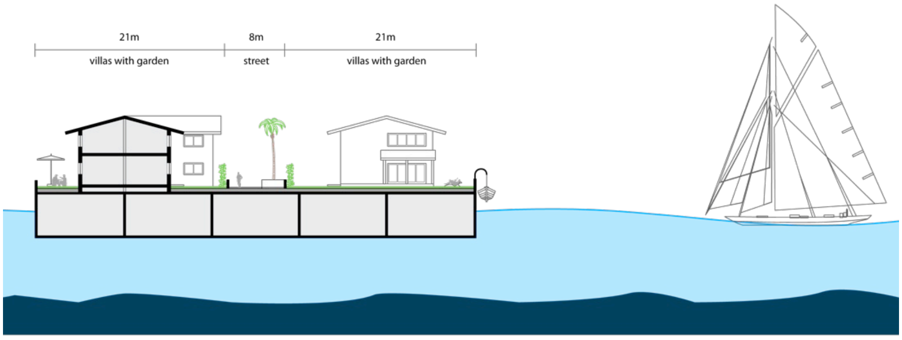




Building footprint:1,200m^2
Street/public space: 900m^2
Private open space: 400m^2

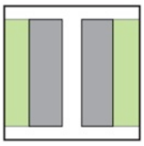
Villas

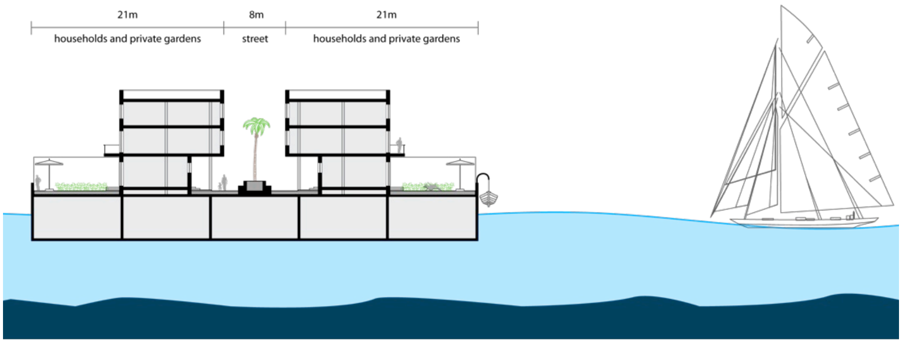




Building footprint: 400m²
Street/public space: 400m²
Private open space: 1,700m²

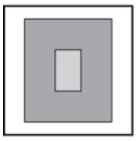
Terraced houses block

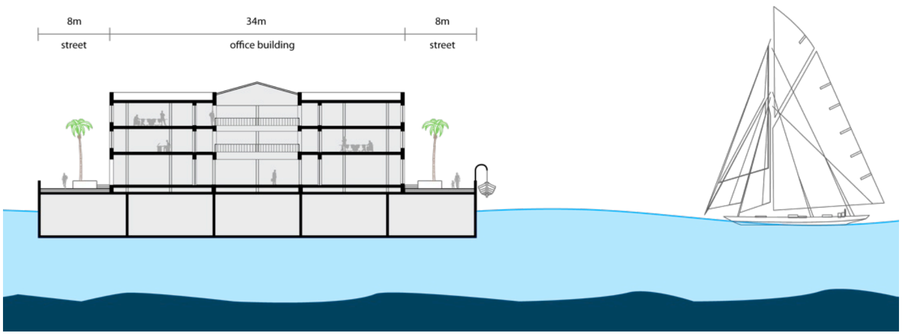




Building footprint: 880m²
Street/public space: 820m²
Private open space: 800m²

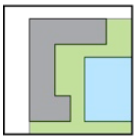
Offices

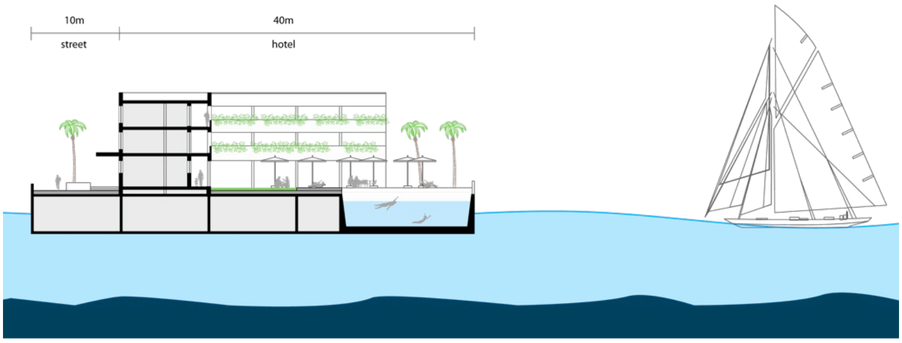




Building footprint: 1,360m²
Street/public space: 1,140m²

Hotel





Building footprint: 660m²
Street/public space: 700m²
Private open space: 1,140m²

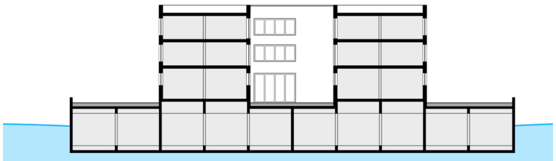
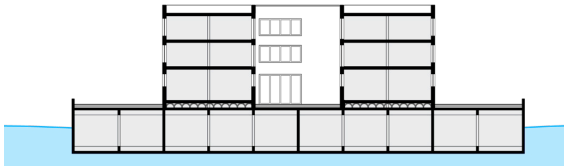
Ground floor

When buildings, roads and green areas are constructed together on one platform, it is important to keep the ground floor of the buildings higher than the space outside, in order to prevent rainwater and dirt from streets and gardens to flow inside. Extensive green on the platform roof for example, can have a total height of 30-40cm, including soil, drainage layer, membranes and floor gradient. This means that building floors need to be raised some tens of centimeters in order to be higher than the exterior space.

For the floating platform, two options are available. The first option is to raise the areas of the platform roof where the buildings are going to be constructed. The second option is to build one flat platform roof and raise the ground floor of the buildings enough to keep water and dirt away. The main pros and cons of each option are summarized in Table 4.4. Option "a" includes different levels on the platform roof, whereas option "b" proposes a standard platform that doesn't need to plan in advance the exact location of the buildings. From the comparison, option "b" appears more optimal from the point of view of construction standardization, flexibility and waterproofing of the floating platform. However, this option requires an additional floor to be built on top of platform. An option to realize it is to use plastic formwork for concrete foundations (Figure 4.6). Those modular elements allow creating a self-load platform where a concrete floor can be poured on. The system is simple to construct, flexible and economical (30-40 euro/m^2). The advantages are rapid construction times, availability of space for pipes under the floor and possibility to keep the area ventilated against humidity. For the feasibility calculation option "b" is chosen.

Figure 4.6 Plastic formwork elements for ventilated foundations and raised floors. www.infobuild.it

Table 4.4: Overview of pros and cons of the two options for the platform roof.

Option "a": multiple-heights platform roof	Option "b": single-height platform roof
	
Pros: • Flooring can be constructed directly on the platform: no need for an extra floor	**Pros:** • Standard platforms with a defined roof height are built for every typology of buildings • Since the platform roof is one flat surface, waterproofing and drainage are easier • Standard columns with the same height can be used in the platform
Cons: • Buildings' type and placement have to be decided in advance before manufacturing each platform • Since the platform roof is made of higher parts (buildings' floors) and lower parts (roads and gardens floors) waterproofing and drainage might present issues • Columns in the platform have different heights • Higher platform costs compared to platform in option "b"	**Cons:** • An extra floor is built to raise the ground floor • Additional costs for the raised floor (~30-40euro/m^2).

4.4. Urban configuration and preliminary design

The conclusions of the previous chapters form the basis of the preliminary design for the first seasteading community. Chapter 2 concluded that smaller interconnected structures would be a promising option. This allows relocation with ordinary tugboats. Floating breakwaters can provide additional protection against waves. In chapter 3 the influence of local conditions were established and in this chapter (chapter 4) it was concluded that medium sized platforms of around 50 m would provide an optimal balance between safety, comfort and feasibility. A strategy for growth, which allows the seastead to start out as a small settlement and gradually grow bigger, has also been taken into consideration. This strategy will be discussed in detail in chapter 7.

Aside from the objectives discussed in previous chapters, the system to be developed needs to address several other considerations:

1. The system should consist of a small number of basic elements in order to keep down costs and allow uniform standardized connections. This will simplify the configuration and later reconfiguration of the urban layout.
2. The system should enable many different variations to keep open future possibilities for the floating community.
3. The system should enable circular layouts in order to efficiently fit a floating breakwater that is as short as possible (a circle has the shortest perimeter for a given area).
4. The platforms should be connected in such a way that they create a dimensionally stable cluster. This means that several platforms will need to connect with more than two other platforms.

A system was developed that meets the above criteria, based on two basic shapes: a square and a pentagonal shape. The results and considerations are illustrated in figure 4.7. A pentagon allows the creation of circular clusters, because two opposing edges are oriented at an angle of 36 degrees. This means that 10 pentagons are required to create a full circle. One or more rectangles can be placed in between the pentagons to change the radius of the circle, or to create a different amount of curvature. The system was further developed into a preliminary design for the initial seastead and a perspective for possible future stages of the seastead (as shown in figure 4.8).

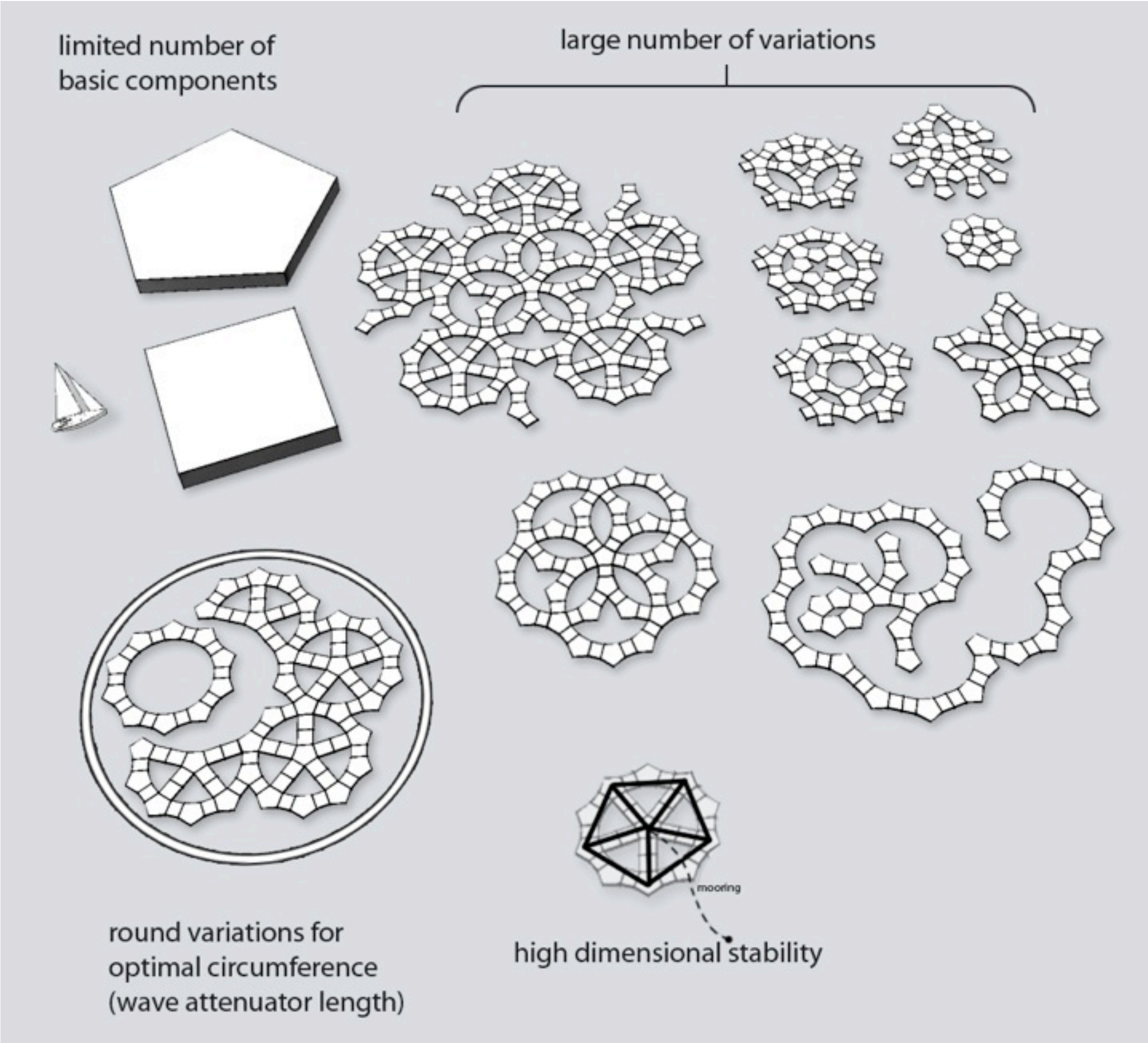


Figure 4.7 System for urban configuration

Figure 4.8 Preliminary design for initial and long-term seasteading community.

5. Sustainability and ecology

After the concept design is finished, the next challenge is to find the appropriate adaptation strategy – a strategy that creates a safe and livable urban environment on the sea, while minimizing impact on the ecosystems and making efficient use of the available resources. In this section, we explain the Blue Revolution concept and apply it to the seasteading concept, in order to find out how it may contribute to providing three necessities: food, water and energy.

5.1. Blue Revolution concept

For centuries, cities have been depending on surrounding areas for land, water, energy, food and materials. In the last decades, raising awareness on the limited amount of natural resources available for a constantly growing population pointed out the necessity of changing the way cities manage those resources to fulfill their needs.

In their process of growing and developing, "Cities transform raw materials, fuel, and water into the built environment, human biomass and waste". [13] The flow of energy and material through cities is called Urban Metabolism. As cities grow, this flow increases, using more resources and producing large quantities of waste, which is often dumped in the environment. This so-called "linear metabolism" leads to a rapid depletion of resources at the beginning of the resource flow and accumulation of waste at the end. In order to make a more efficient use of the finite resources of the planet, the concept of waste needs to be eliminated (figure 5.1).

If the output of one system becomes an input for another, the metabolism of cities will increase its efficiency. Closing the linear resources flow of cities and transforming it into a cycle is fundamental for current and future cities. Those principles are at the basis of the Blue Revolution, which propose floating cities as a solution to reuse the waste (nutrients and CO_2) from existing delta cities, producing food and biofuel on the water, in an efficient way. The following paragraphs will explain which parts of the Blue Revolution concept can be applied to the seasteading design.

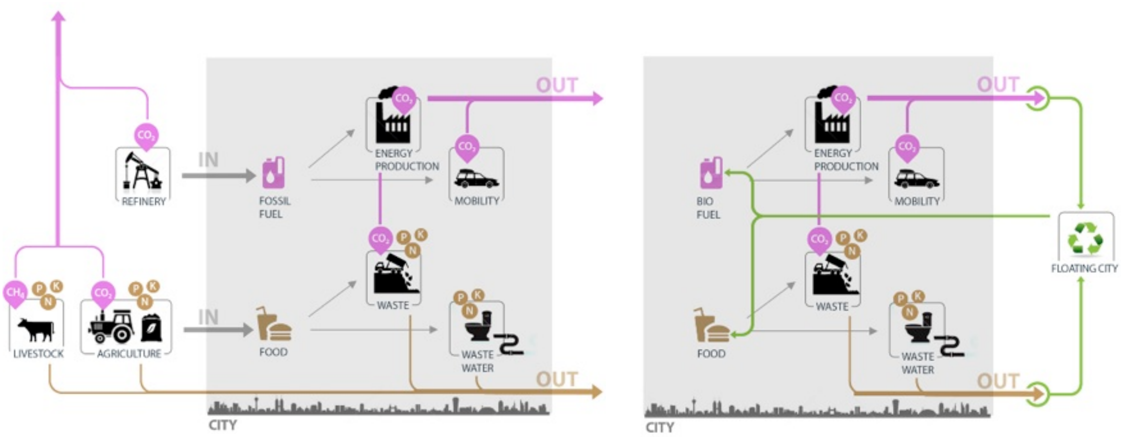


Figure 5.1 Comparison between linear metabolism of current cities and the closed loop of nutrients created by introducing a floating city that uses the Blue Revolution concept (DeltaSync, 2012).

5.2. The reuse of nutrients

A vast amount of energy is required for industrial ammonia synthesis, necessary to sustain the current size of human population. However, at the same time, nutrients introduced in agro-ecosystems are often lost in the environment, polluting water bodies and destroying aquatic life in affected areas. Depletion of nutrients is a serious risk for the food security of cities.

