BUILDING ON WATER

STUDYING THE EFFECTS OF

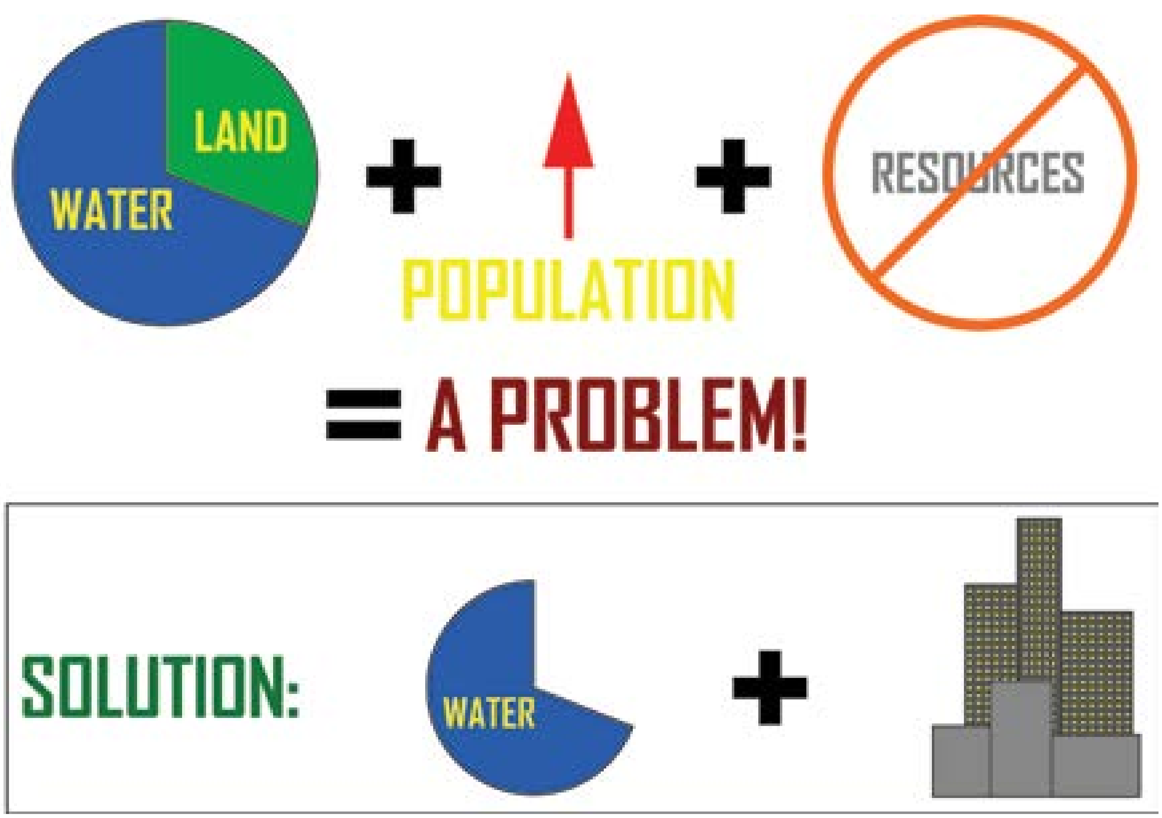
BUOYANCY ON ARCHITECTURAL FORMS

MITCHELL NAGEL
NORTH DAKOTA STATE UNIVERSITY
ARCHITECTURAL RESEARCH STUDIO 771
GANAPATHY MAHALINGAM. FALL 2018

ABSTRACT

Our planet is 71% water and 29% land. That land is filling up quick and is going to look a lot smaller for the coming generations. With an ever-growing world population, that is already at almost 7.5 Billion people, we are looking at a future with scarce resources and overpopulation, but maybe we aren't making the most of what we have available.

With rising sea levels creeping up on our shores, why not build offshore? This research project will investigate the practicality of building on the water. The main challenge with this question of practicality is **how do we make architecture float?** Using simulation and case study research to solve this challenge, this study will theoretically propose that building off the coast, on the ocean, can be done and is a viable option for the future of an ever-developing world.



INTRODUCTION

Watercraft such as boats, large or small, possess the ability to float on water. Large structures, that architecture is known for, are not known to float on water. The motivation behind this study is to find out what it would take to make this possible, as well as the most sustainable, efficient and architectural way to do so. This project will examine questions concerning the practicality of building on the ocean and the best design options regarding form, material and function. The research uses information put into a design program that will then produce the information needed to determine if the object, or form, created will perform well in the ocean. Mathematical investigation and analysis of this output information will help the study to report accurate results. The data will merely show the minimums of what it would take. Therefore, the data will not be a definitive answer to what the design solution will look like, but it will serve as more of a starting point.

For this project, the study is framed in such a way that its results prove to be quantitative and deductive in their reasoning. This is because the outcomes depend on changing variables that can be measured through numerical values producing results that can be explained with cause and effect reasoning. During this study, variables such as volume, shape, weight and material will be plugged into the model to show how they each can affect the buoyancy of an object. This research will also be using the positivist approach because the output of results can be measured by the researcher objectively, while reflecting the reality of the objects ability to float. Throughout the study, the object must achieve a density higher than that of saltwater if it were to float. The computer program used is one that will accurately give the volume of the object created. To find the density of the object, the mass of the material used must be found to be plugged into the density equation. To find the best buoyancy solution for each variable, there will be numerous iterations until the results are promising. The greater the number of iterations, the more promising the results. Remaining objective through the modeling will be important and will be achieved by evaluating a large variety of volumes, shapes, weights, and materials.

PRECEDENT STUDIES

Factors that were considered when looking at potential case studies were the typology, context and innovation that each potential project presented. When looking at the typology of a project, the ones that were mixed-use, naval architecture or ones that were considered aquatecture were the projects that stood out. As far as context, projects that were designed for off-shore use and called a nearby, major city home were aspects that gave the project a sense of purpose in correlation with this research topic. Finally, the level of innovation was considered when choosing potential case studies. Projects that challenged old design techniques and showed exploration into new forms and functions were given more attention.

The following case studies contain information and photographs researched, gathered and analyzed from inter-net sources. The colored diagrams for each project were made by the author of this journal article based on drawings from these projects. All following case studies relate to, and inquire more about, the main question behind this study: what are the effects architectural forms have on buoyancy? Extra contextual information about each project may be presented in the following case studies, but all the conclusions will be drawn in relation to this question of the effect architecture has on buoyancy.


SED
The Water Factory


SED
The Water Factory

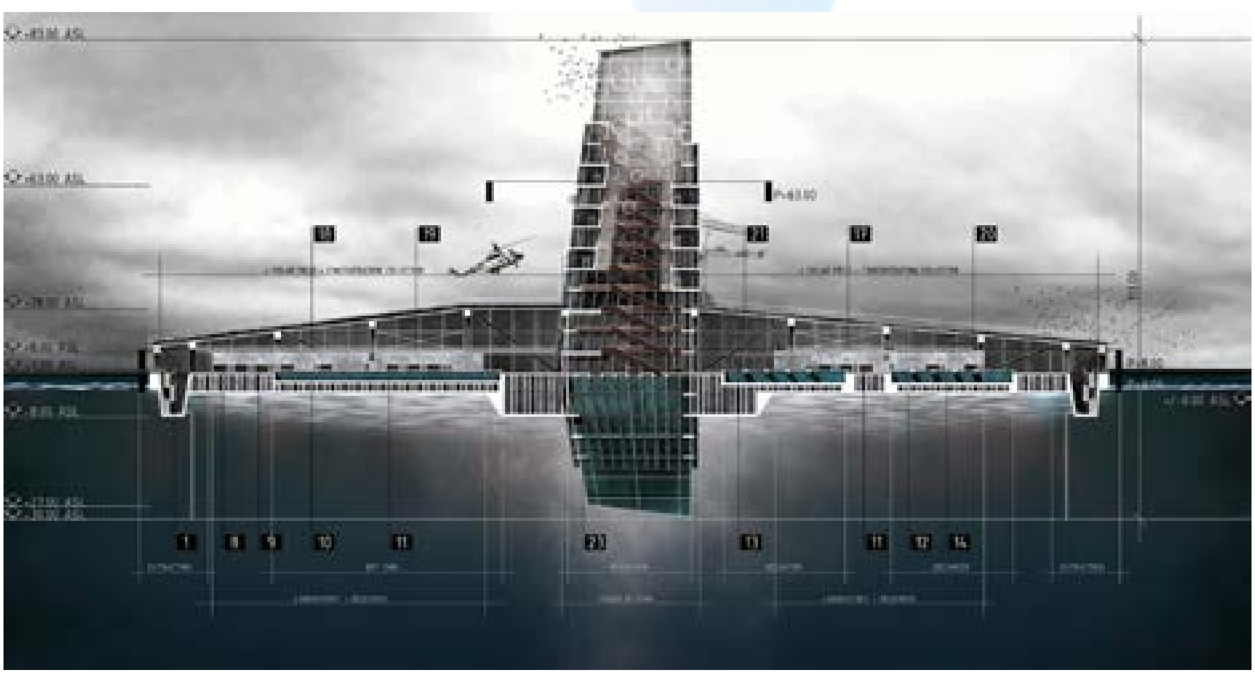
SED THE WATER FACTORY

INTRODUCTION

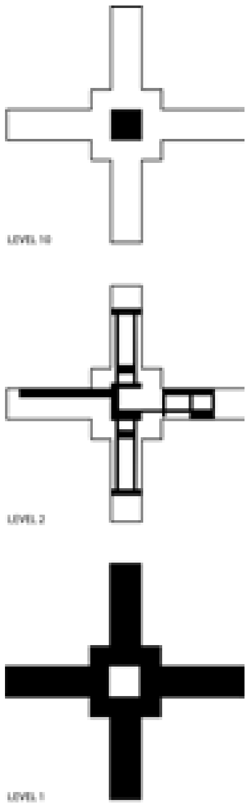
This project is a desalination station, water factory, or in broader terms is aquatecture in its typology, being that it is designed to be built on water. Juan Pablo Accotto, Mauro Ivan Barrio and Matias Damian Martin, the projects designers from the National University of Cordoba in Argentina, intended this project to be based in a bay of Cordoba, Argentina to solve the problem of fresh water shortage for the area. As far as the size of the project, it has a variable size depending on how many water factories are connected. They are initially individual pods in the shape of horizontal plus signs with a tower in the center and then attach in a grid pattern across the ocean water surface. Some distinctive, interesting characteristics of this project are the fact that it is standing on its own, floating in the ocean, and it incorporated sustainable features like turning plentiful, sea water into drinkable, fresh water using a unique method. Also, the project has the potential to be very dynamic in that it could be employed in any coastal city around the world and could be multi-use in the way the designers envisioned it.

