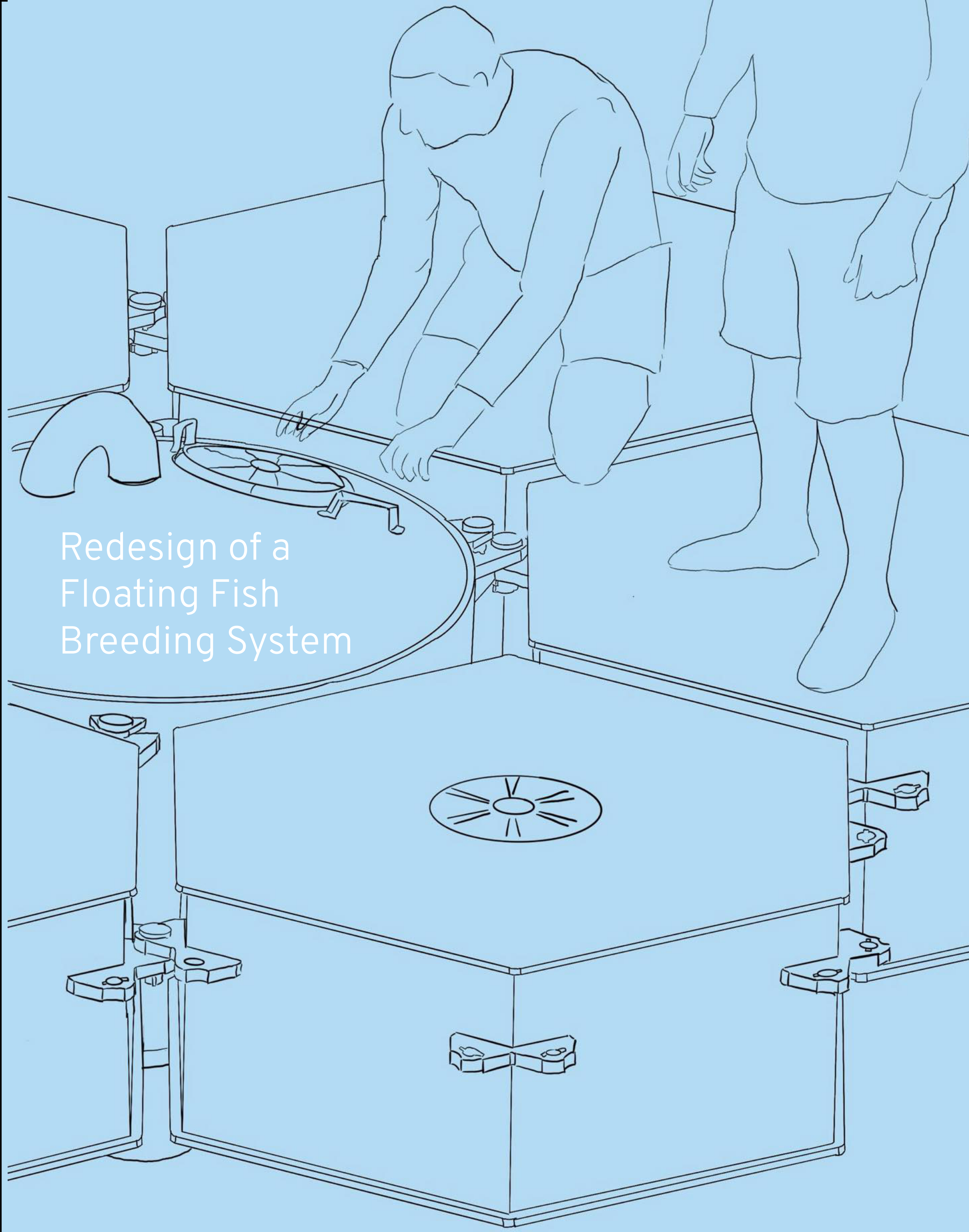

Redesign of a Floating Fish Breeding System

Improved Performance for the Conservation of Reef Fish

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MSc. Integrated Product Design
Master Thesis - October 7th 2024

TU Delft

ROFFA REEFS

Masters Thesis

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Chapter 2: Background

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1

Introduction

1.1 Summary

Coral reef ecosystems are an essential part of the ocean environment and imperative to the health of the entire ocean. With warming oceans, destructive fishing, marine pollution, and other factors, the coral reefs are dying. Losing coral reefs dramatically affects marine biodiversity and negatively impacts food security, shoreline protection, and essential tourism economies in coastal communities. Globally, more than one billion people directly benefit from coral reefs (Souter et al. (eds), 2021).. Therefore, restoring coral reefs is critical to ensure the well-being of both marine and human communities.

This thesis focuses on the redesign of a floating fish breeding system for the coral reef conservation start up, RoffaReefs. RoffaReefs is working on restoring ecosystem through the breeding of reef fish through a first of its kind floating fish breeding system. This system works by allowing fish eggs collected from the reef to grow into larvae in a protected environment before being released back into nature. The overall aim for the redesign was to design a nature-based fish breeding system for improved performance that can be used in various marine contexts.

The proposed design is a modular design with three separate modules: biological, storage, and float. This new design can improve the system's operator accessibility and scalability in future contexts. Through the testing of scale models, it has been shown to improve the stability of the system in wavy conditions. At the end of this thesis, the next version is ready to be manufactured, and a full-scale test in context can be completed.

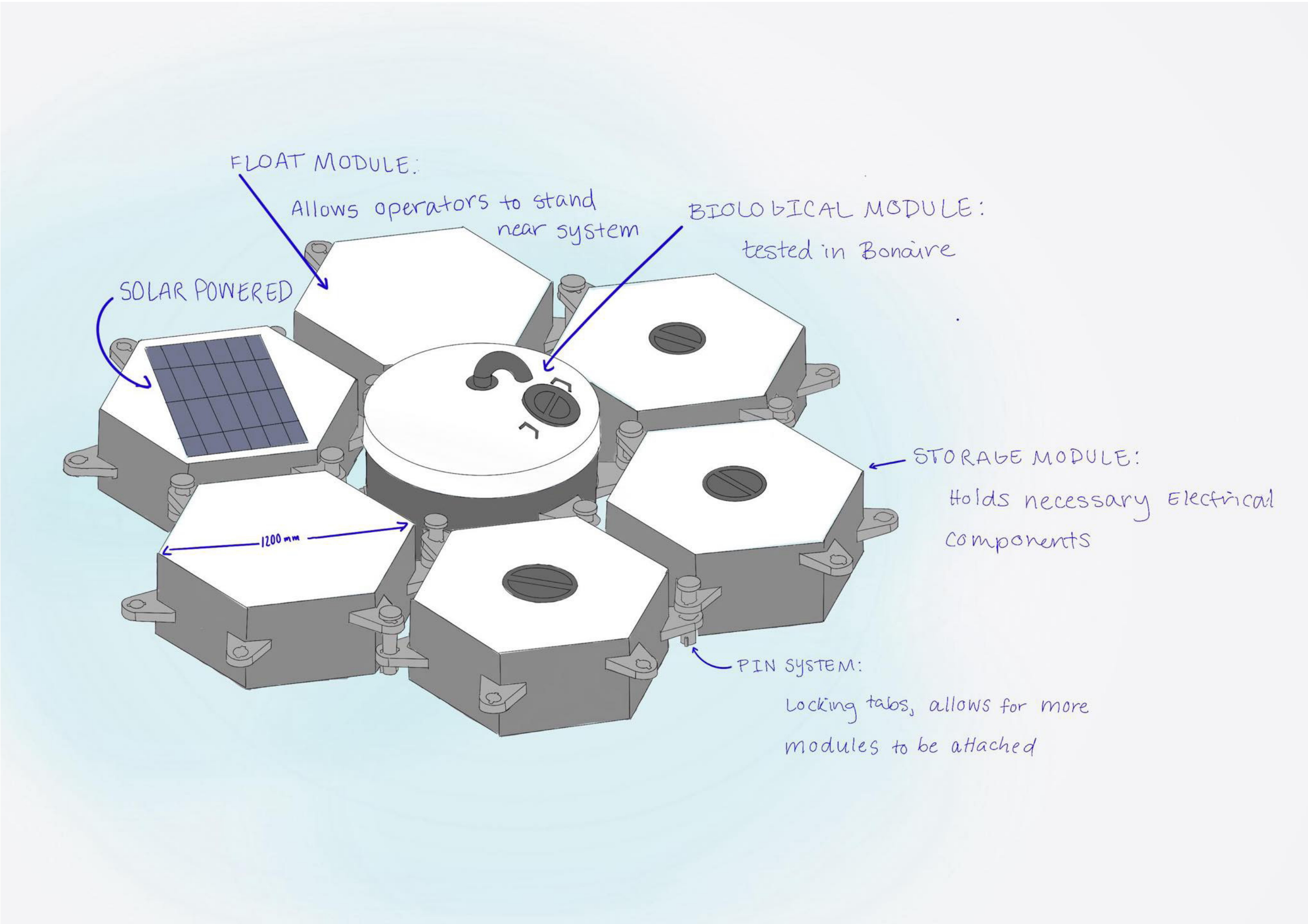


Figure 1.1: System Redesign

1.2 - Project Brief

Coral reef ecosystems are an essential part of the ocean environment and imperative to the health of the entire ocean. With warming oceans, destructive fishing, marine pollution, and other factors, the coral reefs are dying. Losing coral reefs dramatically affects marine biodiversity and negatively impacts food security, shoreline protection, and essential tourism economies in coastal communities. More than one billion people directly benefit from coral reefs (Souter et al. (eds), 2021). Therefore, restoring coral reefs is critical to ensure the well-being of both marine and human communities.