Algae production

Those nutrients now wasted could be used as inputs by floating cities to grow algae and produce food and biofuels (Blue Revolution). Biofuel can be produced on the water, 10 to 20 times more efficiently than crops and without competing for scarce agricultural land. Biofuel production from microalgae has a lipid content of around 40%, giving biodiesel yields of 40 to 50 tons per ha per year.[14] This means that a floating city could be able to produce energy through the reuse of waste products as wastewater and CO_2. Another benefit is the positive impact that floating cities will have on the ecosystems. By extracting nutrients and CO_2, water quality of aquatic ecosystems can be significantly improved.

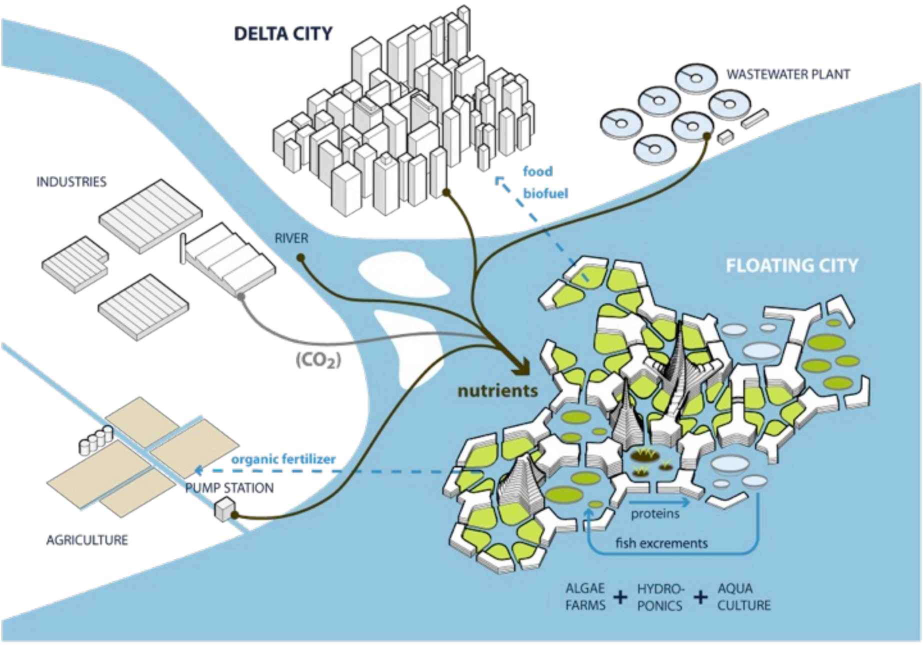


Figure 5.2 Scheme of nutrients and CO_2 flows within the floating city-delta city system. Waste from delta areas is used for energy and food production, creating a symbiotic relation between the land-based city and the floating city (Deltasync, 2012).

Floating algae and seaweed farms could be constructed within the seastead. An innovative system to grow algae on the sea is the OMEGA (Offshore Membrane Enclosure for Growing Algae), developed at NASA by Jonathan Trent. OMEGA is a collection of closed photo-bioreactors constructed out of flexible plastic that can be filled with treated municipal or agricultural wastewater that would normally be discharged into the ocean. The modules float on the sea surface, maintaining the algae in ample sunlight. Forward osmosis membranes allow clean water to diffuse out of the bioreactors, leaving inside an algal paste, which can be easily harvested and processed into biofuels, animal feed, fertilizer, and other bio-products (NASA, 2012).

Food production

In combination with algae culture, food production can be realized in floating cities. There are multiple concepts and technologies available for water-based food production. The concepts of aquaponics and multi-trophic aquaculture could be applied within the seastead, producing local fresh food that can be directly consumed by the city or exported. Local food production is fundamental for some products, fresh vegetables in particular, which would be more difficult to keep fresh while being shipped from the land to the floating city.

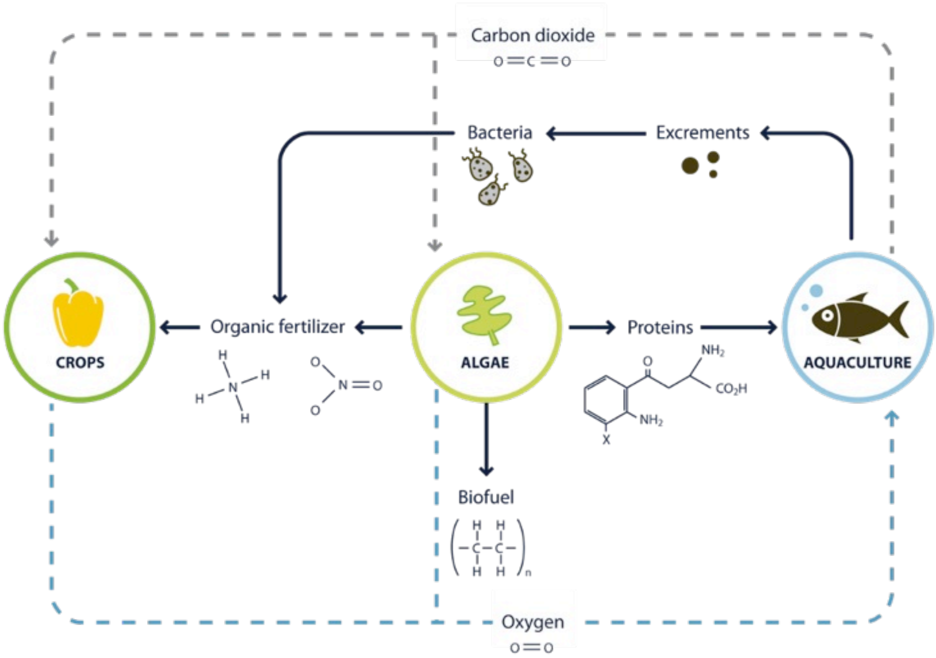


Figure 5.3 Combination of algae culture, aquaculture and crops production in the floating city (Deltasync, 2012).

Fresh vegetables could be grown on the seastead through aquaponics, a food production system that combines aquaculture and hydroponics in a self-contained ecosystem. Hydroponics is a method to grow plants in a liquid solution consisting of water and the required nutrients for a particular plant.[15] Plants and bacteria purify the water using the nutrients that fish create. The water use for crops can be reduced up to one tenth of regular vegetable growing and reduces the water needed for single usage fish farming by 95% or greater. The system can be applied in fresh water growing tomatoes, bell peppers, cucumbers, herbs, lettuce, spinach, chives, watercress and other plants in combination with tilapia, trout, perch, arctic char and bass.[16]

For saltwater fish, another type of aquaculture that can be framed into the idea of circular metabolism is integrated multi-trophic aquaculture (IMTA). In this system, leftover feed, waste, nutrients and by-products of one species are recaptured and converted into fertilizer, feed and energy for the growth of the other species. IMTA combine fish, with “extractive” species that are fed by organic and inorganic nutrients available in the environment. Organic extractors, such as shellfish, absorb small particulate matter like uneaten fish feed and fish feces. Inorganic extractors such as seaweed use the inorganic dissolved nutrients, such as nitrogen and phosphorus, that are produced by the other farmed species. The natural ability of these species to recycle the nutrients, provides a food production system that does not have negative impacts on the ecosystems. The IMTA concept is very flexible and allows the integration of different types of fish/shrimp with vegetables, microalgae, shellfish (bivalves, abalone) and/or seaweed (Neori et al., 2003).[17]

On the seastead, aquaponics and IMTA systems could be used to produce food for the city in an efficient and environmentally friendly way. Compared to conventional farming and agriculture systems, aquaponics allows growing vegetables and fish in a closed system at the same time, while re-circulating freshwater and minimizing water losses. As shown in figure 5.5, about one kilo of fish and seven kilos of vegetables can be grown for every 22 liters of water.[18]

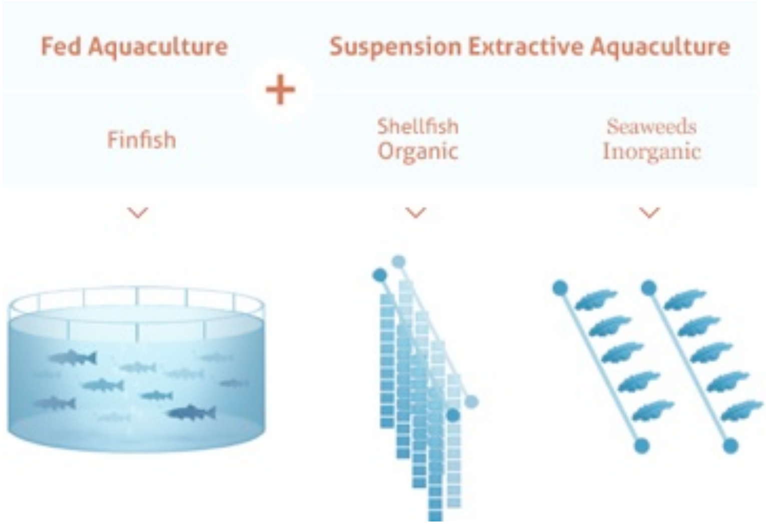


Figure 5.4 Integrated multi-trophic aquaculture (IMTA) operation scheme showing how a combination of varying levels of the food chain in the same environment take advantage of organic and inorganic nutrients made available by the various organisms (www.oceansfortomorrow.ca).

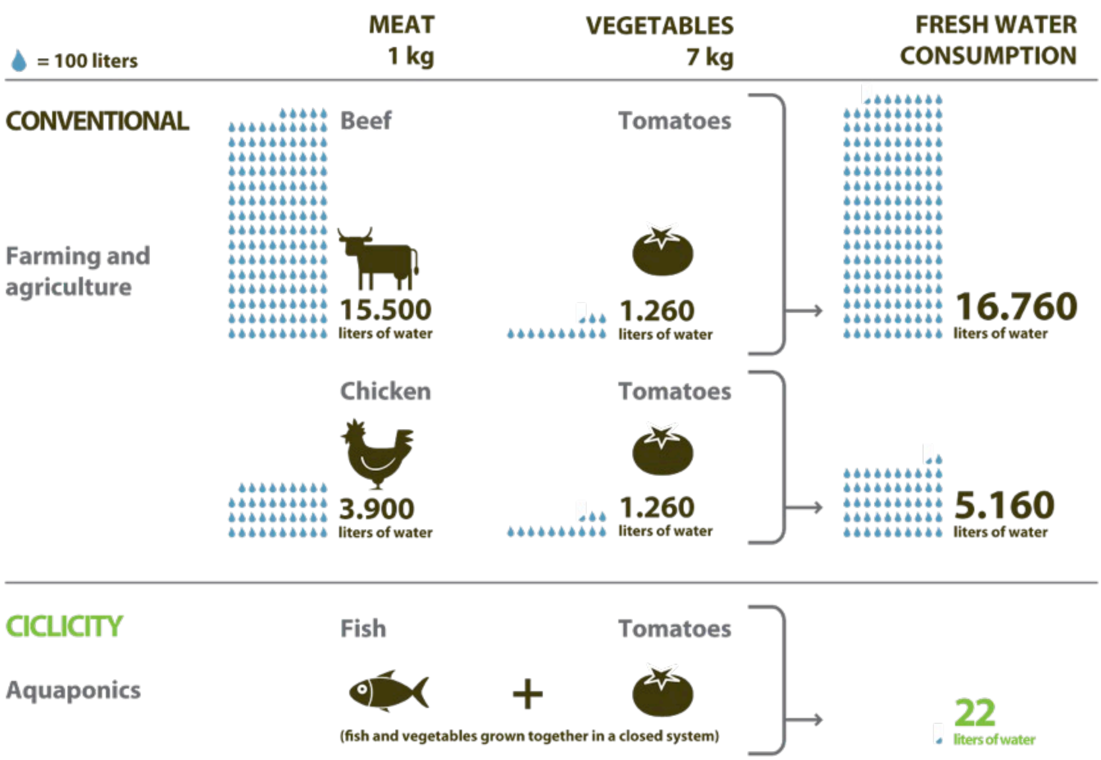


Figure 5.5 Water consumption of food production: comparison between conventional farming / agriculture and aquaponics systems (Deltasync, 2013)

5.3. Sustainable water system

The efficient management strategy for water can be expanded to the water use of the floating city's inhabitants. Cities use clean water as an input and produce wastewater as an output. Rainwater is a resource that is not often utilized – instead it is mainly converted into wastewater in combined sewer systems. However, rainwater can be applied for many purposes. On a seastead in particular, rainwater could be an important resource of freshwater. If rainwater will not be collected, fresh water would need to be imported or produced locally from desalination of seawater.

For these reasons, rainwater collection and storage should be provided on the seastead. In warm-humid climates, dry and rainy periods usually alternate. To ensure the use of rainwater during dry months, adequate rainwater storage needs to be provided. On the seastead, precipitation can be collected using buildings' roofs and the floating platforms, and stored in flexible tanks. Rainwater can be treated and used for cooking, drinking, showering and bathing. After use, water could be collected in another tank for grey water. Grey water is not suitable for drinking use but, with adequate treatment, can be used for washing machines and toilets. While water used for the washing machine goes back to the grey water tank, wastewater from toilets could be used as a free source of nutrients for algae (figure 5.6). When wastewater is pumped in OMEGA floating bioreactors, algae extract nutrients and clean water is slowly released in the sea.

Figure 5.6 Sustainable water reuse system (DeltaSync, 2013).

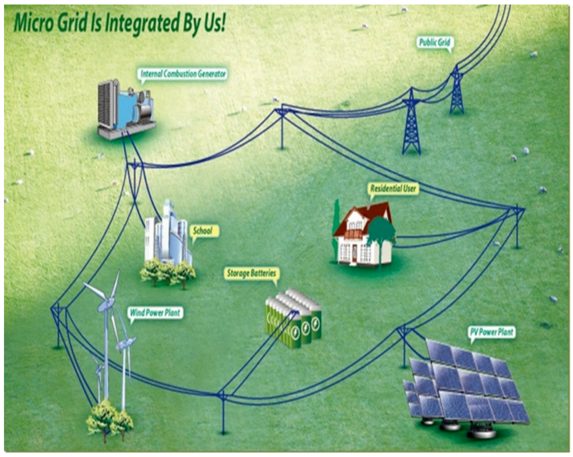


Figure 5.7 Example of a micro grid, source: Phono Solar

5.4. Sustainable energy

One of the anticipations of The Seasteading Institute is to settle in tropical climate zones. One of the benefits of these regions is the availability of a vast amount of solar power. Solar panels generate electrical power by converting solar radiation into direct current electricity with semiconductors. The amount of electricity solar panels can produce depends on the local solar radiation, or 'insolation'. In the case of Honduras, this is around 6 $kWh/m^2/day$ or 2190 kWh/m^2 annually (average).[19] The efficiency of the panels is currently around 15% but increasing rapidly. Expectations are that by 2015 solar panels will be competing with regular electricity prices.

The downside of solar panels is that storage is needed for the time that the sun is not shining. This can be accomplished by connecting the system to the electrical grid, but given that a seastead must be detached and movable from land, this is a less practical option. Alternatively, a micro grid system is proposed, where solar panels would be combined with batteries, and diesel generators would be on hand as an emergency system backup.

6. Cost estimate and feasibility

In this chapter, the cost estimate that is made in the excel model is elaborated, see appendix 6. Along with the cost considerations, the location and the future inhabitants have an important influence on the feasibility. Especially for the first seastead it is important to have reasonable access to the main land for the transport of goods and people and the continuity of economic processes. Furthermore, the number of inhabitants should be able to serve the initial purpose of the seasteading community.

6.1. Connection to coastal city

The combination of the initial small scale of the seastead and the continuity of the economic processes would be easier with a large coastal city nearby. In the past, settlements that developed into cities were usually built as trading centers or as fortifications to defend strategic locations. For this reason, most major cities are located along rivers or harbors, or at the junction of important overland trade routes. This new city should take this into account. The general observation from studying the growth of cities is that three major influences are responsible: economic growth, natural increase and rural-urban migration. The most significant reason to move into a city is economic opportunity. Important pull factors are expectations of jobs and comfort, while the main push factors are adverse circumstances in the countryside.

While experimentation with rules and new forms of government is the highest priority for the seastead, economic influences cannot be ignored. This means the city should be attractive for a diverse array of manufacturing and service-based companies. Also sufficient incentives should be developed for companies and entrepreneurs to move to the seastead. Such incentives should include: clear and simple legislation, low taxes, lower office rents than in the city center, a diverse and well-educated work-force, access to knowledge, technology and innovation, good (public) transport connections to the wider metropolitan area, especially when the city is small at the beginning. Another important asset is the access to global markets by connections to an airport and seaport. The marketing to attract these businesses to the floating city should be very good. The first floating city in the world will also attract a large number of tourists, in order to create opportunities for recreational businesses like hotels and restaurants.