PROJECT ELEMENTS

Extraction Room - Irrigation - Common Spaces - Public Space - Helipad - Lab - Biochemistry Lab - Administration - Brine Filtering - Residence - Circulation - Egress - Port Manufacturing - Pedestrian Entrance - Central Hall - Concentration manifolds - Decompression box

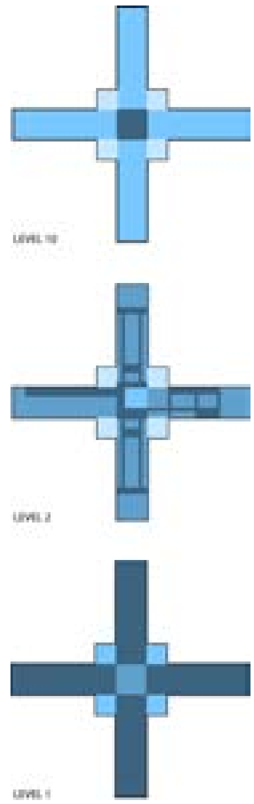


BALANCE



CIRCULATION

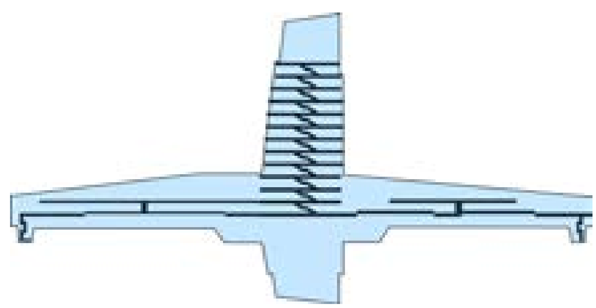
HIERARCHY



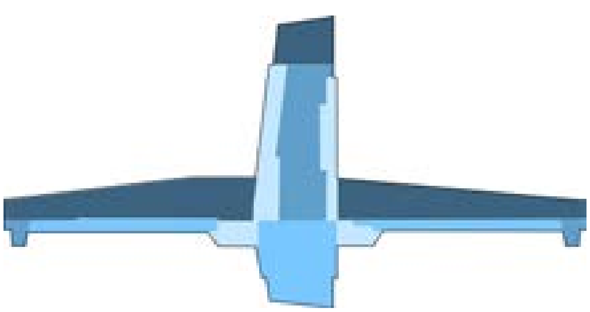
MASSING

BALANCE

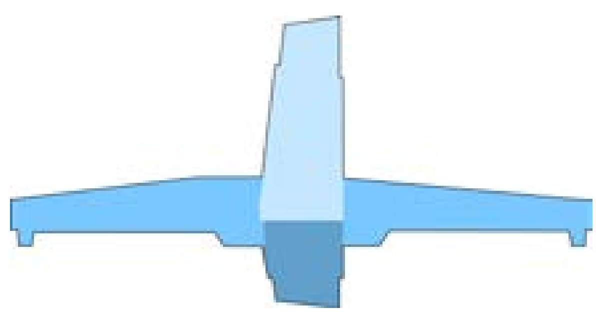
CIRCULATION



HIERARCHY



MASSING



ANALYSIS

Structure

The Structure material is created from a seawater-based magnesium alloy. Magnesium is the 7th most abundant element on earth and the 3rd most abundant dissolved in seawater according to this project. If this wasn't sustainable enough, magnesium alloy is an environmentally friendly material, more so than fiber reinforced plastic, which can be melted down and recycled. This structure has also been proven to be a stronger structural lightweight material than steel due to its weight. All these facts about magnesium alloy, drawn from the project's presentation boards, seem to make the project heavy on the sustainably built side of the scale.

Natural Light

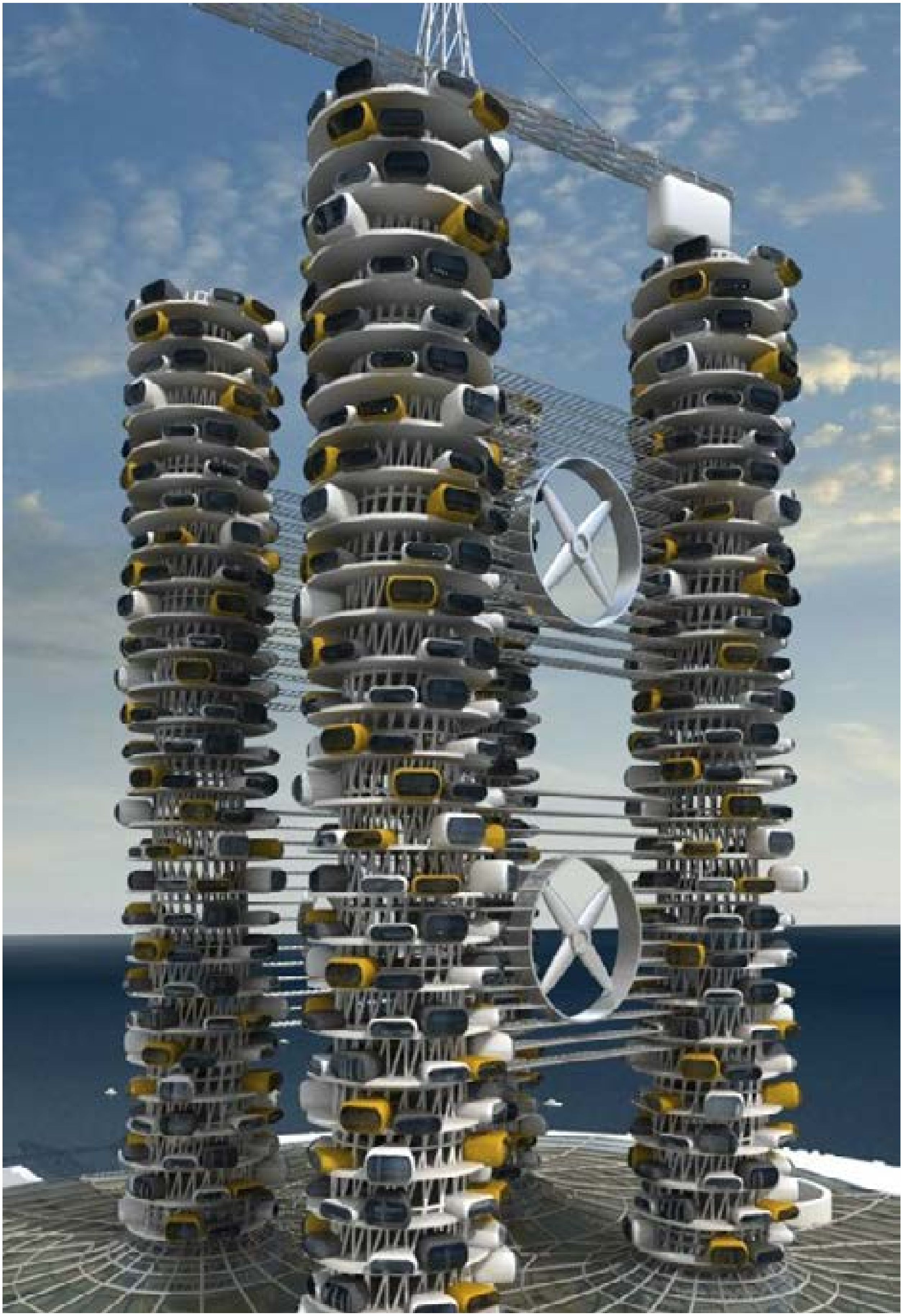
In observation, most of this design is as a greenhouse would be, and for good reason. There are a few spaces, like the solar panel roofing and the walls around the tower, that are solid and do not let light pass through. Most of the spaces would be filled with light, according to the renderings by the designer.

Massing

From a plan view, the form is a balanced plus shape. From a section view, the form is heavily horizontal as it is almost twice as wide as it is tall. Also seen in the section diagram, the tower runs through the base mass but leaves most of the tower mass above the waterline. This allows for the water holding tank, in the bottom of the tower to be below the water line for balance purposes and to be semi-supported by the upward force of buoyancy.

CONCLUSION

The material used in the structure of this project is lightweight and very sustainable. Considering new materials in future projects could be very beneficial to keeping the weight down. This project is very symmetrical in plan and section. When designing on the open ocean where the seas can be rough, this symmetry can help to stabilize the building.