Restoring the coral reefs means addressing the coral and the fish that call the reef its home. While the loss of reefs results in the loss of fish species, the inverse is also true: fish species lost due to our changing climate or overfishing will also mean coral loss.

RoffaReefs is a research initiative born out of the Diergaarde Blijdorp ("Rotterdam Zoo") focused on reef restoration beyond just the coral. They have developed a first-of-its-kind floating fish breeding system that can help increase the survival rate of fish larvae to help restock the reef ecosystem. This aids in meeting the United Nations Sustainable Development Goal 13 Climate Action: to reverse or address the effects of climate change and Goal 14 Life Below Water: Conserve the ocean and promote sustainable use of marine resources (United Nations, n.d.).

Roffa Reefs is looking to develop the next version based on the successes and learnings of the pilot of the breeding system. For this project, the breeding system will be evaluated and redesigned for improved performance.

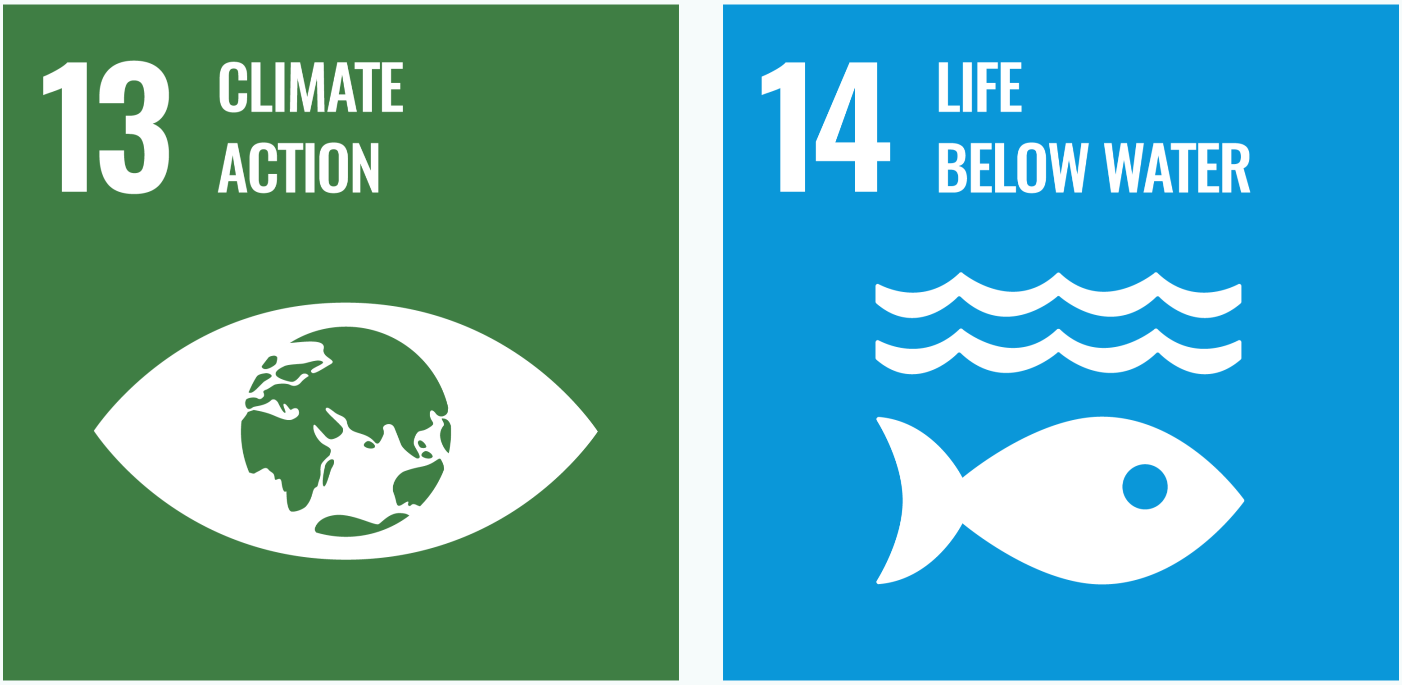


Figure 1.2: United Nations Sustainability goals 13 and 14 (United Nations, n.d.).

1.3 - Project Phases

The project approach was inspired by the Double Diamond steps: discover, define, develop, and deliver (Design Council, 2005). For this project, the double diamond has been extended into three separate converging and diverging phases, with a specific outcome at the end of each phase. From the design brief detailed at the beginning of the process to a full concept proposal at the end. These stages can be seen in Figure 1.3.

Phase One: Direction – This first phase focuses on narrowing the scope of the redesign and understanding the current system and the requirements through talking with experts. This phase will end with a preliminary list of requirements and a design direction. This will be covered in Chapters 2, 3, and 4.

Phase Two: Concept Development – The second phase is concept development with a focus on the chosen design direction. Ideas will be prototyped and tested at a scale as they are developed. This phase will have the development of three concepts and will end with one being chosen for further development. This will be covered in Chapter 5.

Phase Three: Detailing – The third phase details the chosen concept and creates a product that is ready for manufacturing. This will be covered in Chapters 6 and 7.

The final deliverables are the writing of this report, the preparation of designs for manufacturing, and a presentation.

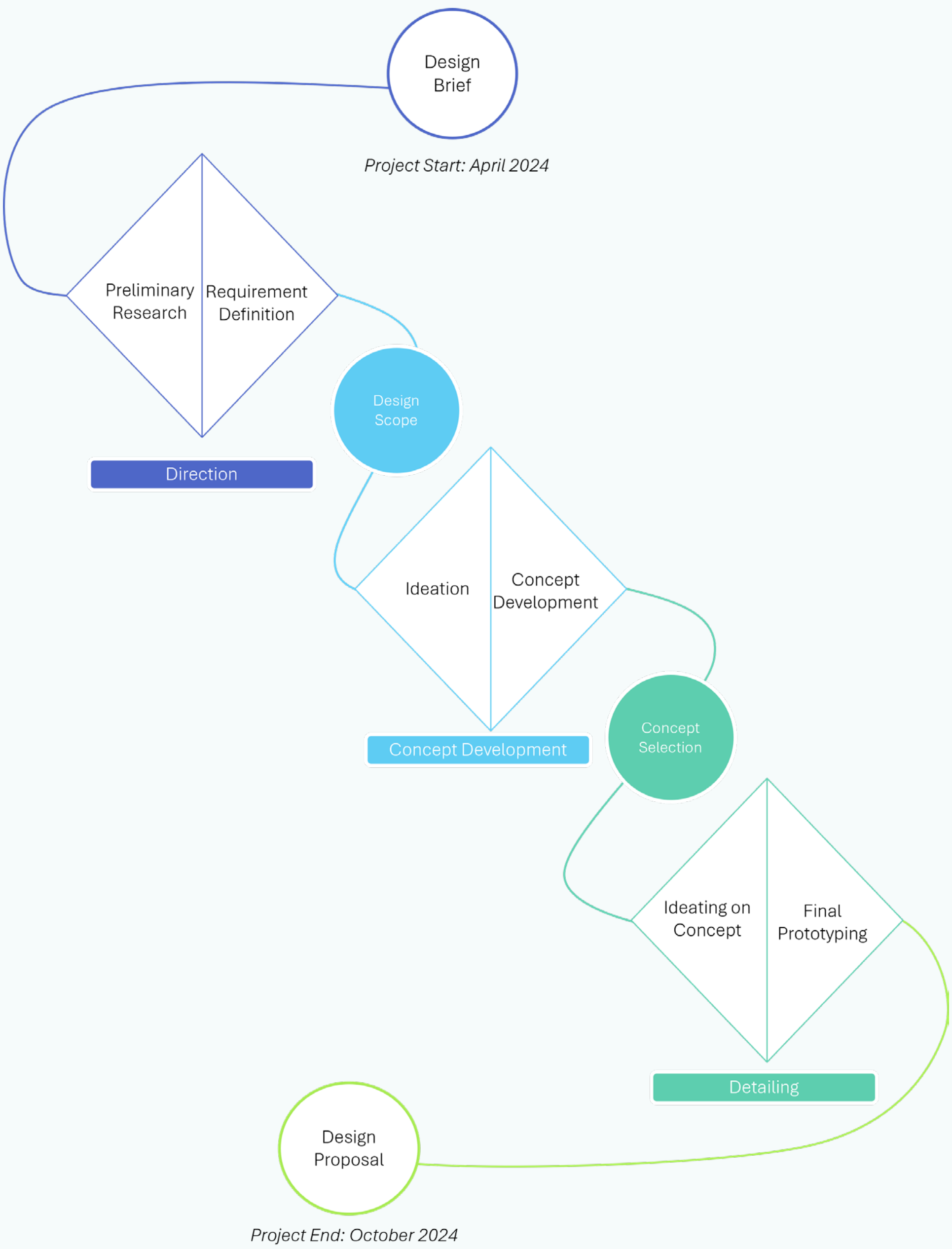


Figure 1.3: Project Phases and approach.

2 Background

This chapter establishes the necessary background information for beginning the design process. The first stage of this project was diverging through conducting research and framing the goals of RoffaReefs into a design project.

