ABSTRACT

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In the face of climate change and rising sea levels, the most common response is to prepare for human migration inland and to implement more protections of coastal communities. A different approach considers the migration of human communities out to sea. Coral reefs and adjacent coastal habitats are biodiverse, life supporting, but also suffer from the effects of climate change, pollution, and collisions leading them to rely on human efforts to restore and implement protections. The relationship between reefs and humans can be strengthened to encourage environmental stewardship and also explore how to better live in marine ecosystems. This thesis will ask how can architects be inspired by the mechanics and processes of reef organisms to design a system that creates built environments that support a reciprocal relationship between humans and marine wildlife?

BUILT IN REEFSCAPE

by

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Table of Contents

List of Figures

List of Abbreviations

(FFS) Forfar Field Station

(GRC) Gerace Research Center

(BCD) Buoyance Control Device

Chapter 1: Introduction

In the past, humans believed the oceans were so vast that our actions could not affect them. They were treated as a place to make undesirable objects disappear; a dumpster for everything from common waste to nuclear testing. While we add numerous unhealthy objects to the oceans, we also take from them. The commercial fishing industry is one example causing dwindling populations and disrupting essential food chains. Only in the past fifty years have we begun to realize how our consumer lifestyles have negatively impacted marine environments as they now directly affect human communities. Rising sea levels resulting from climate change threaten billions of people living on the coasts and islands along with other effects like more frequent tropical storms and hurricanes.

The human condition can be seen as a reflection of the state of the ocean, the easiest to see being the coastal zone. Our physical closeness to intertidal ecosystems puts them the most at risk. This extends to coral reefs whose degradation has been persistent from increasing CO2 levels, overfishing, and coral harvesting. Restoring these habitats is essential for sustaining ecosystems, providing coastal stability from erosion, buffering wave activity, as well as returning natural beauty for ecotourism and human enjoyment. As we switch to protecting these areas there is still a struggle in understanding the complexity of these environments. Our place in the process of restoration is unclear and we need more experience and interaction with this part of the world to become effective in our efforts. A built environment that facilitates deeper research and community engagement can create the necessary space to learn more and produce a sense of ownership encouraging more careful treatment of coastal ecosystems.

Through architecture, new spaces can be created that work in harmony with the ocean, specifically at the coast that interfaces most often with humans. While natural beauty usually draws people to beaches and shores, the threats to coastal ecosystems create a new need for places of research where restoration processes can be studied. Both of these uses can be bridged in a place where research can be revealed to the public as part of a recreational experience. These types of programs can develop into launch points for ecotourism where visitors can participate more intimately in research as a part of community science. The result is a symbiotic relationship where we restore marine ecosystems and in return, it continues to provide us with the services we need at a healthy sustainable rate. Through further exploration and a deeper connection with the ocean environment, we can discover a more sustainable way of living with the ocean and its habitats.

One of the challenges a building on the coast would face is the justification of human involvement in the repair of coastal ecosystems. We will need to be cautious of causing further harm as we interact with these habitats. A built structure can assist in creating a home base for our work to take place but will need to be as non-destructive as possible. Clean energy, minimal waste, and analyzing where the built structure contacts natural zones will ensure the least amount of damage. The use of permanent and temporary pieces should be considered returning to the idea of a building studied through time that evolves. The ability to expand, shrink, and be removed enables structural flexibility that considers both human and environmental needs. Any excess pieces will be addressed possibly transformed, reused, or may even be returned to the coastal habitats as artificial growth structures and additional supporting pieces.

While the coast is a natural place to start as the place where land meets the sea there is the issue of a constantly changing environment to face. Our area of comfort is terrestrial but, in this context, ground extends and recedes into moving tides. A structure that can continuously adapt, both on a tidal schedule and a larger timeline, will be imperative to its survival in an ever-changing setting. Amphibious structures can be considered to transition smoothly from above water to below can help prepare for rising sea levels and natural disasters. Studying the flora and fauna of coastal ecosystems provides many possible solutions to these challenges. Many of these species have evolved to all of the above and using biomimicry for new materials, kinetics, and building functions is possible. Studying coral is key to integration in design. By looking at growth patterns they can be translated to a human scale or inspiration for new biomaterials that can be grown and strengthened over time like coral can be found. As we become closer to these natural systems, the more they can be applied in architecture and design-related areas.

Chapter 2: The Current State of Coral Reefs, Coastal Communities, and Marine Research

Introduction

Coastal ecosystems spanning from shore to intertidal to subtidal and reef habitats are the closest marine environments to human communities however we have still failed to fully understand them much like the rest of the ocean. As we face the threats of rising sea levels and more intense natural disasters along coastal regions, there is no better time to begin to define what human interaction and the built environment should look like in the coastal and marine context. We should look for more sustainable practices and create mutually beneficial relationships including participating in the restoration of coastal ecosystems and what of their natural processes we can learn from. These explorations will lead to new connections between humans and the coastal marine environment.

Why We Should Preserve Coastal Marine Ecosystems

The proximity of coastal marine environments, in particular coral reefs, seagrass beds, mangrove forests, and other intertidal environments, means that there are more opportunities for our actions to affect them both negatively and positively. Presently, most of the effects are negative and for many centuries the ocean seemed too vast to be impacted. This has led us to pollute the ocean by adding harmful things to the sea including trash, fertilizer, and nuclear waste.[1] We have mostly recognized the damage of these practices but will need to take more action to prevent their continuation.

Opposite of introducing harmful substances to the ocean, we have also taken many things. Overfishing is an example of this and is one of the most disruptive activities to marine food webs and coastal ecosystems. Exhausting the seafood supply can be detrimental to many cultures around the world, specifically in the Polynesian and Caribbean Island communities where coral reef seafood makes up 80% or more of their protein diet.[2] Harmful mass fishing practices such as dredging through coral reefs with large nets, and the use of dynamite destroy the habitats necessary to regenerate all the fish taken.[3] It's an unsustainable cycle. Instead, we should strive to lower the demand and protect a larger percentage of these habitats so that they are able to replenish and support what we need.

In some ways, we do appreciate parts of the coastal ecosystem either for their views or for their recreational value. There are many examples of the various building typologies that have appeared on our coasts that allow us to participate in those activities including piers, boardwalks, and seaside resorts. While many of these

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[1] Machado, Augusto A., Bruno P. Masi, Aline A. Aguiar, Maria E.C. Ozorio, Caio N. Salles, Maurício Hostim-Silva, and Áthila A. Bertoncini. 2023. "Rocky Reef Incursions: Challenges Faced by Reef Fishes in a Brazilian Hope Spot Region." *Marine Pollution Bulletin* 193 (August): 115240. https://doi.org/10.1016/j.marpolbul.2023.115240.

[2] Wilkenson, Clive R. 1996. "Global Change and Coral Reefs: Impacts on Reefs, Economies and Human Cultures." *Global Change Biology* 2 (6): 547–58. https://doi.org/10.1111/j.1365-2486.1996.tb00066.x.

[3] Riniwati, Harsuko, Nuddin Harahab, and Zainal Abidin. 2019. "A Vulnerability Analysis of Coral Reefs in Coastal Ecotourism Areas for Conservation Management." *Diversity* 11 (107). https://doi.org/10.3390/d11070107.

building types have been around for a couple of centuries, our investigation on how to improve these structures for human enjoyment is limited to the consideration of wave and tide activity.[4] Even without the necessary improvement, today we crowd coastlines for the commodity of having ocean views and beach access. This has been coined "ocean sprawl" which now contributes to the interruption of natural systems and supports much of the unsustainable mass tourism practices.[5] This is again another way our activities have pushed the boundaries of what these ecosystems can provide.

Other than the previous benefits that can be gathered from coastal ecosystems, seafood and recreation, there is a final one to consider. One of the largest benefits of coastal ecosystems is the protection they provide from the negative effects of climate change. They act as natural buffers dispersing wave energy and preventing coastal erosion and shorelines from extreme transformation.[6] This means our fate is linked to theirs and we should look to change our habits finding our role in reviving these ecosystems. While this includes professional studies and research, our habits as a greater society will also need to change in order to make lasting impacts. The following can tell us how to start this new relationship with coastal marine ecosystems.

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[4] Wylson, Anthony. 1988. *Aquatecture: Architecture and Water*. London: The Architectural Press.
[5] Bishop, Melanie J., Mariana Mayer-Pinto, Laura Airoldi, Louise B. Firth, Rebecca L. Morris, Lynette H.L. Loke, Stephen J. Hawkins, et al. 2017. "Effects of Ocean Sprawl on Ecological Connectivity: Impacts and Solutions." *Journal of Experimental Marine Biology and Ecology* 492 (July): 7–30. https://doi.org/10.1016/j.jembe.2017.01.021.
[6] Asir, N. Gladwin Gnana, P. Dinesh Kumar, A. Arasamuthu, G. Mathews, K. Diraviya Raj, T. K. Ashok Kumar, Deepak S. Bilgi, and J. K. Patterson Edward. 2020. "Eroding Islands of Gulf of Mannar, Southeast India: A Consequence of Long-Term Impact of Coral Mining and Climate Change." *Natural Hazards* 103 (119): 103–19. https://doi.org/10.1007/s11069-020-03961-6.

<u>Challenges and Needs in Marine Research</u>

The current methods of learning about marine environments are inefficient because we do not exist naturally in the water and at the same time it is our limited knowledge of these parts of the world that causes disconnects between human life and life underwater. By encouraging more research we can gain more information that will create more efficient restoration processes.[7] Creating research hubs on the shore, in intertidal zones, and in subtidal zones will allow more in-depth and frequent research. It may be important to study the span between all of these areas to understand their interdependency and investigate them completely.

Ocean research is always constrained by the amount of air a scuba tank can hold and the water pressure a human body can handle. When compared to the time that can be spent researching underwater it is obviously a fraction of the time on land. Everything must be planned to ensure a smooth departure from land and dive.[8] To begin solving these challenges we can look to the patterns of other marine mammals that also need to resurface for air several times throughout the day. Unlike marine mammals, however, researchers would need a hub to refuel, take breaks, and store equipment. Architecture that can exist on water would allow for more spontaneous moments of underwater exploration allowing us to adjust how we would exist in the ocean on a more regular basis.

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[7] Bayraktarov, Elisa, Megan I. Saunders, Sabah Abdullah, Morena Mills, Jutta Beher, Hugh P. Possingham, Peter J. Mumby, and Catherine E. Lovelock. 2016. "The Cost and Feasibility of Marine Coastal Restoration." *Ecological Applications* 26 (4): 1055–74. https://doi.org/10.1890/15-1077.
[8] Nixon, Robert, and Fisher Stevens, dirs. 2014. *Mission Blue*. Documentary. Insurgent Media, and True Blue Films.

The challenges of researching marine ecosystems go beyond the human inability to breathe underwater and the issues we face going into the ocean are conversely similar for the species we remove from the ocean. Transporting samples and creating artificial habitats, especially for coral study, is challenging and often results in limited research.[9] While we cannot always study coral in their natural habitats, it would be better to reduce transport distances to reduce the risk of damage. Farming coral to transplant to struggling reefs is a practice that faces similar struggles.[10] Being able to create areas for healthy coral growth in their natural habitat may be easier and reduce losses. The same idea can be used to help farm other species that we wish to study and are difficult to cultivate in artificial habitats. Instead of bringing the wildlife to us, we can go to them in their true environment.

<u>Coastal Communities and Ecotourism</u>

While professional research is essential to restoring coral reefs and other coastal environments, it will take a change in how society views and treats these ecosystems to make improvements permanent. Teaching the public about all the resources we use from the ocean is one of the steps to educating them on the importance of marine conservation. Some of these benefits are mentioned earlier such as reefs, mangrove forests, and seagrass beds' ability to protect against coastal

[9] Bartlett, Thomas C. 2024. "Small Scale Experimental Systems for Coral Research : Considerations, Planning, and Recommendations." Noaa.gov. 2024. https://repository.library.noaa.gov/view/noaa/736.
[10] Clark, Susan, and Alasdair Edwards. 1994. "Use of Artificial Reef Structures to Rehabilitate Reef Flats Degraded by Coral Mining in the Maldives." *Bulletin of Marine Science* 55 (2-3): 724–44.

erosion as well as reducing storm effects on coastal communities. Others are deeply tied to economies like fishing and reef-driven tourism which in some places make up the majority of the country's income.[11] Only through changing our habits on a large scale can we prevent further harm to coastal marine ecosystems which in turn will benefit us in the long-term.

One of the main ways to spread information about the importance of protection coastal marine ecosystems is through ecotourism practices. Ecotourism is more sustainable than traditional mass tourism as mass tourism usually disregards the natural environment, does not benefit local communities, and is an oversized industry that puts extra stress on resources in the area.[12] Ecotourism looks to do the exact opposite of this and can be a viable solution to improve the hospitality industry's sustainability for the communities that greatly rely on tourism for economic stability.

While it can be difficult to switch from mass tourism to ecotourism, it can be done effectively by tapping into the knowledge of the local community. Chumbe Island Coral Park in Zanzibar, Tanzania is an example of this. By sharing what the people there had learned over generations of living in harmony with the coral reefs, they were able to down size some from mass tourism in order to offer a more

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[11] Moberg, Fredrik, and Carl Folke. 1999. "Ecological Goods and Services of Coral Reef Ecosystems." *Ecological Economics* 29 (2): 215–33. https://doi.org/10.1016/s0921-8009(99)00009-9.

[12] Dimitriou, Christina K. 2017. "From Theory to Practice of Ecotourism: Major Obstacles That Stand in the Way and Best Practices That Lead to Success." *European Journal of Tourism, Hospitality and Recreation* 8 (1): 26–37. https://doi.org/10.1515/ejthr-2017-0004.

sustainable focus on the environment.[13] Applying this same process to other areas can be used to improve management, aquaculture, fishing, and other coastal activities.

Between the local knowledge and research opportunities discussed earlier, information on the importance of coastal marine ecosystems can spread beyond local communities. Even though these ecosystems can be fragile, the goal should still be to share their wonder with others. In ecotourism, we often rely on those familiar to teach visitors how to interact with the natural environment. While nonprofessionals should not interact directly with wildlife, it is acceptable for them to help with taking samples or pictures as a form of community science.[14] This can be used to reveal restoration practices to more people and include them safely in the process. The hope is that these people will want to be more involved and create a network of community scientists who have connected with coastal marine ecosystems.

Marine health is also essential when it comes to tourism because looks matter, especially in coral reefs. Communities should want to take care of these environments because their level of aesthetics impacts how many people will want to come see them. Some studies have shown that a healthy reef will attract visitors while an

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[13] Narchi, Nemer E., Samuel Cornier, Donata Melaku Canu, Luis E. Aguilar-Rosas, Mariana G. Bender, Christian Jacquelin, Marion Thiba, Gustavo G.M. Moura, and Rutger de Wit. 2014. "Marine Ethnobiology a Rather Neglected Area, Which Can Provide an Important Contribution to Ocean and Coastal Management." *Ocean & Coastal Management* 89 (March): 117–26. https://doi.org/10.1016/j.ocecoaman.2013.09.014.
[14] Gaskill, Melissa. 2018. *Pandas to Penguins : Ethical Encounters with Animals at Risk*. College Station: Texas A&M University Press. https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,uid&db=e025xna&AN=1885839&site=ehost-live.

unhealthy reef will result in a reaction of disgust.[15] The correlation of healthy ecosystems and successful ecotourism will encourage communities to invest in conservation efforts and a sense of ownership will start to grow surrounding these habitats.

Biomimetic Inspirations

Using biomimicry of marine species can help us find solutions to the challenges we face designing buildings for coastal ecosystems. In *At the Edge of the Sea*, Rachel Carson describes some of these species as "too fragile to exist in a world of crushing force. Yet every detail was functionally useful…they were merely waiting…for the return of the sea."[16] They display how something can be both beautiful and practical. Architecture always looking to balance these two elements and we can learn how to do so by looking at nature which has already evolved to be both.

In some ways, we already use coral to inspire the artificial growth structures that we use to help them regenerate. Concrete and wood can both be used to make growth structures with concrete being the most effective for hosting new coral growth.[17] By recognizing the cross-over of these materials in both coral growth structures and building materials, a combination of both can be created. The

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[15] Haas, Andreas F., Marine Guibert, Anja Foerschner, Tim Co, Sandi Calhoun, Emma George, Mark Hatay, et al. 2015. "Can We Measure Beauty? Computational Evaluation of Coral Reef Aesthetics." *PeerJ* 3 (November): e1390. https://doi.org/10.7717/peerj.1390.
[16] Carson, Rachel. 1955. *The Edge of the Sea*. London: Unicorn Press.
[17] Clark, "Use of Artificial Reef"

foundations of the building act as surfaces to support coral and other species. Other studies have also found success in using ceramic materials in growth structures for coral reef regeneration[18]. One example uses bioinks that are able to mimic the chemical process that takes place in coral microbiomes.[19] While these would not be useful in a structural application, this material translates well as a facade component. Using materials that fit in the natural environment allows the building to become part of the marine environment.

While there are materials that can mimic aspects of coral allowing for growth, there are also cases of coral being used as a material itself. In many areas of South Asia and Polynesia, coral harvesting is very common and so frequent in some cases that it has damaged many of the reefs in the area.[20] However, rather than harvesting real coral, new investigations can be made to copy the molecular organization of coral creating new materials that are strong but light.[21] With today's technology, these coral-like materials may not be instantaneously produced but rather grown like a crop, even while in use as part of the building. This would allow for a structure that strengthens over time, adding mass to itself in areas where extra support is needed

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[18] Berman, Ofer, Michael Weizman, Asa Oren, Reem Neri, Haim Parnas, Nadav Shashar, and Ezri Tarazi. 2023. "Design and Application of a Novel 3D Printing Method for Bio-Inspired Artificial Reefs." *Ecological Engineering* 188 (March). https://doi.org/10.1016/j.ecoleng.2023.106892.
[19] Wangpraseurt, Daniel, Yazhi Sun, Shangting You, Sing-Teng Chua, Samantha K. Noel, Helena F. Willard, David B. Berry, et al. 2022. "Bioprinted Living Coral Microenvironments Mimicking Coral-Algal Symbiosis." *Advanced Functional Materials* 32 (35). https://doi.org/10.1002/adfm.202202273.
[20] Asir, "Eroding Islands"
[21] Chen, Diana A., Brandon E. Ross, and Leidy E. Klotz. 2015. "Lessons from a Coral Reef: Biomimicry for Structural Engineers." *Journal of Structural Engineering* 141 (4). https://doi.org/10.1061/(asce)st.1943-541x.0001216.

like coral. It would be a new type of smart building that adapts to best fit the conditions.

Studying the specific succession order of coral reefs may help tailor the form and location of building parts that allow for coral growth. Pilot species grow first, which are then taken over by other coral types.[22] If there are specific needs a structure can supply these pilot species, they should be prioritized. While studies have disproven that rougher concrete mixtures make for better growth surfaces, they have found that location and forms that create specific water flows do affect the growth of new coral.[23] Growth structure forms and locations can be selected specifically to induce pioneer species' growth. This will allow the rest of the succession process to begin sooner.