THE FLOATING CITY

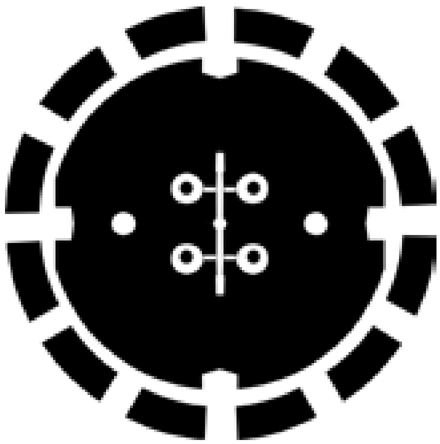
INTRODUCTION

The project typology is aquatecture, but more specifically this project exhibits multiple functions by individualized islands: residential islands, commercial islands, sports complexes, leisure, social equipment, hotels and the different services. Jonny Stica, from Pontifical Catholic University of Paraná-PUCPR, intended this design to be for the Guanabara Bay in Rio de Janeiro, Brazil. Each floating habitation island holds four massive 600-foot-tall towers with a 90-foot-tall base. For each island, the towers and base together are said to be able to house some 5,000 people. Some distinguishing characteristics of this project are that there are a large variety of options as to what this project wants to be. This isn't necessarily a bad thing because it ends up looking like an urban design project but on the water. This project has a very futuristic mode of transportation between the islands. There are balls that the passengers ride in like hamsters and shoot through tubes between the islands or back to land. This project is designed with a sustainable mind. The design is passively heated by the sun, receives freshwater by collecting rain on the roof and is wind powered by wind turbines between the towers.

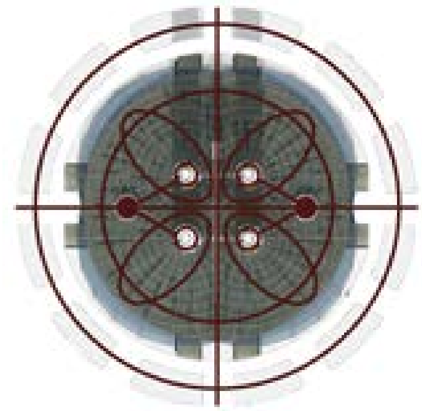
PROJECT ELEMENTS

Residential island option - Greenhouse - A Crane - Circulation - Commercial island option - Boat Docks - Transportation ball tubes - Sports complex island option - Liesure space - Hotel island option - Wind turbines

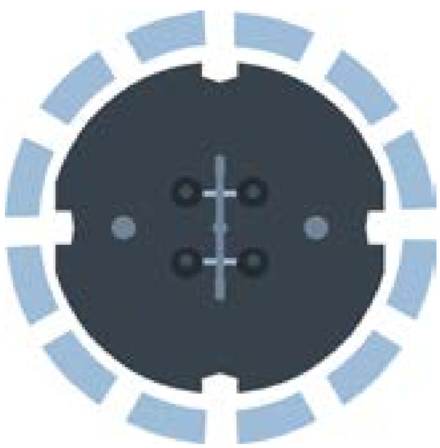
BALANCE



CIRCULATION

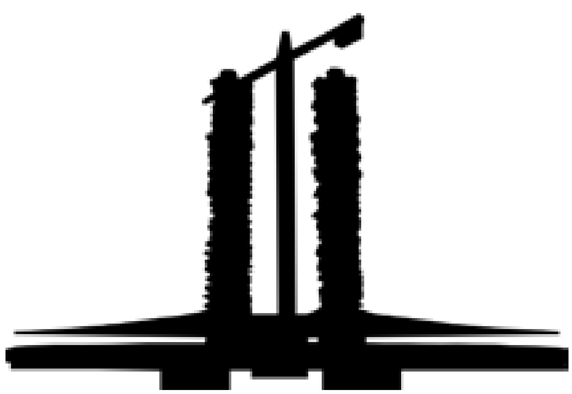


HIERARCHY

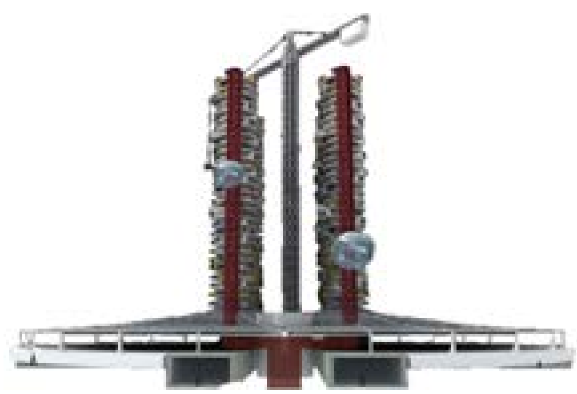


MASSING

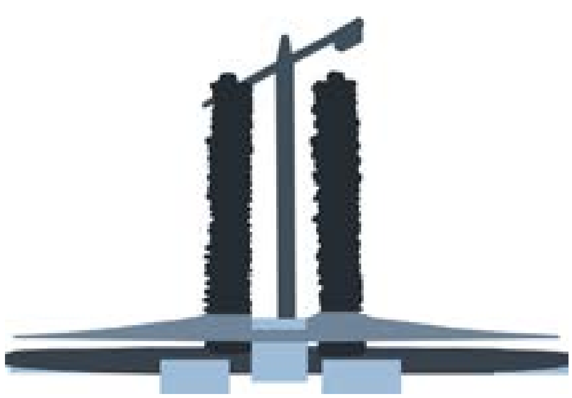
BALANCE



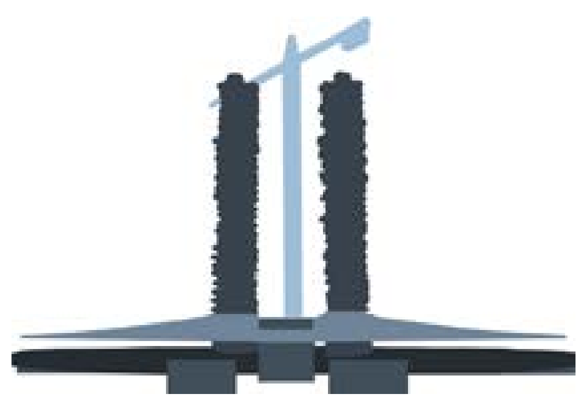
CIRCULATION



HIERARCHY



MASSING



ANALYSIS

Structure

The very center of the residential towers is a vertical glass structure which is supported by stacked v-shaped pillars which stands as the main structure in the towers. These towers hold up the various levels and the living modules that rest on them. The four towers belonging to each island is supported from below by a floating concrete structure. This concrete structure also keeps a greenhouse afloat below the towers.

Natural Light

The towers are very open to natural light, so each housing module would have a good chance at receiving a healthy amount of sunlight. Beyond the resident housing, the greenhouse below is entirely glass covered so it would be taking in as much sunlight as the sun is willing to provide.

Massing

The base form is very symmetrical and provides a large, wide footing to give stability to the towers. The base is essentially made from various sizes of circles when looking at it in plan view. The greenhouse roof also adds a bit of sloping interest to the base form. There are four tall towers extruding from the base, where they are centrally located and square to each other. The massing of the tower may be the most interesting due to the unique and random placement of the family home pods placed on each level. These pods produce little bumps in the towers facades creating an odd texture running up and down the buildings.

CONCLUSION

The large and generally flat base below the towers is the new type of foundation that sets an example for what is required to keep the buildings above stable while not disturbing the environments below, besides a few anchors to keep the mass in one place. This model of how the typical family home could look shows how sustainable living could possibly be capitalized on in the future if our basic individual and family needs are evaluated while considering our resource and space consumption. The only concern that arises is the proportions of how high the towers are compared to the width of the base. If high winds and waves were to pass by this project, it might tip or experience a lot of rolling motion.