Research is conducted through searches of scientific literature and online resources and discussions with experts on the RoffaReefs team.

This section aims to understand the motivations for the design of the system and the knowledge gap this project seeks to fill. The project's overall aim will be established and carried forward through the next report sections and the project at large.

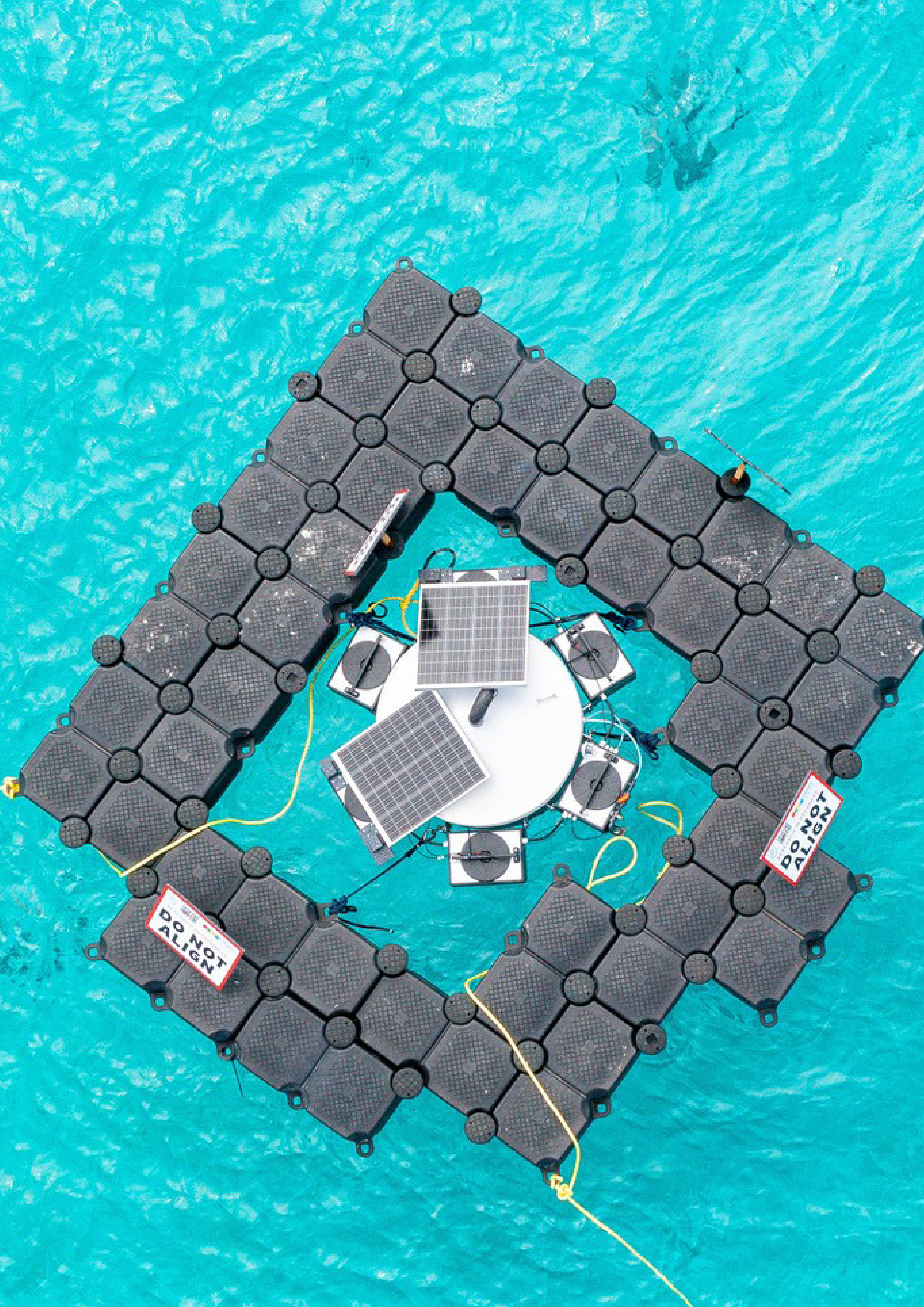
2.1 What is RoffaReefs?

RoffaReefs, founded in 2021, is a start-up born out of the Rotterdam Zoo (Diergaarde Blijdorp), which focuses on breeding fish in the wild for conservation purposes. The initial stages of the project came from exploring how to breed fish in an aquarium with low resources. The first study examined how to breed fish in a tank with other fish, mimicking the real-life reef ocean conditions. After successful trials in the aquarium, the idea came about how this technology could be used in the wild (RoffaReefs personal communication, April 30, 2024).

This was the start of the Roffa Reefs, which expanded into a much larger project. Generally, little is known or documented about the spawning of fish and the development from eggs to larvae in the wild (RoffaReefs personal communication, April 30, 2024). Much of the Roffa Reefs project also focuses on researching and documenting these preliminary stages of fish. These findings are essential to developing the system further.

In 2022, the first pilot of the floating breeding system was launched in Bonaire. Bonaire is an island located on the southeastern edge of the Caribbean Sea, less than 100 kilometres from the coast of Venezuela (Frade et al.). The system was placed above the coral reefs found on the island's leeward side. The pilot successfully brought fish from several species, from the egg to the larvae phase. The RoffaReefs team also captured what is presumed to be the first microscopic photographs of specific fish species in the hatchling phase.

The goal is to help nature heal itself. Most reef restoration projects focus solely on regrowing coral. Neglecting the rest of the ecosystem may reduce the possible success of this restoration. Roffa Reefs hopes to support a more sustainable approach to ocean conservation by creating a nature-based solution to ecosystem regulation.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2.2 Scope of the Project

Roffa Reef's goal is to integrate the biological study of fish with breeding technology to develop a nature-based solution to help restore fish populations around the world. This effort is pursued through three major pathways: biological research, fish breeding, and community engagement. The overview of the three pathways is displayed in Figure 2.1.

The scope of this thesis will be within the fish breeding section of their work, specifically the floating fish breeding device, but the work in this section does influence the others. RoffaReefs' work in biological research is to study reef fish's development and breeding behaviours, as there are currently large knowledge gaps. Currently, this research is being done through daily samples taken from the breeding system, and the eggs are studied under a microscope. RoffaReefs is working with computer scientists to develop an AI program that will automate the identification of fish species' prelarval forms through learning and grouping the captured images.

Community engagement is also an important part of their work. Many people fish on the coral reefs to eat and earn money. Although stopping fishing altogether may be the most effective way to conserve fish, it is impossible due to the coastal communities that rely on it. RoffaReefs recognizes that the most knowledgeable and important people in accepting their work are the fishermen. RoffaReefs is working to create a fish spawning calendar based on information from the fishermen and their own biological research. Working with the fishermen ensures that the fishing standards created can be sustainable for both the planet and the community. From the biological research, they hope to identify when and where fish breeding is occurring and use that information to inform fishermen when certain fish should not be caught to protect the breeding.

The work in Bonaire serves as a proof of concept for RoffaReefs' work. The goal is that the three pathways of biological research, fish breeding, and community engagement can be used in coral reefs and coastal communities worldwide. The next version of the breeding system will take the learnings of the current system to make a new and more scalable solution. This goes beyond developing a fish breeding system just for the Bonaire reefs but a generalized system that could be used in various contexts and reflect the nature around it.