6.2. Cost estimate

To estimate the costs of the first floating structure an excel model has been designed consisting of the following components:

- Housing
- Office space
- Hotel
- Water supply
- Energy supply

Functions that will influence the visuals but are not directly incorporated in the excel model are:

- Port
- A quick connection to a hospital resulting in a helipad
- School annex community center

Model

The initial conditions for this calculation are a platform size of 50 x 50 m that is divided into 10% green space, 10% sidewalks and 80% ground that can be developed for rent or sale (issuable ground) (see table 6.1). The average building consists of three floors and has a gross/net space ratio of 0.78, which results in an average gross space of 3,000 m² and useable floor area of 2,340 m² per platform. We calculated a per person residential area of 75 m² and 25 m² of commercial area. This results in an average of 30 inhabitants per platform, although combining this with commercial space and hotel space will accommodate more people, which will lead to a rich and diverse environment.

Table 6.1

Distribution of ground space		
Platform	100%	2500 m^2
Sidewalks	10%	250 m^2
Green	10%	250 m^2
Issuable Ground	80%	2000 m^2
*Built-up Area**	50%	1000 m^2

We then estimated the per platform costs. This was done using the concept design from the section 4 design platform structure and a price per cubic meter of concrete derived from FDN information on an average price for concrete of €1,000, we used €1,400 for our estimates. This should be calculated more thoroughly in the next phase, when the design for the floating structure is also calculated on the specific wave data. This also accounts for the connections in between the platforms and the mooring system, which will need to be fully designed for more detailed cost information. The concrete structure of the platform with the cables and sewer system will cost about €2,8 million or € 1100/m² (ex.).

During the design process, the designers decided that the flexibility for the configuration of the floating city would benefit form a combination of square platforms and pentagon shaped platforms. The 4,300 m² pentagon platform (using the per square meter costs of the square platform) would cost €4,8 million assuming that all the other cost aspects of the platform stay the same. In the design, four pentagons are used and seven square platforms. The pentagons are larger, although about 10% less efficient in space use, these four new structures would increase the sellable space by 15,000 m² when also calculating with three floors per platform. This space is not accounted for in the water and energy use calculation and is called vacant space in the model.

For the calculation of the real estate €1,100/m² is used as a rule of thumb. In total, including Honduras' Value Added Tax (assuming the seastead would also be constructed there), the cost estimate equals about €130 million for all 11 platforms, including the pentagon considered in this concept.

In addition for cost calculation, our model also allows us to assess the feasibility of sustainable water and energy supply. On both counts, we find the platform could be fully supplied using rainwater and solar power.

Water supply

To calculate the feasibility of a self-supporting water system, we first had to calculate the availability of (rain) water. The numbers we used were based on the monthly precipitation data from the department Valle, Honduras.[20] Next the amount of available water was compared to the water use for the domestic situation (per person per day), for the offices (per square meter per day) and the hotel (per room per day). For each of the three functions, we evaluated a low-water-use (that could be compared to the water use in the Netherlands) and a high-water-use scenario (that can be compared to the water use in the USA). From our calculations it can be concluded that for both the low-use scenario and the high-use scenario, enough rainwater can be collected for all needs.

Water collection is divided per platform and per function, meaning every platform has its own water collection and purification systems. The high-use scenario for a hotel platform was the only one for which the amount of water collected is not sufficient, and would require additional supplies from another platform, such as an office platform, which does not use as much as it collects. The cost estimate for the rainwater and water purification systems are around half a million euros. This figure represents the costs for one year. Every additional year would entail additional costs for new filters, management, maintenance, etc.

Figure 6.1 Example of drinking water transport using a plastic bag[21]

Energy

For the calculations related to solar power, we examined climate data on solar radiation for the location within Honduras. This location features some of the most favorable conditions for solar in the world. Solar radiation data was converted into kilowatt-hours so we could compare it with the electricity demand. We constructed two scenarios, for low and high use, and again split these up into three functional categories; residential, commercial (offices) and hotel. The demand numbers were compared with the yield from the panels, based on the amount of space available on the rooftops. Both scenarios were found to be feasible, i.e., energy supply was at least as great as demand.

Subsequently, the costs of a micro grid system were compared to a diesel generator system and the micro grid appeared to be the most cost effective. While the upfront cost of a solar system is more than the upfront cost of conventional diesel power, the lifetime costs of solar are projected to be substantially less, based on a quote from an installation for the Maldives.

7. Growth strategy

The animal kingdom is a source of inspiration for growth strategies. Several species, like salmon, spend their infancy in calm and protected waters and migrate towards the seas as they grow stronger. Analogously, a seastead is most likely to start in protected waters. After acquiring sufficient size and strength, the seastead will make its way to deeper waters, and finally the open ocean. During the seastead's development, a breakwater should be part of the strategy and can grow at incremental stages. By the time it reaches the high seas, it should be ready to defend itself against the waves it may encounter. Just like the fish, the seastead should be part of the aquatic ecosystem. Because it is manmade it can even help reverse the damage that is done to the ecosystems by remediating surrounding waters.

During the seastead's early years, only a small number of urban functions can be sustained. However, as it grows, additional functions will be added, such as a hospital, a school and perhaps a landing strip. This development will also help the community become more independent of the mainland (and host country). In the end, when the seastead has become completely independent in terms of water and energy, as well as politics and economics, it is ready for its final stage: to take on the high seas.

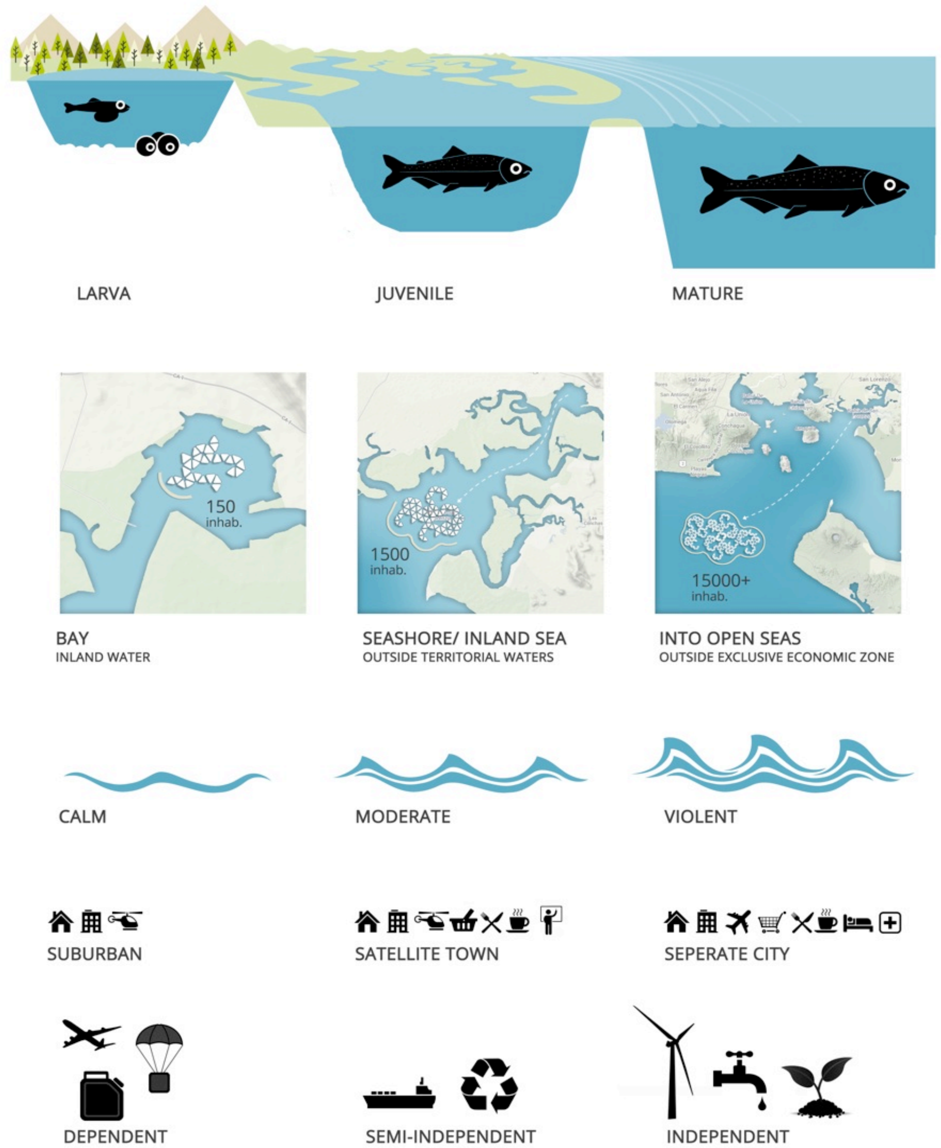


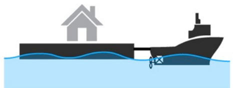
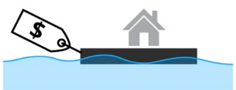
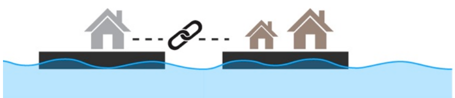
Figure 7.1 Development floating cities

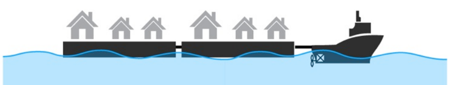
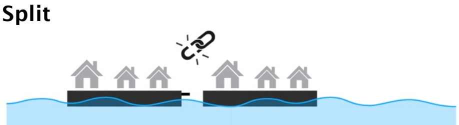
8. Growth dynamics

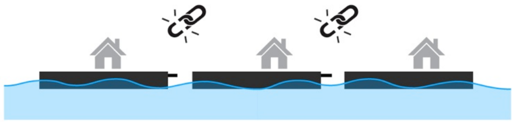
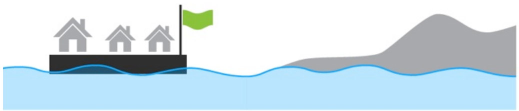
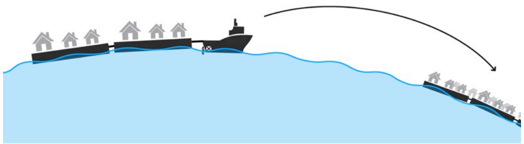
This draft document provides a vision of the different growth dynamics of the floating city. Several levels are distinguished:

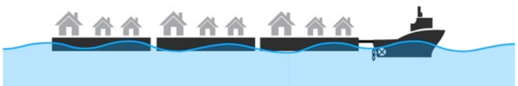
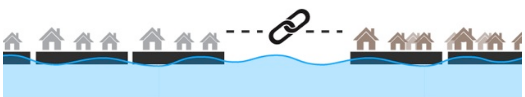
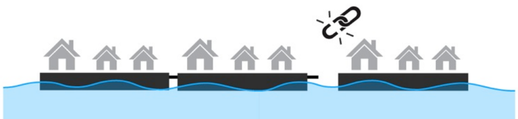
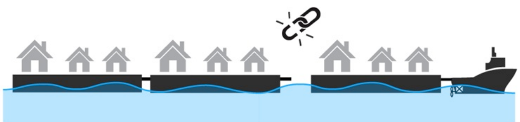
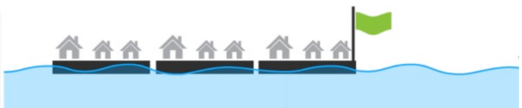
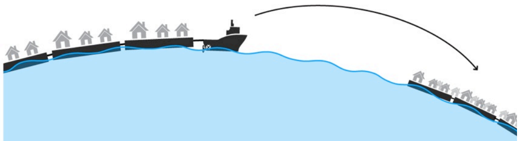
- House
- Neighborhood (500-5000 houses)
- District (5,000-20,000)
- City (20,000- larger)

The dynamics that are distinguished on these levels are listed in table 8.1.

HOUSE LEVEL		
Dynamic	**Description**	**Possible drivers**
Move with house 	Move to another location within the city with your floating house	Unhappy with neighborhood Living closer to work, family or friends
Sell and move 	Similar to land-based city. Sell your house and move to another place within the city or in another city	Unhappy with your house Desire to live on more attractive location
Stay and upgrade 	Stay at the same location. Sell your house on web-based platform. Buy a larger house for your location	Happy with neighborhood but unhappy with house
Unite 	Find other people with the same interests, values and vision and create your own new neighborhood within the city or in another city	Desire to create a great community

NEIGHBORHOOD LEVEL		
Dynamic	**Description**	**Possible drivers**
Move 	Move your neighborhood to another location within the city	Better opportunities for economic growth Move needed for overall growth strategy of city
Merge 	Merge with another neighborhood to create district or larger neighborhood	Become more attractive for companies and inhabitants Increase lobby power with district or city government Improve ability to create good facilities
Split 	Split your neighborhood to create to smaller neighborhoods	Improve human scale Unhappy with neighborhood board
Dissolve	Split neighborhood into individual houses that are free to go wherever	Lack of social cohesion Conflicts

	they like in the city	
Spinout 	Leave the city to start a new floating city in a protected bay near shore with your neighborhood	Unhappy with city government Attractive opportunities to locate near coastal city
Transfer 	Move with your neighborhood to another city	Unhappy with city government Attractive offer of another city

DISTRICT LEVEL		
Dynamic	**Description**	**Possible drivers**
Move 	Move your district to another location within the city	Better opportunities for economic growth Move needed for overall growth strategy of city
Merge 	Merge with other districts to create larger district	Become more attractive for companies and inhabitants Increase lobby power with city government Improve ability to create good facilities
Settle 	Merge with other districts from same city or other cities to create a new city	Better opportunities elsewhere Economic synergy of districts
Split 	Split your district to create to smaller districts	Improve human scale Unhappy with district board
Dissolve 	Split districts in separate neighborhoods that are free to go wherever they like in the city	Lack of social cohesion Conflicts Incapable district board
Spinout 	Leave the city to start a new floating city with your district on the high seas	Unhappy with city government Attractive opportunities elsewhere
Transfer 	Move with your district to another city	Unhappy with city government Attractive offer of another city

These urban growth dynamics would create the necessary conditions for competitive governance. Neighborhoods will have to provide a good value for the cost of living there, or else people leave. There will be a large reward for cost-effective operations, since these will attract a greater number of new citizens and businesses. City governments with taxes that are too high and who do not deliver good services will find their best districts being lured away by other floating cities. With a very incapable city government, the city might even dissolve. These growth dynamics create therefore a great incentive to provide value for money on all levels of government. Additionally they create almost unlimited possibilities for individual and collective freedom.

9. Conclusions and recommendations

One of the important topics in this report has been the question of which platform size would be suitable for the future seastead in terms of the objectives, location characteristic and other factors like financial and construction limitations. The ideal size of individual platforms depends on many factors, some of which can be precisely determined while others remain speculative. The most relevant ones that have been included in this study can be seen in figure 9.1. It can be concluded that the size of the platform would ideally range between 45 and 75 meters. For this design the size of 50 x 50 meter has been chosen as the standard. More detailed data on local wave characteristics and further research on the structural design are needed to evaluate these assumptions.