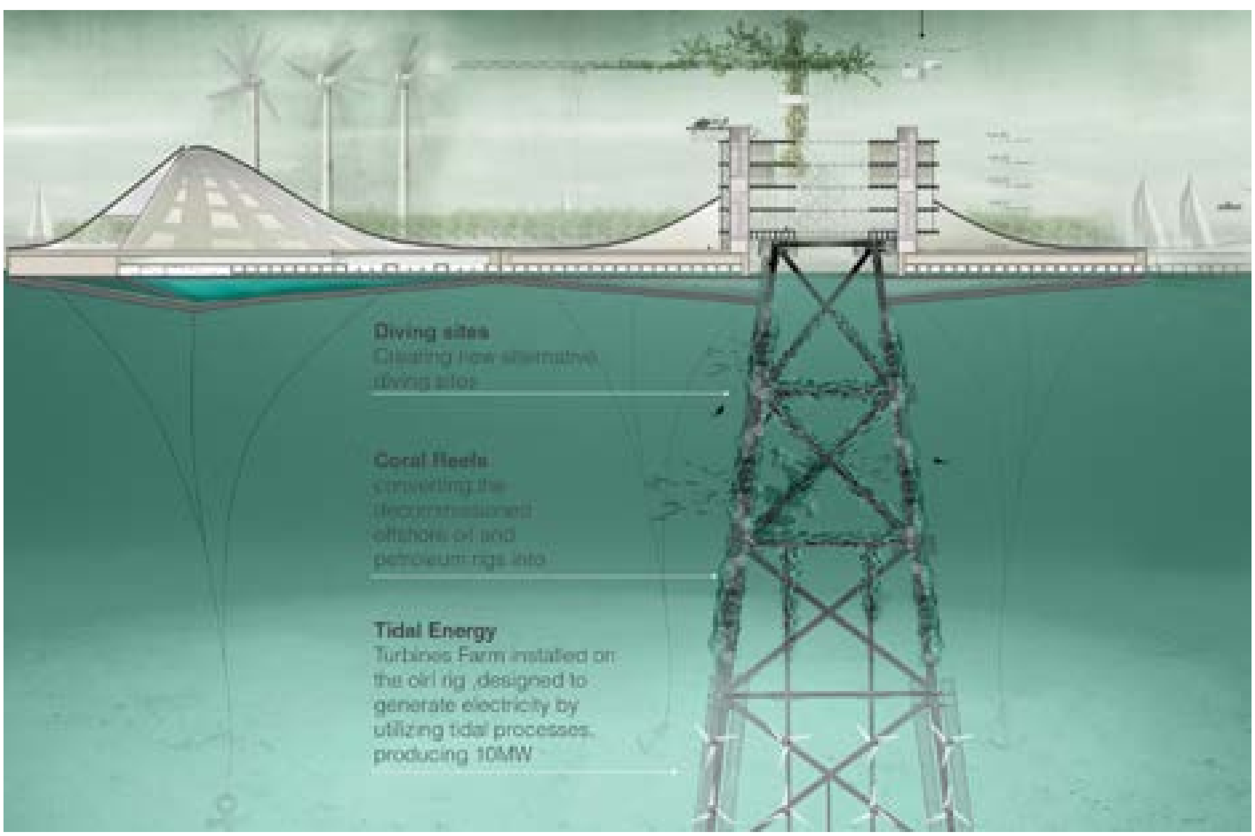
SEA-CURE

INTRODUCTION

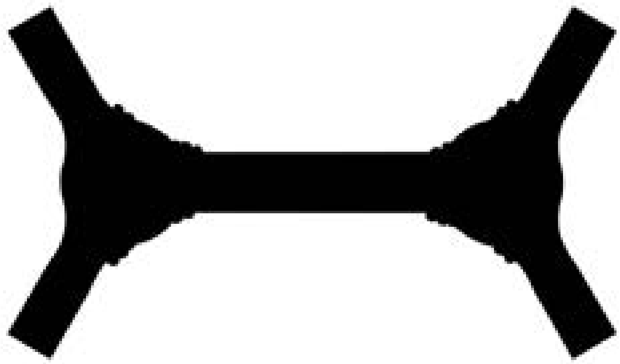
This futuristic case study is an industrial re-use project that is located thirty kilometers west of Ashdod, Israel on the abandoned Tamar oil platform. Rola Abboud, from the Neri Bloomfield School of Design in Haifa, Israel, designed this project for the year 2040, when the oil field will no longer exist in Israel and the Tamar oil rig is no longer in use. The size of this project is variable because it will make use of the 295-meter-tall fixed rig by attaching various numbers of floating, dynamic platforms to it. Some distinguishing characteristics of this project are its ability to heal the ocean life after the damage caused by oil drilling in the area, its re-use of the oil rig to make it something that can benefit the environment instead of cause it harm and the projects ability to be what the area needs right now, but also to be flexible in the future to provide a place of leisure, activity and education in the future.

PROJECT ELEMENTS

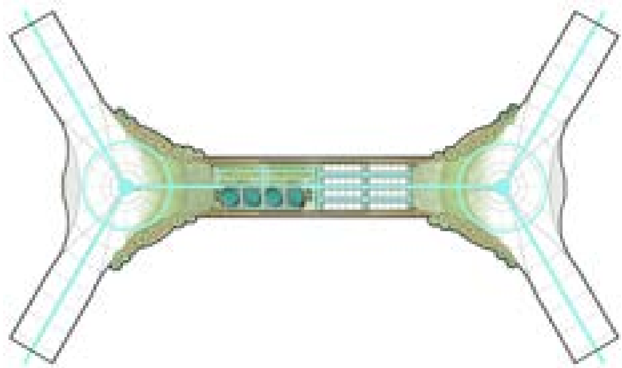
Areas of growth for algae - Mangroves trees - Underwater plants - Fish breeding ponds - Desalination systems - Agriculture – Solar energy collection - Wind energy collection - Tidal energy collection



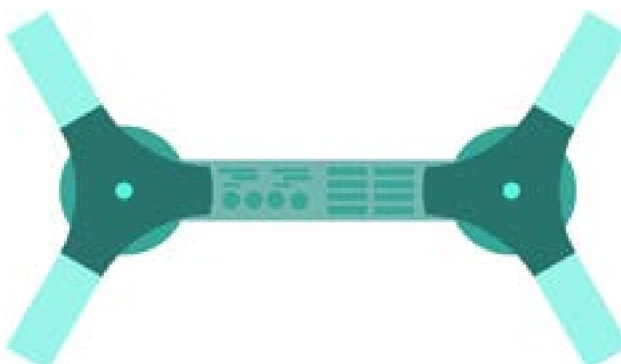
BALANCE



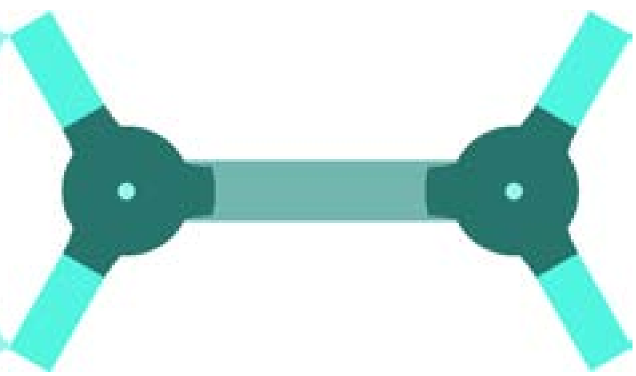
CIRCULATION



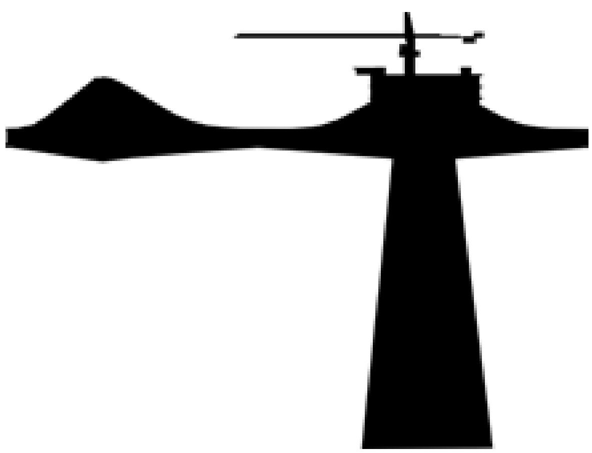
HIERARCHY



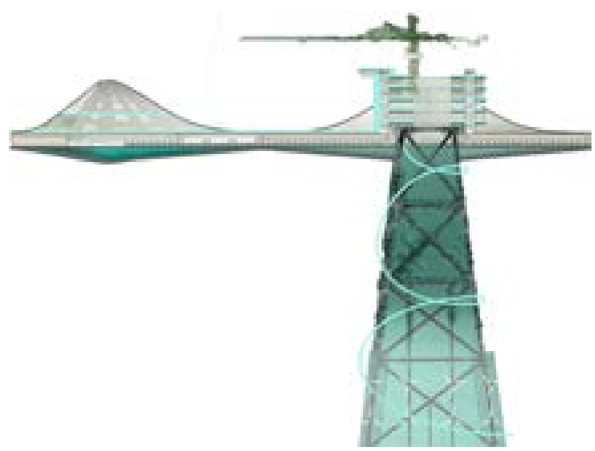
MASSING



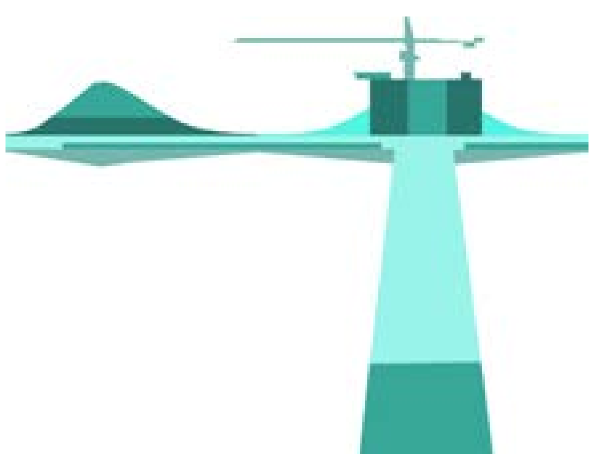
BALANCE



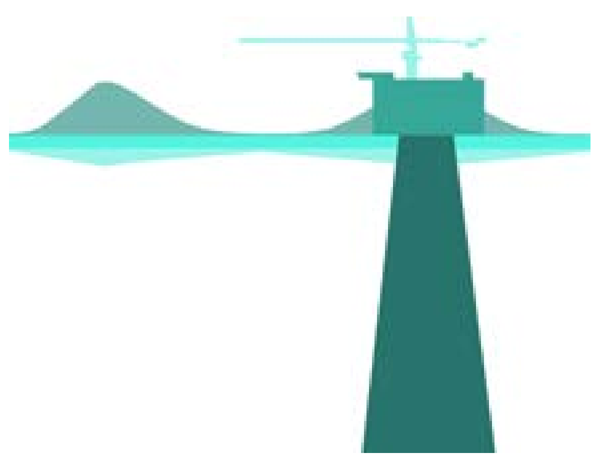
CIRCULATION



HIERARCHY



MASSING



ANALYSIS

Structure

The main structure of each tri-wing platform is a strong, but light concrete base that allows for airspace to keep the platforms afloat. On the bottom of each platform is a magnesium alloy frame where water is held to balance the mass in the ocean. Above the concrete base is a steel framed flooring for the first level, and an upper level above that is where the agriculture can be grown under a greenhouse structure with solar glass as the author describes it. Each tri-wing platform then connects at each wing to create a hexagonal shape in the center.

Natural Light

This project has two main spaces influenced by natural light. One includes the greenhouse, glass structure, that houses the first level and the upper level. The other natural light area is the exterior where the desalination takes place as well as where all the trees, plants and algae grow.

Massing

In plan, the massing of this project looks like an X being pulled apart. Looking at the pods linked together, they form a hexagon shape in the center, much like when elements form bonds to each other. The form tends to look like cells when there are groups of pods together. In section there is obviously a large amount of mass below the water due to the existing oil rig framing, but, ignoring that piece, the rest of the form is very balanced in symmetry. If you do not leave out to the existing oil rig frame, tower and crane, the form is unbalanced in section and a-symmetrical.