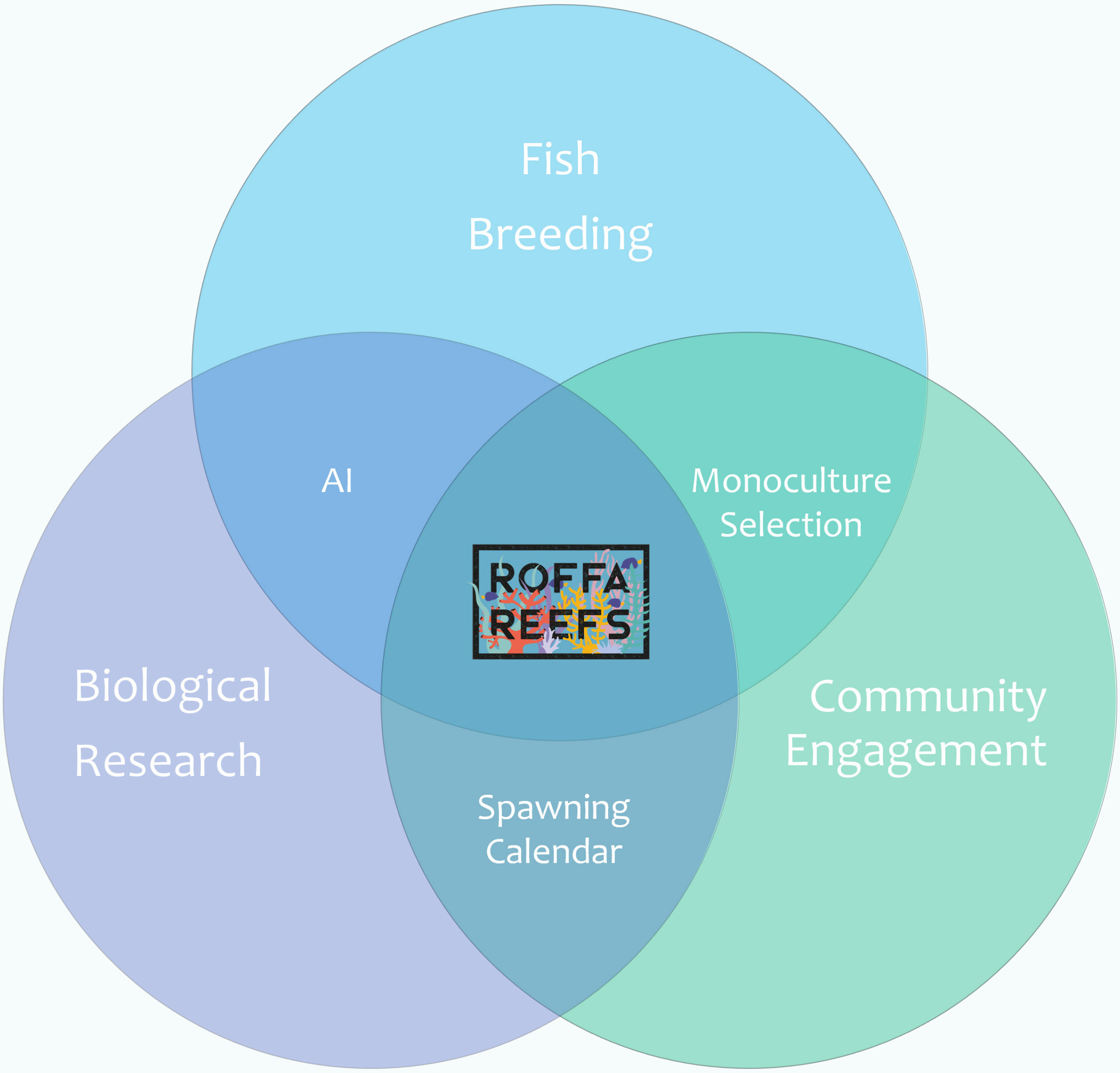


Figure 2. 1: Overview of the three sections of RoffaReef's work and the overlap between them.

2.3 Stakeholder Mapping

In RoffaReefs, the principal stakeholders are the reef ecosystem and its organisms. However, there are many human and organizational stakeholders currently and projected for the future, as seen in Figure 2.2. They can be divided into three categories:

Direct Work Towards - This is for stakeholders directly working on the RoffaReefs project or the breeding system itself. This includes RoffaReefs' team of scientists and engineers—those who directly impact the system's design and daily operation. Diergaarde Blijdorp (The Rotterdam Zoo) also falls into this category as they are the employers of everyone at RoffaReefs and the main point of funding. RoffaReefs has been featured as a part of the 2050 Master Plan for the zoo with the establishment of a Caribbean hub for conservation, research, and general sustainability work. For Blijdorp, it is important to see results to demonstrate the need for and relevance of the projects.

Direct Influence and Interest - Some current stakeholders have direct influence and high interest in the project. STINAPA is the National Parks Foundation in Bonaire. They provide access to the reef and regulate what can be used within it. Their knowledge is important for the project's success, and their allowances are necessary for the continuation. If RoffaReefs expands outside Bonaire, similar agencies will exist in every location.

Similarly, RoffaReefs works with Piskabon, the fishermen's association in Bonaire. Working with the local fishermen relying on the reef is essential to RoffaReefs' work. These local associations will influence the community engagement section of their work and will help in the integration of different communities based on location-based needs.

World Wildlife Foundation provides much support to RoffaReefs, from knowledge to scientists to grant funding. The WWF is influential on the day-to-day RoffaReefs and will continue to be so as the project expands. Similar non-government organizations may become involved with expansion. Like with the Rotterdam Zoo, it is important that RoffaReefs continues to communicate the need and relevance of the project to secure the necessary funding. These funds may also have their own separate needs or interests to cater for.

Influential or Interested -The influential or interested category represents the stakeholders who come towards the end of the project timeline and, therefore, have dependent influence or interest.

Wildlife conservation projects are common in coastal communities where RoffaReefs operates. They can be competitors regarding grant funding or resources but also allies towards a common goal. It is important to see how to collaborate with other conservationists while working in low-resource settings to prioritize outcomes.

Operators represent the maintenance staff or third parties who may have to interact with the breeding system. Although it is important to design with ease of operation in mind, these operators will have to work with the project no matter how convenient. A difficult system will limit the available operators. Overall, it is important to ensure these people can understand or have the resources available to understand their role and work.

Interested scientists refer to those who have an interest in the resulting data and scientific knowledge gained from the use of the system. A part of the goal of RoffaReefs is to learn more about reef ecosystems as well as how to involve coastal communities equitably. These scientists' involvement relies on sharing projects' outcomes and data with relevant people. Their interest comes from project outcomes rather than the overall design and operation.

This is representative of just some of the influences on the RoffaReefs project. Not every stakeholder can be addressed in this project, but they are important to remember. Additionally, as it has been noted, as RoffaReefs expands past Bonaire, new stakeholders will have unique needs.

The information from this will be used to establish the aim of the project. The aim can then be communicated to stakeholders as needed, and their role in the project will be clearer.

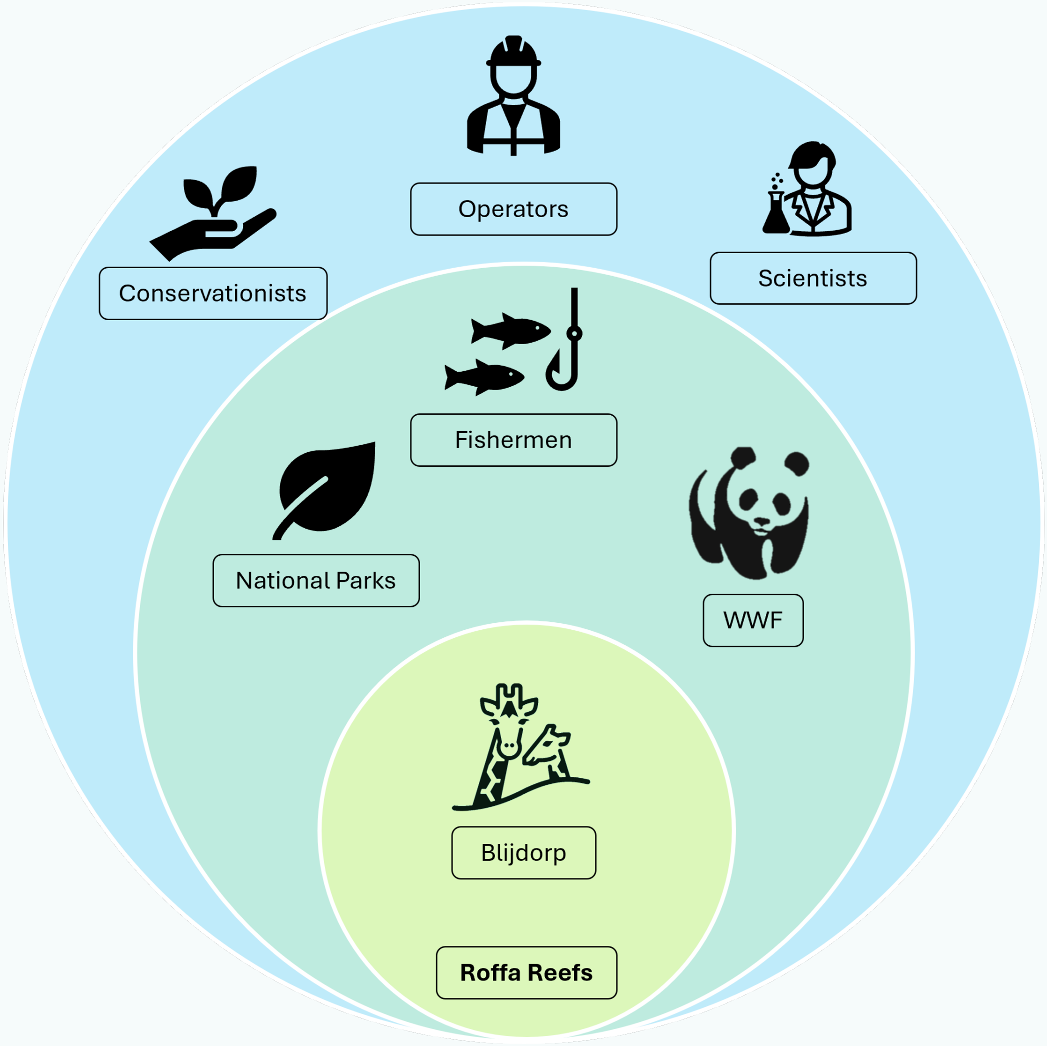


Figure 2.2: Stakeholder Map

2.4 - Introduction to Fish Spawning & Breeding

RoffaReefs currently focuses on breeding bony reef fish. The majority of these types of fish breed through broadcast spawning, where gametes for the adult fish are released into the water column, fertilized through motion within the water, and carried into the open (Randall & Hixon, 2019).

Broadcast spawning typically occurs in aggregations where large numbers of male and female fish come together to breed; one example can be seen in Figure 2.3. These aggregations differ from species to species but are predictable by water temperature, lunar cycle, or a number of other factors (Erisman et al., 2018). What is consistent is that the adult fish play no role in the early developmental stages of their offspring. This is where RoffaReefs comes in. Firstly, by studying when and where these aggregations occur and predicting where they may occur in the future. After the aggregation, they collect the fertilized eggs, identify them in the lab, and place them in the breeding system.