The materials that are being used in marine settings have the ability to not only be nondestructive, but aid in the regeneration of marine habitats. BIOROCK® is an example of this. This product uses low-voltage electric

Fig 2.1 BIOROCK structure in Karang Lestari project, Pemuteran, Bali (Source: Global Coral Reef Alliance)

[22] Stallings, Brenna. 2023. "Examining the Successional Role of a Pioneer Species on Post-Disturbance Coral Reefs: Are They Facilitators or Short-Term Competitive Dominants?" *Bu.edu*, June. https://hdl.handle.net/2144/46351.
[23] Foley, Michael, Yuko Stender, Amarjit Singh, Paul Jokiel, and Kuʻulei Rodgers. 2014. "Ecological Engineering Considerations for Coral Reefs in the Design of Multifunctional Coastal Structures." *Coastal Engineering Proceedings* 1 (34): 30. https://doi.org/10.9753/icce.v34.management.30.

pulses through metal to help grow more resistant coral reefs (fig 2.1).[24] While these emerging technologies are useful, we should be wary of their unknown long-term effects and we should also recognize that restoring the actual habitats will provide more benefits than an artificial one.

Another example of how we can learn from coral reefs is by looking at how are designed to support a variety of marine species. We can learn what needs to be provided in order to attract a wide range of users in a building. The main reason for the wide biodiversity in reefs is the many niches within the coral that provide shelter for animals of all sizes.[25] All of the small spaces have different microbiomes that host various chemical processes that the species benefit from.[26] Each space seems to be tailored to a specific user providing the required shelter and function. In architecture, providing a place that can be used for many different activities is the best way to get a large variety of people to come. Each space should be intentional and while not all need to have a prescribed use at all times, some should draw users there for specific purposes to ensure the building will have consistent usage.

The formal qualities of coral can also be used to inspire the placement of program in architecture. The niches mentioned above develop carefully to protect and strengthen the coral. The level of porosity is organized based on the amount of stress

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[24] Bakti, Arifin A, Delphine Robbe, Arben Virgota, and Thomas J Goreau. 2010. “BIOROCK Reef Restoration for Sustainable Ecotourism in Gili Trawangan.”
[25] Tarazi, Ezri, Haim Parnas, Ofri Lotan, Majeed Zoabi, Asa Oren, Noam Josef, and Nadav Shashar. 2019. “Nature-Centered Design: How Design Can Support Science to Explore Ways to Restore Coral Reefs.” *The Design Journal* 22 (sup1): 1619–28. https://doi.org/10.1080/14606925.2019.1594995.
[26] Wangpraseurt, “Bioprinted Living Coral”

each piece of coral will be subjected to.[27] This means that coral not only demonstrates how different sizes of program attract diverse users but that we can also place them in efficient ways that create a stronger form. Following this formula will help create structural stability in the face of natural disasters both in and out of water. By scaling up these forms, programmable areas that speak a similar formal language to coral connect humans and marine ecosystems (fig 2.2).

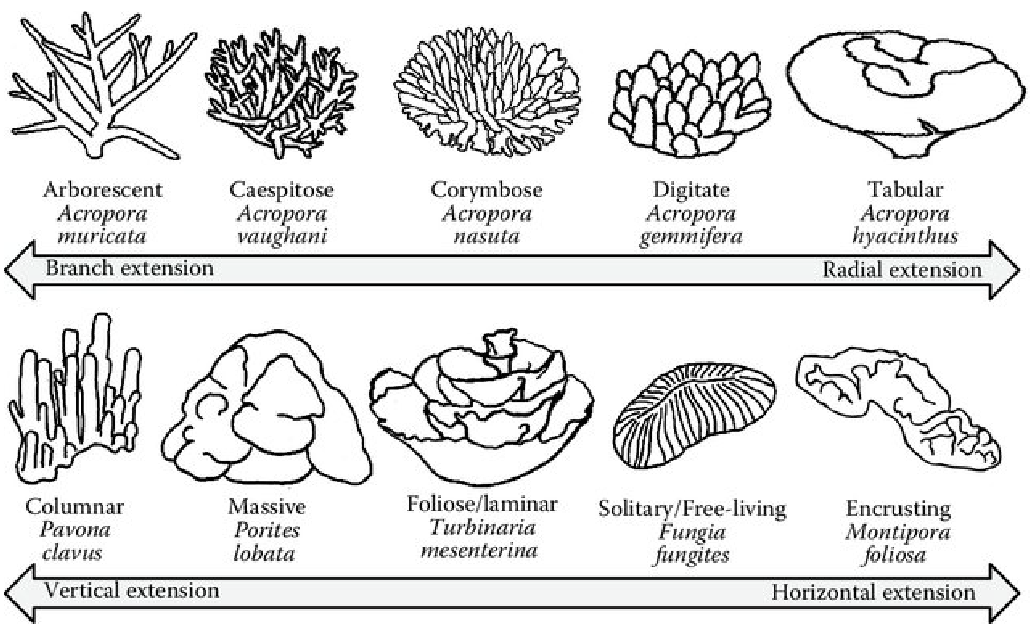

Fig 2.2 The Range of Coral Growth Patterns (Source: Oceanography and Marine Biology)

Mimicking coral forms can also help disperse wave energy around the building. This is one of the main benefits of coral reefs and intertidal ecosystems; they often decrease coastal erosion and lower the impacts of tropical natural disasters.[28] This provides a reason for communities to care about the regeneration of

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[27] Chen, "Lessons from a Coral Reef"
[28] Karthikheyan, T.C. 2010. "Environmental Challenges for Maldives." *South Asian Survey* 17 (2): 343–51. https://doi.org/10.1177/097152311201700210.

coral reefs as they can be essential to the protection of coastal areas. Artificial reefs can already be designed to take advantage of ocean currents, optimizing forms that control the flow of water around the habitats within.[29] Designing ways for buildings on the water to do the same will help assist the coral reefs until they have regrown to their full capacity.

To achieve this, all the variables of the marine environment have to be assessed which can be difficult with the volatile nature of the ocean. Kate Orff is a landscape architect familiar with similar challenges and she advocates for the designing of repeatable processes rather than one-off structures.[30] This allows solutions to be more widely applicable. Parametric design tools and 3D printing have already been used in small coral growth structures and are essential in creating effective, complex, and realistic forms for artificial marine habitats.[31] Using these techniques, unique forms based on environmental inputs can be made easily. With these technologies applied at an architectural scale, buildings can have similar benefits as reefs and fit into the natural context better.

Architecture in Coastal Settings

A research and tourism center on water sounds ideal but there are many issues that make their construction challenging. Structure stability, dealing with sea level

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[29] Foley, “Ecological Engineering”
[30] Orff, Kate. 2016. “Toward an Urban Ecology.” Gatech.edu. Georgia Institute of Technology. October 12, 2016. https://repository.gatech.edu/entities/publication/b63a368d-c564-4c09-bb17-4354c45dbd7d.
[31] Berman, “Design and Application”

changes, and protection during natural disasters all threaten the building. Meanwhile, the building also threatens the ecosystem and must be designed to avoid as much damage as possible.

One of the traditional ways to build structures in water is with a pier typology. Piers have a long history of being used to extend the built world into the ocean.[32] In some places, piers have been recognized for creating their own ecosystems at their foundations but in a place where we would like to conserve the existing ecosystems, this would not be the desired result.[33] If we are to build in coral reef habitats, we should be very conscious of the points at which the structures contact the ocean floor. These points should be minimized and less destruction methods of securing foundations used such as gravity foundations in place of pile-driven ones.[34] Piers pose a familiar architectural typology that provides lots of opportunities for flexibility in design. This would make it possible for one design to be adapted and used in many contexts easily.

Other possibilities include floating architecture which would be ideal for disconnected pieces of structure. As large-scale floating structures become more common, they become a more plausible solution to sites threatened by water level changes.[35] Small versions of floating structures, such as boat houses, have been used

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[32] Wylson, *Aquatecture*

[33] Tong, Xinzhao, Marcus H. Y. Leung, Zhiyong Shen, Justin Y. Y. Lee, Christopher E. Mason, and Patrick K. H. Lee. 2021. "Metagenomic Insights into the Microbial Communities of Inert and Oligotrophic Outdoor Pier Surfaces of a Coastal City." *Microbiome* 9 (1). https://doi.org/10.1186/s40168-021-01166-y.

[34] Bishop, "Effects of Ocean Sprawl"

[35] Schrenk, Manfred, Vasily Popovich, Peter Zeile, Pietro Elisei, Clemens Beyer, Horst Stopp, Peter Strangfeld, and Anna Malakhova. 2016. "Floating Architecture and Structures -an Answer to the Global Changes."

for much longer and provide good examples of how modular structures can be put together. Some of the concerns that exist in floating structures include how to stabilize them as well as the shadows they cast on the ocean floor interrupting ecosystems.[36] Even with these challenges, floating architecture may be a less destructive alternative to pier structures because of their minimal touchdown points. Floating buildings would also be able to remain above water as the sea level rises and falls. This may also work well in a hybrid situation with pier structures. The pier would provide stability while the floating structures support programs that need to be above water throughout the changing water levels.

As much as we can try to be as non-disruptive as possible, sometimes it is best to remove human interference completely. It has been found that on structures that connect the shore to the ocean, such as piers, entirely new microbial communities are created. This is because of the overlapping interactions of humans, ocean and marine life, and the various materials of the pier.[37] There is some risk in introducing new microbial communities that could damage marine ecosystems. A semi-permanent structure can be provided when needed and removed or relocated in the most sensitive areas of the reefs.

If there were a case in which human activity on the water was found to be damaging, every piece of structure may not have to be removed. Abandoned

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[36] Moon, Chang-Ho . 2013. "A Study on the Floating Building as a New Paradigm of Architecture †Chang-Ho Moon." *Journal of Korean Navigation and Port Research* 37: 315–20. https://doi.org/10.5394/KINPR.2013.37.3.315.
[37] Tong, "Metagenomic Insight"

structures can act as growth structures and become integrated into the habitat.[38] This is not the case for every type of structure or material. Even though retired vessels are often used to create artificial reefs, they are not as effective or healthy for the environment as other materials.[39] With this in mind, we can think of how to design buildings with structures and materials that could be left behind intentionally in order to be part of the long-term revitalization process.

Conclusion

The relationships between human communities and marine environments have been turbulent in the past as we draw resources from the ocean at increasingly unsustainable rates. Further damage is caused by the pollutants released into the sea. These are especially felt by the marine environments closest to the shore where we have the most influence over how we interact with coastal, intertidal, and subtidal ecosystems. These habits need to improve so that we can continue to benefit from the goods and services provided by these ecosystems, primarily the ones that help mitigate the effects of climate change on coastal communities. Many of the struggles we have with making these changes have to do with the lack of knowledge we have about these habitats. Currently, marine research is difficult due to the limitations of technology but some of these stresses can be reduced by creating research hubs on

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[38] Dafforn, Katherine A, Tim M Glasby, Laura Airoldi, Natalie K Rivero, Mariana Mayer-Pinto, and Emma L Johnston. 2015. "Marine Urbanization: An Ecological Framework for Designing Multifunctional Artificial Structures." *Frontiers in Ecology and the Environment* 13 (2): 82–90. https://doi.org/10.1890/140050.
[39] Berman, "Design and Application"

water that will shorten transportation and travel distances and lessen the amount of planning needed for a dive. These can be developed using professional knowledge, along with local knowledge. The design can also allow this knowledge to be shared through the expansion of ecotourism encouraging environmental stewardship that begins making change on a larger scale. As we learn more about coastal marine ecosystems, we can begin to take inspiration from the flora and fauna for further design applications. Using biomimicry will be one of the most important strategies to discover how to create more efficient structures in the ever-changing setting of the ocean shore. This is even more necessary in the face of rising sea levels. By combining this and the building typologies that we are already familiar with we can start to bring our communities closer to ones in coastal environments creating sustainable relationships.

Chapter 3: Methodology

The subject of architecture in marine settings, especially in sensitive ecosystems like coral reefs, has much to be explored. Some investigations will be used to learn about non-architecture-related ideas such as interdisciplinary studies and research and learning local knowledge from communities deeply tied to the ocean. Other methods will be more standard for architectural practices including precedent studies, physical and digital modeling, and material studies. By studying both sides and then searching for overlaps, ways the designed environment can assist in coastal ecosystem restoration can be found.

Cross Disciplinary Studies

Connecting ocean environments to buildings is an indirect path and many lessons can be learned from other disciplines. The subjects chosen are meant to discover the needs of marine ecosystems and how architecture can be part of the solution. Specifically, solutions for design issues around coral reefs, the integration of buildings into these sensitive environments, and best practices for human interaction are important to consider. Review of research by experts in marine biology, structural and environmental engineers, and ecotourism hospitality are the most useful in finding lessons and strategies from elements of nature and other sustainable methods. Beyond these fields, more qualitative studies can come from other disciplines revealing new perspectives and insights such as the cultural histories of the coast and reef. The ultimate goal is to understand these ecosystems in three facets: the ecological systems reefs are a part of, the past, present, and future significance in human communities, and how they can inspire new technologies. While this can mostly be done through the literature review of several peer-reviewed papers, such complex habitats also require more than a 2D explanation and other sources such as documentaries and live discussions with professionals are essential to gaining a full understanding of the needs of coral reefs and where an architectural intervention may be relevant.

Architectural Precedent

Looking at other disciplines helps fill in context from the non-architectural perspective but looking at architectural precedents can still be used to inform design. Those that interact intimately with water are the most useful and can help piece together what will be required of the final structure. Some of the options for precedents did not have to be strictly a singular building or piece of architecture and expanding into adjacent areas such as landscape architecture and urban design has also been beneficial. Other important perspectives to consider include non-Western design as well as places with personal experience tied to it. With no perfect project

Fig 3.1 Makoko Floating School by NLÉ Works (Source: Archello)

that can be followed or expanded on, it has been more useful to take specific attributes of projects that can later be stitched together to create the desired end result. Some of the main qualities that categorize what can be learned from a particular precedent include structures in or on water, water as a design element, and programs appropriate for an ocean context (fig 3.1, fig 3.2). These studies act as a foundation for understanding what already exists and works when it comes to building in the water allowing for the next step to be taken in pushing the boundaries of marine-based architecture.

Fig 3.2 Topics of Study for Architectural Precedents (Source: Author)

Experimentation of Materials

As details of the structure become more important, a study of materials and how to organize them to both strengthen the building and integrate into the natural environment becomes necessary. Many of the existing studies on materials are on concrete compositions, ceramics, plastics, and even wood.[40] Using previous

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[40] Clark, "Use of Artificial"

information gathered from cross disciplinary discussions on coral, biomimetic inspiration informs how to apply these materials in nondisruptive design. A physical model of these materials as facade pieces or structural systems to test in real life is valuable for understanding the reality of the challenges working with different materials, if their application in these manners is feasible, and aesthetic qualities. Different methods of assembly are also important to explore and return similar conclusions. These methods can be pulled from what is already used in the making of coral growth structures; they include 3D printing, casting, and securing masses together using different fasteners.[41] Other technologies have also been involved such as parametric design.[42] Testing the combinations of materials and methods leads to which studies are most beneficial to both the coral reef ecosystems and have practical applications in architectural design.

Local Communities and Knowledge

A last piece of qualitative research to be conducted is the surveying of communities deeply connected to the ocean and coral reefs to gather local knowledge on the subject. Many of these communities have come to rely on reefs to provide food and as an economic source. Through this, traditional practices have emerged and a codependency is formed between the community and the ocean meaning that the negative effects of an unhealthy reef have been more impactful on these groups of

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[41] Berman, "Design and Application"
[42] Orff, *Toward an Urban Ecology*

people. Their methods of living with the natural environment are often more sustainable than modern-day practices and discussion on healthy fishing practices and how to implement ecotourism effectively is important to start changing how noncoastal communities interact with coral reefs and the ocean. Not only is it important to gather knowledge from these communities, but information can also be shared as the effectiveness of ecotourism relies heavily on local involvement. It is good to discover what is realistic for a place to implement and if the structure being designed can be appropriately managed through the community. These discussions take place across many different communities from various locations but the most valuable will be those connected to the site chosen. Input from this group allows the design to be tailored to specific needs unique to the area.

Conclusion

Coastal ecosystems and all the living beings they support are complex to understand and the application of knowledge gathered from these environments in architecture is limited. The cross-disciplinary discussion and research, the study of existing architectural examples designed with water and the ocean, the experimentation of methods and materials, and connecting with relevant coastal communities all help in defining the next steps in marine-based architecture. Finding site-specific details further determines what is appropriate and manageable for both the local communities and wildlife in the design. All of these investigations lead to the discovery of how and if built structures can exist in delicate habitats like coral reefs in not just non-destructive manners, but also to help heal the natural environments.

Chapter 4: Architectural Precedents

As this thesis takes a step in a new direction in the exploration of architecture in marine ecosystems, it has been important to recognize that no one precedent could fit the perfect example to follow. Instead, it has been more useful to categorize what elements would be important to investigate in order to later piece together a new, complete concept. The categories chosen include structure and methods of building on water, the theory of designing with water, and programs that allow life and interaction in water. An intentional decision is made to study precedents from a variety of places and cultures, especially those that are unfamiliar. Since this thesis looks to act as an example that can be later repeated, exploring diverse precedents is beneficial in preparing the final design to be used in diverse situations. Phenomenology is also considered and applicable precedents in which I have personal experience become a valuable resource to learn about the intangible qualities of space. With these objectives in mind, five precedents have been used to investigate these topics to inform a new path in nondestructive design in coastal environments.