CONCLUSION

This case study is the only one that makes use of an existing element and is especially significant because the re-use of this oil rig represents the turnaround of something destructive to the environment, giving the project a huge environmental benefit behind the design. This case is also made of a few very light, sustainable yet strong materials. Beyond that, the form is very symmetrical and looks like it would stay very balanced in rough seas because of the way the pods connect together in an octagon.

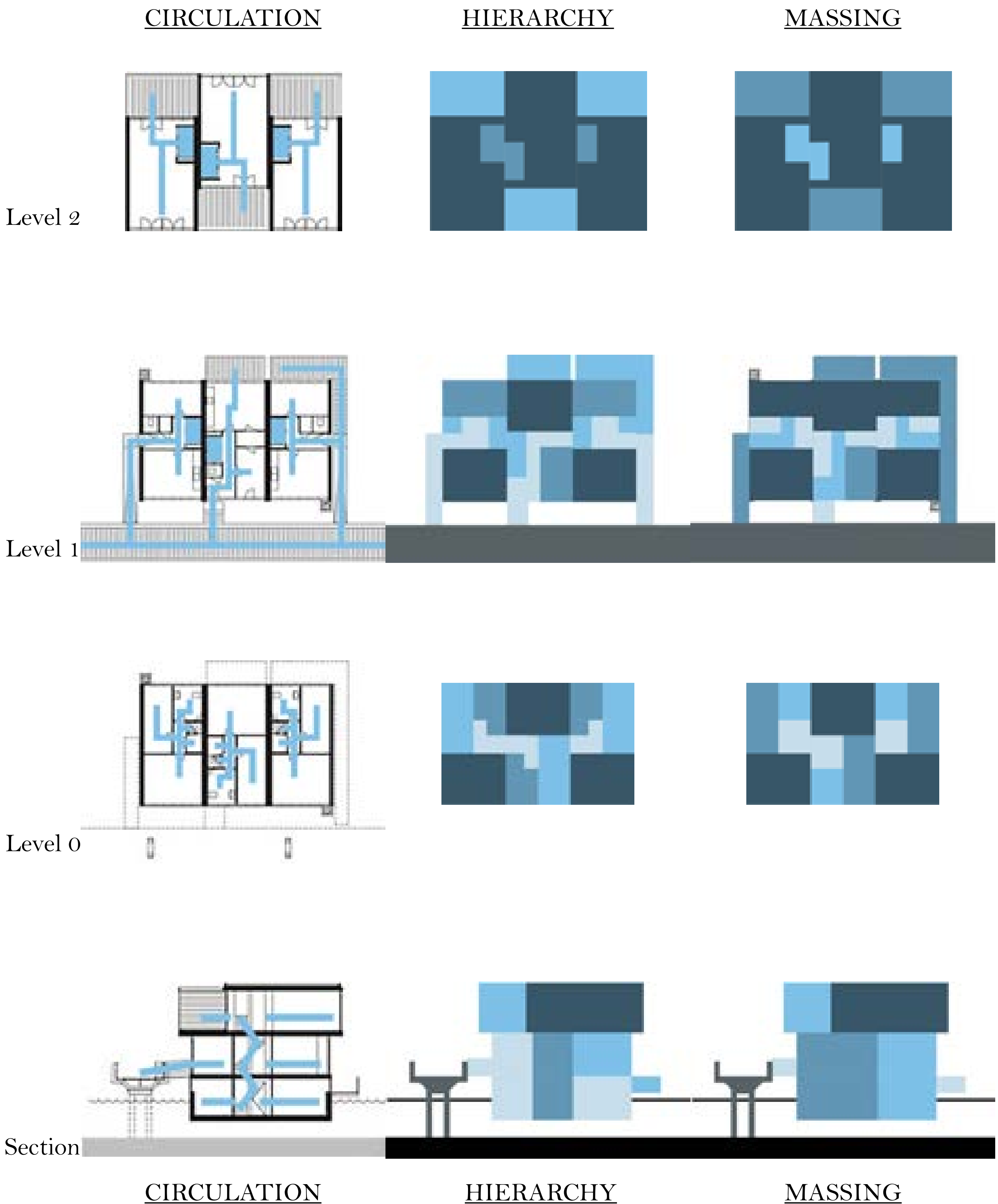
AMSTERDAM FLOATING HOUSES

INTRODUCTION

This residential aquatecture project, located in IJburg's Waterbuurt development in Amsterdam, was designed by project developer Arthur van der Vegt (Woodstone & Sparkey bv), in collaboration with Andries Laane of Villanova Architecten. In total, there are now 93 floating homes within the development, with plans for 72 additional homes. Waterbuurt West has reached a density of around one hundred houses per hectare, where one hectare is about two and a half acres. The distinguishing characteristics of this project include it being a residential neighborhood floating on the waterfront, having individual single-family homes, connected homes for stability, and simple buoyant construction with concrete tub bases.

PROJECT ELEMENTS

- 13 Vancouver (solo); residential space 156 square meters, owner-occupied
- 24 Sydney (duo) 107 sq. m., owner-occupied
- 18 Seattle (trio) 100 sq. m., free sector rental


CIRCULATION
HIERARCHY
MASSING
Level 2
Level 1
Level 0
Section
CIRCULATION
HIERARCHY
MASSING

ANALYSIS

Structure

Concrete tubs support the floating homes, as they sit in the water half a story in depth. A lightweight steel frame construction is built on top, which can be fastened with glazing and paneling made of colored plastic. Owner options include adding extensions, such as sunrooms, verandas, floating terraces, awnings, etc. Once constructed in a covered manufacturing facility, the houses are then neatly docked to a jetty in the shallower water closer to shore. There it will be riveted to two mooring poles. The jetties have a concrete base and an aluminum surface for walking. The selected type of aluminum is low maintenance and is a non-slip surface when wet. The houses must be balanced, and if they are not then a balance tank of water must be used to level out the house for safety.

Natural Light

The concept of natural light is completely up to the owner as to how much they want. These houses are very individual and unique depending on what the owner wants in terms of privacy and design.

Massing

The massing is more controlled than the option to incorporate natural light. The restrictions for the building envelope a width of 21 feet, length of 30 feet, height above the water of 22.5 feet, depth under the water of 4.5 feet and the 3rd story must be 50% of the maximum surface.

CONCLUSION

The simplicity of this project shows that building on the water does not have to be complicated. Also, building above and around the environment below the water does not mean it has to be in the deep ocean. The use of concrete tubs for floatation is interesting because we think of concrete as such a heavy material, but really it has a low density making it great for this situation. Light and sustainable materials were used in the making of the houses as well as the jetties connecting the homes. Each home is very individualized as well.

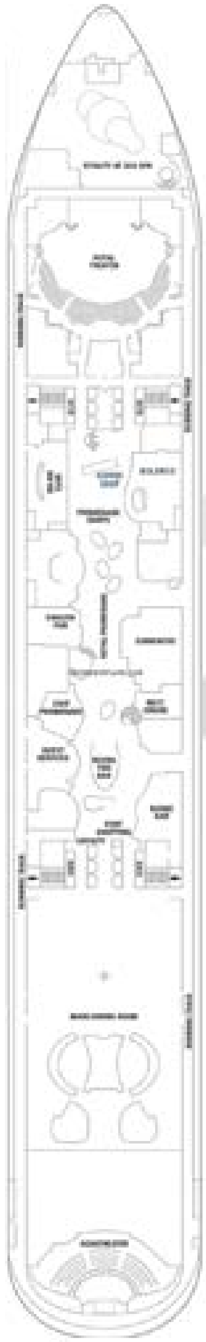
CRUISE SHIPS

INTRODUCTION

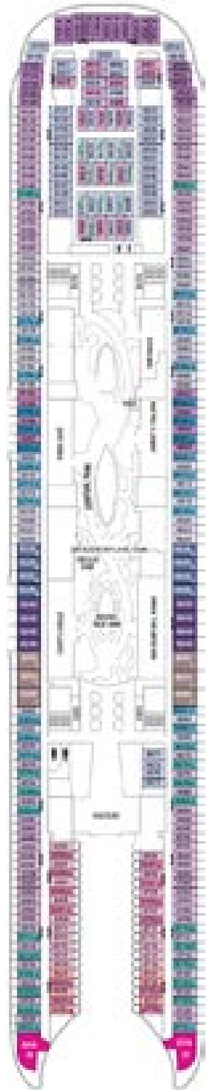
Cruise Ships could be classified as naval architecture, residential, commercial or maybe even aquatecture. They are the type of design that does it all, like a floating city in the shape of a large boat. Cruise ships can travel almost anywhere in the world that is connected to the ocean and allows the ship safe passage. They can range in size anywhere from a small river cruise to the largest cruise ship on the market, Symphony of the Seas by Royal Caribbean. Being the largest cruise ship on the water, this ship measures in at 1,188 feet in length, 215 feet in width and has 18 decks stretching upwards to a total height of 238 feet. Of these 238 feet in height, only 30 feet sit below the water allowing for as much of the ship to see natural light as possible. Many of the interior spaces of the ship receive natural light as well thanks to the open center reaching down to a green park on the 8th deck. This Cruise is nothing short of a small city floating around the Caribbean hosting 5,518 guests while housing 2,200 crew to serve the guests and keep the ship in operation. The ship not only houses over 6,700 people, but also includes a variety of spectacles for the passengers to enjoy including 22 unique restaurants, 24 pools, a central park, boardwalk, aqua-theater, ice rink, indoor theater and much more.