RoffaReefs uses the conservation method of "headstarting". Headstarting is a traditional method of wildlife conservation where species are raised in isolation during the preliminary stages of their lives and released into the wild (Cerilla, et al., 2023). Fish have an extremely high mortality rate in their early stages of life, mostly due to their extreme vulnerability. They could be eaten by predators, washed up on a beach in a storm, destroyed by a boat, or an infinite number of other events. Therefore, it is not uncommon to see fish lay millions of eggs but with a 95% or higher mortality rate (Cerilla, et al., 2023). Due to this, headstarting could be extremely effective as if even a small percentage decreases that mortality rate, it could equate to thousands of eggs getting the opportunity to reach maturity that they may not have gotten the opportunity to otherwise.

Once fertilized, an egg goes through three major stages: egg, hatchling, and larvae, one example in Figures 2.4 and 2.5. As eggs, they require very little as they do not eat or produce waste. Most reef fish only spend 24 hours or less as eggs (Colin, 2012). As eggs and early hatchlings, fish exist like plankton or other floating organisms, and they have no control over where they move to in the water. The hatching phase is the very beginning of their life as larvae, as over a few days, they will develop eyes, the beginnings of fins, and a gut. The start of the larvae stage is defined by their ability to eat. Once the fish reach the larvae stage, they can eat external food, produce waste, and orient themselves (Colin, 2012). In the breeding system, the fish are collected within the first 24 hours of their existence as eggs and placed in the system. As the length of time spent in each phase differs from species to species, their development is monitored by daily samples as they grow. With the breeding system, RoffaReefs is looking for proof that the fish have eaten before releasing them into the wild.

There is a significant knowledge gap in the early development stages of most fish species, as few species have been thoroughly documented. Due to the adult fish having no interaction in the early development stages, eggs, hatchlings, and larvae are difficult to track and study. Roffa Reefs is uniquely positioned to be the first to document microscopic images of the pre-larval stages of reef fish.

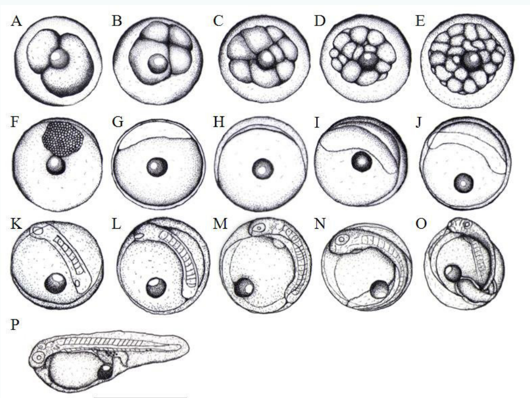


Figure 2.4: Development of Sevenband Grouper from Egg to Hatchling (Park, et al., 2014).

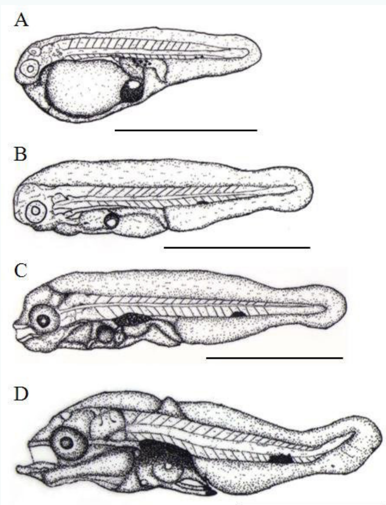


Figure 2.5: Development of Sevenband Grouper from Hatchling to Larvae (Park, et al., 2014).

Figure 2.3: Spawning Aggregation of two-spot snappers in Palau (Wu, 2016).

2.5 - State of Coral Reefs Ecosystem

2.5.1 Loss of Coral Reefs

Coral reefs are the most biodiverse ecosystem on the planet. 25% of ocean fish rely on coral reefs despite only making up 0.2% of the ocean floor (Souter et al. (eds), 2021).

The relationship between reef fish and coral is integral for both their survival. The relation has four major roles: cleaning, pest control, fertilization, and shelter (NOAA Fisheries, 2022). Herbivore fish help clean the coral of algae. If left untreated, algae can take over the coral's space or suffocate the coral. Similarly, fish are also responsible for controlling the population of corallivores, animals that feed on coral, in the reef. Fish can bring nutrients to coral from eating elsewhere and excreted into a different reef. Many fish species call the reef their home, whether through hiding spots for smaller fish or plenty of food for predators (NOAA Fisheries, 2022).

Coral reefs around the world are in extreme danger. From 2009 to 2018, the loss of coral amounted to 14% (Souter et al. (eds), 2021). This is more than the total number of reefs in the Caribbean region. Coral bleaching events are the leading cause of coral loss and are becoming increasingly common. In response to warming oceans, coral will release their essential microalgae and turn white, as seen in Figure 2.6. While coral can recover from bleaching, if the triggering conditions last too long or happen too frequently for recovery, the coral will die (Souter et al. (eds), 2021).

Other issues, such as coral blights, outbreaks of corallivores, extreme weather, and destructive fishing practices, have been eating away at the coral that survives bleaching (Souter et al. (eds), 2021). The spread of algae in reefs has rapidly increased due to the loss of coral. Coral and algae compete for space on the ocean floor. A 20% increase in algae on the reefs from 2010 to 2019 (Souter et al. (eds), 2021).

Figure 2.6: Example of Coral Reef Bleaching off of America Samoa the images were taken 14 months apart. (Normile, 2016)

2.5.2 Loss of Reef Fish

Quantifying and monitoring the biodiversity loss of marine fish is a challenge due to imperfect methods. The typical methods involve visual surveys by divers or fishing surveys. However, both are flawed, where the divers influence the fish, which could be observed or biased towards profitable fish (Cuttat, 2023). Acoustic sensors are also used in coral reefs where ambient noise is processed with AI to identify species in the area. There are limitations in what species can be reliably identified and the ability to identify when there is a lot of background noise (Cuttat, 2023). Due to these factors, it is difficult to understand the current biodiversity loss within the reefs truly. We do know that fish have been lost due to the effects of climate change.

As stated previously, reef fish play a vital role in controlling the spread of algae, which has seen a rapid increase in the last decade. Based on the projects coordinated by the WWF, most reef fish conservation projects in the Caribbean focus on sustainable fishing practices. There are projects that work to restore other marine life, like corals, molluscs, and amphibians like sea turtles (WWF-NL, n.d.)The biggest threat to reef fish currently is climate change. They are particularly vulnerable to rising ocean temperatures as the warm tropical waters they are used to are already within a few degrees of their limit (Bodin, 2017).

2.5.3 Coral Reef Ecosystem Insights

The importance of coral reef ecosystems to the ocean and greater planet health cannot be understated. Unfortunately, the reefs have suffered significantly due to climate change, destructive fishing, and pollution. Reef fish have also been decreasing, but at an amount that is more difficult to track.

There is a demonstrated and urgent need for reef restoration. Although there are many other conservation projects out there, there are limited to none focusing on actively restoring the disappearing reef fish. This is the niche that Roffa Reefs can reside in.

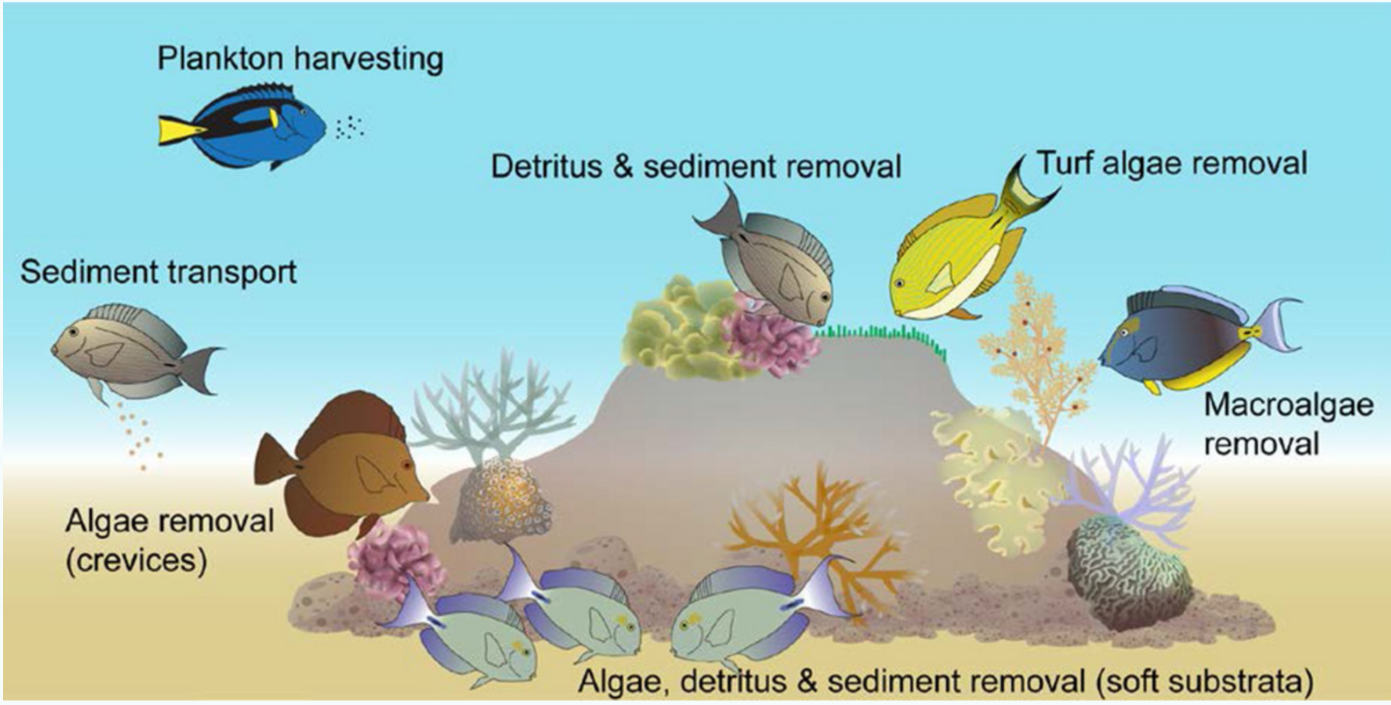


Figure 2.7: Functions of surgeon fish in a coral reef ecosystem (Tebbett, Siquiera, & Bellwood, 2022).