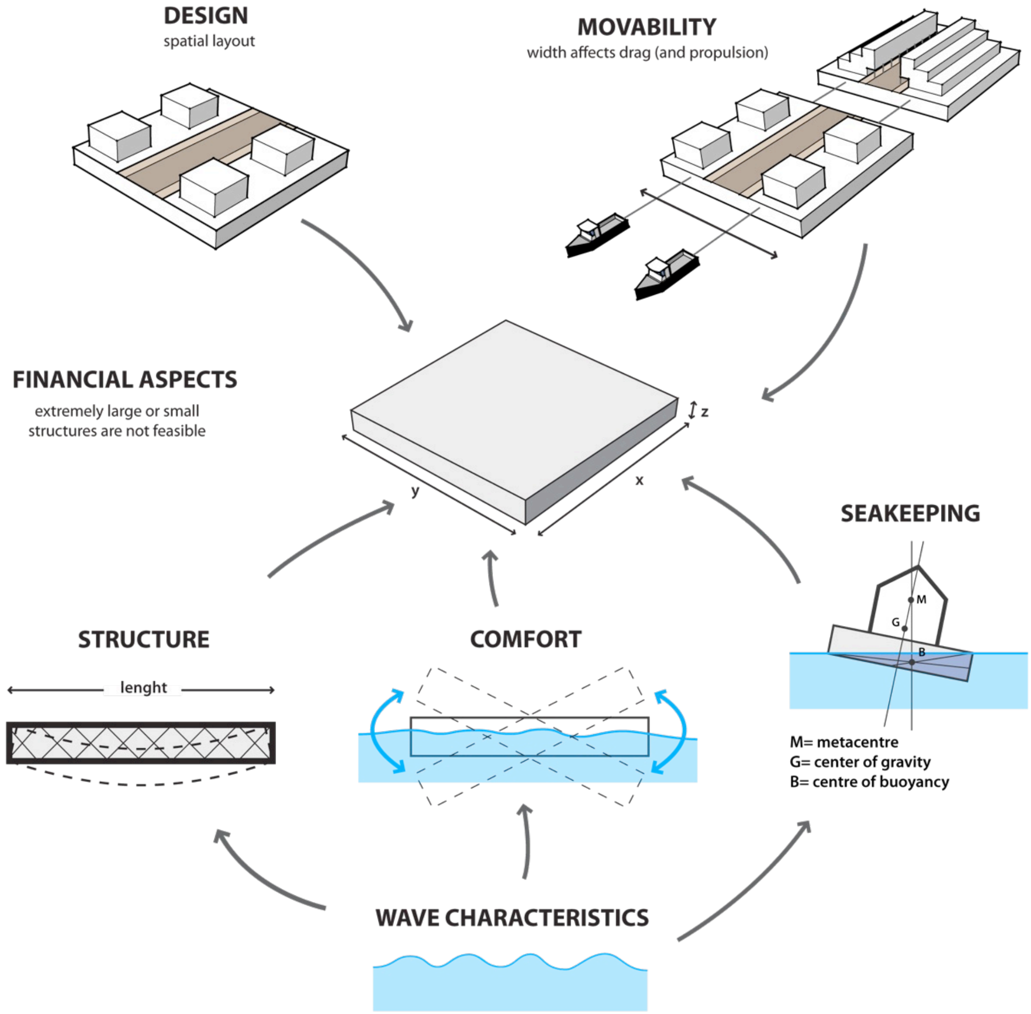


Figure 9.1 Factors that influence the optimal size of a floating platform

The most challenging objective was seakeeping. First, it had to be decided for which location the structure should be suitable. During the concept design phase the initial location – a protected bay – and the future location – the high seas – clashed frequently. Eventually an important decision was made that while future seasteading communities are envisioned to withstand the high seas, the first communities in The Floating City Project will start out in more protected waters, and will only be in higher seas occasionally and for short periods of time, such as when moving or fleeing hurricanes.

Movability

During the research it has been concluded that the seastead should be able to move away in the event of a hurricane. It would be important to conduct simulations of this situation to see if the estimated time to escape the path of the hurricane is feasible. The main research questions for this future investigation would be which type of tugboat and which configuration of the platforms would be most suitable for this transport. It may be an option to transport several interconnected platforms at once in a train configuration, quite similar to barge tows. This combination creates a longer vessel, which is more favorable in terms of water resistance. Therefore, it is important to research what hull shape could be the most suitable in terms of costs and manufacturability, and if this would be only necessary for the front platform or if all of the should be designed this way. Furthermore it should be tested how these platforms and how the interior of the real estate would behave during this transport.

Connections

An aspect that is directly linked to this transport is the connections between the platforms, which should be easy to disconnect at some places. These connections should be dimensioned differently when the platforms are towed separately or towed in a row. For the current cost estimation the data for the interconnection is based on existing structures, for this unique purpose, this would have to be designed and recalculated.

The mooring systems should also be easy to disconnect, and the specific engineering must be further developed and the cost calculated. Subsequently the question arises of what will happen with the seastead during its temporary residence when fleeing from a hurricane, and how it will be kept in position in the temporary location. Depending on the connections between the platforms and the expected forces in the bay, the system must be optimized, which will probably favor fewer connections and larger anchors.

Location

The simulation would also have to include the seakeeping performance given the expected wave characteristics. When there is more certainty about the first location for the seastead, the characteristics of that specific location should be further examined. More detailed information is needed on the waves, bathymetry and other local conditions like nature and pollution. The current estimate is made on basic principles and assumptions. For the wave characteristics, data from two nearby buoy points have been used as input. Since information is probably not currently available in the actual location, a buoy could be placed to measure the wave characteristics. This could be done right away in one or more potential future locations.

Water and energy supply

The analysis of available solar energy and other climate factors like precipitation demonstrate the feasibility of a floating city harvesting enough of these gifts of nature to support itself. This depends on specific climate characteristics of a location, and further research would need to be done for other locations.

Platform

The platform is now sketched and not designed. Very rough estimations have been made to be able to see if the platform to assess its suitability for sea conditions. The risk of under- or over sizing the platform exists, and a more detailed design and calculation is needed in the next phase. Furthermore a conservative concrete structure is now used for the calculation. More innovative systems based on composites and plastics may possibly be much more appropriate for this environment. Some of these systems are currently in development and if more accurate data is available they could substitute the concrete structures in the cost calculation model.

For the next design phase, rules and regulations for the buildings and platforms on fire hazards and collision risks should be taken into account. Furthermore the use of the space in the platform should be determined, for example for food storage, water storage, and commercial applications.

In the current design, two shapes have been used for the platform: a square and a pentagon. The pentagon configuration can be connected to the square platforms and, in large enough configurations, can create a circular cluster, since the two opposing edges are oriented at an angle of 36 degrees. The structure of the pentagon and the distribution of the real estate on the pentagon should be taken into account during the next phase.

The current status of the cost calculation is shown in table 9.1.

Table 9.1 Costs

General		
Average costs per platform	€	11,278,799
Costs gross space	€/m²	3,135
Costs usable space	€/m²	4,019

General		
Average costs per platform	$	15,226,378
Costs gross space	$/ft²	393
Costs usable space	$/ft²	504

Appendix 1 Formulas

Ocean surface current speed

The following two formulas were used to roughly determine the amount of force that a seastead may deal with at a given ocean surface current speed. Drag is not yet taken into account.

$p_d = 1/2\, \rho\, v^2$

where

pd = dynamic pressure (Pa)
ρ = density of fluid (kg/m³),
1025 kg/m³ for surface sea water;
1.225 kg/ m³ for air (15°C).
v = velocity (m/s)

$F = A\, P\, C_d$

where

F = force
A = area
P = pressure
C_d = drag coefficient (1)

Formulas for wavelength:

$$L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)$$

Where "g" is the gravitational acceleration, "T" is the period and "d" the depth. To solve this equation Hunt (1979)[22] used an approximation that gives:

$$\frac{gT}{2\pi}\tanh\left(\frac{2\pi d}{L}\right) \approx \sqrt{\frac{gd}{F}}$$

where $\sqrt{\frac{gd}{F}}$ is an approximation for the wave celerity and

$$F = G + \frac{1}{1.0 + 0.6522G + 0.422G^2 + 0.0864G^4 + 0.0675G^5}$$

and $G = 2\pi\left(\frac{d}{L_0}\right) = \left(\frac{2\pi}{T}\right)^2 \frac{d}{g}$

The wavelength then is given as:

$$L = T\sqrt{\frac{gd}{F}}$$

Appendix 2 Saffir-Simpson Hurricane Scale

Saffir-Simpson Hurricane Scale[23]

Saffir-Simpson Hurricane Scale

Category	Wind speed mph (km/h)	Storm surge ft (m)
5	≥156 (≥ 250)	>18 (> 5.5)
4	131 – 155 (210 – 249)	13 – 18 (4.0 – 5.5)
3	111 – 130 (178 – 209)	9 – 12 (2.7 – 3.7)
2	96 – 110 (154 – 177)	6 – 8 (1.8 – 2.4)
1	74 – 95 (119 – 153)	4 – 5 (1.2 – 1.5)
Additional classifications		
Tropical storm	39 – 73 (63 – 117)	0 – 3 (0 – 0.9)
Tropical depression	0 – 38 (0 – 62)	0 (0)

Appendix 3 Location analysis

Inside the gulf, there are small islands that are part of Honduras and El Salvador. The larger islands are El Tigre (Honduras), Conchaguita and Meanguera (El Salvador). According to nautical maps, the bathymetry of the gulf varies from 0 to 10 m within 10 km from the coastline, in the Chismuyo bay (Nicaragua) and in the islands' area (figure A3.1&A3.2). At the inlet of the gulf, water depth increases from 10m to about 40m between Cape Cosiguina and Cape Amapala. Several rivers flow into the Gulf of Fonseca: Goascoran River, which defines the border between El Salvador and Honduras, Negro River and Choluteca, flowing in Honduras, and Estero Real River, which is part of Nicaragua.

Figure 1 and 2. Gulf of Fonseca map and satellite image. http://www.worldatlas.com/aatlas/infopage/fonsecag.gif, Google Maps

According to the Koppen classification, the climate in the Gulf is humid equatorial, with two distinct seasons, the rainy (May - November) and the dry (December - April). From May until November thunderstorms are quite common (over 70% of the precipitation happens during thunderstorms), and hurricanes might occur in the area (See appendix 3). The Gulf receives nearly 80% of its total yearly rainfall of 1400–1600 millimeters during the rainy season[24]. The dry season contributes to an annual evaporation rate of 2800 millimeters. As a result of less water in the Gulf, the currents tend to flow inward from the Pacific Ocean, the levels of salinity in the estuaries increase and seasonal drought occurs[25].

The tidal difference (predominantly semidiurnal) is on average 2.5 meters per day[26]. During low tides the soils are inhabited by crabs, conch, and other species. During the high tide the mangrove forests serve as a feeding ground, habitat and refuge for fish, shrimp, and other species[27].

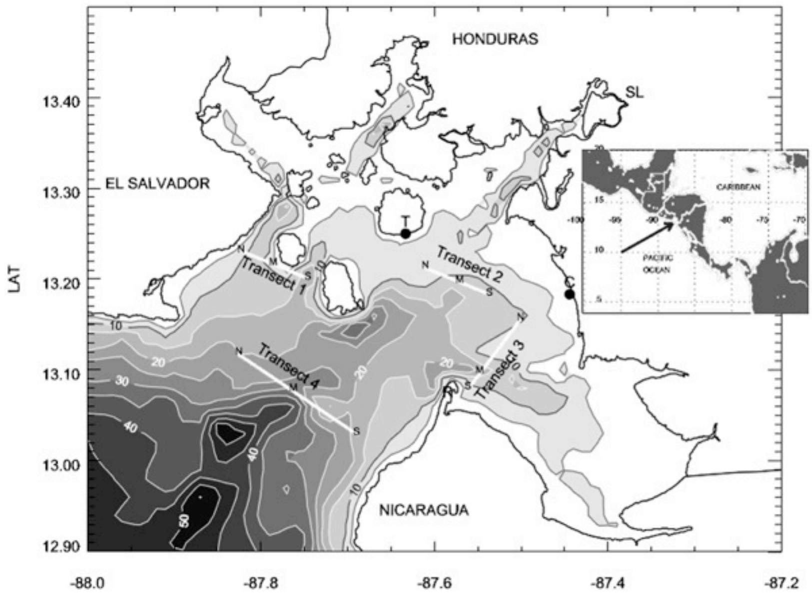


Figure 3. Gulf of Fonseca, nautical map. Areas in blue represent salt marshes, areas in light blue include sea floor depth between 0 to 10m, and areas in white represent sea floor depths deeper than 10 m (http://marine.geogarage.com/routes)

Currents in the dry season exhibit different behavior compared to those in rainy season: in dry months the water enters from the surface and exits at the bottom (reverse estuary type), whereas in rainy months the opposite happens and water that comes in from the bottom exits from the surface (estuary type).

The Cosiguina Peninsula and several extinct or dormant volcanic islands protect most of the Gulf of Fonseca from ocean waves. The significant wave height is between 0.5 and 2 m in more than 95% of the cases. High waves occur mostly in autumn (October - November) and in Spring (May - June), as a consequence of tropical storms. High wind waves in combination with high tide can generate waves up to three meters or even higher in rare cases. According to an alert emitted by Copeco authorities (Comisión Permanente de Contingencias of Honduras) at the beginning of October 2011, during a tropical storm, waves could have reached up to 10 feet height (about 3 m), with periods between 12-14 seconds[28]. In November 2011, Honduran authorities declared a green alert in the coastal zone of the Gulf of Fonseca, Pacific, after the tsunami occurred in Japan. After this phenomenon, generated by an earthquake of 8.9 on the Richter scale, Copeco emitted preventive measures in case the tsunami could have generated high waves that would have been introduced to the mainland[29]. Another source reports data on a storm in June 2012 that was expected to cause waves height of 7 to 9 feet (2 to 2.7 m)[30]. Data on the average wavelength was not found. If period values between 12-14 seconds are chosen, waves length will vary between 190-240 m at the inlet of the Gulf (sea floor depth of 40m) and 100-130m at 10 km circa from the coast (sea floor depth of 10m).

Temperatures in the Gulf are between 24 and 34 °C. March and April are the warmest months; October and November the coolest. Relative humidity varies between 45%-80% in dry months, and 68%-90% in the rain season. Average water temperature in the Gulf of Fonseca is usually around 26°C. In the open sea, at a few hundred km distance from the Gulf, high water temperature might further increase.

Water pollution, habitat loss, excess sedimentation and over-exploitation of fisheries affect the Gulf's environment. In the last 40 years, pollution, deforestation, and inappropriate land use put enormous pressures on the coastal ecosystem and have contributed to loss and degradation. The mangrove ecosystem has been diminished to provide space for shrimp aquaculture. Satellite images from 1973 and 2006 show the significant loss of mangrove swamps as a result of the expansion of shrimp farming in the region of Estero La Jagua. Effluents from shrimp farms, rich in nutrients and organics, flow into the Chismuyo Bay and contribute to eutrophication and hypoxia in the gulf. Hypoxia has caused fish mortality and decline in artisan fishery of all species. Actions to restore the environment in the area are important also for the productivity of shrimp aquaculture, which is now the third largest export of Honduras, after bananas and coffee[31].
Moreover, the livelihoods of many species are connected to the health of the mangrove ecosystem.
"The indigenous plant and animal life in the mangroves depend on the delicate balance of fresh and tidal waters. Mangroves provide drainage and filtration, stabilize shorelines that protect the coastline and the surrounding farmland, and offer natural windbreaks as well as fresh water conduits (Martínez 1991; Hamilton and Snedaker 1984). They also serve as a prime source of fish, shrimp and other crustaceans, fuelwood, and timber for surrounding communities and the broader population"[32].

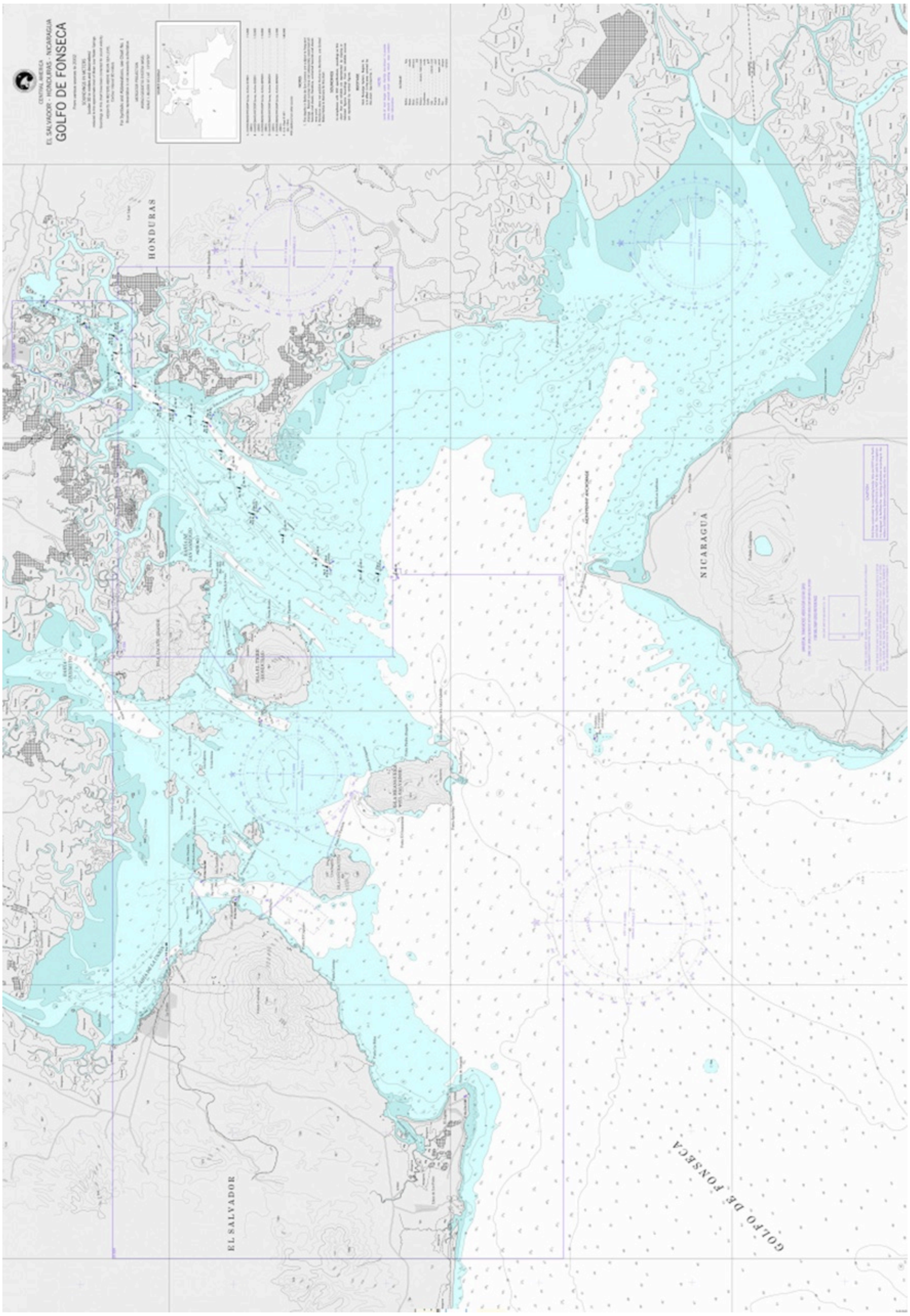


Figure 4. Climate map of Central America (http://www.boqueteweather.com/images/world_climate_map.jpg)