Structure

Ha Long Bay, Vietnam

ddBuilding on water comes in old and new forms. Boat houses were used at the earliest stages of shelter on water. In many cases, it seems like we constantly move away from this practice, and lakes, bays, and other bodies of water are filled in to create land. The villages of Ha Long Bay are a great example of an ancient town

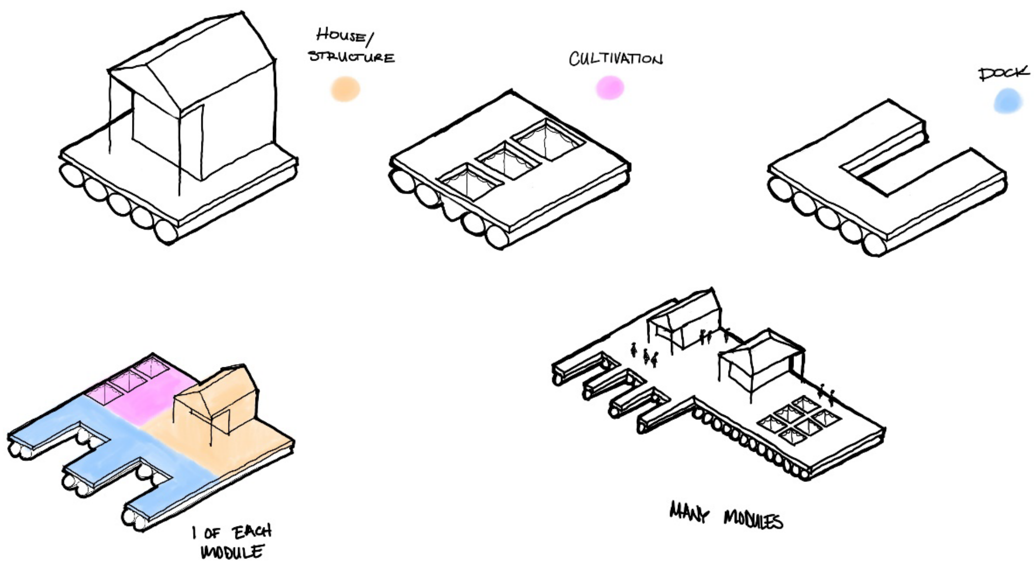

Fig 4.1 Floating Modules of Ha Long Bay (Source: Author)

that has persisted and still exists as a community on the water in Vietnam. The people here continue to use many of the traditional fishing and seafood agriculture methods that are more sustainable than today's practices. The structures are built in a vernacular way using wooden framed rafts with a finite number of types to assemble. The main three modules are shelter, agriculture, and platform which can be used to create a network that can be quickly constructed and grow and shrink as needed (Fig. 4.1). These are placed in the bay to take advantage of the existing land formations to channel wind and protect from turbulent water (Fig. 4.2). Even though much of life is spent on the water, including domestic and farming duties, the people in Ha Long Bay still maintain close connections to life on the mainland where they travel to participate in economic activities.

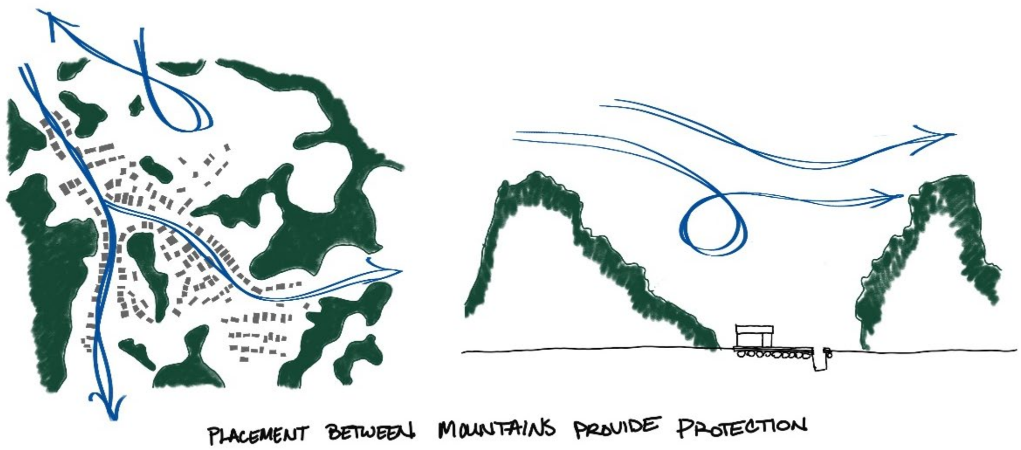

Fig 4.2 Placement in Context (Source: Author)

Living Breakwaters

There are modern examples of in-water structures that use similar practices to those of Ha Long Bay. Living Breakwaters by SCAPE Architects is one of these. Located off the eastern coast of Staten Island, New York, this project focuses more on how the designed structure can support wildlife with the help of humans. Using concrete, modular pieces, a wave break is created with the various textures and niches to become habitats for fish, mussels, birds, underwater vegetation, and much other local flora and fauna (fig. 4.3). Similar to the Ha Long Bay villages, these are organized to best fit the existing landscape. With new site analysis technology, a parametric code can create specific forms unique to the conditions, so while the structure is never the same, the process of design is. In addition to the breakwaters, SCAPE creates "water hubs" that act as educational centers for the public connecting

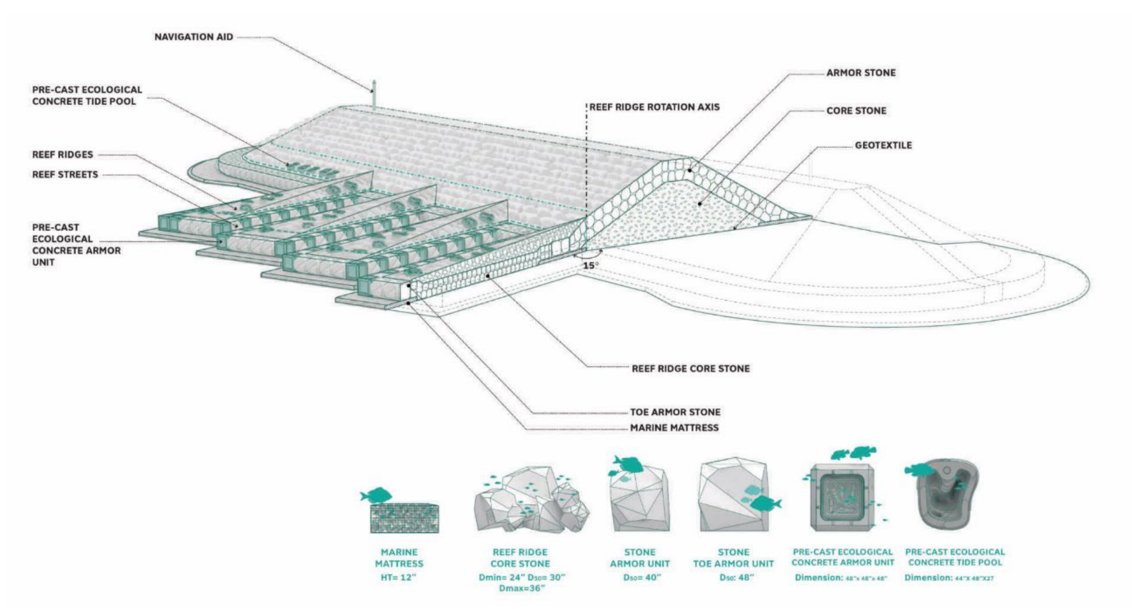

Fig 4.3 Modules of Living Breakwater are created for specific species (Source: SCAPE)

humans and wildlife (Fig. 4.4).[43] By considering both sites, land and water, and both communities, humans and natural, a structure is created to serve both.

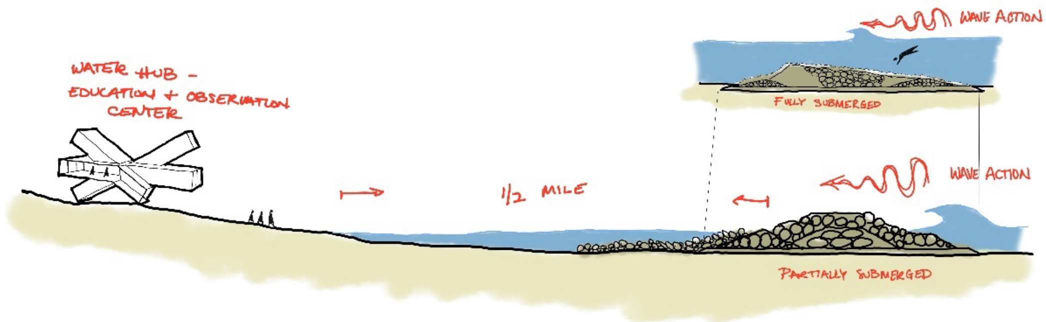

Fig 4.4 The relationship between Water Hubs and the Living Breakwaters (Source: SCAPE, Adapted by: Author)

Comparison and Conclusion

Comparing these two projects has shown how similar they are in organization and structure. Modular construction simplifies the building process in a complex environment of changing bodies of water and shore. The materials of these two projects, wood and concrete, also align with other previous research on the best materials for artificial marine habitats. This supports using either for both building and creating natural ecosystems. A mix of methods gathered from the precedents, traditional and using new technology, inspires the process used for this new design.

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[43] Orff, *Toward an Urban*

Theory

Querini Stampalia

When it comes to design with water in mind, typically the goal is to bar moisture from entering the building, however, this is the opposite in the case of Querini Stampalia. Querini Stampalia was originally a dwelling for a noble family in Venice, Italy, and was built in the traditional style of a Venetian palazzo with doors that opened directly onto the canal. Later it was converted into a museum including an intervention by Carlo Scarpa in 1961 and while Venice is known for being built on a lagoon, Scarpa takes this concept to a new extreme by creating spaces that allow the flow of water in and out of the design (Fig. 4.5).

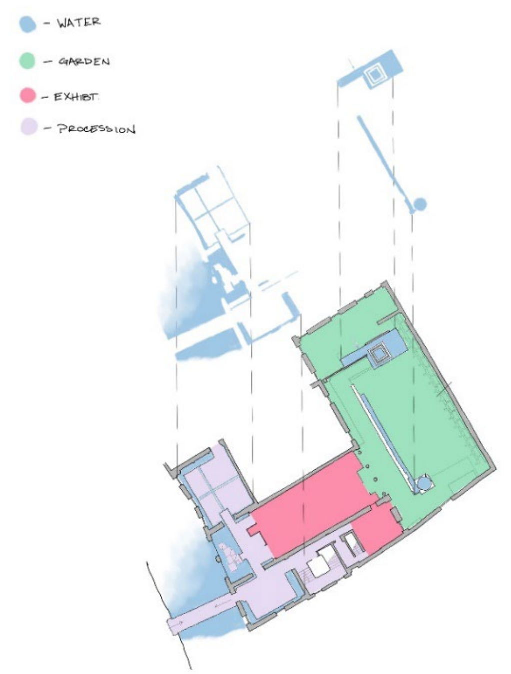


Fig 4.5 Querini Stampalia Circulation and Water (Source: Author)

Even though water is prevented from flooding the first floor today, it continues to be inseparable from the structure as seen from personal experience. Architectural details of groves, pools, and fountains are seen on the interior and are still in use on the exterior (Fig 4.6). These provide an auditory and visual element engaging the senses of the user with constant movement. The entire building can be seen as a representation of the city of Venice with the sophisticated intertwining of land and infrastructure connected through canals. These techniques transform the mundane element of water into one that is celebrated and functions as a wayfinding element. The theory behind Querini Stampalia and its ability to control the animated nature of water can be used to learn how to design spaces that can create many layers to the user experience.

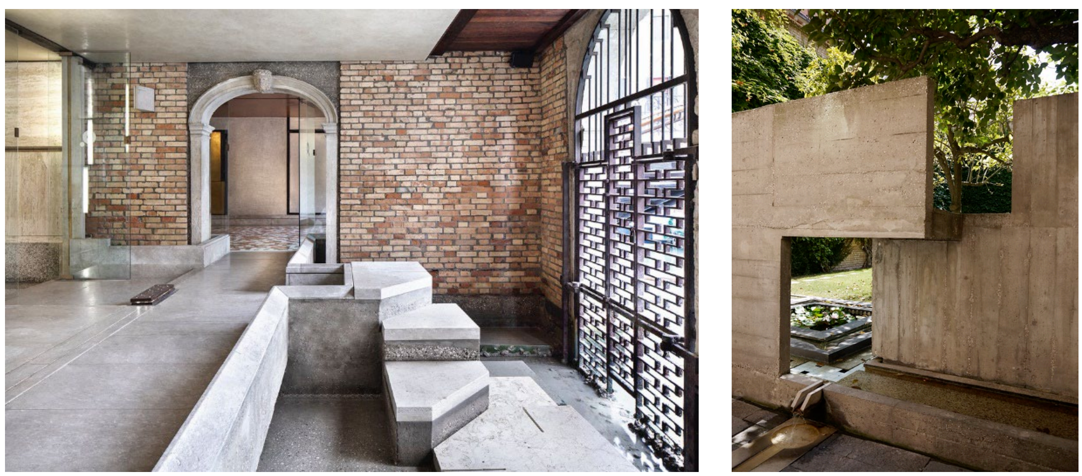


Fig 4.6 Details Querini Stampalia Guiding Water (Source: Arqui Scopo)

Program

The Brock Environmental Center

The program of this thesis is meant to benefit both human communities and natural ones just as the structures should be able to support both. The precedents on program are meant to explore the wide range of scale, level of enclosure, and ways of inducing interaction between people and nature. All the spaces within the building should help further their ultimate goals of education, sustainability, and interaction. The desire to study the integration of educational, recreational, and research into one building drove the decision to study both the Brock Environmental Center in Virginia Beach and the Monterey Bay Aquarium in Monterey, California.

The Brock Environmental Center is part of the Chesapeake Bay Foundation, an organization that strives to preserve its namesake and educate the public about the services provided we benefit from. The designers, Smith Group, have worked with the Chesapeake Bay Foundation on other projects are are familiar with creating buildings that support their goals of sustainability like the Phillip Merril Building in Annapolis, Maryland. The Brock Environmental Center is small and only one story with a very outward-facing program to add emphasis to the panoramic views of nature surrounding the building (Fig 4.7). Many of the spaces are intended to be flexible with open plans and movable walls sometimes allowing spaces to open and the structure to sprawl seamlessly into the landscape.

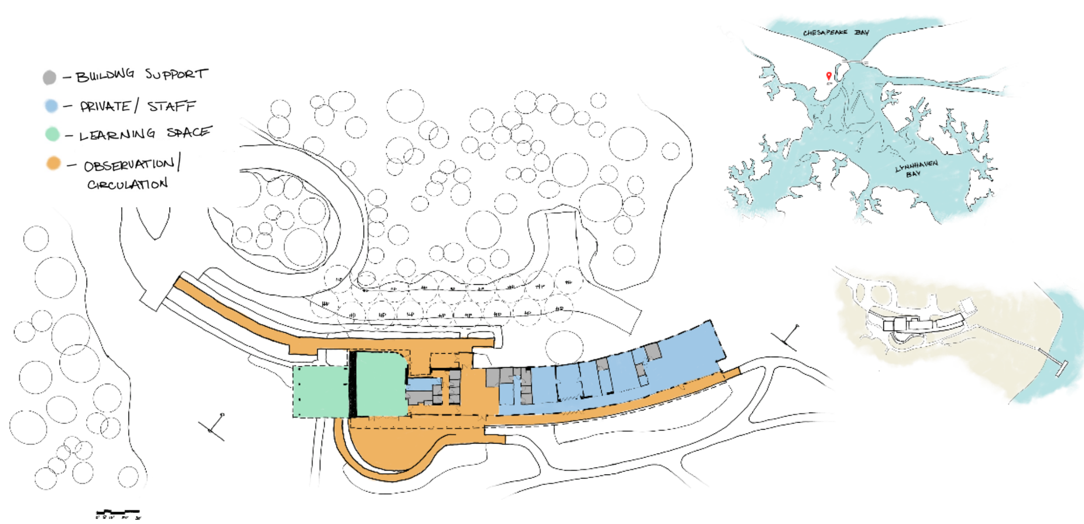


Fig 4.7 The Brock Environmental Center acts as a space to pass through as users traverse to the Chesapeake Bay (Source: SmithGroup, Adapted by: Author)

The overall smallness of the building is meant to allow for a more tailored focus on passive strategies enabling the Brock Environmental Center to be one of the few to complete the Living Building Challenge. Formally the building is long and thin with the elongated sides oriented north and south. This allows for solar shading and gain strategically used based on Viginia’s seasonal temperature swings. Natural cooling through operable windows and stack ventilation is implemented as well (Fig 4.8). Supplemental energy is provided through geothermal wells and wind turbines.

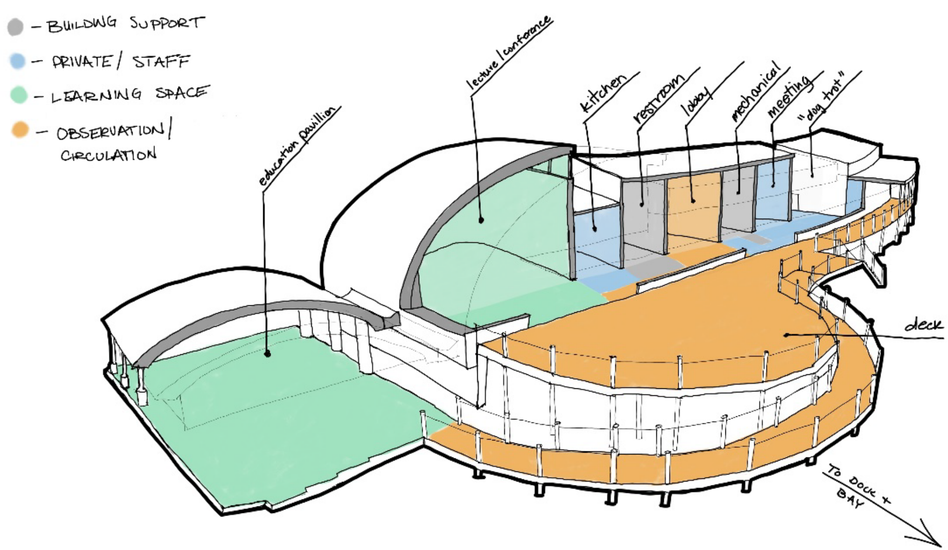


Fig 4.8 Section Axon of the Program (Source: Author)

The Brock Environmental Center is a great example of a building that serves only to support the natural landscape it sits in. It strives to be as nondisruptive as possible not only in a small physical footprint but also with a small carbon footprint being completely self-sustaining. The program combines private and public uses and acts as a gateway and information center for visitors to pass through on their way to the bay more than an actual place to stop and rest. This inspires a building that makes a big impact despite its size.

The Monterey Bay Aquarium

In contrast to the previous precedent, the Monterey Bay Aquarium is a much larger and mostly internal program. Designed by EHDD Architects, it is also an example of adaptive reuse being built in an old sardine cannery. The structure was new technology at the time of its design using a new special type of concrete meant to withstand the corrosive ocean water. This was important as the building spills out from the bay onto the bay and even used the tide as part of an exterior exhibit. While most of the program attached to the Aquarium is private and not accessible to public passersby-ers, there is a piece of observation deck reserved for anyone to access.

The program of this aquarium, like most others, emphasized educating visitors through several, fun, exhibitions. While some of these are the traditional tanks and enclosures that encourage looking but not touching, there are others that are made for interaction with visitors. The controlled nature of these can help introduce users to healthy interactions with marine species that will hopefully spark stewardship and interest. These exhibits are divided into different zones each representing a type of habitat. With such a large program and users that only visit the building on occasion, wayfinding and a clear path of circulation are essential to organize the space.

This building is also a good example of how to organize space not just horizontally on one floor plate, but vertically between levels (Fig 4.9). To create the same effect as the layering of ecosystems that takes place in the ocean, there are several enclosures that can be viewed on different floors. Atriums and catwalks are used regularly to allow visitors to see more of their surroundings to orient themselves.

This adds another layer of complexity to circulation and creates clear paths for navigating.