2.6 - Aquaculture

Roffa Reefs takes a lot of inspiration and knowledge from aquaculture for the breeding system. Therefore, it is important to know the different types of aquaculture and typical practices surrounding breeding fish. The goal is to address three things

What do we do normally?

What is missing?

How does it need to be adapted to the ocean?

2.6.1 Typical Aquaculture Practices

Aquaculture can be traced back to ancient China and the rearing of carp, but today refers to the breeding, rearing, and harvesting of fish, shellfish, and algae as well as other water-based plants and animals (National Oceanic and Atmospheric Administration, n.d.). Aquaculture can be divided into two main categories: freshwater and marine. Fish farming separates systems into completely closed, semi-closed, and open systems (European Commission, n.d.).

Completely closed systems recirculate water with a water recycling system. Recirculating aquacultural systems, or RAS, are used in commercial aquaculture and aquariums. Despite high upfront costs, aquaculture is considered the lowest-risk type due to minimized waste output, lower risk of disease, and the near-impossible ability for fish to escape (SeaChoice, n.d.). However, closed-system aquaculture requires much energy due to the filtration and pump systems. In a closed system, there is much work to create and maintain the proper conditions for fish. Heaters or chillers could be required for temperature control and consistent refreshing with potentially limited water for pH control (SeaChoice, n.d.). Although these systems are low risk for the surrounding environment, a lot of energy and resources are needed to run them.

RoffaReefs system most closely resembled an Open-net system used in marine aquaculture where fish are held in large nets offshore, as seen in figure 2.8. Although common, these systems are considered high risk as there is no barrier between inside and outside the system. The outside environment of the system is at risk of getting contaminated by fish waste, uneaten fish food, chemicals used in the process, and diseases from the farmed fish (SeaChoice, n.d.). However, open-water aquaculture does not require the large filtration or pump setups that RAS needs. Open-net systems rely on the natural flow of the ocean to regulate temperature and provide filtration. This is a risk as one of the most common pollutants is uneaten fish food (Environmental Protection Agency, 2024). The uneaten feed can disrupt the nutrient balance in the surrounding water.

In aquaculture, there is a lot of development surrounding fish monitoring within these offshore systems (Hunt & Isabella, 2020). In the past decade, artificial intelligence systems have been employed to monitor fish in offshore farms to monitor fish health, track contamination, and calculate the amount required to reduce uneaten food (Hunt & Isabella, 2020).

Almost all aquaculture farms focus on cultivating one species in high quantities. However, there is research into integrated multi-trophic aquaculture where multiple species are raised together, and their by-products can feed one another (National Oceanic and Atmospheric Association, n.d.).

Figure 2.8: OffShore Aquaculture System

2.6.2 Hatcheries

Most fish in marine aquaculture start their lives in hatchery. It is relevant to investigate hatcheries as RoffaReefs' work focuses on the prelarval stages of fish. Hatcheries work to spawn, hatch, and grow fish larvae until they are large enough to be placed in the fish farm (NOAA Fisheries, 2022). Fish hatcheries are less developed than aquaculture and are considered a bottleneck in the expansion of aquaculture (Phelps, 2010). Fish broodstock, or mature fish used in aquaculture for breeding, are often wild-caught and brought to a hatchery. Once fish are brought to the hatchery, they are given hormones to induce spawning (Phelps, 2010). Modifying fish genetics or hormones is typical in these hatcheries as they try to make as many fish as possible and have them all survive. This differs from nature, where, as previously stated, the mortality rate of fish is quite high.

2.6.3 Aquaculture Insights

The biggest difference between RoffaReefs' work and aquaculture is the goal. Aquaculture aims to produce as much as possible while minimizing costs, energy, and negative effects.

The most direct inspiration can be taken from open-net fish farms. Normally, conditions inside the farm must be heavily regulated or monitored through a recycling system. The farm relies on the ocean to help maintain conditions inside the farm, but it may also do so at the cost of the surrounding environment.

What is missing is a strong understanding of fish spawning and breeding. Currently, only a few species are being bred consistently, and this is done with the help of genetic modification and hormonal treatment. RoffaReefs can help show how larvae can be bred utilizing only what the ocean provides.

In adapting to the ocean, the system should try only to use what is around in the ecosystem and not add anything. Using the ocean water where larvae naturally get their feed so there will not be a risk for contamination.

2.6 - Nature Based Solutions

Part of Roffa Reef's vision for ocean conservation is to provide a nature-based solution for coastal communities. The International Union for Conservation of Nature (IUCN) defines Nature-based solutions as "...actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." (Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.), 2016). The IUCN-defined principles for Nature Based solutions can be seen in Figure 2.9.

The entire Roffa Reefs project hopes to address these principles, but the breeding system can only address a few in isolation. In the redesign, principles 1, 2, 3, 5, and 6 need to be included, especially as the system should apply to global coral reefs, not just the southern Caribbean.

A critique or drawback of the nature-based solution framework is that it is hard to validate the results (Seddon, et al., 2020). This is true for the breeding system. There are significant knowledge gaps in knowing what fish to breed and how. It also works on an educated assumption that more fish equals healthier reefs; however, adding more fish cannot prevent something like a coral bleaching event. Knowing all of the benefits or unforeseen harm these solutions could bring is impossible. In the design and execution of the RoffaReefs' project, it is important to remember what assumptions are being made so that they can be adjusted in the future.

The breeding system should serve as a scientific research tool as well as a conservation device. As the system is used, a better understanding of the behaviours and needs of the coral reef ecosystem will be discovered, and this can be improved. This adaptability to future scientific study and discovery should be included in the redesign.

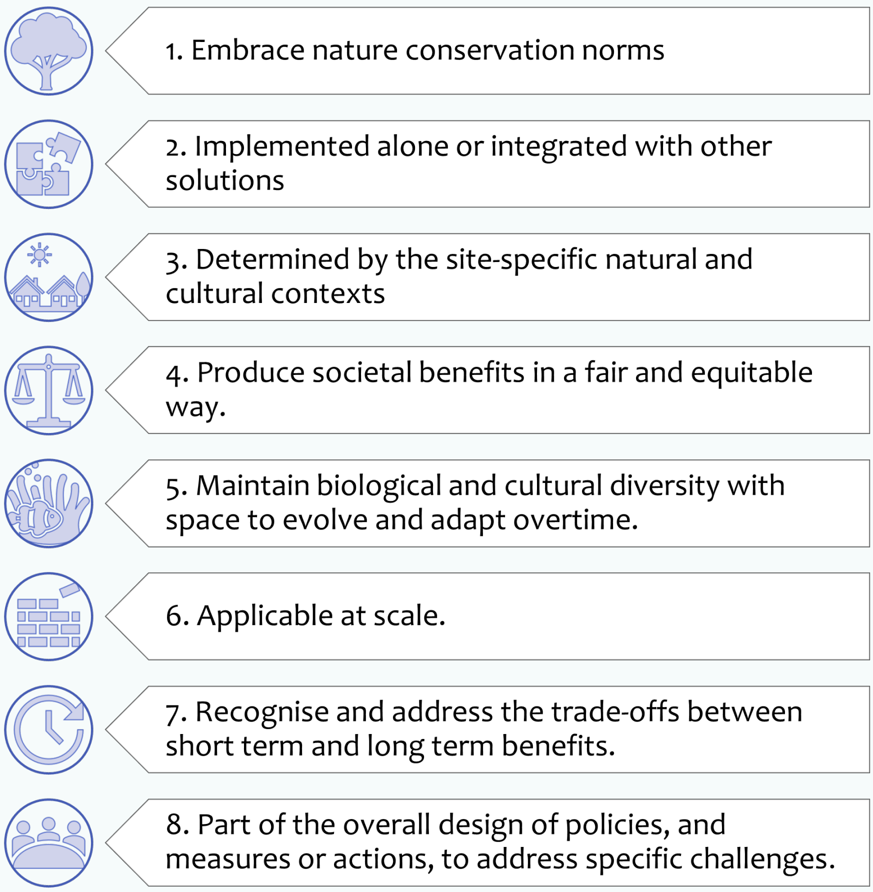


Figure 2.9: Principles of Nature Based Solutions (Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.), 2016).

2.7 Conclusion

The overall approach of RoffaReefs is to actively address reef and wildlife conservation. However, due to a lack of similar projects, there are knowledge gaps in the biology of fish and how to involve the coastal community effectively. The breeding system aims to serve as both a tool for conservation and a scientific research device. The aim of this project is to...

Design a nature-based fish breeding system for improved performance that can be used in various marine contexts.