PROJECT ELEMENTS

2,759 Guest Cabins - 1,100 Crew Cabins - 22 Restaurants - 24 pools – Casino - Conference Room - Fitness Center - Indoor Theater - Indoor Ice Rink - Outdoor Theater - Clubs/Bars – Spa – Shops - Central Park – Boardwalk - Sports Court - Mini Golf - Rock Climbing

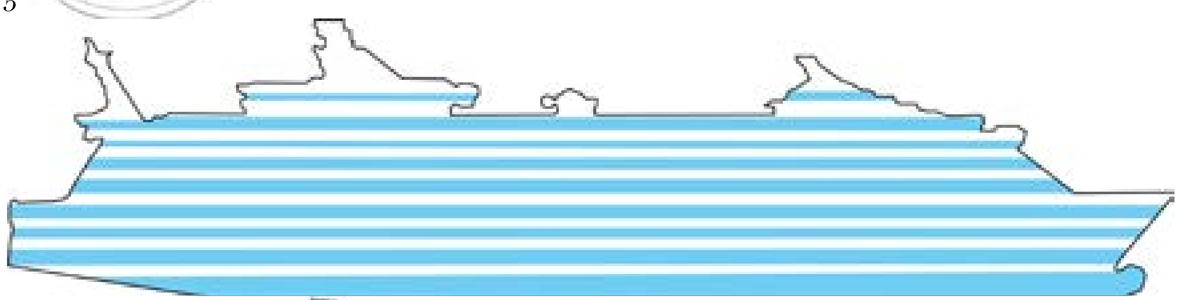


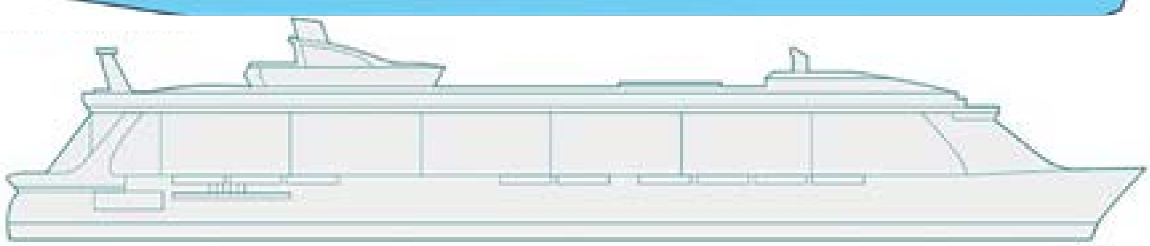
Level 5



Level 8

Level 15





ANALYSIS

Structure

Cruise ships are constructed in sections, mostly made of light weight metals such as aluminum and high-strength steel to keep the center of mass low despite their size. First, the hull of the ship is constructed and then the superstructure is built on top of that. The heaviest components to the ship are placed in the lower parts of the ship for stability.

Natural Light

Every guest room on the ship has windows on at least one side allowing light to fill the rooms. There is a central park that is outdoors and enjoys sunlight through the middle hours of the day because it is in the center of the mass of the ship with rooms on either side but nothing above. As expected, all the pools and decks receive as much sun light as is available.

Massing

The massing of the ship is much longer than it is wide. The ship is not a box though, the bow, hull and stern are curved to guide the water around the ship with ease. The bulk of the ship, including the cabins and all the activities are what make up the upper half of the ship. This mass is blocked off where the rooms meet the side of the ship and towards the front and back of the ship are where aerodynamics come into play as well as architectural form. This mass accommodates the central park, as well as all the pools and the rest of the main attractions.

CONCLUSION

This case study gives considerable insight into building materials, weight distribution, capacity for entertainment and activities and the possibilities of sheer size of the project. This all speaks to the practicality of building on the ocean and how floating a small city above and around the environments below is possible. The one thing studying cruise ships did not explain was how to make living on the ocean more sustainable.

MIAMI RESIDENT INTERVIEWS

INTRODUCTION

There were interviews conducted while visiting Miami for the purpose of asking Miami citizens a few questions related to this buoyancy study. The questions are listed below, and each question leads up to finding out what the interviewees think of the idea of this project. This interview process is important for this qualitative research because part of the project's practicality will be brought to light and this project will be designed specifically for the people of Miami, so it will be a better product produced if it has a good relation back to the citizens that could potentially be making use of it.

A total of seven people were interviewed, all meeting a handful of standards set by the interviewer. Each person interviewed had to be willing to participate, eighteen years of age or older, and had to be residents in the Miami or Miami Beach areas. No personal, identifying information was required from the interviewees.

1. **What city do you currently live in?**
2. **How long have you lived there?**
3. **What qualities does Miami have that you value?**
4. **Have you noticed higher water levels since you have lived in Miami?**
5. **How would you feel about living on a stationary, floating apartment complex on the ocean?**
6. **What would you like this floating apartment complex to include to make it feel more natural and at home for you?**
7. **What fears might you have about living on the ocean?**
8. **Do you believe in the effects of climate change?**

RESULTS

Question #1

Of the seven interviewees, four of them admitted to living in Miami Beach and three were from the rest of Miami. This question did not have much impact on the interview results besides making sure it was recorded that the interviewees were able to be credible and knowledgeable about the area.

Question #2

There was a variety of answers to the question of how long the interviewees have lived in Miami. Most of the answers were ten years or less (1, 2, 3, 7, and 10 years), but two answers were thirty years and thirty-four years having lived in the area. This result could mean that most people in Miami have not lived there their whole life, but it could also mean that Miami is a growing city, like census statistics show.

Question #3

A lot of the interviewees valued similar aspects of the Miami culture, especially the warm weather year-round and outdoor activities like walking the beautifully landscaped boardwalk along Miami Beach, all the nicely upkept parks and walking the streets around all the shops and restaurants. Some other answers included enjoying things like the nightlife, clubs, the nice community and how everything is located close together and is within walking distance when it is nice out.

Question #4

The repeated answer to number four was an echoing, "no". This answer was expected by the interviewer because the recorded ocean level change in the past few years has been minimal. The water level difference will likely be a slow rise, but still a rise, nonetheless. The only change interviewees noted was the flash flooding that occurs yearly during the hurricane season Florida endures.

Question #5

There were a few different answers to question number five, with three interviewees that loved the idea, two that thought maybe they would give it a try and two people who did not care for the idea. It was anticipated that some people would not be too sure about a concept that is so new to most people. There are a lot of variables that come up with this question including safety and transportation. Safety and transportation were the two concerns of the two people that said no to the idea of this project. The two that said this was maybe a possible consideration for them felt they needed more information to see if it was a good fit for them. This answer leads to the conclusion that if the design is done right, people will come.

Question #6

Of the five people that said this project concept could be considered or it was a good idea, some of the responses to what they would like to see as program elements in the project were social and relaxation areas like a beach or pools, making sure the project is self-sufficient, including outdoor activities and things to do on board and making sure that the residents have privacy, room for personal space and a homey feel.

Question #7

Of all seven interviewees, the fears they had included situations involving storms, waves (rolling motion), sinking, sharks and not being able to get back and forth between land. These are all valid fears but are easy to design for to make the residents more comfortable.

Question #8

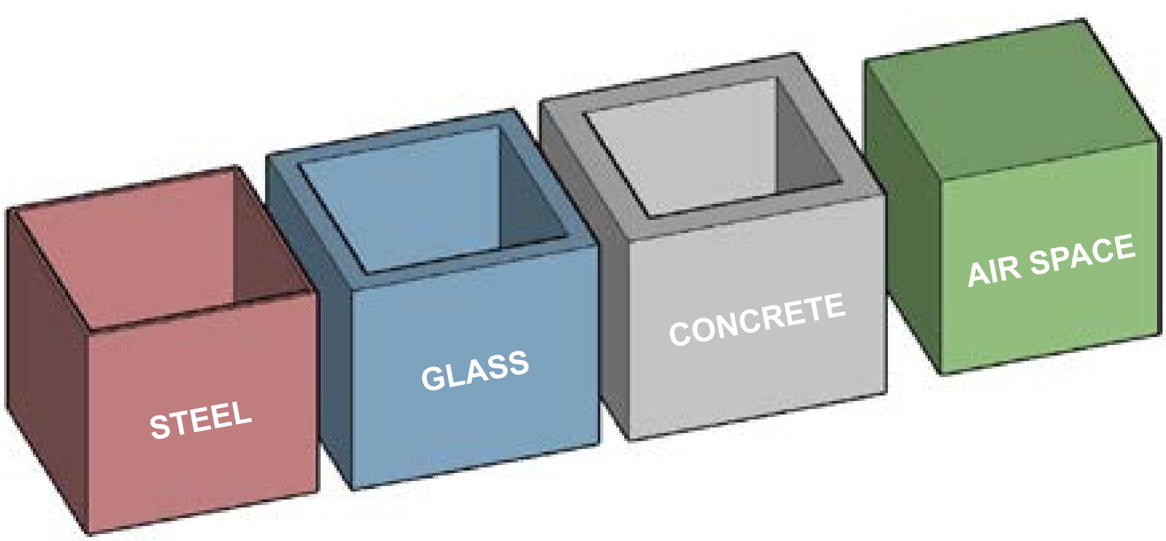
There was a variety of answers on the realness of the concept of climate change. Three people said they agreed that climate change is a real issue, two people said they were not sure and needed more hard evidence and two people said that they did not believe in climate change as an issue. This question was important to validate the reasoning behind the project. If the people, the project is for, do not believe in the project's concept then it will be harder to keep the project realistic.

CONCLUSION

In conclusion, these interviews were useful in finding out how the people of Miami felt about the idea of this project. The interviews would have been more informational for the interviewees if they had a better idea of what the project might look like or entail. A few main concerns from the interviewees to be considered are stability, safety, making sure the project has a strong connection to land and making sure the project has decent entertainment and activities. Things the interviewees would like to see in the project that can be designed for are self-sufficiency, a home-like feel for the residents, social spaces, relaxation areas, and making sure the residents have things to do to stay active, inside and outside. Again, this project is meant as an educational project for others to learn about how climate change will affect our future but also how we can design around it.