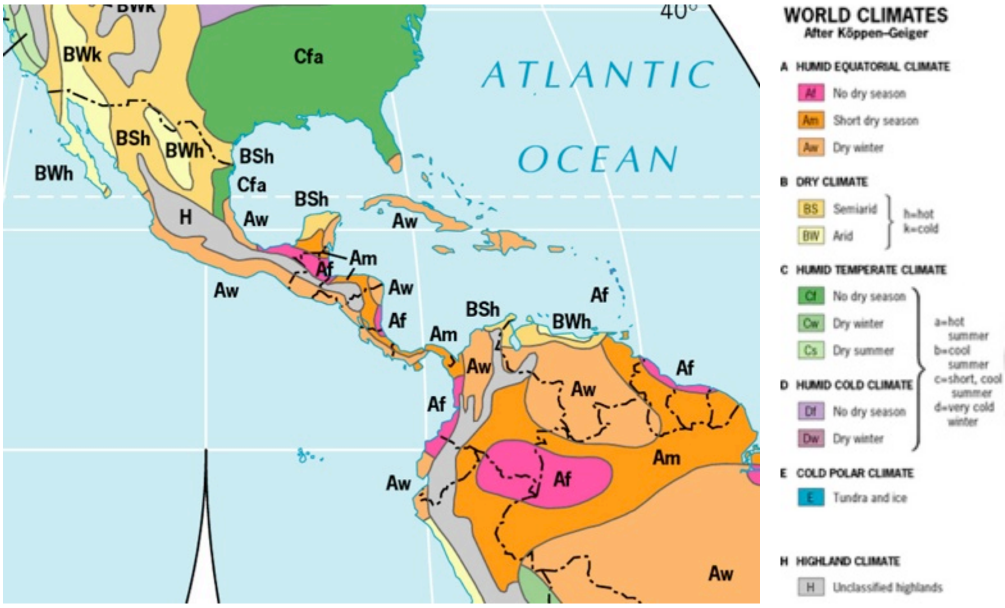
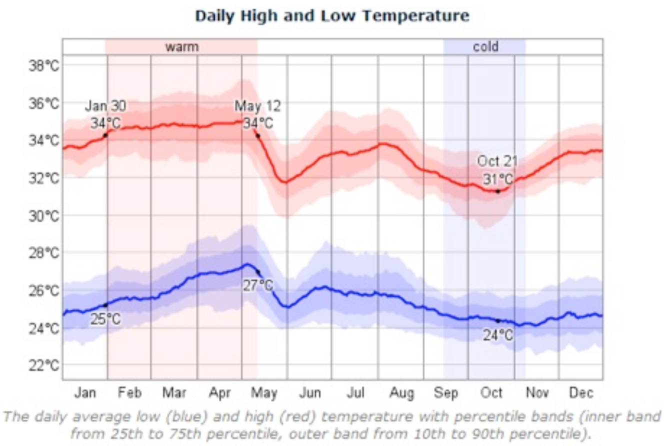


Figure 5. Monthly data on average temperature and humidity in the Gulf of Fonseca (Ampala, Honduras) (http://weatherspark.com/averages/32506/Amapala-Valle-Honduras).



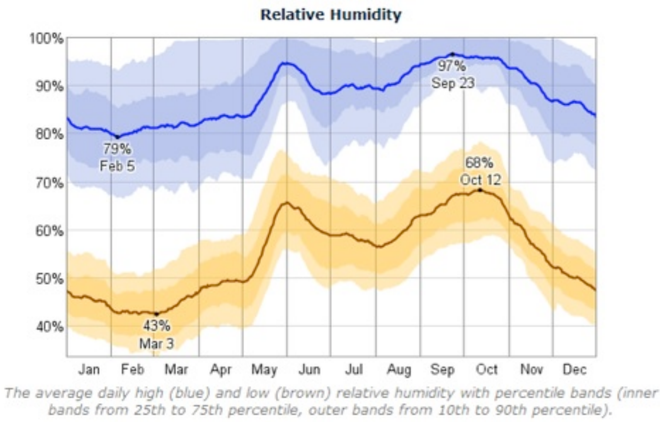
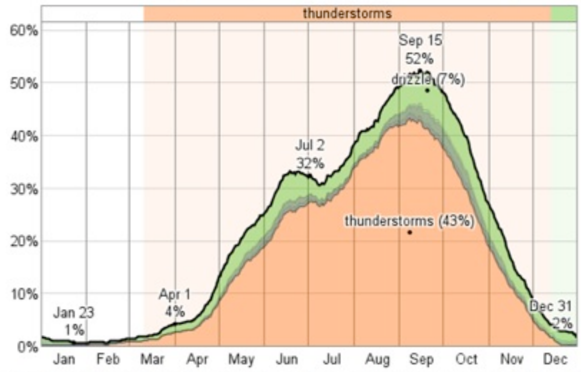
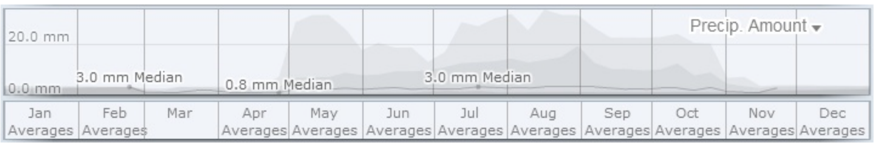


Figure 6. Monthly data on precipitation in the Gulf of Fonseca (Ampala, Honduras) (Source: http://weatherspark.com/averages/32506/Amapala-Valle-Honduras).

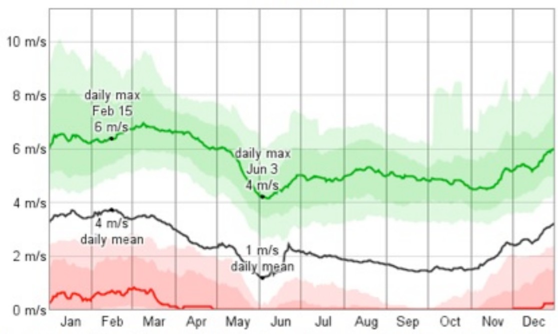
Probability of Precipitation at Some Point in the Day



The fraction of days in which various types of precipitation are observed. If more than one type of precipitation is reported in a given day, the more severe precipitation is counted. For example, if light rain is observed in the same day as a thunderstorm, that day counts towards the thunderstorm totals. The order of severity is from the top down in this graph, with the most severe at the bottom.



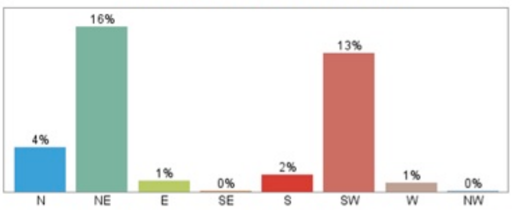
Wind Speed



The average daily minimum (red), maximum (green), and average (black) wind speed with percentile bands (inner band from 25th to 75th percentile, outer band from 10th to 90th percentile).

The wind is most often out of the *north east* (16% of the time) and *south west* (13% of the time). The wind is least often out of the south east (0% of the time), north west (0% of the time), west (1% of the time), east (1% of the time), south (2% of the time), and north (4% of the time).

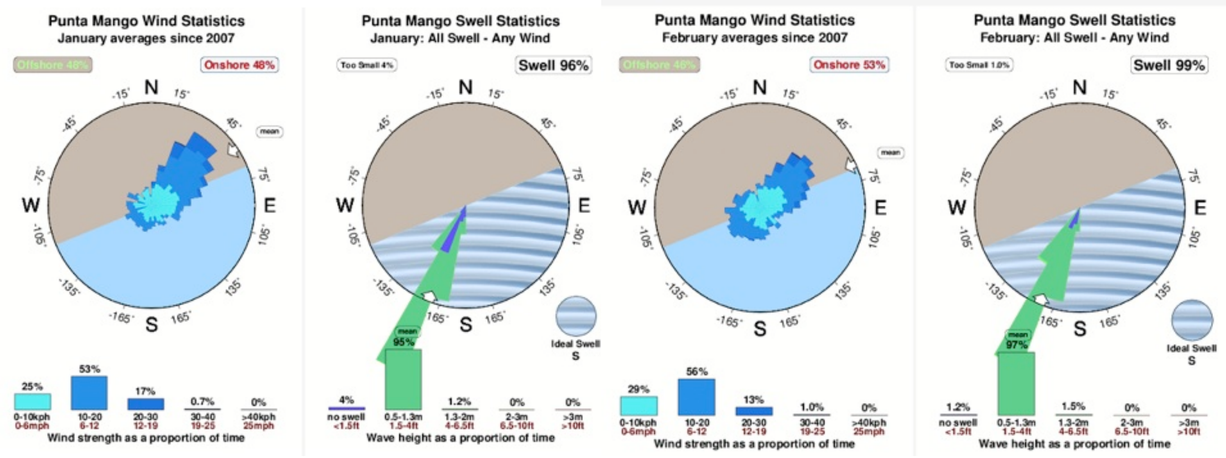
Wind Directions Over the Entire Year



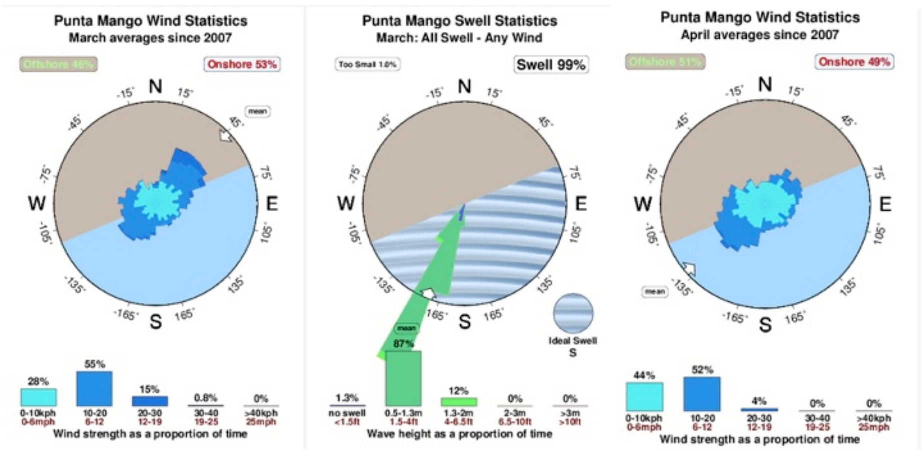
The fraction of time spent with the wind blowing from the various directions over the entire year. Values do not sum to 100% because the wind direction is undefined when the wind speed is zero.

Figure 7. Monthly data on wind in the Gulf of Fonseca (Ampala, Honduras) (http://weatherspark.com/averages/32506/Amapala-Valle-Honduras).