Where a performance improvement is defined as more demands and wishes of the product are met than the current version. There is a knowledge gap in the conservation of reef fish due to a general lack of knowledge about the ocean. There are many ways RoffaReefs can use its unique place to tackle this gap. However, it is important to establish a specific project aim to guide the next steps of the design process.

The insights from fish spawning, aquaculture, and nature-based solutions should be reflected in the next design. The current system must be detailed to improve performance, and the pilot must be assessed.

3

Current System

Following understanding the necessary background information, it is important to look at how that knowledge has been applied to the current system.

Beginning with breaking down the system into subsystems, their functions are described through a systems analysis.

This section aims to look at the learnings from the pilot to establish more system requirements and improvements needed. Combining the background information and the current system's performance will enable the next steps of concept development.

3.1 – Overview of the Current System

The design process began with understanding the current Roffa Reefs system in Bonaire. This has all been done through personal communication with the RoffaReefs team. The system is technically quite complex, so the components and functionality will be divided into three subsystems biological, structural, and power.

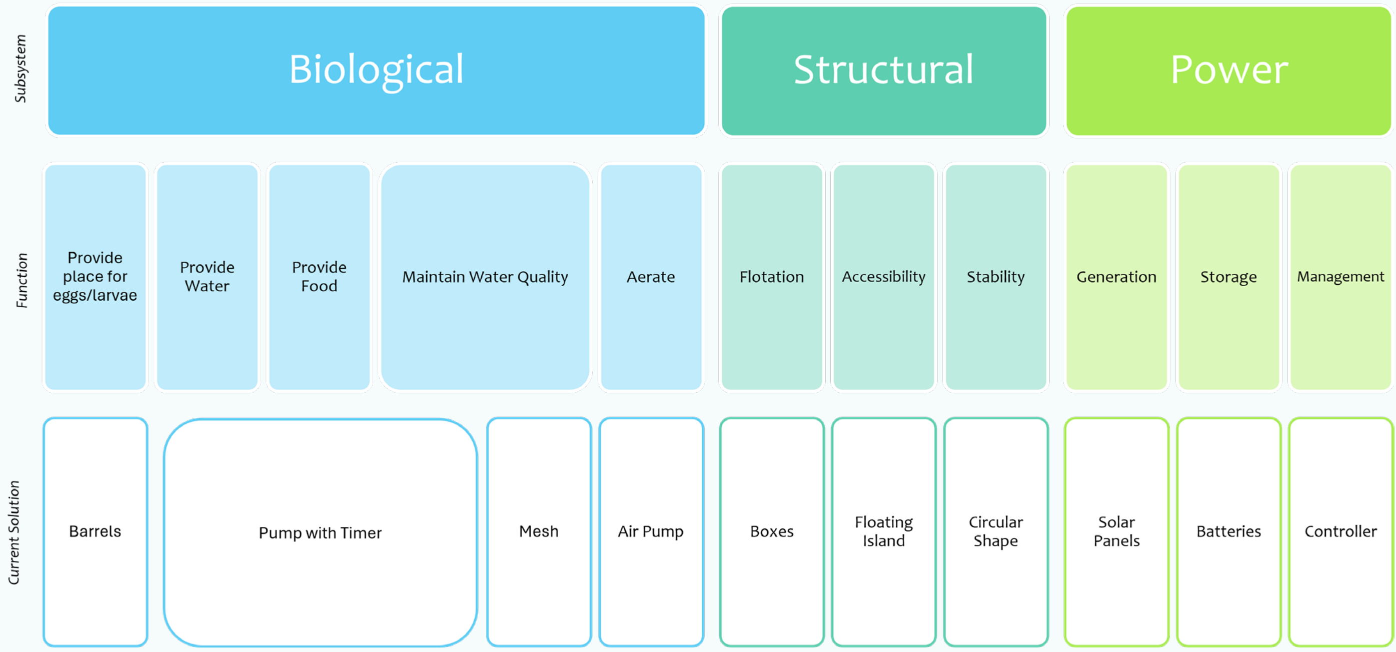


Figure 3.1: System Tree

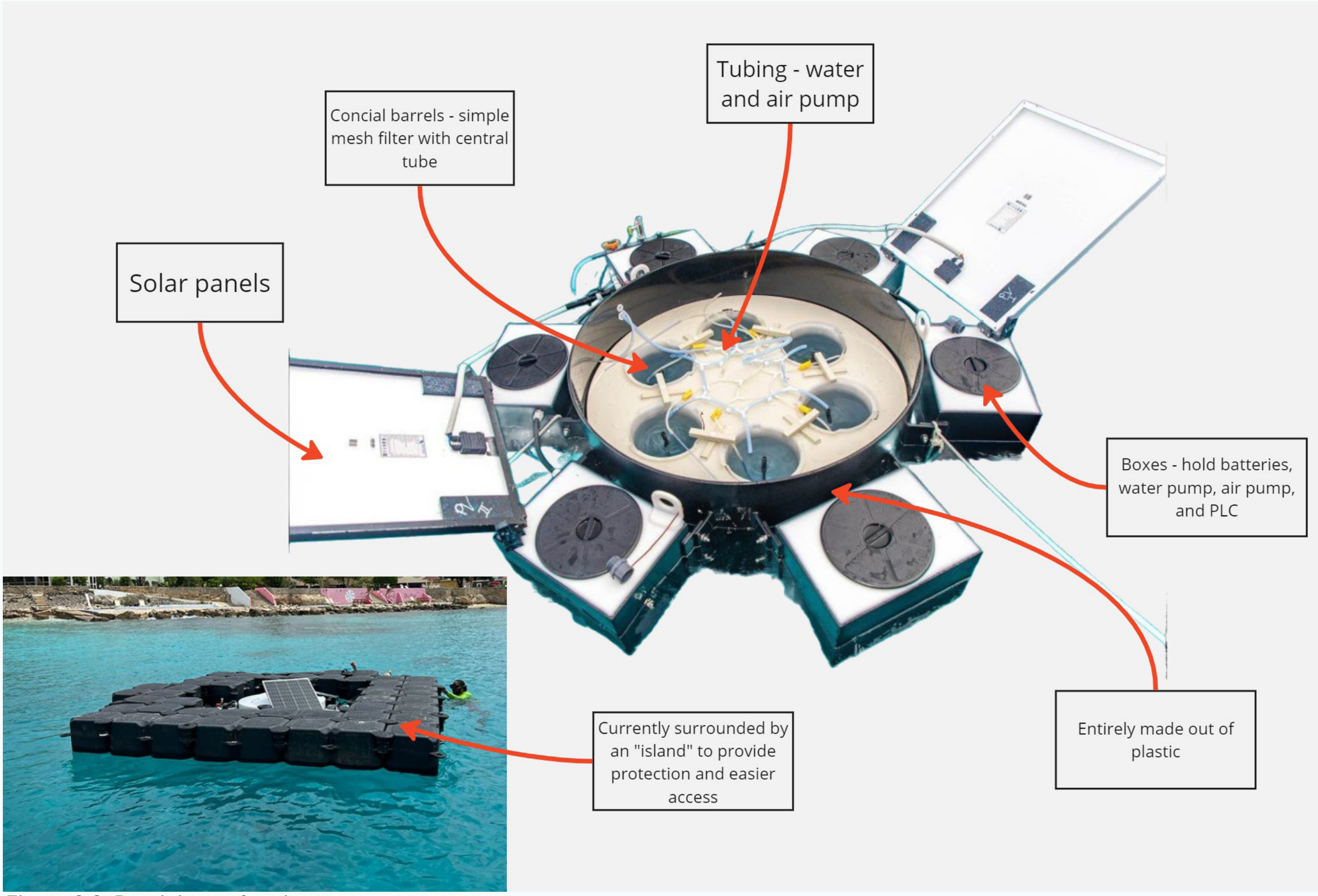


Figure 3.2: Breakdown of system

Beginning with the overall use of the system. The eggs are collected from egg-collecting devices, seen in Figure 3.3, and are taken to the lab. Under a microscope, the fish species are identified, and a monoculture is selected. Following this, the eggs are placed in the breeding system, as seen in Figure 3.4. In the previous tests, they were kept there for 5 days and then released.

Collecting data on the development of fish through these early stages is essential to Roffa Reefs' work. Currently, samples are collected daily by hand. Operators visit the breeding system, take a sample from the system, bring it to the onshore lab, take data, and then return the sample to the system.