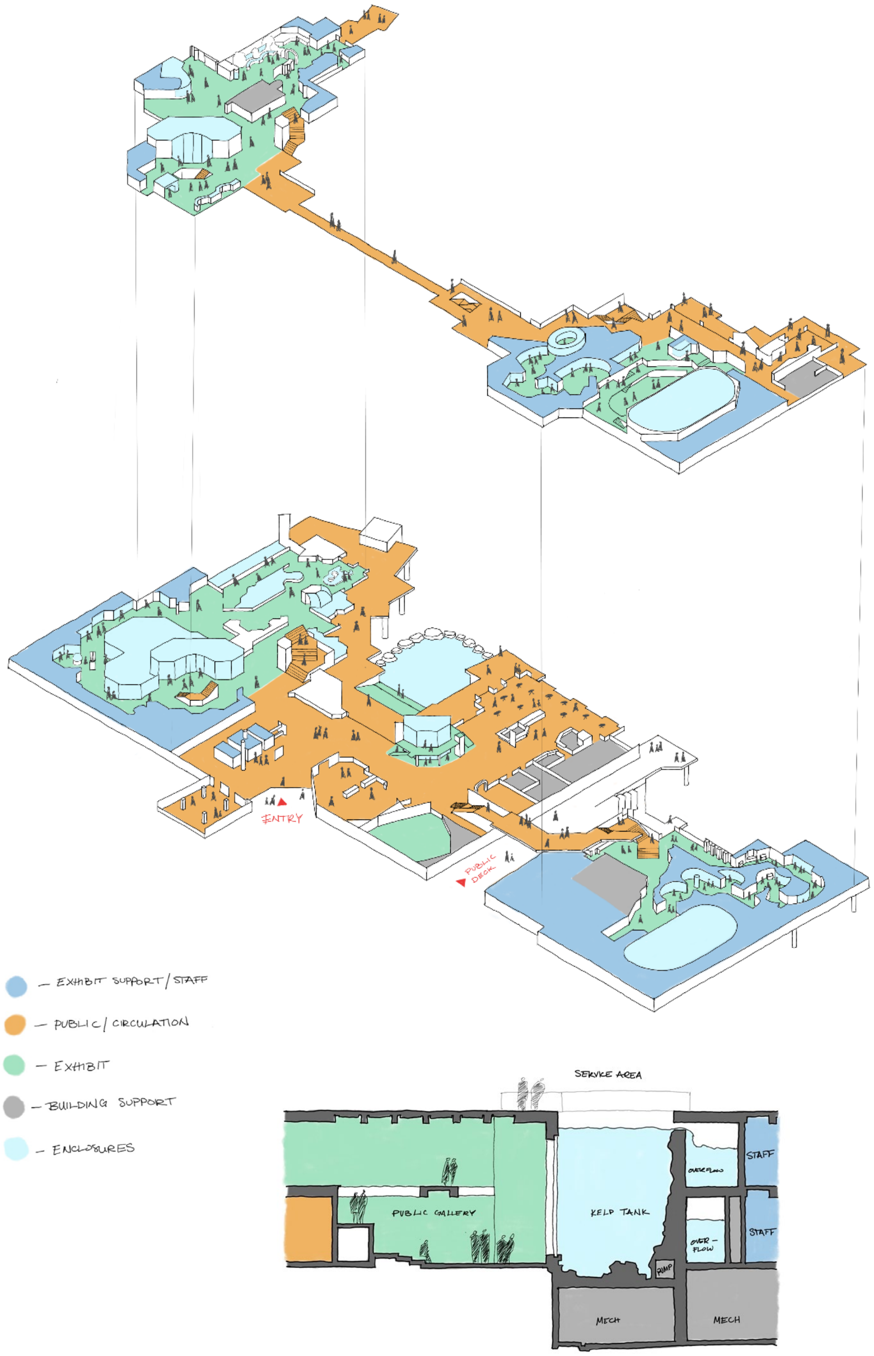


Fig 4.9 Connecting Horizontally and Vertically (Source: EHDD and The Monterey Bay Aquarium, Adapted by: Author)

The is another large zone of the Monterey Bay Aquarium that is hidden from the public eye which is the building support. While the exhibits seem like the largest part of program to the public eye, hidden behind the enclosures are support spaces just as large. Maintaining artificial habitats, especially marine-based ones, is extremely complex and requires large amounts of equipment. There is also space for staff to consider which can create a whole secondary set of circulation. It can be assumed that these areas are not easy to navigate as they are designed around the public realm and meant to only be used by the daily workers who get to know the building more intimately than the occasional visitor.

Using the lessons from the Monterey Bay Aquarium, ideas about progression and wayfinding through a larger building can be formed. It displays how interactive and attention-grabbing exhibits can be used to keep users moving and spark interest. It is a good example of how intense the building support systems have to be when enclosures for marine life also have to be considered. All these qualities take place in an existing building and that weave the existing pieces together.

Comparison and Conclusion

The two projects have shown how program can be used to support design goals. How they interact with the site, what programs are chosen to reveal, and how they interface with the public all display how the program is organized affect the user experience, and encourage different interactions with the public. Even though the Brock Environmental Center is more about pushing the user to explore the exterior site and the Monterey Bay Aquarium has much of its program internalized, the way the program can be categorized overlaps. Both of these projects integrate aspects of research, education, and public enjoyment. The zones of program are similar and can be used to inform the types of spaces that would be appropriate for this thesis.

Conclusions

The five precedents studied are great examples of how architecture can interface with water. While those on structure display ways to respond to a marine-based site, those on theory and program show how to take advantage of water to generate a cohesive building purpose. The program zones discovered inform the important spaces required of a building that are meant to teach the public and support professional research. By piecing together the lessons learned from all of the studied projects, the next step can be taken to a design integrating water that supports both human communities and natural habitats.

Chapter 5: Program

Abstract and Introduction

The program of this building is meant to bring together different users with overlapping goals. Spaces for professional researchers and nonprofessional observers, including members to the local community and visiting tourists, to interact in new ways and reveal scientific processes are used to educate and induce interest and ownership over the coastal ecosystems so that humans can learn how to better search the environment. All of these will be placed and designed in ways that are non-destructive to the surrounding ecosystems and will keep the third user group, the natural environment, in mind. With this at the forefront of design, the temporality and necessity of each program piece will be considered carefully. By paying close attention to program adjacencies and scale, the organization of spaces can help support the goals of the design to create sustainable relationships between the built environment and sensitive ecosystems like coral reefs and other adjacent habitats.

Precedent Program Deep Analysis

Using the same buildings used to investigate program in the previous chapter we can learn about scale and ratio of program zones to each other through a more thorough breakdown of spaces. Their various spaces will be categorized creating zones that can later inform the program for this design. Both the Brock Environmental Center and Monterey Bay Aquarium will be reverse-engineered and compared in this more complete study to reveal how their different focus in the overall program has affected the topics of scale and proportion.

Brock Environmental Center

As mentioned previously, the Brock Environmental Center is a small building and the program has large portions that are both interior and exterior. The spaces are clearly divided by what is public and what is private. On one end there are learning pavilions and a flex space used for conferences and events. On the other side, offices, staff spaces, and building service areas are kept separate and intended to be private. Between these two sides, however, nearly one-third of the program is exterior with the majority being reserved for public use. The exterior observation deck is the most public and the most prominent program piece of the whole building. The areas for observation and relaxation being 47% of the overall program, 80% of which is unenclosed, suggests that by providing ample outdoor, semi-protected space, users may find more appreciation in the surrounding natural context.

Because of the building’s focus on being net-zero, it has allowed for minimal mechanical support program within the building also contributing to the building's small physical footprint. A single mechanical room is enough to provide the necessary services to the other parts of the building and is easily integrated into the core of the form. Other utility areas such as major storage, a janitor’s closet, and several wash closets are also found in the core near the mechanical room minimizing the amount of piping runs needed for water supply. By providing a wash closet with a shower, the staff is encouraged to bike to work supporting sustainable and healthy habits.

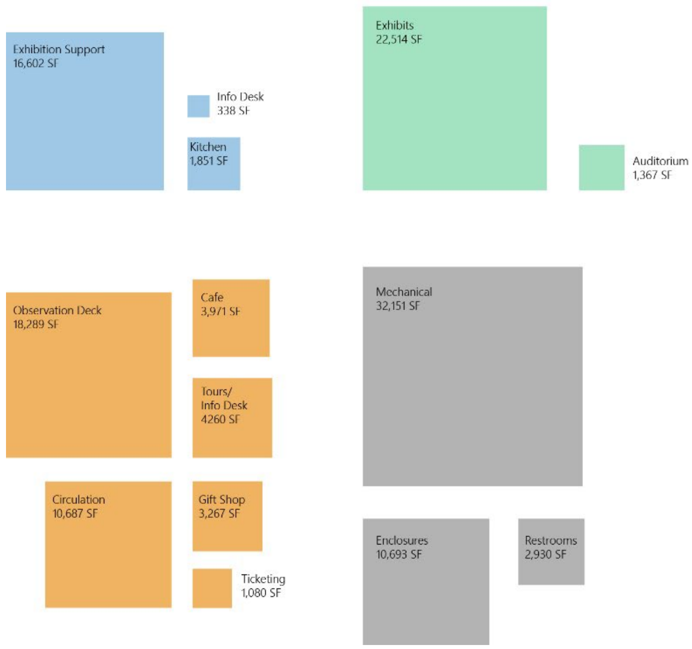
Monterey Bay Aquarium

The Monterey Bay Aquarium, as observed earlier, is about seven times the size of the Brock Environmental Center and this is because of the amount space that is required for the mechanical systems that support the artificial habitats. When compared to the overall square footage of the building, building support is 35% of the whole building. While this helps create a precedent for what the ratio of building support could be to complex artificial habitats, it also supports the argument for reviving the real and natural habitats that we can because it would take a lot more space for us to recreate the same ecosystems.

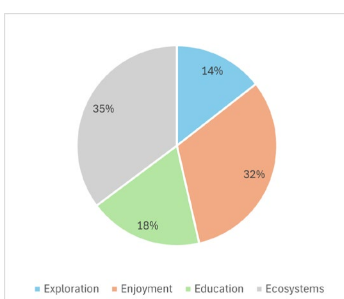
Comparison

While the amount of building support is the largest difference between these two projects, if this is removed from consideration, the other zones and their ratio to each other and the whole is more consistent (Fig 5.1). Like the Brock Environmental Center, the Monterey Bay Aquarium has a large amount of space dedicated to the leisure of guests. This includes the same outdoor observation space but also adds spaces such as a cafe and multiple gift shops that would provide monetary support to the aquarium. Areas for learning and research are close in ratio in both cases. This comparison shows how even at different scales, the ratio of certain zones can remain consistent.

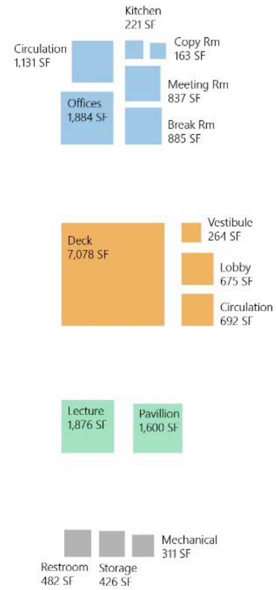
Monterey Bay Aquarium



Program	Area		No.
Exhibit Support	16,602	SF	5
Kitchen	1,851	SF	1
Ticketing	338	SF	3
Exploration	**18,791**	**SF**	**9**
Circulation	10,687	SF	1
Giftshop	3,267	SF	3
Café	3,971	SF	1
Observation Deck	18,289	SF	4
Tours/Info Desk	4,260	SF	1
Ticketing	1,080	SF	1
Enjoyment	**41,554**	**SF**	**11**
Exhibits	22,514	SF	4
Auditorium	1,367	SF	1
Education	**23,881**	**SF**	**6**
Enclosures	10,693	SF	15
Restroom	2,930	SF	4
Basement Mechanical	32,151	SF	1
Ecosystems	**45,774**	**SF**	**20**
Total	**130,000**	**SF**	**46**



Brock Environmental Center



Program	Area		No.
Staff Kitchen	221	SF	1
Meeting Room	837	SF	3
Copy Room	163	SF	1
Break Room	885	SF	2
Offices	1,884	SF	2
Circulation	1,131	SF	1
Exploration	**5,121**	**SF**	**10**
Lobby	675	SF	1
Vesibule	264	SF	2
Deck	7,078	SF	2
Circulation	692	SF	1
Enjoyment	**8,709**	**SF**	**6**
Lecture	1,876	SF	1
Pavillion	1,600	SF	1
Education	**3,476**	**SF**	**2**
Storage	426	SF	3
Restroom	482	SF	9
Janitor	28	SF	1
Mechanical	283	SF	2
Ecosystems	**1,219**	**SF**	**15**
Total	**18,525**	**SF**	**33**

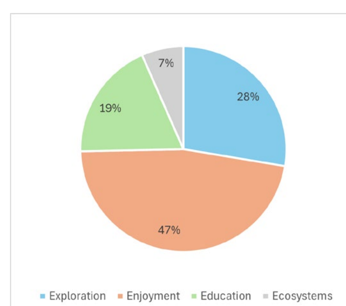


Fig 5.1 Comparing Precedent Programs (Source: Author)

Designing Program

Using the example of the precedents, the program can be divided into four similar, main categories: exploration, education, experience, and ecosystems (fig 5.2). “Exploration” is designed for professional researchers and includes lab facilities required to study the coastal ecosystems. Some of these areas are intentionally adjacent and embedded in areas for education. These overlaps reveal the methods to onlookers and can be used as learning tools. Other examples of spaces for education taken from precedents are classrooms and exhibits where users can learn at their own pace with as much guidance or interaction as they desire. Areas used for experiences are recreational and allow users to inhabit a place with the only intention of appreciating it and its context. The observation decks on both precedent projects are good examples of a space that would fit into this zone. These parts of the program may also overlap with the previous two zones such as observation decks attached to educational exhibits or dive points used by both ecotourists and researchers. These spaces allow for various levels of involvement with both above-water and in-water experiences in the coastal habitats. Lastly, the “ecosystem” zone refers to support spaces for both the building and the surrounding natural

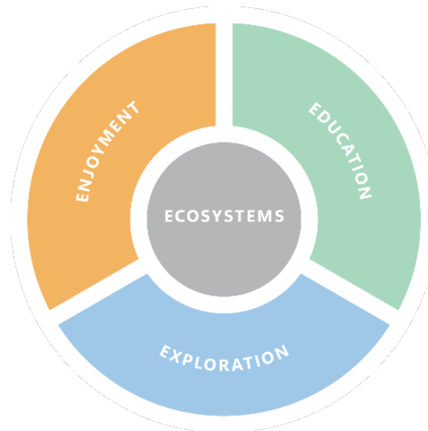


Fig 5.2 The Program Proposal (Source: Author)

environment. These are unseen but essential and ensure stability through the changing context of the ocean coastline.

Shore and Sea

The program is divided into two parts, one in the context of the shore and one in the context of the ocean and reef. Both are designed with the consideration of what would be the healthiest for the natural environment, the scale and spatial organization of this building is more likely to be like the Brock Environmental Center with a heavy focus on passive strategies and a small footprint. Like the precedent, this will help minimize the space used for mechanical and make the "ecosystems" zone smaller compared to the other.

On the shore, spaces are more enclosed and permanent to serve as a field office for long-term research. Along with labs and places for staff to gather, a welcome area for visitors and introductory exhibits are also included. Other permanent programs like classrooms or a flex space for conferences and events are also appropriate for the structure that exists on shore.

To supplement more intensive habitat research, a temporary program is designed to exist in or near the reef. These are fast to deploy and easy to disassemble and relocate when research on a particular area is complete. It can be compared to tactical urbanism strategies used to improve urban environments except here, the goal is to improve natural environments. Haling back to the precedent study done on the Ha Long Bay Villages, these programs are modular to speed up construction. Each module is based on a different zone and space of program and range in the level of enclosure and scale. Examples of these pieces are a module for diving or a module for immersive learning. Using modules allows the space for humans to grow and shrink as necessary and may multiply in non-adjacent places so that a network of reef checkpoints can be created. The structure, materiality, and systems of these spaces will have to be the most carefully considered as they are the closest to the ecosystems of study. Formal inspiration comes from the various growth forms of coral and mimic how a reef is formed with different coral species playing different roles. The connection of these programs varies based on distance from each other so while some may be physically bridged, others include boat docking points that avoid destruction to the reef. In all situations, accessibility is crucial to consider allowing the public to still be very involved in interacting with the reef.

Conclusion

By designing program around both human users and users in the natural environment, the final product can be an example of spaces that promote sustainable relationships between all groups. The zones of exploration, education, and experience are all supported by the fourth zone of ecosystems that aims to create a built environment that is healthy for all the considered users. Inspired by how coral reefs provide a variety of forms to support a biodiverse ecosystem, the spaces created are tailored to support people with a range of intentions to learn, interact, and research with coastal environments. By focusing on the design in two parts, a permanent half for professional long-term research work and a starting point for the nonprofessional visitor can be created without worrying about how it may have negative effects on the coral reefs. The other part can focus on being precise and careful about how it interacts with the habitats as a temporary space for humans to interact more intimately with the coastal ecosystems. With both halves working together, research and community stewardship can advance to heal these important ecosystems through a built environment.

Chapter 6: Site Selection

The success of this design relies heavily on how it affects its context and users, both human and wildlife. Using these perspectives six criteria points are chosen to help decide on an appropriate site that would support interaction from both. With one of the main goals for this thesis being repeatability, a site that would enable the project to be a widely applicable example is also considered. Proximity to diverse ecosystems and communities becomes an overarching theme among these criteria points for this reason.

Using the Caribbean region as a starting point, three site options are chosen to study more intensely through the lens of the six criteria points. The Caribbean region is deemed appropriate based on the desire to visit the site within the period of this thesis as well as its prominent reef population. Not only will these options provide one final site for the thesis project, but they will also be used as a tool to gather more information about how different aspects of the site can be expected to impact the overall design.

Site Criteria

The site criteria can be seen as the most important points to consider between the site and the design. They help guide the research on each site option and are used to measure the appropriateness of the site using a rating system. Both qualitative and quantitative criteria are considered, and they apply to both ecological and humanistic aspects of the site as well as speculating how each site would allow for overlap and interaction between the groups.