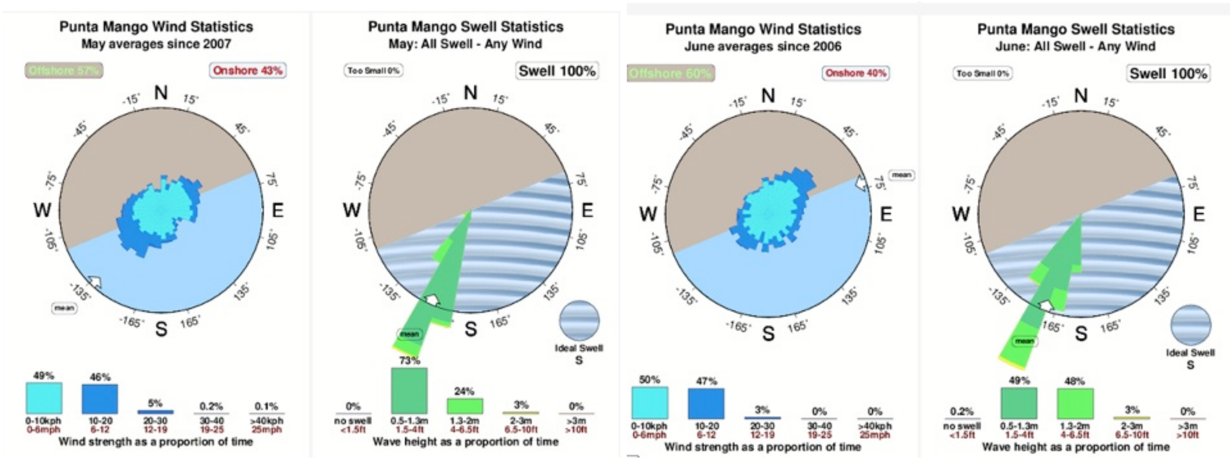
January and February



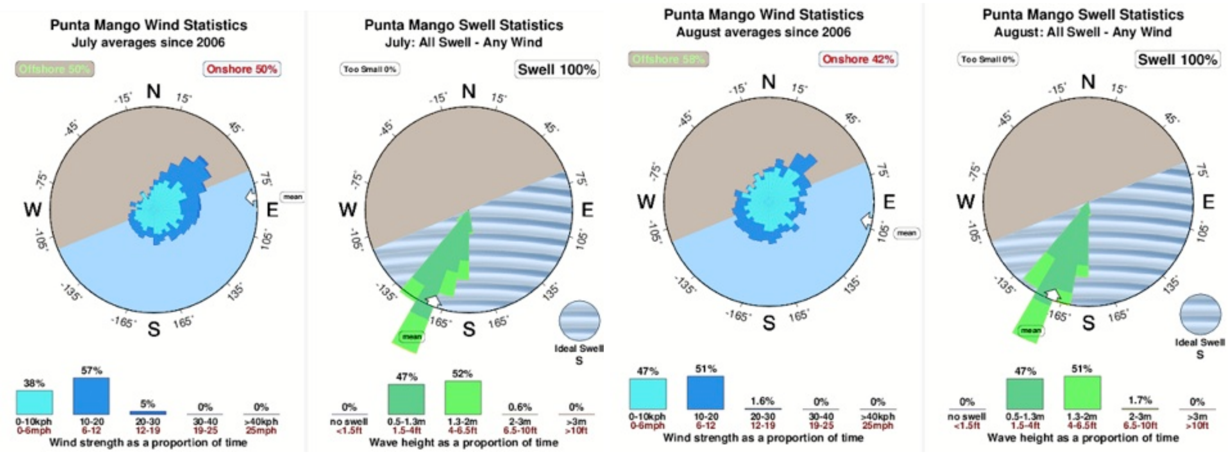
March and April



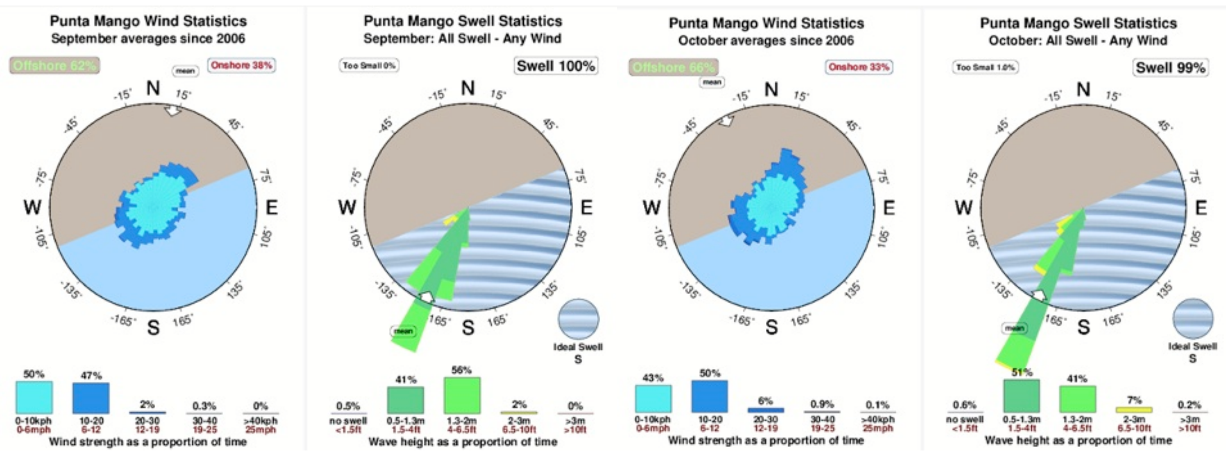
May and June



July and August



September and October



November and December

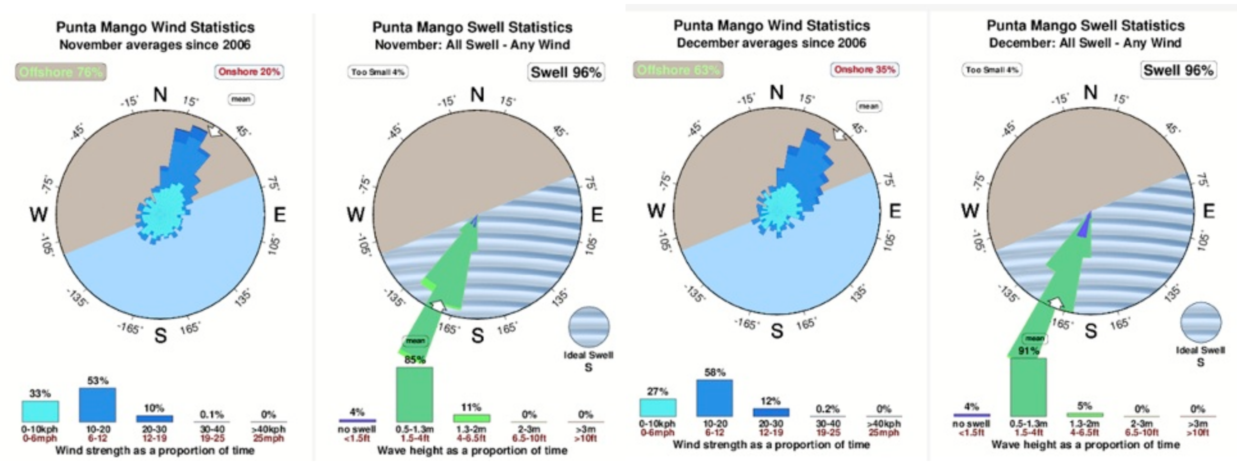


Figure 8. Monthly data on swell and wind in Punta Mango, 50 km from the Gulf of Fonseca, for near shore open water (http://www.surf-forecast.com/breaks/Punta-Mango).

	no swell	0.5 - 1.3 m	1.3 – 2 m	2 – 3 m	> 3 m
Summer (%)	0	48	50	1.9	0.1
Autumn (%)	1.8	63	32	3	0,2
Winter (%)	3	94	3	0	0
Spring (%)	0.4	80.5	18	1,1	0
Yearly average (%)	**1.3**	**71.4**	**25.8**	**1.5**	**0.1**

Figure 9. Graph of the tidal movements in the Gulf of Fonseca, 11th October 2013 (Source: http://www.fisica.uniud.it:8080/locations/3297.html).

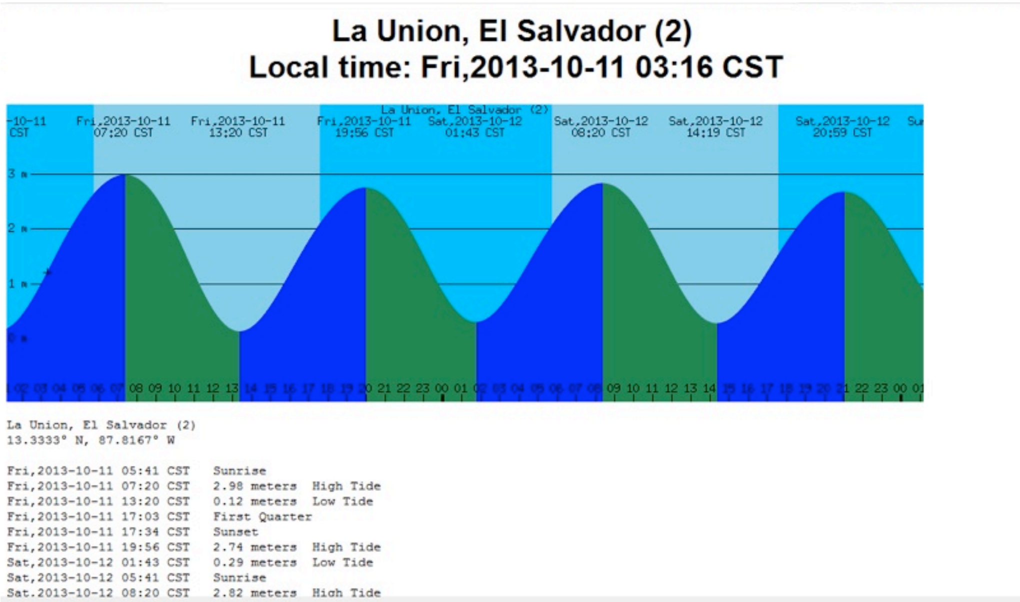


Figure 10. Average surface streams March 9- April 13, 2001 (www.marn.gob.sv/phocadownload/pp_nn_13.pdf from Valle-Levinson, A., and K. T. Bosley, Reversing circulation patterns in a tropical estuary, J. Geophys. Res., 108(C10), 3331, doi:10.1029/2003JC001786, 2003).

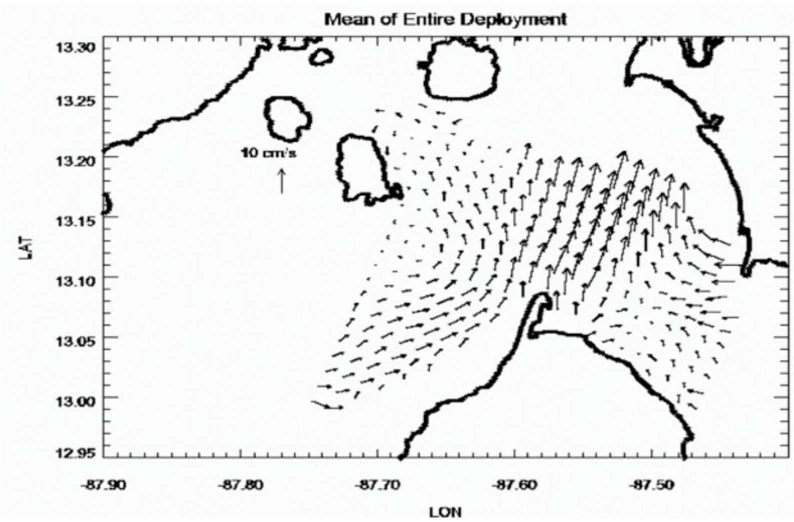
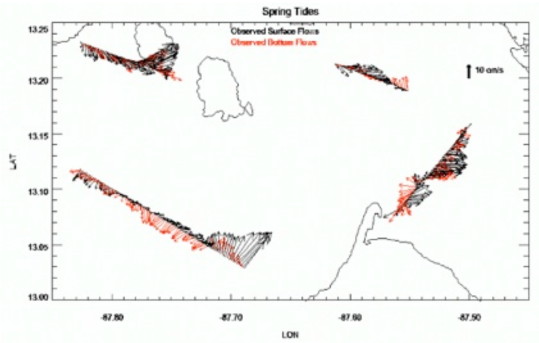


Figure 11. Circulation patterns in the Gulf of Fonseca, dry and rainy season (www.marn.gob.sv/phocadownload/pp_nn_13.pdf from Valle-Levinson, A., and K. T. Bosley, Reversing circulation patterns in a tropical estuary, J. Geophys. Res., 108(C10), 3331, doi:10.1029/2003JC001786, 2003).

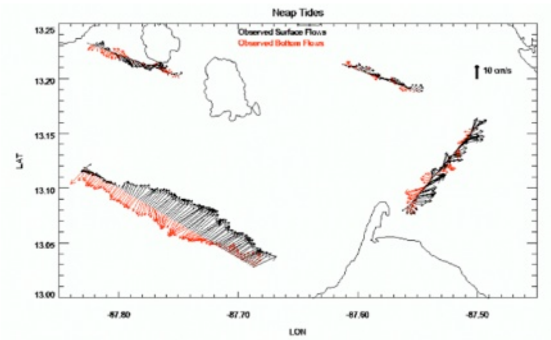
Circulation in dry season

Reverse estuary type: water entering from the surface (black arrows) and exiting at the bottom (red arrows).

Spring tide



Neap tide

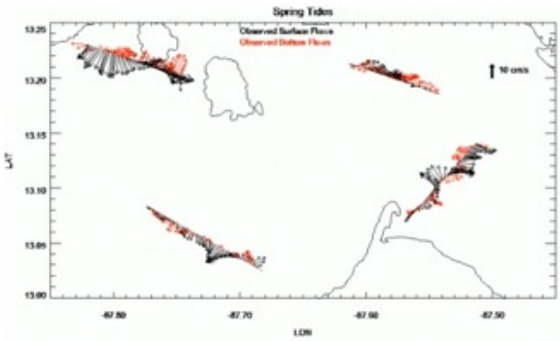


Observed surface flows: black
Observed bottom flows: red

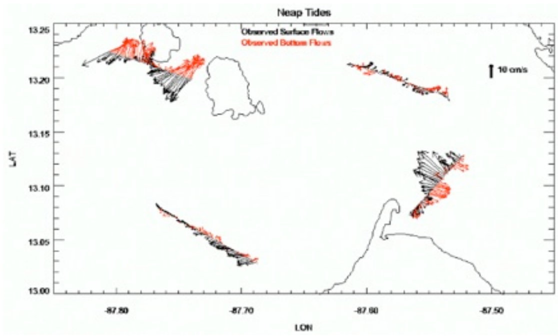
Circulation in rainy season

Estuary type: water exiting from the surface (black arrows) and entering from the bottom (red arrows).

Spring tide



Neap tide



Observed surface flows: black
Observed bottom flows: red

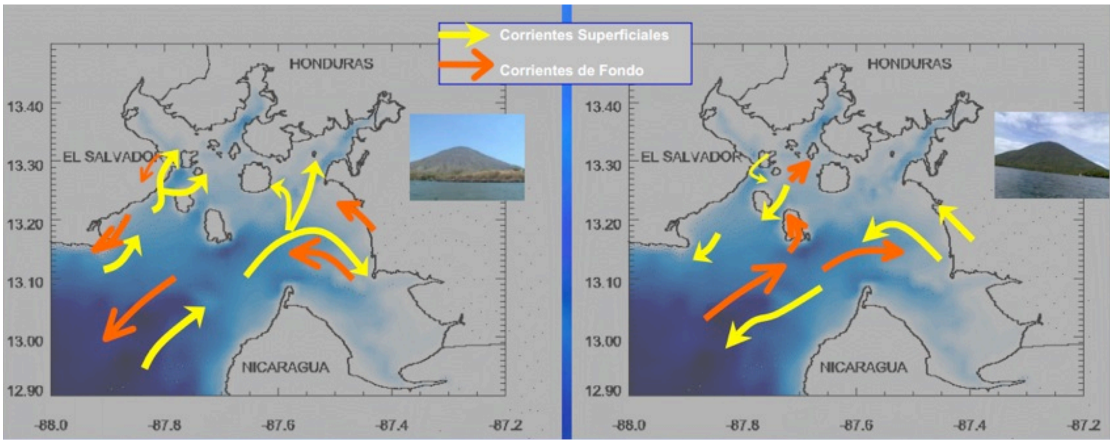


Figure 12. Significant wave height in meters on 11th October 2013 (http://www.surf-forecast.com/maps/Honduras/significant-wave-height/6).

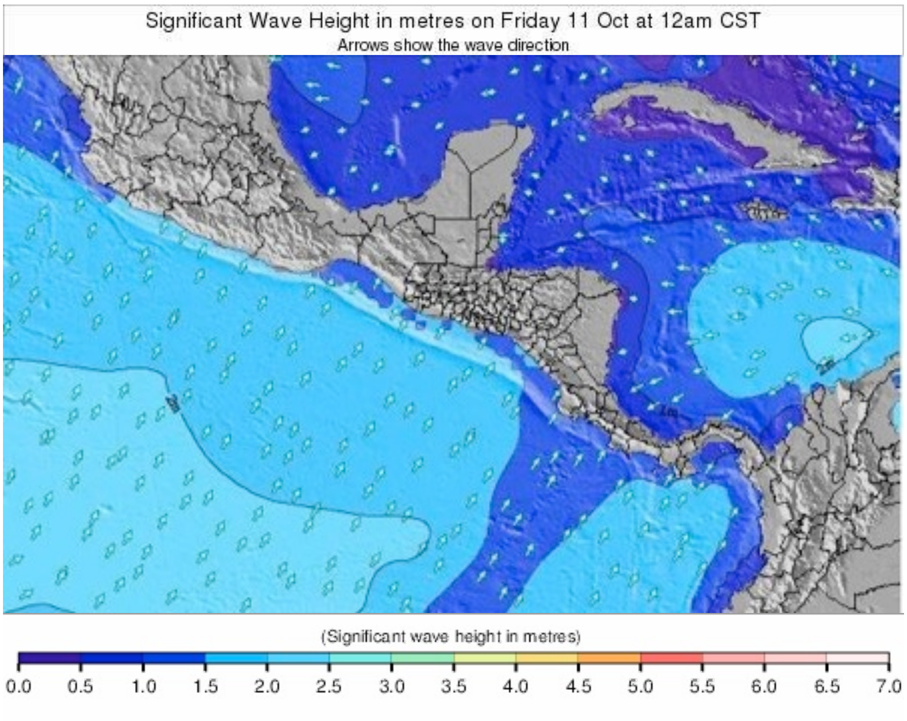
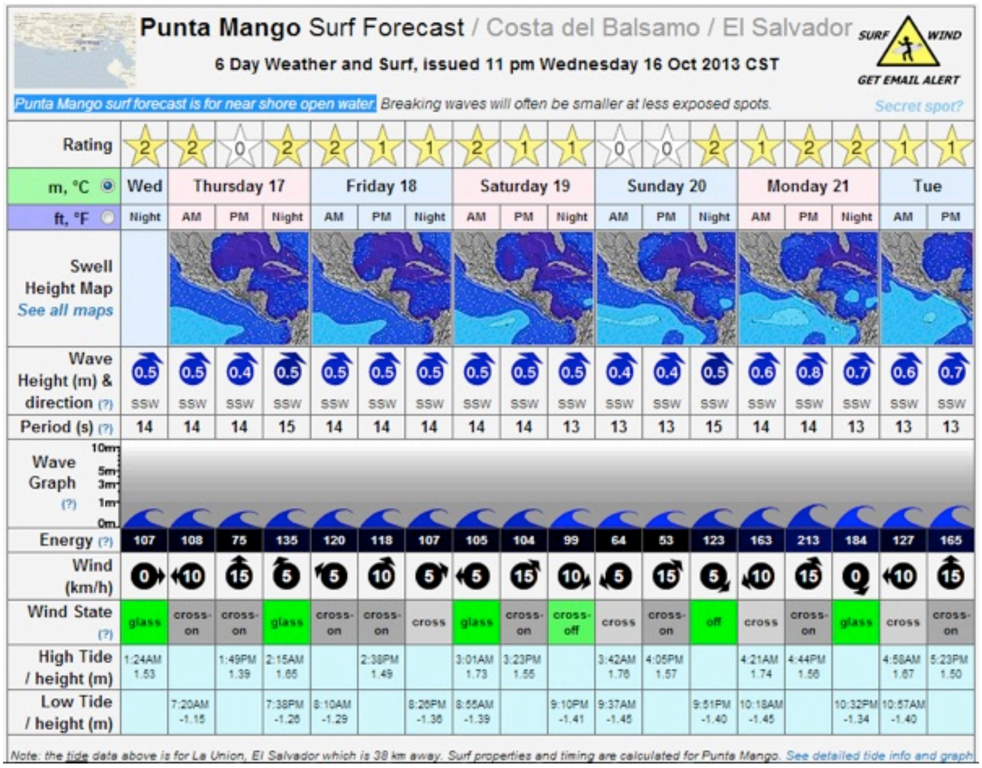


Figure 13. Surf forecast for Punta Mango (El Salvador) (http://www.surf-forecast.com/breaks/Punta-Mango/forecasts/latest/six_day#)