METHODOLOGY

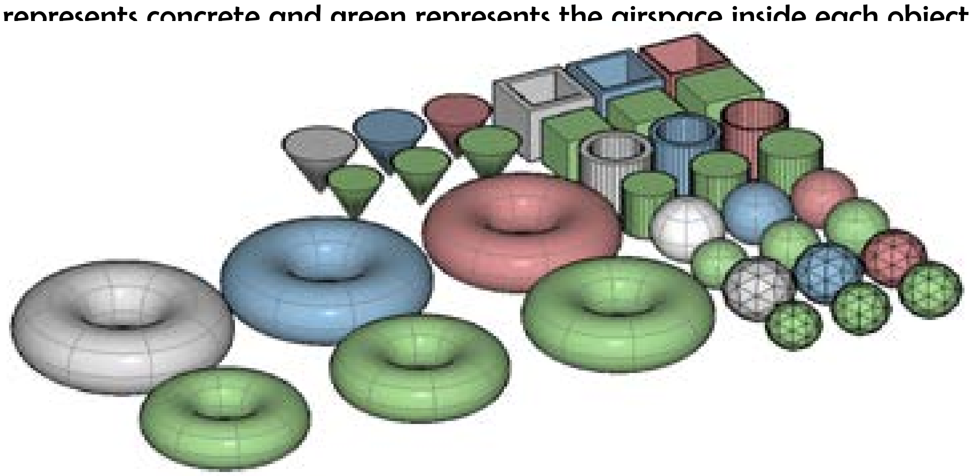
Through precedent studies, how cruise ships and floating habitats are constructed, what makes them successful and any improvements that could be made will be determined. Simulation research will also be used within a computer program to draw up a model and then test it. This will be done multiple times until the objects are diverse enough to produce enough quality data. The computer program to be used is called 'formZ', a modeling software in which lines and shapes can be drawn, transformed in various ways and then measured for quantitative data. The models to be drawn will be forms that could possibly represent a building to be built on water. Size of the object should not matter if the ratio of mass to volume stays the same. Once the ratios are found and the individual objects are deemed to be theoretically buoyant, the percentage of the object that is required to be dead load will be known. The dead load will consist of structure mostly, but from there the space available for other aspects of the project can be determined. The findings will be represented in two sections. The first will consist of a group of common 3D building-block-like shapes using the uniform size of 10 ft x 10 ft x 10 ft between all the objects. From this group, three different materials will be tested using each shape to determine the balance needed between airspace and material to make each object float. From this data, the ratio of material to airspace needed for each material will be known to be used on a much larger scale. The second section will be a group of plausible forms that could represent a building on the water. There will be three forms in this second section with three iterations for each form. Through this study, possible designs for a thesis project could take form by creating iterations of computer mass models that include various sizes of forms, materials, general structure and levels that could work as a final product.



RESULTS

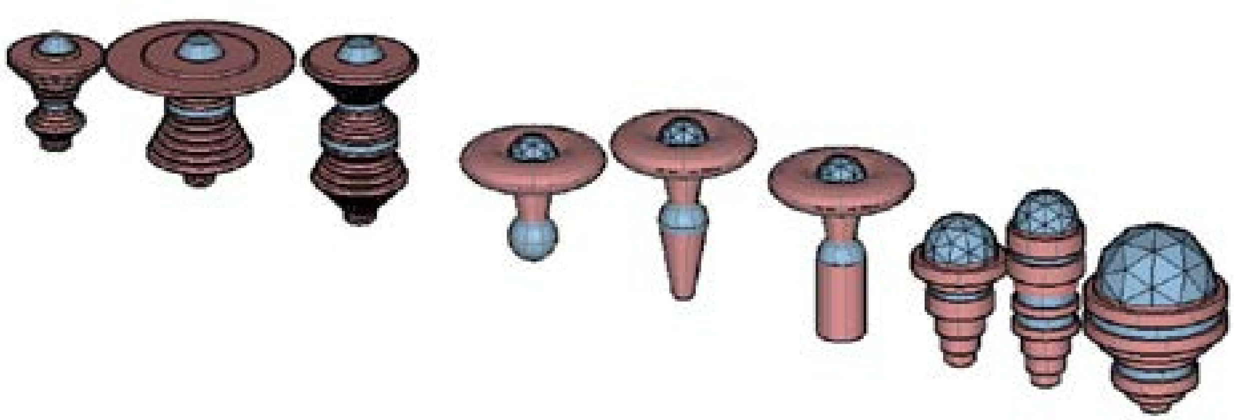
The first task completed involved finding the formulas through which it could be concluded whether an object would float. It was found that knowing the volume of the body of the vessel and the density of the material used in the vessel was needed to derive its mass. After, the mass of the water displaced by the vessel needed to be found. To do this, the volume of the vessel and the volume of the airspace inside were added together and then multiplied by the density of saltwater, which produced the mass of the saltwater that the vessel would have displaced. The mass of the liquid displaced, and the mass of the vessel were then used to determine if the vessel would float. If the mass of the vessel, or the force downward due to gravity, was less than the mass of the displaced saltwater, or the upward force r the buoyant force, then the vessel would be deemed buoyant.

The second task, after figuring out how to determine if an object would float, was to replicate this process by simulation within the computer program, 'FormZ'. Various three-dimensional shapes, consistant in size, would be created while testing a few different materials. By doing this, a handful of shapes and materials would be produced that would work best. From there, six basic 10'x10'x10' shapes were created in the forms of cubes, cylinders, cones, spheres, donuts and a spherical object with multiple sides. Each of these shapes had three iterations, one for each material: Steel, Glass and Concrete. The difference in material meant that, because each material possessed a different density, each of the three iterations for each object would require a different amount of material, making each iteration heavier or lighter than the previous. The trick of this task was using the formulas in the previous task to see what it would take to make each object float depending on the shape and the material. Shown below are the objects. Red represents steel, blue represents glass, grey represents concrete and green represents the airspace inside each object.



At the end of this task, there were eighteen theoretically floating objects varying between six shapes and three materials. From this task I found that shape and material both had an impact. While investigating the different shapes, it became clear that the more spherical shapes, like the sphere, spherical object with sides and the donut, required there to be less material for the object to float. While studying the different materials and their effects, the steel was most dense and therefore required that there be less material to float, the concrete was the least dense allowing the most material while staying buoyant and the glass was much lower than the steel in terms of the amount of material required for buoyancy but was still in between concrete and steel.

The third task completed was to create forms that would be representational of viable forms for a large floating habitat. To do this, and keep the study correlated between the steps, the same shapes and materials were used as in the previous task, but they were enlarged to a more practical size for a building and their proportions were changed creating three unique forms, and three iterations each. With a total of nine forms, it was then determined what percentage of the vessel volume would be allowed for each material. To do this, the previous tasks data was used to find the percent of material to volume, as well as the percent of airspace to volume, for each shape and their iterations with each material. Using these percentages, the average for each material was found to determine how much of the larger forms would have to be a certain material and how much volume could be airspace based on that material.

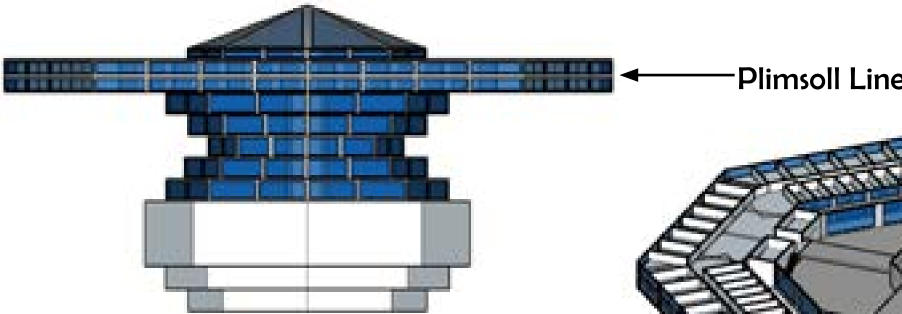


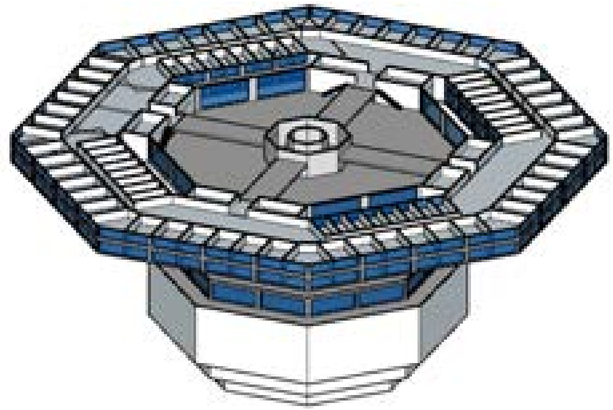
The found percentages of material to volume and the percentages of airspace to volume for each material are as follows:

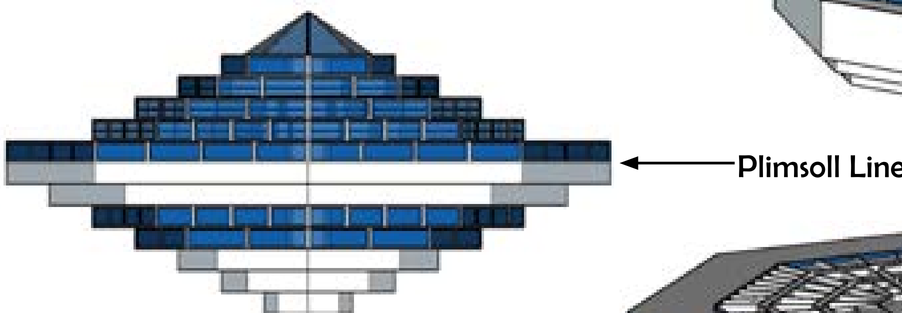
- The Vessel will float if no more than 12% of Total Volume Displaced is Steel. This would mean there is at least 88% of Air Space within the Total Volume Displaced.
- The Vessel will float if no more than 40% of Total Volume Displaced is Glass. This would mean there is at least 60% of Air Space within the Total Volume Displaced.
- The Vessel will float if no more than 53% of Total Volume Displaced is Concrete. This would mean there is at least 47% of Air Space within the Total Volume Displaced.