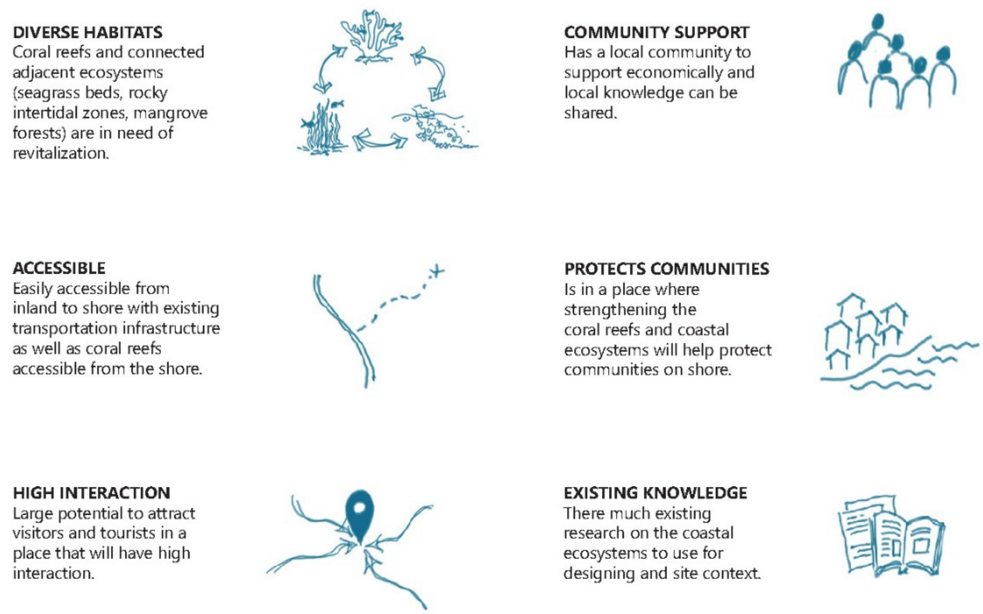


Fig 6.1 Defining Site Criteria (Source: Author)

The first criterion is ecological diversity. Coral reefs exist within a larger web of habitats and ecosystems and cannot be studied in isolation. By looking for an area with many other environments we can further understand the various connections between reefs and other areas. Other habitats such as seagrass beds, mangrove forests, and open ocean have proven to be essential collaborators with coral reefs. The species that inhabit reefs often spend portions of their lives in these other habitats. Not only will having a diverse environment help support reefs more effectively but it will also provide a more diverse set of examples to be used in the future.

A diverse ecosystem is only useful if it is also accessible and drive high interaction. Accessibility comes in multiple parts and has to consider not just the connection from infrastructure to shore but also the shore to the reefs. The distance between shore and other marine habitats will dictate the inclusion of docks, piers, buoys, or other pieces of the program to deal with transportation between the two. Taking advantage of existing infrastructure is also important because adding new paved roadways would not support the goals of a design that is nondestructive to the environment. Other factors besides accessibility affect the amount of interaction a site receives and elements such as the distance from major towns, the amount of tourism in the area, and existing local interest also make a difference. Being off the beaten path can help protect the ecosystems from uncontrollable human interference but can also discourage people from visiting the area. Finding the best point between these two things is essential in ensuring that the structure can achieve its goal of teaching ways of connecting humans and nature. Connection to areas with tourism was a larger consideration since this program has to serve both everyday and occasional users. This would also allow the design to be used to convert areas of mass tourism into a healthier version of ecotourism.

The next two criteria pertain to the relationship between the site and the nearby communities. This thesis being used to create symbiotic relationships between people and marine ecosystems means that the community is required to take part in supporting the ecosystems and in return the ecosystems can continue to provide their services to the community at a sustainable rate. This requires close proximity to a community with existing interest and ties to the environment that has built a history and local knowledge to pull from. By using this existing understanding and building upon it to create skills to assist in the ecotourism economy, the locals can benefit more directly. As communities discover ways to restore these ecosystems, they will see benefits such as a healthier food supply or better protection from storms and hurricanes. So not only will the communities need to be positioned at a distance that will make it possible for them to serve the ecosystem, but the ecosystems have to be positioned in a way that they can help provide for the communities. This again must balance in a way that any constant human actions will not damage the environment further.

The final criteria chosen is less about the physical attributes of the site and more about how easy it will be to study it. Since this thesis is about the design around and with coral reefs and not strictly researching coral reefs, some of this research must already exist to be successful. This is similar to having a community with local knowledge except that it can extend beyond the regular inhabitants and must also include professional research. By having data on the current state of the marine ecosystems, topography, and bathymetry; the topography on the ocean floor; the design process can be completed more confidently tying to real-life conditions. It has been found that the best way to ensure that this research exists is to choose sites that have a direct connection to an organization or institution that has dedicated its resources to studying the area. All of the sites evaluated have an existing group that helps support and gather information that can be used later.

Selected Site Studies

The Caribbean contains a significant amount of the world's coral reefs considering its small overall footprint. Fringe coral reefs are also very common in the region meaning that the reefs are close to the shore if not directly adjacent. These two reasons plus it being the most reachable for me made it the ideal place to start searching for potential sites. The focus turned specifically to Ponce, Puerto Rico; stemming from a previous connection to the city, and the Bahamas. One site studied is to the west of Ponce and two are in the Bahamas, one on San Salvador and the other on Andros.

EcoElectrica Power Plant and Ponce, Puerto Rico

Ponce, Puerto Rico is the second largest city on the island after the capital San Juan. It holds similar governing power and is also a popular tourist destination due to the reefs and historical district within the city. These tourist practices are not sustainable for the environment, however, and could definitely use improvement. Puerto Rico is also a frequent victim of hurricanes and tropical storms that the coral

Fig 6.2 Analysis of EcoElectrica Site (Source: Google Earth, Adapted by: Author)

reefs near Ponce used to help protect the city from but the recent decline of the reefs has lessened this. Just 20 miles west of Ponce is a peninsula with several industrial complexes that reach into the center of a chain of coral reefs. This peninsula offers a central point to begin restoring this chain to help protect the cities on shore.

The company EcoElectrica occupies the tip of the peninsula with a Natural Gas Power Plant. Although this plant produces fossil fuels, EcoElectrica is proud of its contributions to the restoration efforts of the nearby ecosystems. These include coral reefs, seagrass beds, and habitats for sea birds. While much of EcoElectrica's actions are harmful to the environment, their other ideals on sustainability make them a good candidate for beginning to transform this industrial area. Overall this site fits many of the criteria dealing with communities because of its closeness to Ponce as well as several smaller towns along the coast. On the other hand, the habitat diversity is low, and much of the information that can be gathered is skewed as it comes from EcoElectrica. This site opened the idea of using existing structures to adaptively reuse or expand upon. This would allow for a strong foundation for design on land and a more free design to take place on the water. Keeping this in mind, the sites in the Bahamas are also chosen based on what structures are already there.

Fig 6.3 EcoElectrica Power Plant (Source: Matrix PDM)

Gerace Research Center, San Salvador, Bahamas

San Salvador is one of the more isolated islands of the Bahamas. It is small with the 30-mile Queen's Highway encompassing the whole island. It is best known as the supposed initial landing point of Christopher Columbus which draws some tourists as well as the several existing coral reef dive points. A system of lakes is also present inland and helps connect some of the settlements. Being on the edge of the Bahamas, the interior shore experiences very different wave energy than the exterior

Fig 6.4 San Salvador Reefs and Natural Formations (Source: Gerace Research Center)

Fig 6.5 Analyzing Northern San Salvador (Source: Google Earth, Adapted by: Author)

facing shore and it relies heavily on the reefs to protect it. These reefs, however, are declining and most are in bad condition.

Much of the research being done on San Salvador is thanks to the Gerace Research Center (GRC) which sits at the northern point of the island. GRC has a complex of labs, dorms, and other living amenities that make use of an old USA Air Force Base. The University of the Bahamas is the main collaborator but there are also several other educational institutions and conservation organizations that are able to conduct study abroad programs or long-term field studies thanks to the living facilities provided. While the GRC provides a good source for research, there are not many other sources to pull from. Other disadvantages such as the overall isolation that causes lower interaction and disengagement from the communities outweigh the advantages of the diverse and numerous coastal habitats present. Even though this was not chosen as the final site, the layout of the GRC as a larger complex for living and research inspires how to include space for long-term stay in the final program.

Fig 6.6 Plan and Program of GRC (Source: Google Earth, Adapted by: Author)

__Forfar Field Station, Andros, Bahamas__

The third and final site chosen is the Forfar Field Station (FFS) on Andros Island. This island is the largest in the Bahamas but has one of the smallest permanent populations. Andros has become important for the several national parks it houses as well as its adjacency to the Andros Barrier Reef which is the third longest barrier reef in the world. Even though this area is less essential to the protection of human communities than the other sites, it is essential to the natural communities due to the immense amount of diverse species in the habitats on this island.

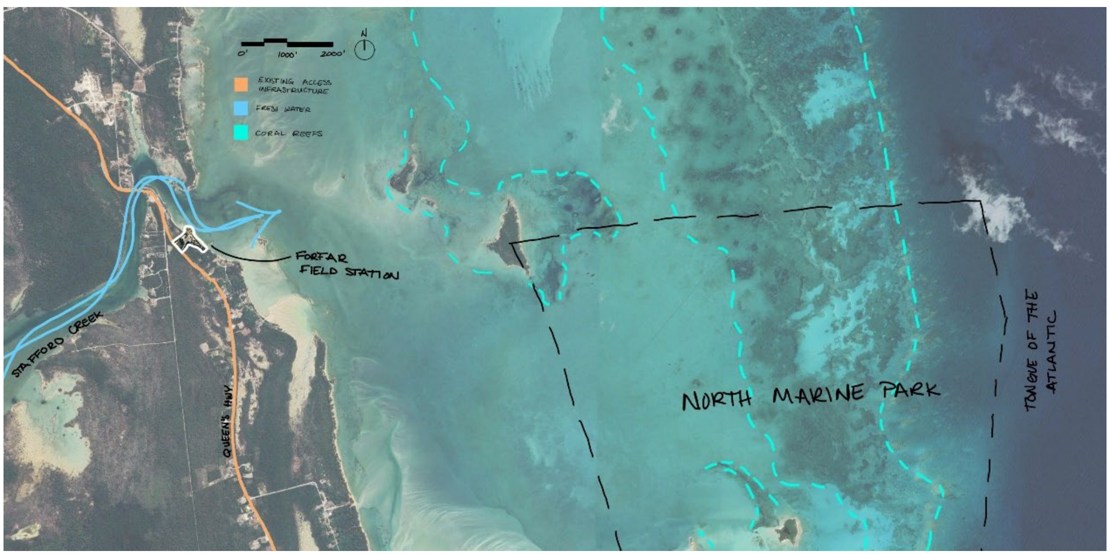


Fig 6.7 Analyzing Forfar Field Station to The Andros Barrier Reef (Source: Google Earth, Adapted by: Author)

The Forfar Field Station is in the ideal location on this island being right on the edge of two of the nature parks, the Northern Marine Park protecting part of the Andros Reef and the Blue Holes National on the interior of the island. Located at the mouth of Stafford Creek, the nearby ecosystems are numerous and include mangrove forests, sea grass beds, and the lagoon containing some small islands before reaching the reef. The Andros Reef itself is located on the edge of the "Tongue of the Ocean," a steep drop-off in the ocean floor, which causes the reef to have a large range of depth. This is what causes the heightened biodiversity of this particular reef. The FFS is similar to the GRC in that it includes living amenities for long-term stays. It also serves several educational institutes and organizations that come to research the area. Between the FFS and the resources of the parks, there are several sources to pull information from. This site provides the opportunity to improve the conditions of the ecosystems not protected by the parks and extend the capabilities of the existing Forfar Field Station.

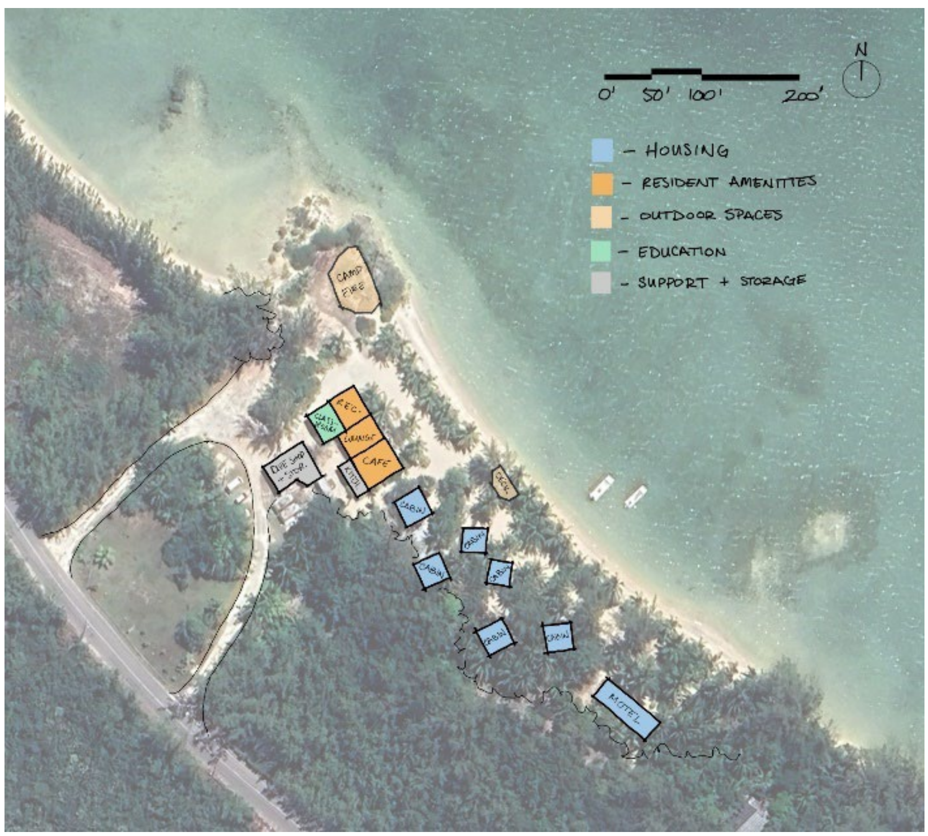


Fig 6.8 Plan and Program of Forfar Field Station (Source: Google Earth, Adapted By: Author)

	PONCE, PUERTO RICO - ECOELECTRICA POWER PLANT 		SAN SALVADOR, BAHAMAS - GARACE RESEARCH CENTER 		ANDROS, BAHAMAS - FORFAR FIELD STATION 	
DIVERSE HABITATS Coral reefs and connected adjacent ecosystems (seagrass beds, rocky intertidal zones, mangrove forests) are in need of revitalization.	3/5	Pests like coral eating snails and bleaching due to high ocean acidity has left the ecosystems in need. There are seagrass beds, lagoons, and magrove forests to also work with.	4/5	The various bays and types of coral reefs create different habitats near this research center. There is also the opportunity to look at water sources inland of the coast.	5/5	This area is extremely diverse from inland ecosystms to the shore and coast. The Andros Barrier Reef provides lots of diverse species to consider.
ACCESSIBLE Easily accessible from inland to shore with existing transportation infrastructure as well as coral reefs accessible from the shore.	3/5	The power plant is connected directly to a major road. An existing pier can be used to extend into the ocean.	5/5	The research center is only 7 miles from the main town and airport on the island. Then entire island can be driven around completely in one hour and the penisulas, keys, and shoals provide many points to emerge from the water between reefs.	3/5	The research center is slightly further from the main town but is right along the highway. The main reef is a barrier reef meaning that it is far off the coast (2.5 miles)
HIGH INTERACTION Large potential to attract visitors and tourists in a place that will have high interaction.	4/5	Ponce has a high tourism economy as well as the nearby major road being lined with many tourist amenities like places to stay, eat, and find entertainment.	2/5	San Salvador is visited mostly for the Christopher Columbus landing point and is not nearly as popular as some of the other islands in the Bahamas. The Gerace Research Center interfaces with mostly educational or professional institutes.	4/5	Forfar Field Station is right between two very popular national parks and has space for diverse groups to visit and stay.
COMMUNITY SUPPORT Has a local community to support economically and local knowledge can be shared.	4/5	This area is near to Ponce (20 miles) and two other smaller towns (less than 10 miles) that can provide local support to the program.	3/5	This island is less populated meaning there is less knowledge to draw upon and less community support to provide.	4/5	Andros has many small towns as well as those who work in the nearby parks that can help support the programs being offered at Forfar Field Station.
PROTECTS COMMUNITIES Is in a place where strengthening the coral reefs and coastal ecosystems will help protect communities on shore.	5/5	Puerto Rico has many frequent tropical storms and hurricanes. This site is on the south side of the island which is less protected from the usually currents of the Caribbean. However the coral reefs would provide limited protection to a	3/5	The Gerace Research Center is the only concentrated area of settlement however because of the large extension of the reefs to the north of San Salvador, reviving these may help buffer other islands on the interior of the Bahamas.	2/5	There are few large settlements nearby but the overall health of this reef is very significant to the rest of the Bahamas as it is so big.
EXISTING KNOWLEDGE There much existing research on the coastal ecosystems to use for designing and site context.	3/5	EcoElectrica is trying to be a environmentally concious and has done some research and revitalization of the nearby ecosystems providing data to use for further investigation of the site.	2/5	Garace Research Center provides the main source of information gathered from this area. There are few other sources to pull from.	5/5	Research of the Andros Reef, the island, and the parks all contribute to the research of this area. The Tongue of the Ocean is also a frequent topic of the area providing some Bathymetric data.
TOTAL	22/30		20/30		23/30	

Fig 6.9 Site Matrix (Source: Author)

Conclusion

Of the three sites considered, the Forfar Field Station on Andros Island in the Bahamas proved to be the most viable for this particular project. It fit the site criteria best and would support the diverse ecosystems in the area by connecting human communities and increasing the efforts for restoration. While the other sites were not chosen for this thesis, studying them helped inform what other aspects of site were important to consider even if they were not initially part of the site criteria. This included the consideration of using existing structure and organization to find research as well as how to incorporate living facilities into the program. The Forfar Field Station provides the best foundation to build upon as well as a large variety of coastal habitats to integrate into the final design allowing it to go forward as an example that can be repeated for other struggling marine ecosystems.

Chapter 7: Early Schemes and Concepts

For this thesis the site must be analyzed and concepts produced at two scales in order to tie together two existing contexts. The first is the small-scale study of the existing Forfar Field Station and the second is the connection from this point on shore to the reef and all the significant points in between. Each point or node may become its own small-scale site needing its own analysis just as is done for Forfar Field Station. Designing and understanding how these two scales relate and connect is essential to creating spaces that integrate and feel a part of the natural environment. After a general scheme is chosen, an appropriate program and structure can be applied to each piece at its specific location.

Schemes

Large Scale Schemes

A series of four general schemes designed at a large scale are tested first to understand how individual pieces can relate to each other (fig 7.1). Being the only existing structure, the Forfar field station acts as an anchor and launch point for each of these. For schemes A, B, and C, there is a primary path that stretches from shore to the end of the Andros reefs with different intersection points that expand. In these three schemes, the secondary paths away from the intersections behave differently and be described as perpendicular for scheme A, spokes in scheme B, and nets for scheme C. It should be noted that the number of intersections also vary in each of these schemes and affect the amount of human intervention that should be expected. The fourth large-scale scheme, D, diverges from the singular primary path concept and instead proposes three paths stemming from the Forfar Field Station, one for ocean, land, and shore. As general concepts, these four schemes provided a library to use in the analysis of the small-scale schemes at Forfar Field Sation.