Punta Mango Surf Forecast / Costa del Balsamo / El Salvador

6 Day Weather and Surf, issued 11 pm Wednesday 16 Oct 2013 CST

SURF WIND GET EMAIL ALERT

Punta Mango surf forecast is for near shore open water. Breaking waves will often be smaller at less exposed spots. Secret spot?

m, °C	Wed	Thursday 17			Friday 18			Saturday 19			Sunday 20			Monday 21			Tue	
ft, °F	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM	Night	AM	PM
Rating	2	2	0	2	2	1	1	2	1	1	0	0	2	1	2	2	1	1
Swell Height Map See all maps																		
Wave Height (m) & direction (?)	0.5 SSW	0.5 SSW	0.4 SSW	0.5 SSW	0.5 SSW	0.5 SSW	0.5 SSW	0.5 SSW	0.5 SSW	0.5 SSW	0.4 SSW	0.4 SSW	0.5 SSW	0.6 SSW	0.8 SSW	0.7 SSW	0.6 SSW	0.7 SSW
Period (s) (?)	14	14	14	15	14	14	14	14	14	13	13	13	15	14	14	13	13	13
Wave Graph (?) 10m 5m 3m 1m 0m																		
Energy (?)	107	108	75	135	120	118	107	105	104	99	64	53	123	163	213	184	127	165
Wind (km/h)	0	10	15	5	5	10	5	5	15	10	5	15	5	10	15	0	10	15
Wind State (?)	glass	cross-on	cross-on	glass	cross-on	cross-on	cross	glass	cross-on	cross-off	cross	cross-on	off	cross	cross-on	glass	cross	cross-on
High Tide / height (m)	1:24AM 1.53		1:49PM 1.39	2:15AM 1.65		2:38PM 1.49		3:01AM 1.73	3:23PM 1.55		3:42AM 1.76	4:05PM 1.57		4:21AM 1.74	4:44PM 1.56		4:58AM 1.67	5:23PM 1.50
Low Tide / height (m)		7:20AM -1.15		7:38PM -1.26	8:10AM -1.29		8:26PM -1.36	8:55AM -1.39		9:10PM -1.41	9:37AM -1.45		9:51PM -1.40	10:18AM -1.45		10:32PM -1.34	10:57AM -1.40	

Note: the tide data above is for La Union, El Salvador which is 38 km away. Surf properties and timing are calculated for Punta Mango. See detailed tide info and graph

Figure 14. Severe storm tracks (Google Earth, http://upload.wikimedia.org/wikipedia/commons/2/23/Global_tropical_cyclone_tracks-edit2.jpg)

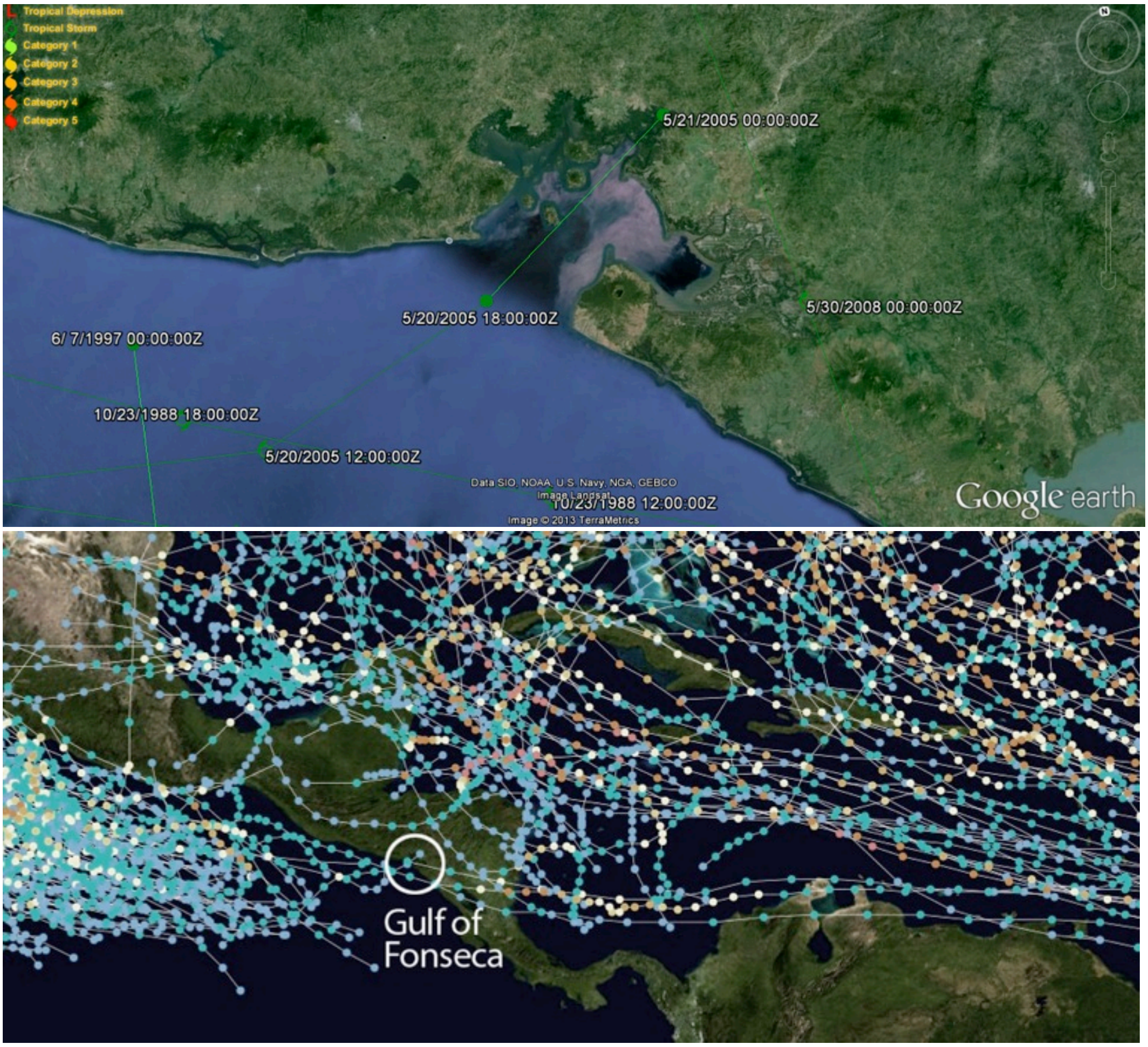


Figure 15. Sea Surface Temperature in °C (9-14/03/2001 (www.marn.gob.sv/phocadownload/pp_nn_13.pdf)

In the gulf: Tropical storm Adrian, 5/20/2005

Within 100 km radius: Tropical storm Alma 5/30/2008, Tropical storm Andres 6/7/1997, Tropical storm Miriam 10/23/1988, Tropical storm Olivia 9/21/71.

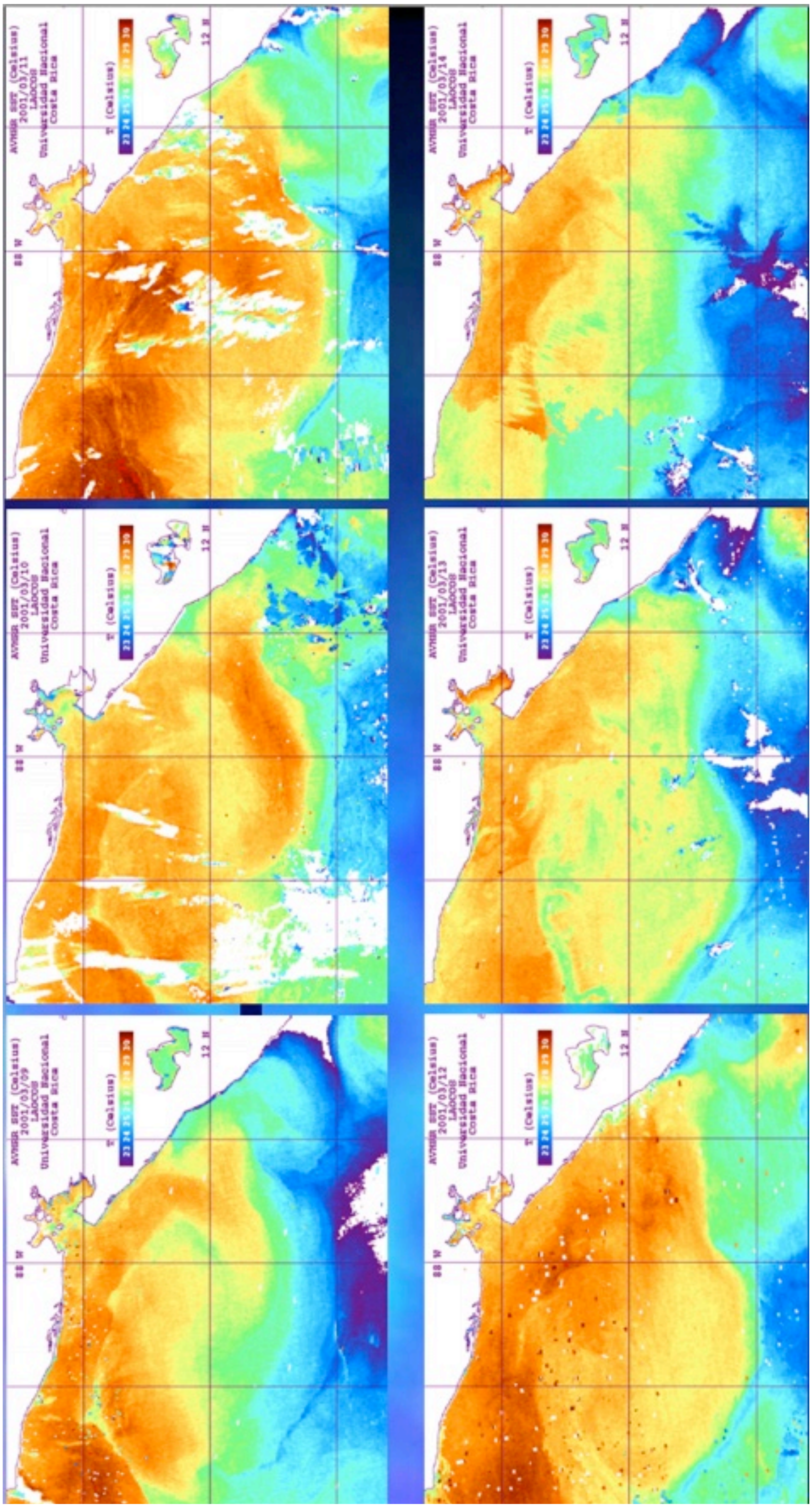
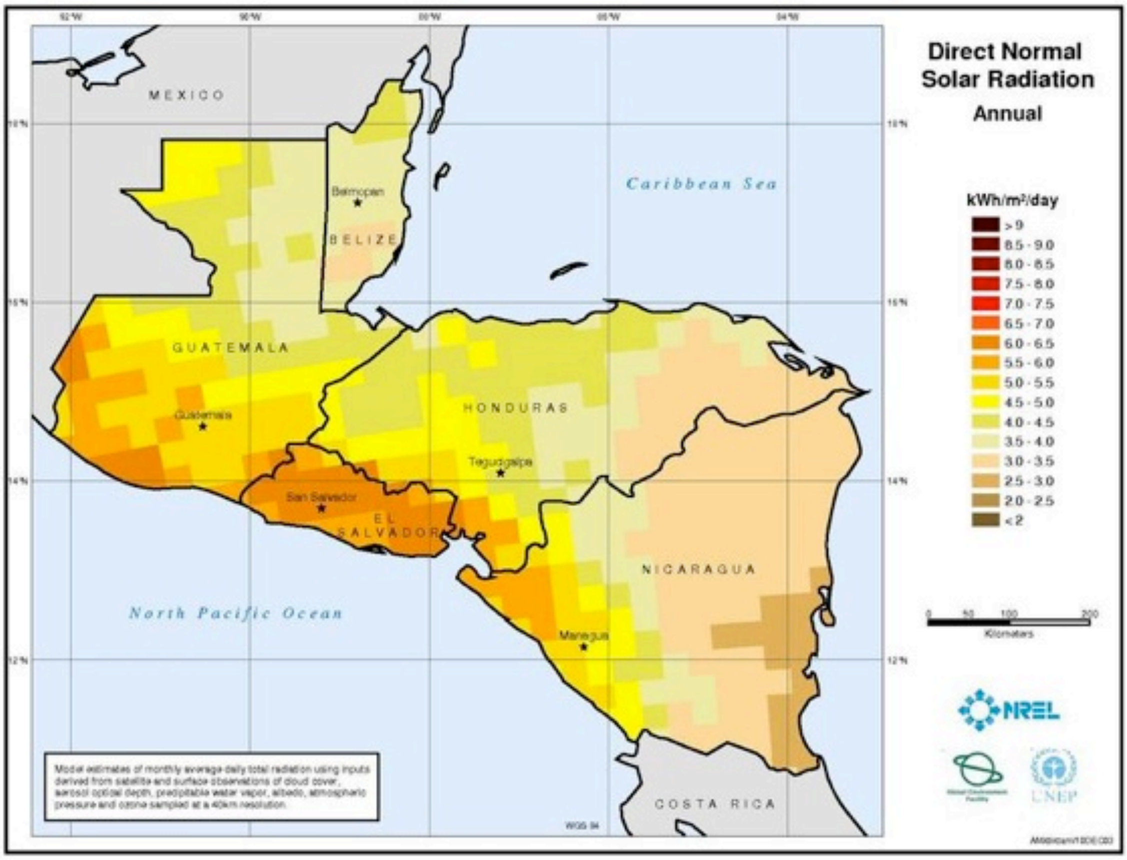


Figure 16. Satellite images of the Chismuyo Bay showing the large sediment plume flowing from the shrimp farms to the Gulf's water (Source: NASA).

Figure 17. Satellite images of Estero la Jagua and Chismuyo Bay in 1973 and 2006, after the conversion of the wetland areas into industrial shrimp production. (http://www.cathalac.org/lac_atlas/index.php?option=com_content&view=article&id=44:gulf-of-fonseca-honduras&catid=1:casos&Itemid=5).

January 1973 April 2006

Figure 18. Annual direct normal solar radiation in Honduras (http://en.openei.org/w/index.php?title=File:NREL-camdirann.pdf&page=1).



Douglas scale with the estimate of the state of the sea. The "wind sea" is the motion of the waves generated by the wind blowing directly on the observed sea area or in its immediate vicinity.
http://www.eurometeo.com/english/read/doc_douglas

DOUGLAS SCALE

WIND SEA

	DESCRIPTION TERM State of the sea	WAVES AVERAGE HEIGHT
0	Calm (glassy)	-
1	Calm (rippled)	0 - 0,10 metres
2	Smooth	0,10 - 0,50 metres
3	Slight	0,50 - 1,25 metres
4	Moderate	1,25 - 2,50 metres
5	Rough	2,50 - 4 metres
6	Very rough	4 - 6 metres
7	High	6 - 9 metres
8	Very high	9 - 14 metres
9	Phenomenal	over 14 metres

SWELL

WAVE LENGTH AND HEIGHT	
0	**No swell**
1	**Very low** (short or low wave)
2	**Low** (long and low wave)
3	**Light** (short and moderate wave)
4	**Moderate** (average and moderate wave)
5	**Moderate rough** (long and moderate wave)
6	**Rough** (short and heavy wave)
7	**High** (average and heavy wave)
8	**Very high** (long and heavy wave)
9	**Confused** (wave length and height indefinable)

SPECIFICATION	Metres
Short wave	< 100
Average wave	100 - 200
Long wave	> 200
Low wave	< 2
Moderate wave	2 - 4
Heavy wave	> 4

NOTE
The swell reports also comprise the wave direction according to the eight main directions of the wind rose expressed in the english notation (N, NE, E, SE, S, SW, W, NW). For instance: Swell 2 from SW or Low swell from NW.