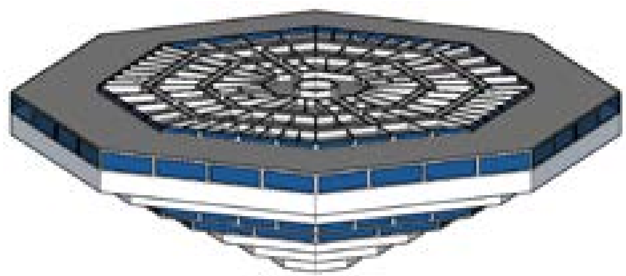
Using these percentages, the total volume was calculated, including the volume of each material and the airspace inside. Using the material volume and the density of each material, the mass of each vessel was able to be calculated. To find the mass of the displaced saltwater, the total volume displaced was used and multiplied by the density of saltwater. Finally, to find out if the vessels would float, the mass of each vessel was looked at and compared to the mass of the saltwater each vessel displaced. Again, it was known that each vessel would float if the mass of the displaced saltwater was greater than the mass of the vessel.

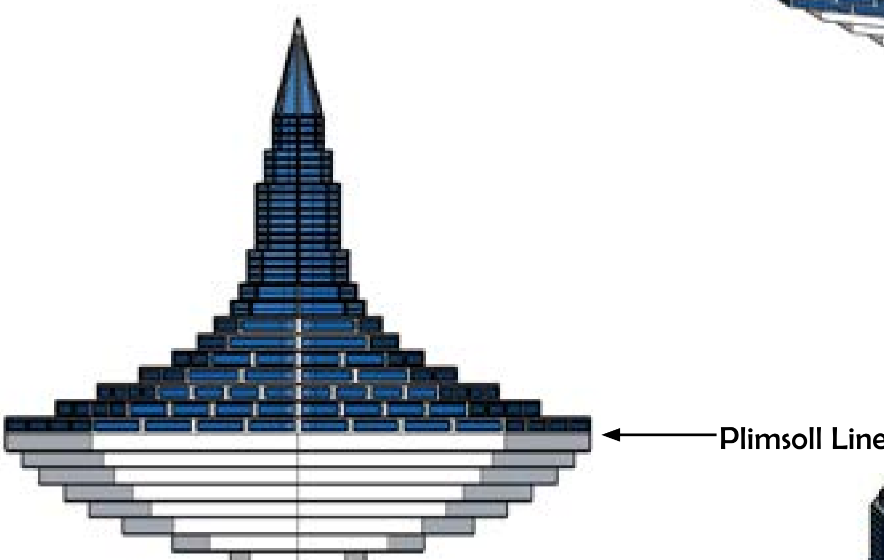
The final task completed was finding where realistic project forms would sit, depth-wise, in the water. In other words, the plimsoll line needed to be found to determine a safe water level for the project to sit at. This task began by creating three separate forms that are more developed than in the previous tasks. In addition to being more developed, the final products incorporated all the previously acquired knowledge gained within this study. After creating the separate forms, materials and the amount of each material used was determined. Each project consisted of steel, glass and concrete with proportions similar to the previous tasks. Once the forms were created and the materials were assigned, floor plans and space assignments were developed specifically for each project. Gathering the mass of each vessel, according to the amount of each material used, and the mass of the water displaced by each vessel, according to the volume of the vessel below the plimsoll line, each project was deemed theoretically buoyant putting forth three individual projects that could be taken further, such as in a design thesis project. The three forms vary in size as well as in shape, but they all are theoretically buoyant and sit at a specific water level that makes sense for stability and balance making these forms a practical solution to the question of designing architecturally-based buildings to float.

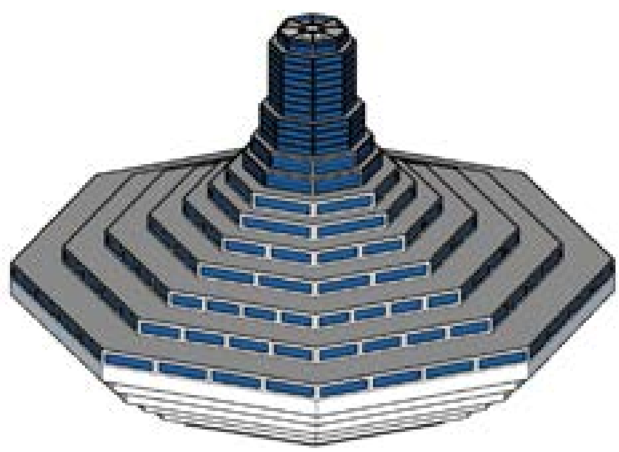

Plimsoll Line




Plimsoll Line




Plimsoll Line



CONCLUSION

In conclusion, it does not seem like a far stretch to be building on the water. This study brings the notion of floating cities closer to the line between what is a farfetched future and what is near reality. Through careful calculation using quantitative data and deductive reasoning, several variables were able to be solved for including volume, mass and material. The one conclusion drawn immediately from the several variables this study brought forward was that shape was an unneeded variable that the other variables did not definitely depend on. The other variables proved that they were all imperative to finding out whether the object would float or not due to their involvement in the calculations. Shape was a small factor in buoyancy, but the results found did not show that shape affected the buoyancy a large amount. Once the computer program 'formZ' was used to simulate the use of three different materials in numerous 3D shapes, the ratio of material volume to airspace volume was able to be calculated within the form. This mathematical deduction for each material led to the conclusion that density will affect the space allowed within the structure of the forms and will eventually influence the design. The third task, creating masses that would represent simple, but still plausible, forms for a building on water brought me to the assumption that I can make any form float while not questioning balance. The main variable that did control the buoyancy of the form was the material of the structure, facades and amount of each material used. The material variable in this task brought up the conclusion that, if a building was to be built on water, the biggest point to be looked at would be the balance of materials within the project. The fourth and final task concluded that realistic projects including accurate forms, sizes, materials, weights and buoyancy could be developed for future architectural project use.

REFERENCES

Abboud, R. (2017). SEA-CURE. Retrieved October, 2018, from http://www.archiprix.org/2019/?project=3732

Accotto, J. P., Barrio, M. I., & Martin, M. D. (2013). SED The Water Factory. Retrieved October, 2018, from http://www.archiprix.org/2019/?project=3188

Announcing Our Newest Ship: Symphony of the Seas. (2017, March 10). Retrieved September, 2018, from http://www.royalcaribbean.com/connect/announcing-our-newest-ship-symphony-of-the-seas/rising-seas

Chanev, C. (2018, October 02). Cruise Ship Design Construction Building. Retrieved September, 2018, from https://www.cruisemapper.com/wiki/757-cruise-ship-building-construction-design

Elliott, A. F. (2018, March 28). Symphony of the Seas: Everything you need to know about the world's largest cruise ship. Retrieved September, 2018, from https://www.telegraph.co.uk/travel/cruises/news/symphony-of-the-seas-worlds-largest-cruise-ship0/

Floating Houses IJburg. (n.d.). Retrieved October, 2018, from http://www.rohmer.nl/en/project/waterwoningen-ijburg/

Gallery of Floating Houses in IJburg / Architectenbureau Marlies Rohmer - 25. (2011, March 20). Retrieved October, 2018, from https://www.archdaily.com/120238/floating-houses-in-ijburg-architectenbureau-marlies-rohmer/5013bad228ba0d3963000c6b-floating-houses-in-ijburg-architectenbureau-marlies-rohmer-sections

Kim, S. (2018, May 03). 13 things you didn't know about cruise ship design. Retrieved September, 2018, from https://www.telegraph.co.uk/travel/cruises/articles/cruise-ship-design-things-you-didnt-know/

Mecking, O. (2017, August 21). Are the Floating Houses of the Netherlands a Solution Against the Rising Seas? Retrieved October, 2018, from https://psmag.com/environment/are-the-floating-houses-of-the-netherlands-a-solution-against-the-rising-seas

Millay, S. (n.d.). Symphony of the Seas Deck 4 Deck Tour. Retrieved September, 2018, from https://www.cruisedeckplans.com/DP/deckplans/deckbydeck.php?ship=Symphony-of-the-Seas&deck=4

Stica, J. (2011). FLOATING CITIES - CITIES OF THE FUTURE. Retrieved October, 2018, from http://www.archiprix.org/2019/?project=3012

Wilde, C. (2018, June 19). How Are Cruise Ships Built, and Who Builds Them? | Cruise1st UK Blog. Retrieved September, 2018, from https://www.cruise1st.co.uk/blog/cruise-ships/how-are-cruise-ships-built/

Witsen, P. P. (2012, March). Floating Amsterdam. Retrieved October, 2018, from https://www.ansa.it/documents/1334931625986_AmsterdamFloating.pdf

AUTOBIOGRAPHICAL SKETCH

Mitchell James Nagel is a Graduate Research Student in the Department of Architecture at North Dakota State University working under the direction of Dr. Ganapathy Mahalingam. Mitchell is currently completing his Masters in Architecture and his thesis is on the up and coming architectural building typology of aquatecture and being able to design for building on the ocean in the face of climate change and rising ocean levels on the coasts.