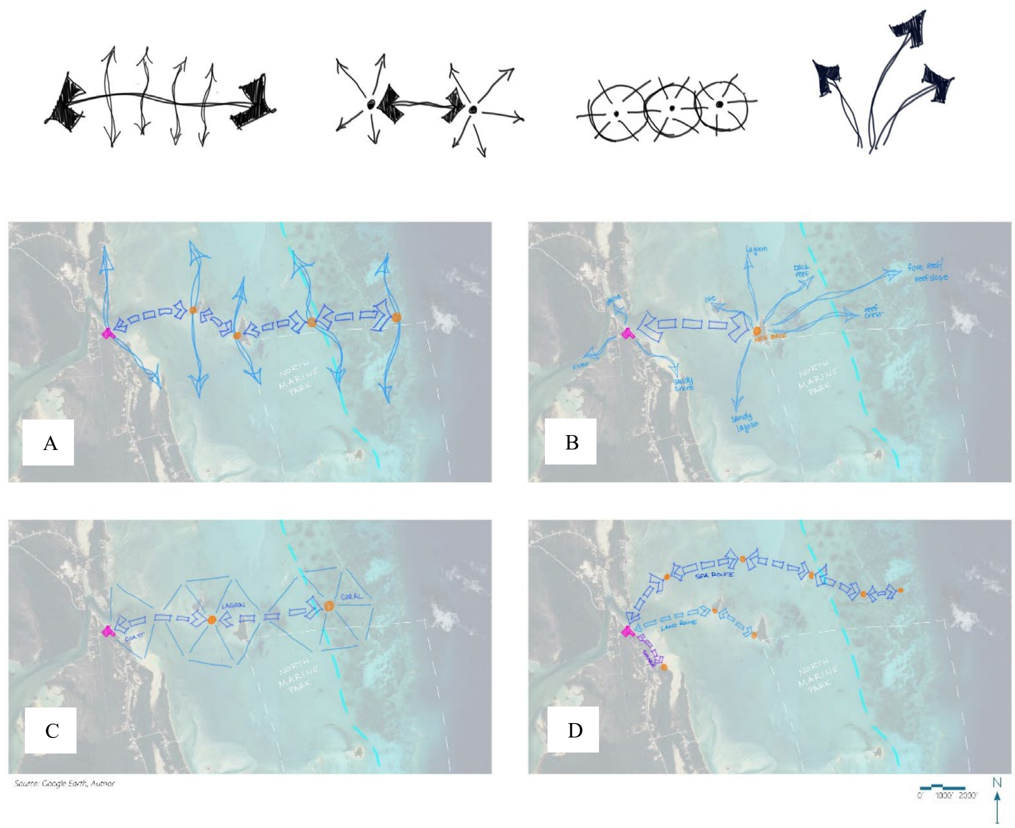


Fig 7.1 Large-scale schemes from shore to reef. A – Perpendicular, B – Spokes, C – Nets, D – Tails (Source: Google Earth, Adapted by: Author)

In looking at the pros and cons of each large-scale concept, it was quickly determined that having a singular primary path would be better than three disconnected ones eliminating scheme D as an option. While schemes B and C have similarly, scheme A stuck out as too non-specific and rather than tactical and small interventions, represented a restoration strategy that would rake over the coastal marine landscape. Moving into small scale analysis schemes B and C remained as concepts that support this project's main ideals to later be synthesized into a final scheme.

Small Scale Schemes

The existing structures at Forfar Field Station act as the intersection of land and water before further launching into the marine ecosystems. An additional building that can mark the beginning of this path as well as areas for vessel launches along the shore are studied through four more schemes at a smaller scale (fig 7.2). Some of these schemes carry similar themes to the previous large-scale ones such as perpendicular intersections as in scheme F, nodes with spoke like scheme G, and diverging paths like in scheme H. Scheme E emphasizes the large-scale schemes that rely on a singular primary axis by focusing on a new area of development that mirrors the existing main building.

Like the large-scale schemes, each concept is analyzed for its pros and cons. While E is clear and direct it ignores the water adding a traditional building that is disconnected to the overall theory of designing with the ocean. The other three place the new structure on the shore seem to either include or exclude the existing student program too much. Balancing the privacy of the long-term users as well as their needs will be the main consideration pulled from these studies when creating the final synthesis.

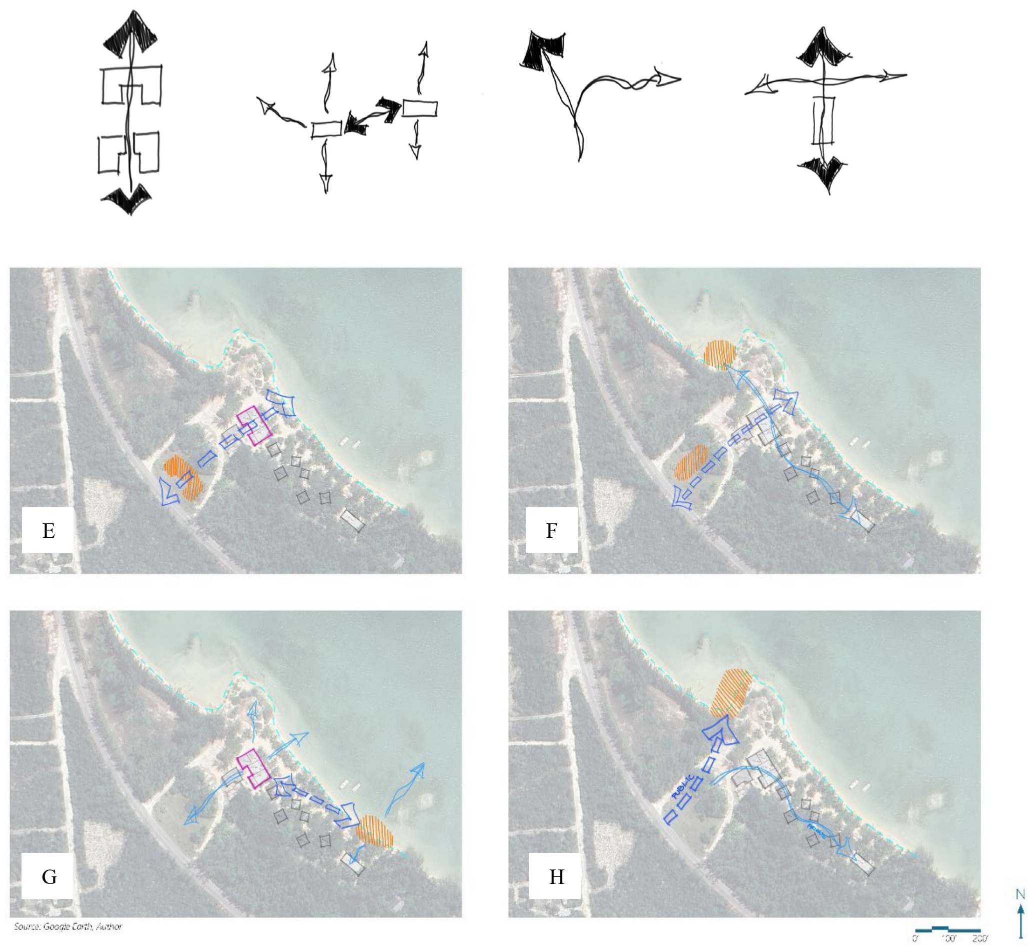


Fig 7.2 Small-scale schemes at Forfar Field Station. E – Through, F – Perpendicular, G – Spokes, H – Tails (Source: Google Earth, Adapted by: Author)

Scheme Synthesis

Using the previous studies of schemes at both scales, a more refined synthesized scheme is created (fig 7.3). A combination of the scheme B, “spokes,” and scheme C, “nets” is used with three major hubs at the shore, lagoon, and reef.

Forfar Field Station is used one of these at the shore. Branching out from these are the habitats strategically placed in the distinct habitats that appear between the shore and reef. The network of nodes that work in a hierarchy can been seen as mirroring the natural world with individual species creating communities in habitats that work together to support a larger ecosystem.

At the smaller scale of the addition to Forfar Field Station, the consideration of private and public users leads to a scheme that creates two new structures for each group. These both reach out into the water and while one focuses on providing information and a place to relax and observe, the other provides space for education and research primarily catering to the students and staff. Both of these can act as points to launch into main primary path to the other two new nodes in the lagoon and reef.

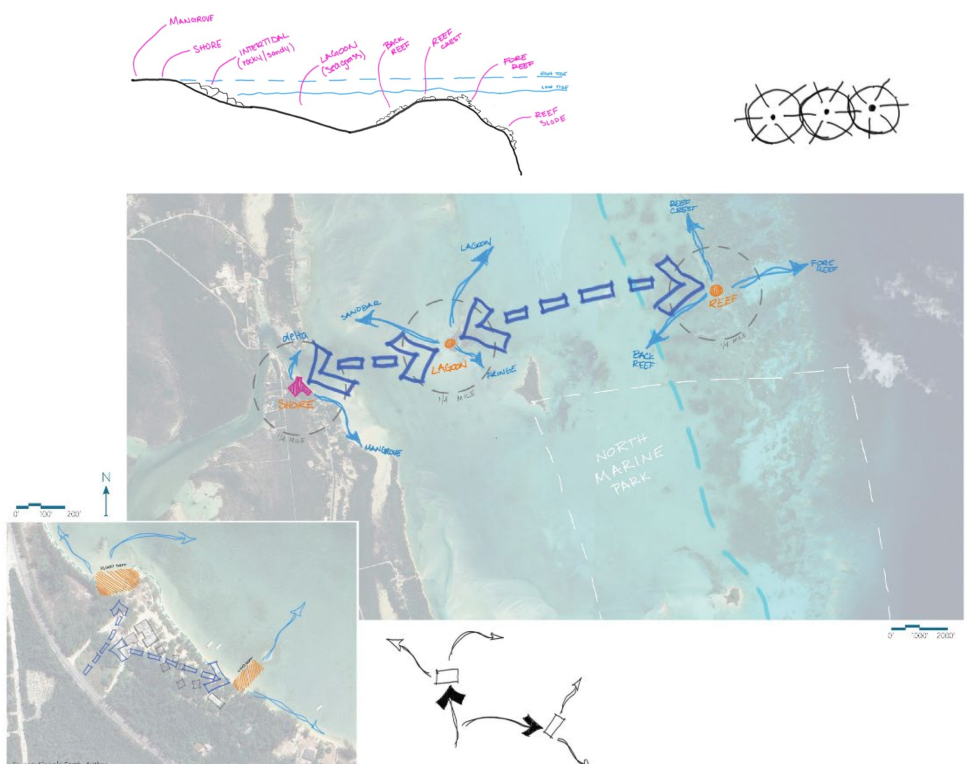


Fig 7.3 Final scheme synthesis (Source: Google Earth, Adapted by: Author)

On-Water Building Typologies

Pulling greatly from the previously studied precedent, the Brock Environmental Center, the program is decided to be a smaller footprint and strive for strategies allowing for minimally invasive design. As there are three locations or types to consider, land to water, in water-off reef, and in water-on reef.

As the environment and ecosystem changes at each point, a variety of on-water building typologies are studied in addition to the previous precedents to satisfy the diverse conditions of the building sites. Spaces can be on rafts or partially submerged and supported, anchored, or confined in many ways. Some of these strategies include the use of a network of piers, anchors or ties to the shore or ocean floor, or a border of nets that entrap a free-floating space (fig 7.4). Each of these typologies are also studied for their level of mobility both in the vertical motion of the rise and fall of sea level and the horizontal direction moving with the currents. While the pier typology keeps the structure static in the water, the raft and end concept allows for considerable movement. Anchor and tie typologies allow for change in control completely depending on the number and looseness of the attachments.

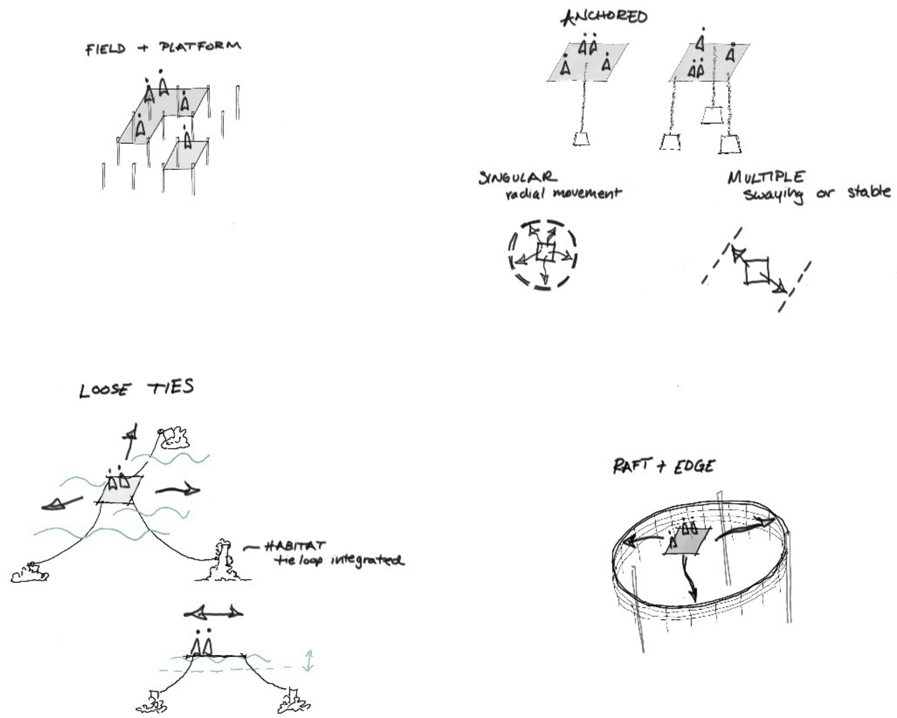


Fig 7.4 Studies of on-water structure typologies (Source: Author)

New spaces are created on the shore, considered "land to water", adding to the existing structure on the Forfar Field Station. This area is less sensitive than the reef and would be able to handle a more invasive structural typology. With a catalogue of structure types, the best fit for these can be devised using either a singular type or a combination. At the shoreline a pier would be most traditional, however the disruption this may cause with the flow of currents or wildlife should be considered. The sandbars that may form around the pier feet can cause many changes to the adjacent ecosystem.[44] A typology lifted off the sea floor can be less damaging as well

[44] Dafforn, "Marine Urbanization"

as allow for movement with the rise and fall of the tides. Something similar to a rafted dock or boat house attached to the land and still provides the stabilization required larger enclosed program while being adaptive to the context.

At the “in water-off reef” sites, the footprints are significantly smaller and provide the learning and research essentials with a focus on areas adjacent to the isles. Interjections into the sea floor habitats should be surgical in nature and as minimal as possible while fully in the marine environment. The already planned interventions at the artificial habitats branching off from the reef node may be the best opportunity to anchor or contain this hub (fig 7.5). The raft and edge design can be used to allow movement across an area of observation, but disruptions caused by the net should be considered. Loose ties at the habitat points may be better and still allow for plenty of movement on the water.

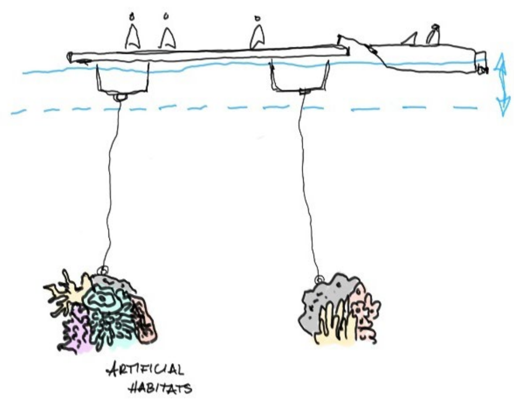


Fig 7.5 Artificial reefs as and marker (Source: Author)

The “in water-on reef” spaces are the most sensitive; minimal anchoring points or avoiding anchoring points all together should be considered. Something acting similarly to buoys tethered to the artificial habitats which may also mark the location of recovering habitats and can include monitoring devices that gather data.

Together these three locations should provide a small footprint with program that considers both human and marine wildlife needs. Like the Brock Environmental Center the majority of the program can be centered around spaces for users to enjoy, reflect, and observe looking out in to the surrounding context.

<u>Conclusion</u>

With these concept studies looking at two scales that apply program and structural typologies, as basis for more in-depth design is created. At this point in the process, all the typologies studied have been to support floating program above the water. Further exploration in the design phase will look at how these systems can be adapted for semi or fully submerged spaces that integrate more fully into the ecosystem. Tests on materiality and tectonics of connection point between designed and natural environments will also need to be analyzed to determine the least harmful method. Finding materials that support habitat growth will be at the forefront of these experiments. The core idea will tie these details to the overall scheme and while items may shift to find their best fit in the context, the foundation of the final concept and structural systems ensure that all the previous research and considerations continue to be.

Chapter 8: Design Explorations

At the beginning of the design process a decision was made to first focus on the least explored areas of structures on water and around the reef and less on those attached to the shore. These areas would require defining a new typology and process that would allow for the most sensitive approach to building in the reef habitat.

Determining the Typologies of Focus

Concept Generation

The nouvelle setting of the ocean requires new inspirations and a reset of thinking about architecture in the traditional manner. New concepts are generated without site only thinking of the manner in which a structure could exist in and on water. The initial concepts are closely attached to a marine organism or an existing human experience in water that provide inspiration primarily in a formal sense (Fig 8.1). The concepts are meant to be scalable and had the potential to apply to something as large as the complete structure or as small as a building detail. While many of these concepts are generated in the first phases of the design process, throughout the entire exploration, they are returned to, added to, and adjusted as the foundations of the various following iterations.