The "Swell" waves are generated by winds blowing over a distant sea area which travel rapidly over the surface with a regular period and flat crests

Appendix 4 Ship sizes

Type	Name [33], [34] , [35], [36]	Length (m)	Length (ft)	Beam (m)	Beam (ft)
Cruise ship	Royal Caribbean – Allure & Oasis of the Seas	360	1,181	63	208
Cruise ship	Royal Caribbean – Freedom, Liberty & Independence of the Seas	339	1,112	56	184
Cruise ship	Royal Caribbean – Navigator & Mariner of the Seas	311	1,020	49	161
Oil Tanker	TI-Class Supertanker	380	1,247	69	226
Bulk Carrier	MS Vale Brasil	362	1,187	65	213
Container ship	Mærsk - Mary, Majestic & Mc-Kinney Møller	398	1,306	58	190
Container ship	CMA CGM - Marco Polo, Alexander von Humboldt & Jules Verne	396	1,299	54	177
Container ship	Mærsk - Emma, Estelle, Eleonora, Evelyn, Ebba, Elly, Edith & Eugen	398	1,305	56	185
Aircraft Carrier	**USS Theodore Roosevelt, John C. Stennis**	333	1,092	77 (deck)	252
Barge	Heerema H-851	260		63	

Appendix 5 Floating breakwaters: opportunities and challenges

A seastead protected by floating breakwaters presents an alternative to large ship-like or semi-submersible structures and may be worth investigating. The main benefit of applying a breakwater structure is that it provides a shelter for the seastead by breaking or reflecting large waves. Behind the breakwater, floating structures would not have to deal with such large waves. This allows smaller structures to be constructed that have a better water experience and allow for a more dynamic urban structure.

While the concept of a breakwater seems simple, it is quite a challenge to neutralize the enormous power of ocean waves. Most other strategies for dealing with enormous waves are actually based on evading wave energy. For example, ships are designed to either cut through water or plane on the water (lifting it on top of the water) and semi-subs and spars are designed with rounded or slender structures to minimize the effects of waves and water forces. Instead of evading waves, breakwaters have a brute force approach, facing the waves head-on. This means that both the structure and the mooring system need to be able to deal with enormous forces. Another complicating factor is that floating breakwaters are difficult to design, because the buoyant structure responds to waves, while it alters the waves at the same time.

Floating breakwaters that are anchored, instead of tautly moored, are only effective against relatively small wavelengths: According to Mani[37] this type of breakwater needs to be at least as wide as 0.3 times the wavelength in order to halve the height of incoming waves (K_t<0.5). This is because at longer wavelengths the breakwater will tend to move along with the wave instead of breaking it. This property of floating breakwaters is not a real issue, because as explained in the Seasteading Engineering Report[38] the most harmful waves are typically not the long wavelengths but the shorter and higher waves.

When 100-meter waves are considered, it can be assumed that they will be lower than 20 meters (waves that are higher than $1/5^{th}$ the length are not able to support themselves). In order to break such a wave and bring it down to 10 meters, we would need a breakwater of at least 30 meters wide. Theoretically, a second breakwater of the same length (for a total of 60m) would bring it down to 5 meters, which at a wavelength of 100 meters should present no threat.

However, if the breakwater is somehow fixed it becomes more effective, reaching K_t<0.5 at a width of around 0.15 times the wavelength[39]. It becomes more effective because rolling and swaying of the structure are prevented. In this case, the width of the breakwater discussed above could be halved. While this is an interesting option for relative shallow waters, where piles may be used to secure the breakwater, it seems an unlikely solution for a structure that is to be placed in the high seas. 'Fixing' a breakwater in the middle of the ocean would require extremely taut mooring and a high amount of buoyancy to compensate the downward force. At the same time the structure and mooring system will be under additional stress from the waves and tidal influences. Such a system, which requires the elements to be fixed to one spot, is also very inflexible and would present many challenges when the seastead is to be relocated.

Perhaps there are alternative strategies to create downward force, other than using taut mooring systems. One possibility is to use the water mass itself to push down the breakwater, by creating a ramp-like structure. This structure may act as an artificial shore. Waves that approach it will 'feel bottom', slow down as they climb the ramp, build up until they become too steep and eventually break. At the same time the water creates a downward force that prevents the structure from rolling or drifting up. In this scenario the breakwater will not be exposed to the full strength of the waves.

Inclined plate breakwaters have been researched extensively with positive results at widths between 0.25 and 0.75 times the wavelength[40]. Considering that this data is based on flume testing, rather than real-life situations, additional research will be necessary.

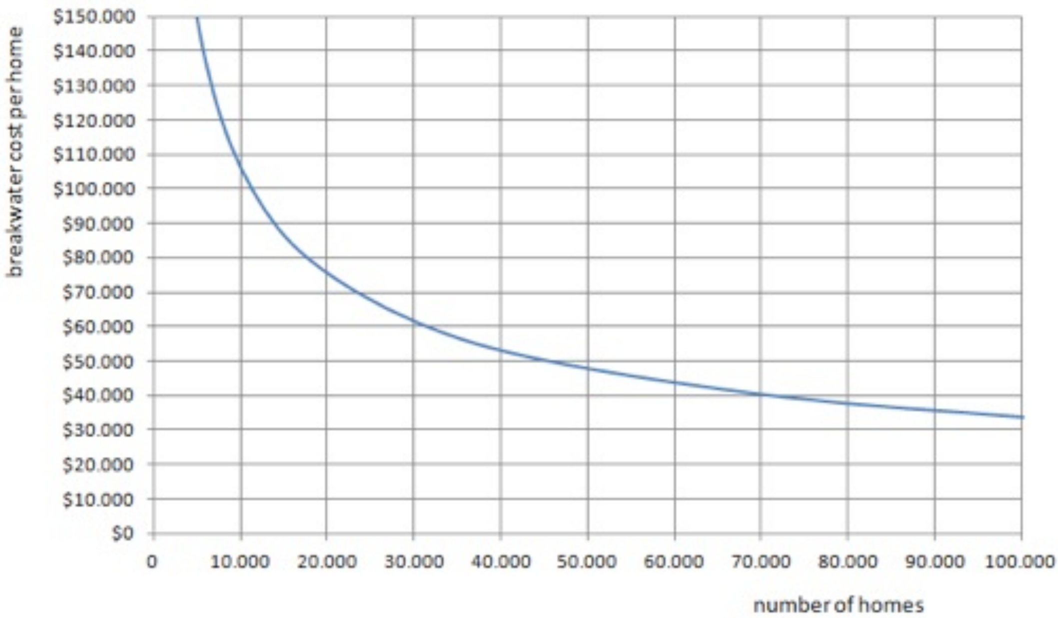
If a breakwater were designed for the most destructive wavelength reported in the ClubStead paper, which has a steepness of 0.12 and a length of 86 meter, the breakwater would need to be up to 65 m wide. The costs for the breakwater can be based on taking the volumetric costs of reference projects, for example FDN's estimates, which are between \$125 and \$320 per m^3.

Assuming a thickness of 5 meters and cost of €330 per m3, the breakwater would cost €108,000 per meter. If 80% of the structure were submerged, it would weigh 260t/m and the cost per ton per meter would be about €415. These costs include a mooring system for shallow water. For deep water additional costs will be made to secure the breakwater. These costs are directly proportional to the depth of the water and the amount of force the lines need to be able to withstand[41]. The Seasteading Engineering Report assumes that for a water depth of 2,000 meters mooring facilities amount to roughly 1/4th of the estimated costs for hull construction. If the same relation holds true for breakwaters, it implies a total cost of €135,000 per meter.

In order to judge these costs, they must be considered in relation to the size of the seastead. When the breakwater is conceived of as a perfect circle drawn around a community of homes, the length of the breakwater is equal to the radius times two□ . Because the size of the community will increase exponentially as the radius increases, the per capita costs for the breakwater will decrease rapidly as the community grows. Figure XX illustrates this; it is based on 20 homes per hectare and breakwater construction costs of \$35,000 per meter. A 5,000-home seastead would require about \$150,000 per home, whereas a 100,000-home Seastead would require only about \$34,000 per home.

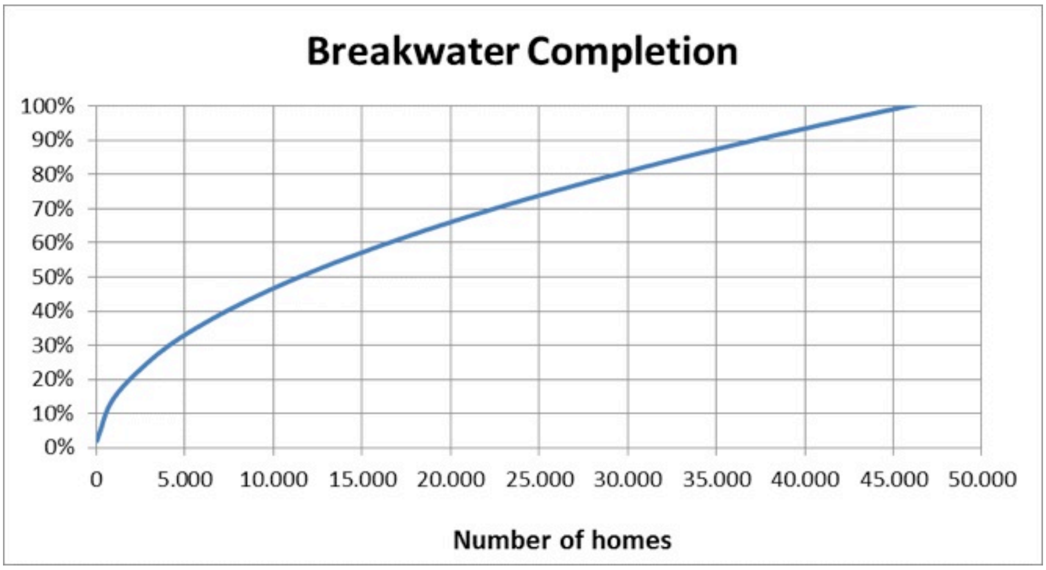
Table X Cost reference data FDN[42]

	T-Block 	U-Block 	Heavy Duty U-Block 	Monaco 
Length	up to 20 m	up to 30 m	50+ m	352 m
Width	3 – 4 m	4 – 7 m	7 – 18 m	30 m
Height (total)	3 – 4 m	4 – 7 m	7 – 18 m	30 m
Section area (est)	10 m^2	20 m^2	80 m^2	900 m^2
Water depths	up to 6 m	6 – 12 m	> 12 m	175 thousand tons
Wave heights	up to 1.1 m	1.1 – 2.5 m	> 2.5 m	
Cost estimate	€ 3,000 / meter	€ 5,000 / meter	€ 10,000 / meter	€ 150 million
Cost / m3 construction	€ 300	€ 250	€ 125	€ 320



Breakwaters are also an interesting option because they don't have to be applied right from the start. When a seastead starts at a bay or other sheltered water surface and is not yet exposed to large waves, there is no need for wave protection. As it grows larger, at a certain point it may be able to finance a breakwater, especially if there is future growth potential. For many alternative options, such as seaworthy ships or semi-submersible rigs, their seakeeping measures are an integral part of the structure and cannot be applied later on.

Figure below illustrates the process of completing the breakwater if every home finances $50,000 or 37 cm of breakwater. At 10,000 homes, half of the breakwater will already be financed. At 47,000 homes it will be finished.



Appendix 6

COST ESTIMATION TOTAL OVERVIEW

General input			total
Amount of inhabitants			225
Gross floor area		m²	39.576
Residential space	75%	m²	28.182
Office space	25%	m²	9.394
Hotel		m²	2.000
Vacant space (pentagon addition)	GFA	m²	15.076
Total amount of platforms			11

Development costs	per unit		total
Platform costs	3.242.495	€	38.909.940
Mooring system	37.500	€ / platform	3.300.000
Connections between islands	70.000	€	770.000
Bridges between islands	330.000	€	3.630.000
Real estate	1.000	€ / m² GFA	39.576.000
Water and energy			2.433.193
TOTAL COSTS ex			**88.619.133**
Total + development costs (fees, financing etc.)	25%	€	110.773.916
Tax (Honduras)[1]	12%	€	124.066.786

General		
Average costs per platform		11.278.799
Costs GFA	€ / m²	3.135
Costs GFA	€ / ft²	291
Costs GFA without energy and watersystem	€ / ft²	282
Costs UFA	€ / m²	4.019
Costs UFA	€ / ft²	373
Costs UFA without energy and watersystem	€ / ft²	364

Systems		high
Energy - micro grid	€	2.017.943
Energy - generator	€	1.499.055
Water	€	415.250
Total costs	€	2.433.193

GFA = gross floor area

UFA = usable floor area

In the first block the total space is larger than the space distributed among the functions; residential, offices and hotel. This is because this space is not jet been assigned to a function (vacant space). The platform for this space, as also the square meter costs are already calculated the systems for energy and water are not.

Background calculations

Floating platform cost estimate

Sewerage, drainage, cables and wires					
sewer/drainage pipes	100	m¹	375,00		37.500
cables and wires	2500	m²	0,75		1.875
sidewalks top layers	250	m²	30,00		7.500
additional floor	780	m²	35,00		27.300
TOTAL SEWERAGE					**74.175**

Basement structure				
ground floor (hollow-core)	735	m³	50	36.750
basement floor ²	1210	m³	1.400	1.694.000
outer walls	349	m³	1.400	488.236
inner walls	364	m³	1.400	510.149
TOTAL BASEMENT				**2.729.135**
TOTAL PLATFORM				**2.803.310**

Pentagon platforms	4.821.693	4	19.286.771
Square platfroms	2.803.310	7	19.623.169
		3.242.495	**38.909.940**

Maritime constructions

mooring system	37.500	/piece	8		3.300.000
connections between islands	70.000				770.000
bridges between islands	2000	costs/m²	3,00	5,00	330.000
TOTAL MARITIME CONSTRUCTIONS					**4.400.000**

Systems

Energy low scenario			Demand		
Micro grid⁴ on time price for the system	0,71	€/kWh	996.943	kWh	709.695,4
	0,33	l/kWh	64.000	kWh	17.991
Annual costs (price based on 2012³)	0,85	€/litre			
TOTAL SUSTAINABLE LOW SCENARIO					**727.687**
Diesel generator³					
	32.000		8	units	256.000
Annual costs	0,33	l/kWh	1.060.943	kWh	298.243
Price based on 2012³	0,85	€/litre			
TOTAL CONVENTIONAL LOW SCENARIO					**554.243**

Energy high scenario			Demand		
Micro grid⁴ on time price for the system	0,71	€/kWh	2.764.615	kWh	1.968.051,5
	0,33	l/kWh	177.478	kWh	49.891
Annual costs (price based on 2012³)	0,85	€/litre			
TOTAL SUSTAINABLE HIGH SCENARIO					**2.017.943**
Diesel generator³					
	32.000		21	units	672.000
Annual costs	0,33	l/kWh	2.942.093	kWh	827.055
Price based on 2012³	0,85	€/litre			
TOTAL CONVENTIONAL HIGH SCENARIO					**1.499.055**

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(2) http://www.gwwmaterialen.nl/soortelijk-gewicht-materialen/
(3) http://knoema.com/atlas/Honduras/Pump-price-for-diesel-fuel-USdollar-per-liter, 2012
Generators 0,28 - 0,4 litre per kWh 400 kw : 40k - 47k pp
(4) based on data from Phono Solar, the price of a micro grid per kWh for a solar system with a diesel engine backup is 1 per kWh 0,71187196
This price per kW/h for the solar system is higher than the average price on the main land, and the conventional energy scenario due to the independent micro grid system, which is a one-time installation (based on an actual installation in the Maldives). The useful life of solar equipment ranges from 7-10 years for batteries and 25 years for panels themselves. Therefore, the actual cost per kW/h would be much lower in the micro-grid scenario.

Real Estate

Platform size	Length		Width			
	50	m	50	m	2500	m^2

Distribution of ground space			
Platform	100%	2500	m^2
Sidewalks	10%	250	m^2
Green	10%	250	m^2
Issuable Ground	80%	2000	m^2
*Built-up Area**	50%	1000	m^2

Floor space		
Built-up Area	1000	m^2
Amount of floors	3	floors
Total *Gross Floor Area* (GFA)	3000	m^2
Gross - Usable ratio	0,78	
Total *Usable Floor Area* (UFA)	2340	m^2

Average floor area per person (GFA)		
Residential	75	m^2
Office	25	m^2
Total	100	m^2

Hotel		
Floor space per person	40	m^2
Amount of people	50	people
Hotel size (on 1 platform)	2000	m^2
Amount of floors	2	floors

Roof space per person		
People per platform	30	people
Total roof space	1000	m^2
Platform space per person	83	m^2
Platform space per person (hotel)	50	m^2

Totals based on inhabitants		
Total amount of inhabitants	225	people
Total amount of people	275	
Residential platforms	8	
Office platforms	2	
Hotel	1	
Total amount of platforms	11	platforms

Rooms in hotel	30
People / household	2

Distribution of ground space pentagon		
Platform	100%	4300 m^2
10% less efficient	10%	3870 m^2
Sidewalks	10%	387 m^2
Green	10%	387 m^2
Issuable Ground	80%	3096 m^2
*Built-up Area**	50%	1548 m^2

Floor space	
Built-up Area	1548 m^2
Amount of floors	3 floors
Total *Gross Floor Area* (GFA)	4644 m^2
Gross - Usable ratio	0,78
Total *Usable Floor Area* (UFA)	3622 m^2

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