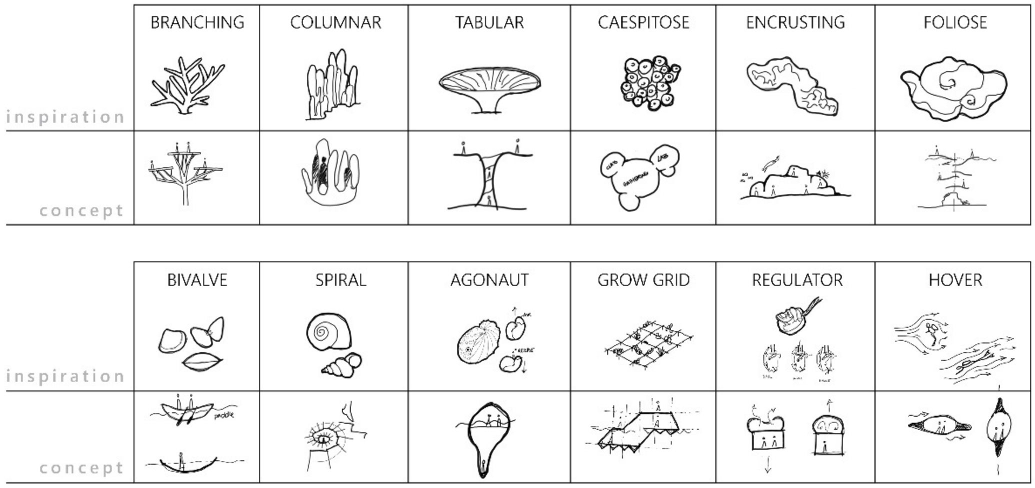


Fig 8.1 Marine-inspired concept generation (Source: Author)

Site Parameters

Choosing to focus on extremely sensitive coral reefs became not only important as a means of further investigating marine-human relationships, but also as a steppingstone that would take us into the rest of the ocean by first designing for the ecosystem that requires the most restriction. In looking for reusable typologies, the typical section of shore-to-reef is generalized and reapplied to the chosen site to help pick specific focus areas (Fig 8.2). The specific ecosystem type became more important in context of the standard shore-to-reef section where instead of the previously noted conditions, land to water, in water-off reef, and in water-on reef. The shore, lagoon, cays (previously known as isles), patch reef, and barrier reef became terms that would better describe the

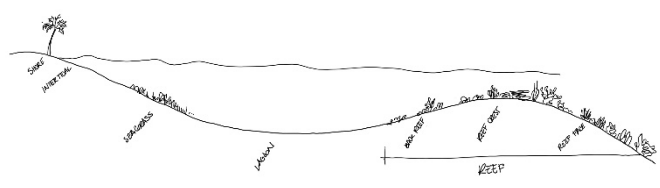


Fig 8.2 Typical Shore to Reef section (source: Author)

locations' depth and sensitivity qualities. As an extension to these, areas between ecosystems, known as ecotones, are discovered to be of extra interest as a place that is directly adjacent to extremely sensitive areas, like the reefs, without quite being set inside them (Fig 8.3).

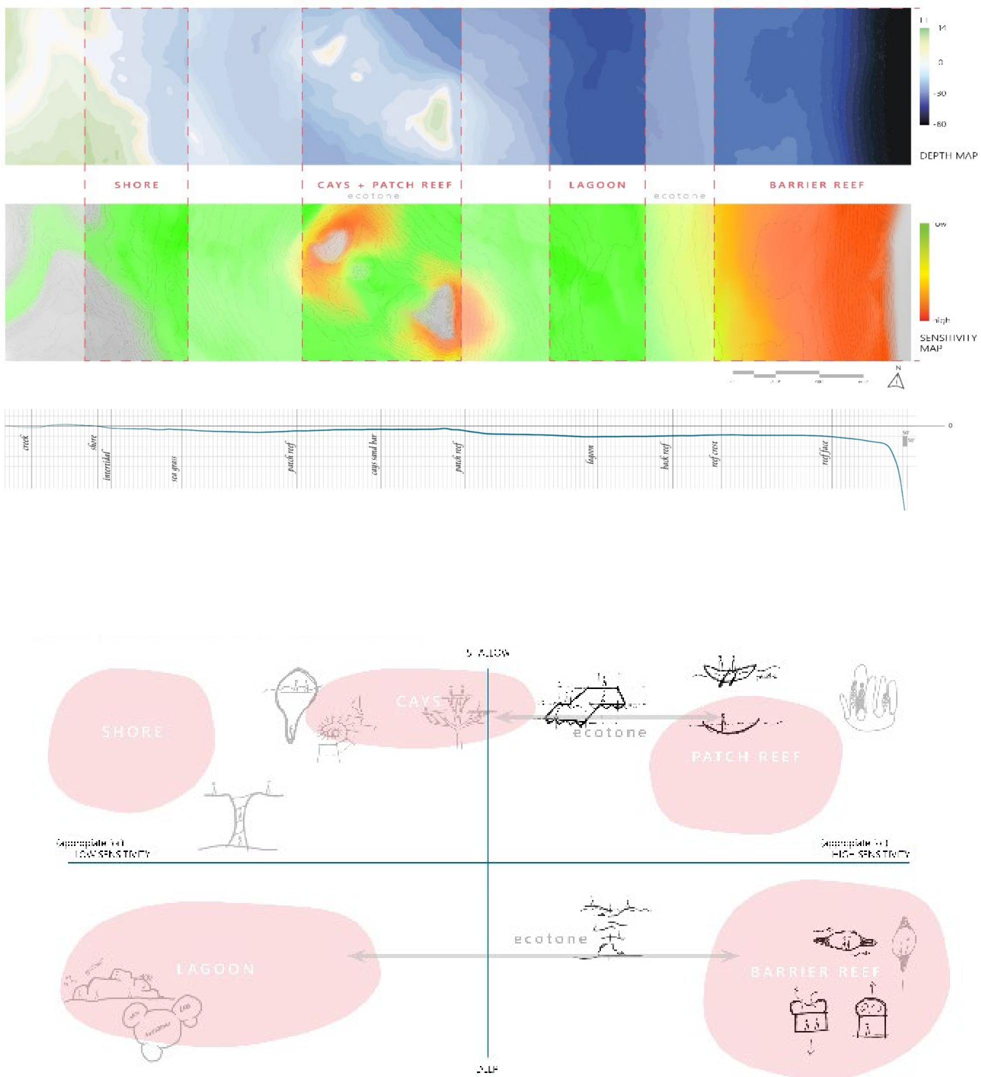


Fig 8.3 Depth and Sensitivity of Site creating parameters (Source: Author)

Using these two qualities a set of parameters is set and applied to the concepts. Based on personal interest in certain ecosystems and conditions and which concepts were most appropriate for those depths and sensitivity levels, typologies can be extracted. In this case, the focus on ecotones and reefs lead to four typologies determined by the depth and sensitivity of the ecosystem they are attached to (Fig 8.4).

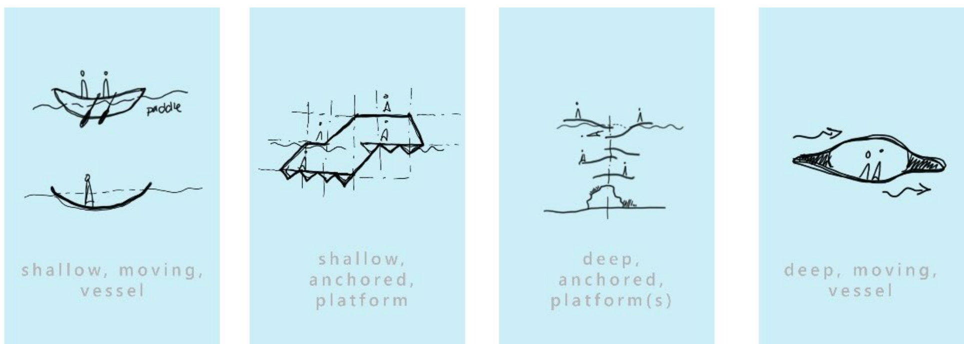


Fig 8.4 Four Chosen Typologies (Source: Author)

Areas of Investigation

In developing these typologies, several iterations took place which are shared later. In each iteration, there are three main categories of investigation that were used to respond to various challenges of the site and overall language of the four typologies. These categories also have ties back to the observations made during the original concept studies and behaviors of humans and marine organisms help inform what is most important to consider when inhabiting a marine environment. These three categories are evolution, movement, and structure. More than discovering what subjects should be considered, there is also the discovery of what techniques and tools are best used to investigate each category.

Evolution

Studying evolution stems from the desire to have these four typologies feel unified across the greater coastal and reef landscape. Two studies by D'Arcy Wentworth Thompson are used from his book *On Growth and Form* – grid deformation, which Thompson primarily studied through fish species, and the layered growth of bivalve shells [45]. In both of these methods of evolution, there is a base form that is then distorted or layered on top of to create the next step in the evolution. Without changing the previous step, this can be repeated again making a string of related forms. Like genetics passed down through a family tree, these separate objects are all connected through their relation to the base form and previous evolutions.

To mimic this effect in a design process, the application Rhinocerou3D is used. Rhino3D creates geometries from gridded meshes with control points and curves from handles; pushing and pulling these points allow for unified distortions that gradually change the geometry and can also keep symmetry similar to how it would appear in nature (Fig 8.5). The forms created through this can be nearly infinite and depend on the base form, the next chosen distortion and the order of each allowing a wide range of experimentation.

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[45] D'arcy Wentworth Thompson. 1968. *On Growth and Form, Vol. 1.* Cambridge, Cambridge University Press.

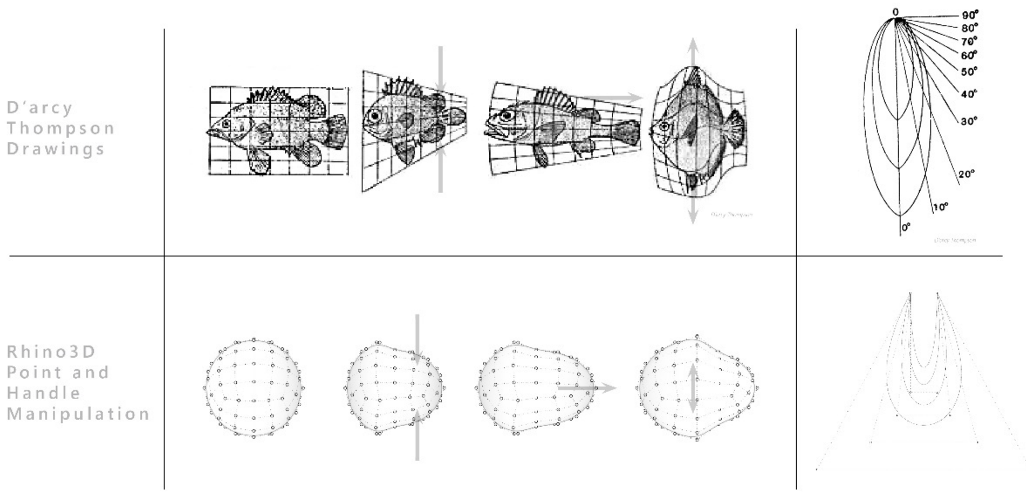

Fig 8.5 Recreating Evolution methods observed by D'Arcy Wentworth Thompson (Source: D'Arcy Wentworth Thompson and Author)

Movement

Movement responds to the challenges of designing for the ocean depth. Observed in the vertical direction and in the horizontal direction, the movement of a structure can assist in its adaptability, something essential in the everchanging ocean, but can also affect stability and usability. It is important to understand the balance of these two in context of each sub-ecosystem and usage.

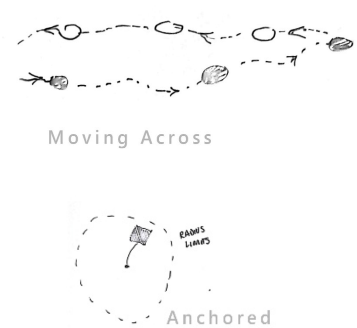

Fig 8.6 Anchored or Drifting (Source: Author)

Horizontal movement is controlled by anchoring the structure and has varying levels depending on how many anchors are used. There is also the option to allow a structure to be completely unrestrained and able to drift at the surface or through the water (Fig 8.6). The on-water typologies studies earlier focused mainly on this dimension of movement in forms of rafts and buoys and the usage of boats and other water vessels displays the depth at which this has already been explored throughout history.

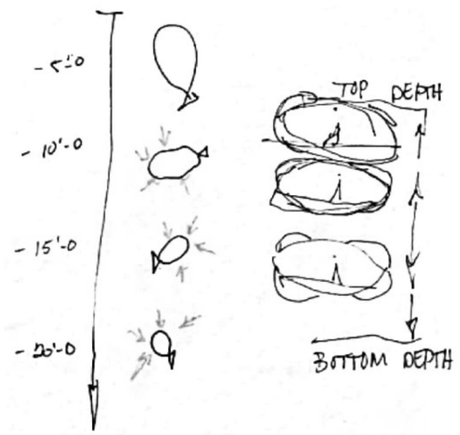

Fig 8.8 Vertical movement through the water column (Source: Author)

The second dimension to be studied, the vertical dimension, is one of the unique characteristics of designing in water and required more in depth exploration. Water which has weight and perceivable volume unlike air means that pressure, light, and temperature all change as one move downward through the water column (Fig 8.7). Understanding the effects of this on structure and especially on the human body became essential and self-immersion is the best medium to understand this. Through PADI SCUBA Certification, not only is there a better understanding of the ocean's effects on the body but also the equipment that is used to allow human occupation at depths (Fig 8.8). Through comparing this equipment to natural marine organism functions, adaptations can be used to apply at larger scales in built environments. The experience of moving from shore to diving in the ocean also lead to a study of all the interaction of humans and water posing the question of how to maintain this full range of experience in structures that exist only at sea (Fig 8.9).

Fig 8.7 SCUBA Equipment (Source: Author)

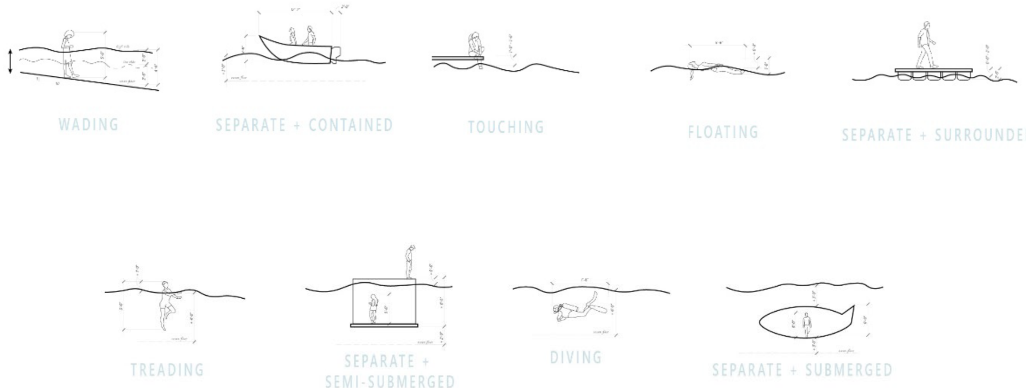

Fig 8.9 Interactions of humans and water (Source: Author)

Structure

Each of the following iterations stem from a study of various structures. Like the concept studies performed earlier, these stem from ocean grown objects and organisms in tandem with the human tools for marine inhabitation. Each study done becomes another binding motif used across all of the four typologies and the tools used to study and create the forms vary based on each iteration.

<u>Design Iterations</u>

Modular Design

Based on artificial coral growth structures, a modular design is created. Artificial growth structures usually use joints and thin members that can be assembled underwater at various scales (Fig 8.10). Even though the forms are repeatable, they can be configured into complex forms quickly to replicate the forms found in natural reefs.

Fig 8.10 Modular artificial reef (Source: Reef Design Lab)

This iteration looked to mimic this and uses hand drawing and physical modelling as the main form of exploration. The modules are found to be easily scalable and quickly move from flat platforms to spatial volumes and are reminiscent of the structural systems and assembly we are familiar with on land.

Some of the challenges that arose from a modular based design were the constraints any chosen module would pose. The module would dictate the overall form and usually did not lend to a hydrodynamic form that would allow movement. Because of its close similarity to the existing building structures already used, it failed to push the typologies to a new realm fitting of the new setting of the ocean.

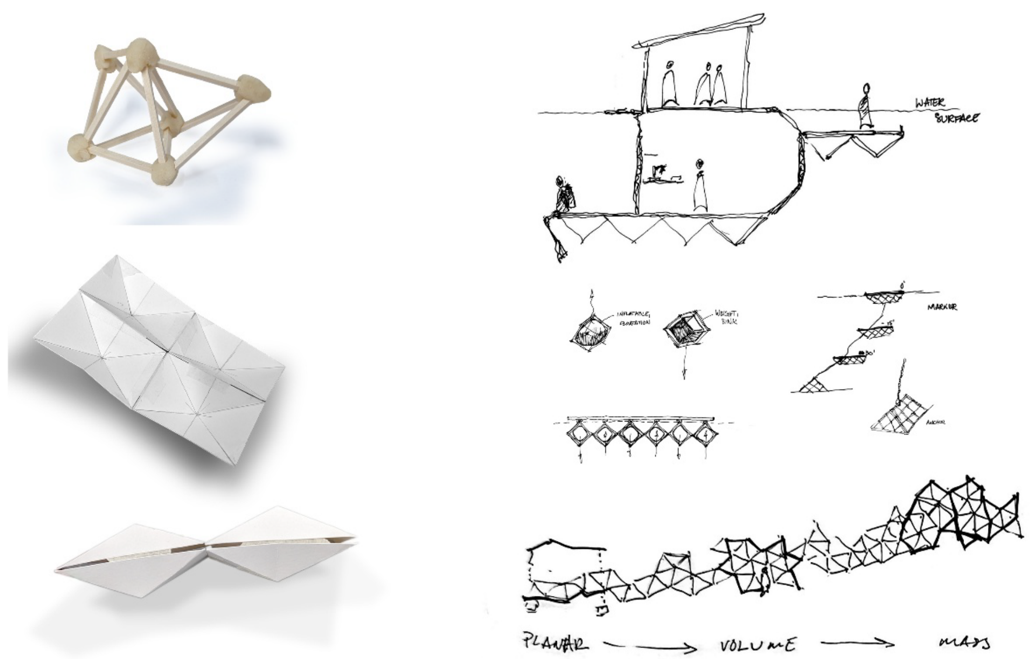

Fig 8.11 Models and sketches on a modular-based structure (Source: Author)

Differential Growth Design

Instead of looking at how humans would construct things underwater, the next iteration looks at how coral would construct something underwater. Coral growth patterns are known as differential growth and are influenced by environmental factors such as sediment, water currents, temperature, and more (Fig 8.12) [46]. This can be roughly predicted by complex mathematics which can translate into the use of visual coding tools such as Grasshopper paired with Rhinocerous3D (Fig 8.13).

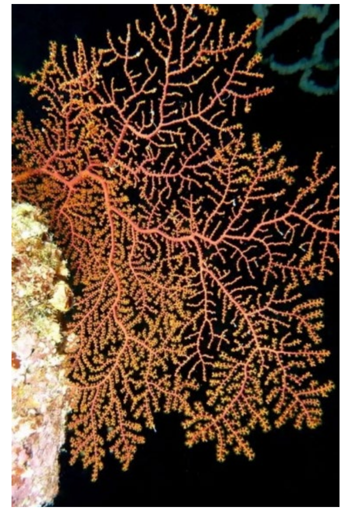

Fig 8.13 Differential growth displayed in a fan coral (Source: Flickr)

Computational design allowed not only for a formal output that closely mimicked the result of a growing coral, but could animate each layer of growth as if it were occurring over time.

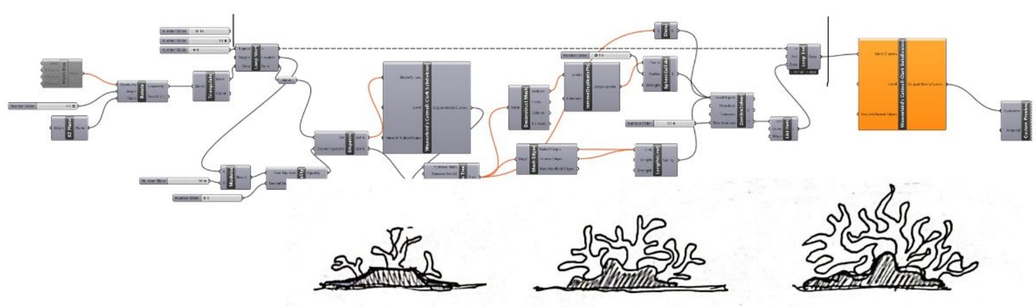

Fig 8.12 Grasshopper script for differential growth (Source: Author)

[46] Thomas, Greig. 2024. "Coral Reef -Differential Growth." IAAC Blog. Institut d'Arquitectura Avançada de Catalunya. March 5, 2024. https://blog.iaac.net/coral-reef-differential-growth/.

The code and mathematics quickly become too complex to allow for a fully developed time allotted to this series of explorations. While it showed great potential for further exploration, personal skill level and understanding of the tools being used limited the design work that could be done. A question of whether or not the structure should be mimicking the coral while being so far from the actual thing also halted a deeper investigation of this iteration.

Despite these challenges, the subject of a structure that changed and grew over time became a new point of exploration (Fig 8.14). The impacts of an evolving physical form on built space for both humans and wildlife could pose a new type of intelligence if the growth pattern were perfected. The search for a materiality that would allow this also contributed to iterations going forward.

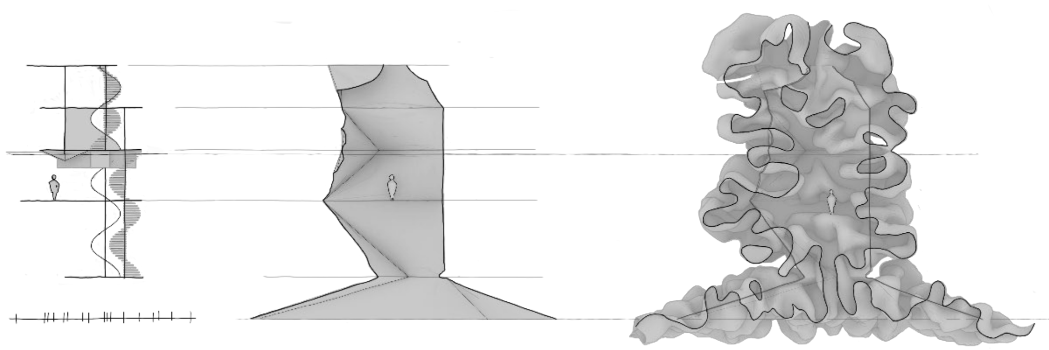

Fig 8.14 Platforms, lofted, and distorted through differential growth (Source: Author)

Buoyant Shell Design

The third and most recent iteration uses mechanics of the argonaut organism. An argonaut is a cephalopod that is the evolutionary step between benthic organisms, organisms that live on the sea floor, and pelagic organisms which live in the water volume of the ocean (Fig 8.15). They are able to float and sink by collecting air in a soft shell and releasing it to control buoyancy[47]. One piece of SCUBA equipment called a buoyancy control device (BCD) acts similarly to this. The familiarity of a human tool that could be pushed further into an architectural feature seemed like the best next step in exploring ocean architecture.

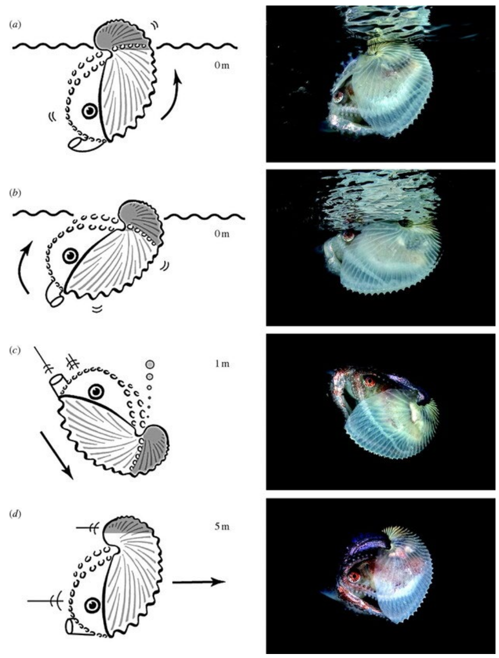

Fig 8.15 Argonaut buoyancy (Source: Julian Finn, Kate Nolan)

The personal experience with SCUBA gear greatly assisted in the understanding of what would be required to make each volume float in terms of weight, volume, and the air required to inflate a bladder. Using this and inflated forms created in Rhino3D, a spatial volume is created (Fig 8.16). Other existing vessel forms such as boats and submarines helped guide the overall geometry and objects like a ballast and space for hatches in enter and exit also influence the form. Armatures modelled after the features of various marine organisms are added to assist and define the structures' main functions.

[47] Finn, Julian K., and Mark D. Norman. 2010. "The Argonaut Shell: Gas-Mediated Buoyancy Control in a Pelagic Octopus." *Proceedings of the Royal Society B: Biological Sciences* 277 (1696): 2967–71. https://doi.org/10.1098/rspb.2010.0155.

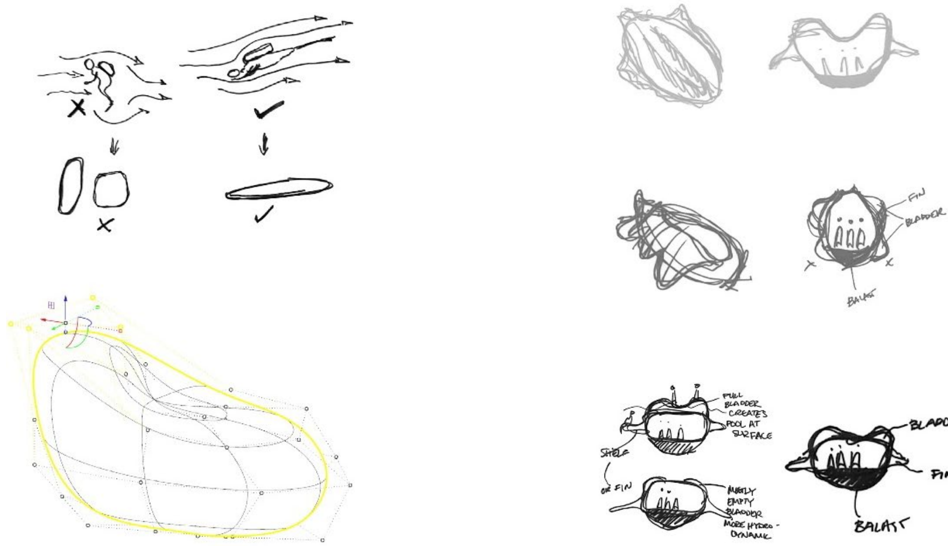

Fig 8.16 Buoyant shell studies (Source: Author)

Application of Buoyant Shells

The buoyant shell iteration is developed beyond the first two and specific variations are created for the four previously mentioned typologies (Fig 8.17). At this stage the investigation moves backwards through the three categories of study with the structure already being defined.

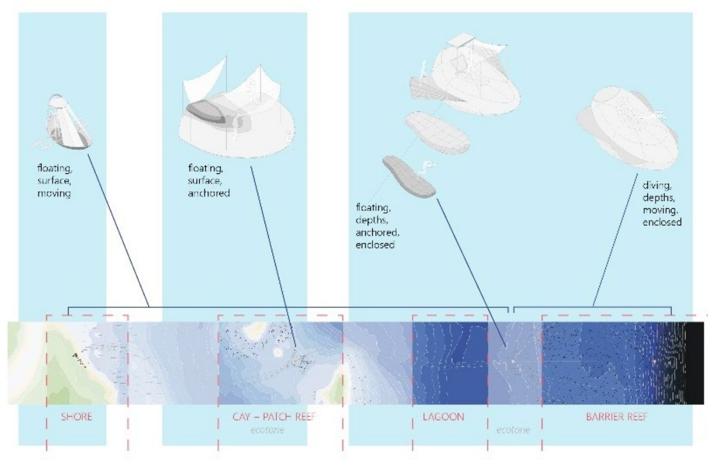

Fig 8.17 Buoyant shells in site (Source: Author)

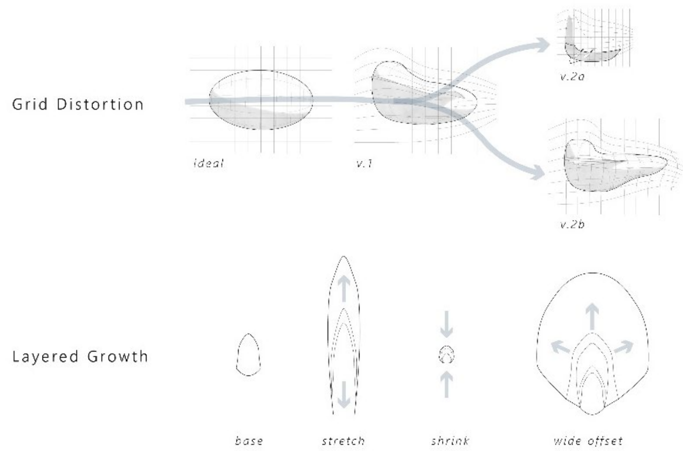

Fig 8.18 Applying grid deformation and layered growth evolutions (Source: Author)

In movement, what is found is that an inflated shell is appropriate for deeper waters or for drifting forms. On the other hand, shallow water, especially in cases where the structure would not be moving as much requires a platform geometry. With these two sets of forms, a volume and a surface both based on shells, a hydrodynamic ellipsis base shape is determined, and the studies of evolution help create individual pieces. The volumetric forms used grid distortion whereas the platforms were created through layered growth (Fig 8.18). These created the watercraft, the platform, the tower, and the submersible.

<u>Program, Assembly, and Materials</u>

With each form defined, program and details can be determined. In each case considerations are made for human use and marine wildlife use and each piece measures distance from shore, depth, and stage of coral growth when observed in section (Fig 8.19).

Fig 8.19 Programing pieces (Source: Author)

Starting with The Watercraft, this is ultimately the only piece that interacts with the shore (Fig 8.20). Program at the shore and FFS is minimalized to a landing and launch point for the watercraft and the rest of the previously examined program is reallocated to the other three pieces completely on the water. The Watercrafts is the connector from shore to reef and can be piloted via paddles and sails avoided motors that can disrupt nearby marinelife.

In the sandy spots of the Cays away from the patch reefs, The Platform allows for rest, work on a steady, anchored surface, and a place for the watervessel to land. The Platform has a piece of inflated shell allowing it to float, however does not serve as inhabitable space. Below the platform, a grid of framework and rope act as a propagation garden

Fig 8.20 Watercraft at shore (Source: Author)

for coral in a controlled environment that is slightly more protected because of the surrounding islands.

The Tower and The Submersible are at the reef. The Tower anchors itself just off the reef and acts as a floating lab with space for observation end entering and existing the water. Below the main body, a series of platforms float at various depths to act as guides for divers and areas of rest and observation for a structured artificial reef for adolescent coral (Fig 8.21). Also attached to The Tower is The Vessel which drifts through the water above the adult, natural reef. Also containing inhabitable space for research and observation, The Vessel does not touch the ground or sensitive coral and relied on its attachment to a tower and a stragically placed anchor to control its drift radius.

Fig 8.22 Observing and diving under The Tower (Source: Author)

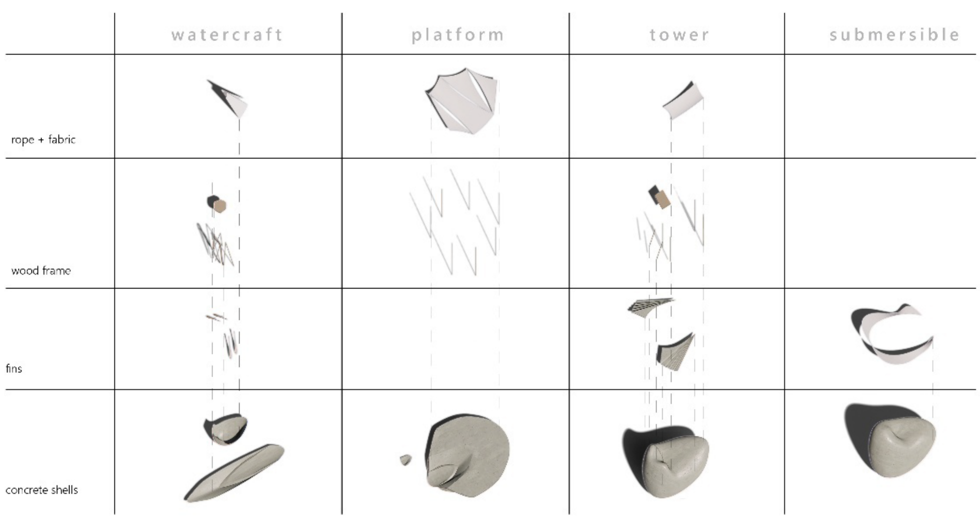

Fig 8.21 Chart of common materials (Source: Author)

Beyond a formal connection, the four pieces are also related through materiality (Fig 8.22). Materials that have been historically used, such as rope, netting, fabric, and wood, are used in each strucutre to create frameworks, teathers, and shades. The main bodies of the structures are made of cyanobacteria-based bioconcrete. Concrete is selected as material due to its ability to form double curve surfaces with minimal seams and its potential lightness and durability. However, traditionally used Portland cement concrete is unsustainable and causes concerns over longterm affects to marine environments due to acidity. Using cyanobacteria not only sequesters CO2 through photosynthesis but also can be collected off of coral to prevent smothering[48]. Cyano-based concrete also acts similary to coral both chemically and physically and may be better suited to the marine environment (Fig 8.23).

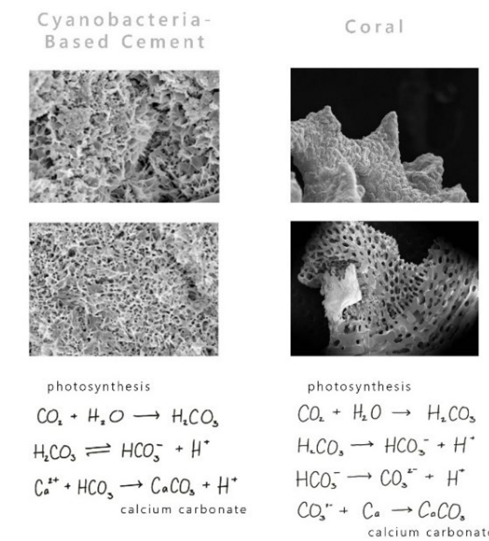

Fig 8.23 Comparing cyanobacteria-based cement and coral skeletons (Source: Elsevier, Author)

[48] Zeeberg, Amos. 2020. "Bricks Alive! Scientists Create Living Concrete." *The New York Times*, January 16, 2020, sec. Science. https://www.nytimes.com/2020/01/15/science/construction-concrete-bacteria-photosynthesis.html.

The overall composition of the four pieces allow for a cycle of coral growth and cyanobacteria harvesting which can then be used for the built structures or pieces of artificial reefs (Fig 8.24). The structures attach themselves naturally to a stage in the cycle not only supporing human research, observation, and recreation, but also coral regeneration.

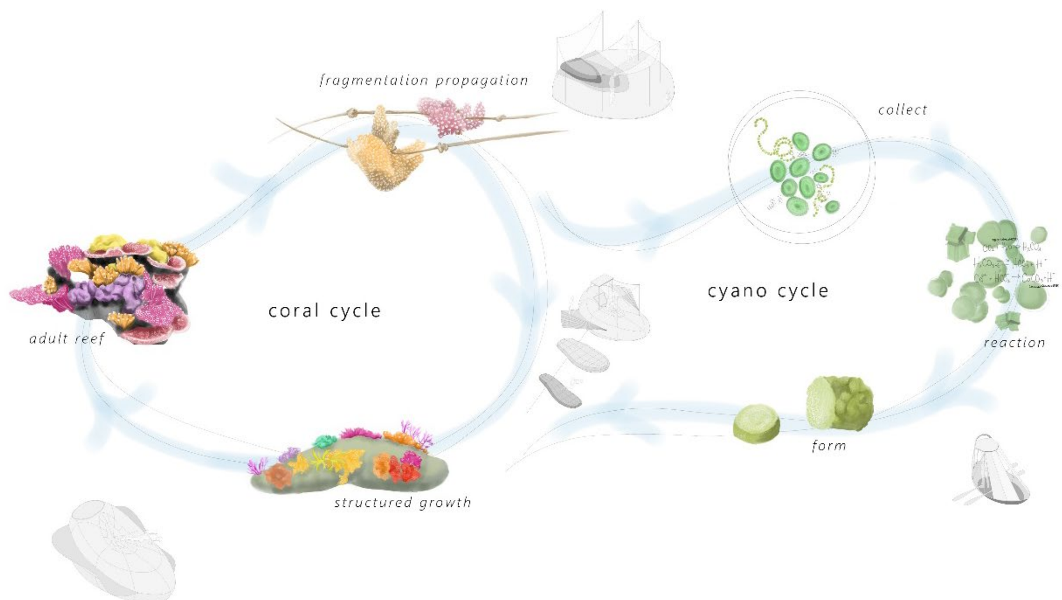

Fig 8.24 Coral and cyano cycles (Source: Author)

Conclusion and Reflection

It should be noted that this is only three iterations of a greater journey that leads to larger, sustainable, human communities on the water. While many of the programmatic components that involve public and community interaction was not explored in the iterations presented, this will have to included in next steps to allow for an accessible architecture. A continued exploration is required that learns from each previous iteration pushing us toward an architecture that relies less and less on human designed tools and more on methods that mimic the mechanics of marine organisms. With many questions surrounding not only the appropriateness of human occupation of reefs but also the technical systems that allow for human occupation of any marine environment, studies will need to continue to challenge what is known and unknown in marine architecture.

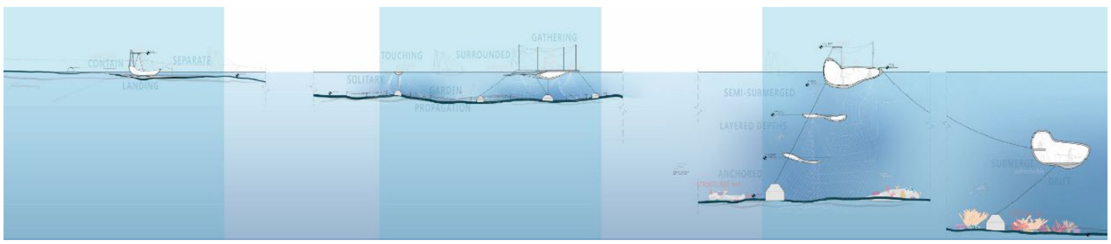

Fig 8.25 Buoyant shell iteration in section (Source: Author)

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