Figure 3.3: Egg Collecting Devices

Figure 3.4: Placing the Eggs into the system

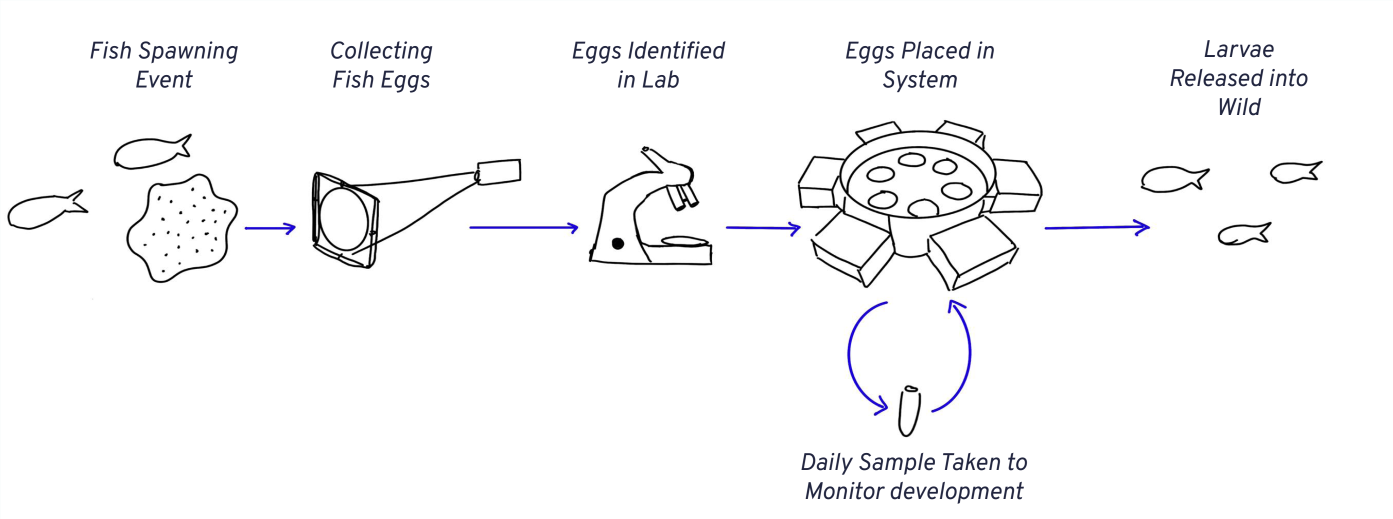


Figure 3.5: Story Board

3.2 Biological Subsystem

The biological system, at its simplest, is just a container for the fish eggs to grow in. The goal is to keep the conditions inside the system as close as possible to those outside the system. The barrels need to protect from outside predators. With this, the system is made up of a water pump, an air pump, a mesh filter, and barrels, as seen in Figure 3.6.

The water pump ensures the “refresh rate” in the barrels or when enough water is pumped into the barrels, so all of the water has been replaced. In many aquaculture applications, the water pumped in is filtered water; however, in the Roffa Reefs system, the water is ocean water. The water is unfiltered for two reasons: to mimic the outside conditions and provide food for the larvae.

The system is designed to refresh the water much more frequently than typical in an aquarium or traditional aquaculture. Water quality maintenance and temperature maintenance is only done by this consistent refreshment. Once eggs hatch into larvae, they get their food from tiny microalgae and plankton in the water. This is also pumped in with the ocean water. Currently, the conditions inside and outside the system are not measured or monitored, but Roffa Reefs works on the assumption that a high refresh rate will ensure the conditions are the same in and outside. Currently, the water pump is on a timer.

It is important to create flow within the system for the refresh rate and filtration. This is done with the air pump. The air pump runs the entire time the system is running and can be adjusted by hand by operators.

Each barrel has a simple filter system consisting of a pipe up the centre covered by a mesh filter. From earlier testing and the system’s current operation, there is not a significant amount of waste or contamination built up within the barrels. Before the fish develop their guts in the hatchling phase, they do not produce any waste. Due to this, the mesh filter combined with the air and water flow is enough to maintain the conditions inside the barrels. After the larvae are released into the wild, the barrels are rinsed thoroughly to avoid long-term build-up.

The barrels are conical shapes. This is derived from aquaculture research and testing by Roffa Reefs. Having a circular or conical shape maintains the flow within the barrel.

This current biological subsystem has been performing well. Improvements would look at introducing remote monitoring and data collection. As stated previously, daily samples are taken from the system and documented under a microscope. Future development of the biological system should have data collected directly in the system.

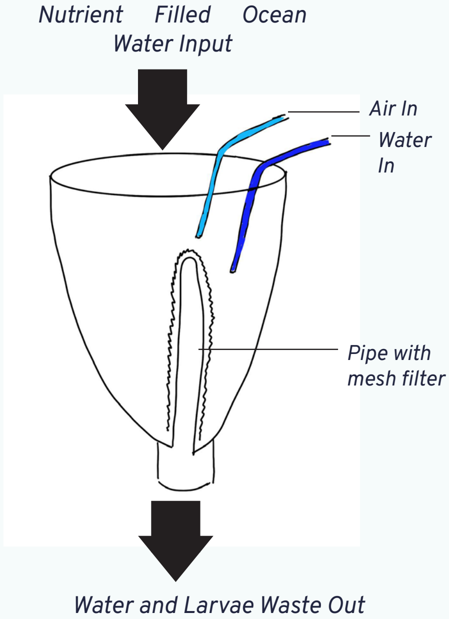


Figure 3.6: Barrel Schematic

Figure 3.7: Water and Air Tubing in current system

3.3 Structural Subsystem

The structural subsystem is responsible for withstanding unpredictable ocean conditions, stability in ocean waves, accessibility for operators, and flotation.

The system comprises a plate that freely floats within the cylindrical body. The plate-free floats ensure the barrels of the breeding system are submerged at the water level. Attached to the outside structure are six boxes. These boxes provide flotation as well as housing for necessary components. These components include the water pump, air pump, solar panel batteries, and power management system. This can be seen in Figures 3.8 and 3.10.

The system must withstand constant sun and salt water. Due to this, the system is made of plastic to avoid rusting. The system must withstand varying waves, currents, and winds. Birds and other wildlife can also cause damage. Currently, the system is secured in place by two anchoring points to the sea floor. Ideally, there would be more to increase stability. Adding more anchoring points is decided by the national parks of Bonaire. Overall stability or low movement, even under wavy conditions, should be ensured, especially within the barrels.

During the pilot testing, there was one time when the system got loose due to intense weather related to a hurricane. This occurred due to a fastener connecting the anchoring becoming loose as the system pulled on the moorings in high waves. Overall, the system should withstand the intense weather that only occurs once a year and the typical milder weather.

There are three factors of accessibility: approaching the system, standing near the system, and accessing the barrels. Currently, the system is approached by swimming. Operators must carry all of their tools in a dry bag and climb to the floating island next to the system, as seen in Figure 3.9. Climbing onto the floating island from the water is a bit awkward and could be improved. Accessibility of standing near the system was solved by the floating island, as seen in Figure 3.9. This is integral to the system's operation; collecting samples would be extremely difficult or impossible without it.

Lastly, the operators must remove the system lid to access the barrels. The lid is in place to protect the barrels from rain, birds, and marine predators. The lid, however, is large (over a meter in diameter) and very awkward to remove, especially if an operator is alone. The lid must be removed frequently as the samples are taken daily to monitor the eggs.

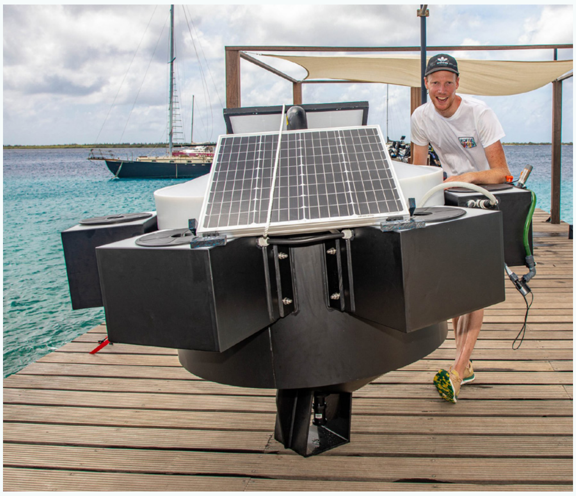


Figure 3.8: Breeding system out of the water

Figure 3.9: Floating island around the breeding system used by operators

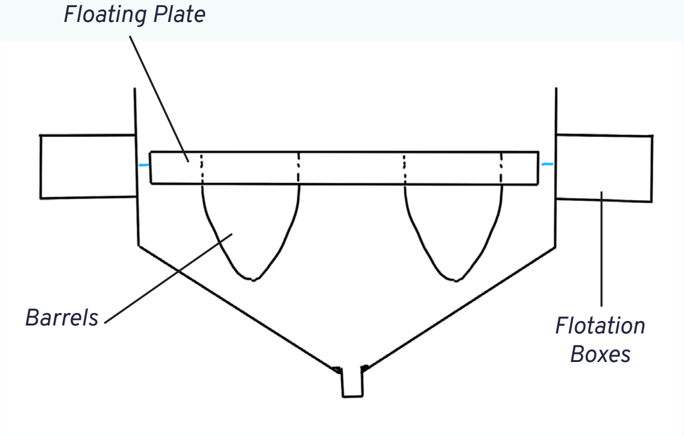


Figure 3.10: Cross section of breeding system

3.4 Power Subsystem

The biology subsystem directly determines the demand of the power subsystem. It is responsible for generating, managing, and storing power within the system.

Currently, the system generates its power through two large solar panels. The system must run continuously even when there may not be sun for the solar panels.

Power generated from solar panels is stored in batteries. Typically, solar panels generate more power than is needed throughout the day. The excess power is stored in the batteries for use during the night or at times of low sun. The batteries must be checked regularly to monitor their health. Over time, batters can degrade where they cannot hold a consistent charge, and at this point, they need to be replaced. Currently, the battery health is checked by operators in the system using a multimeter. With this, either the batteries should be made accessible for these regular checks or remote monitoring should be introduced.

Power must be distributed to the different components within the system. Currently, this setup is very simple as it is only responsible for providing power to the water and air pumps. A programmable logic controller or "PLC" is used. In the future, this setup could get more complicated when remote data is collected.

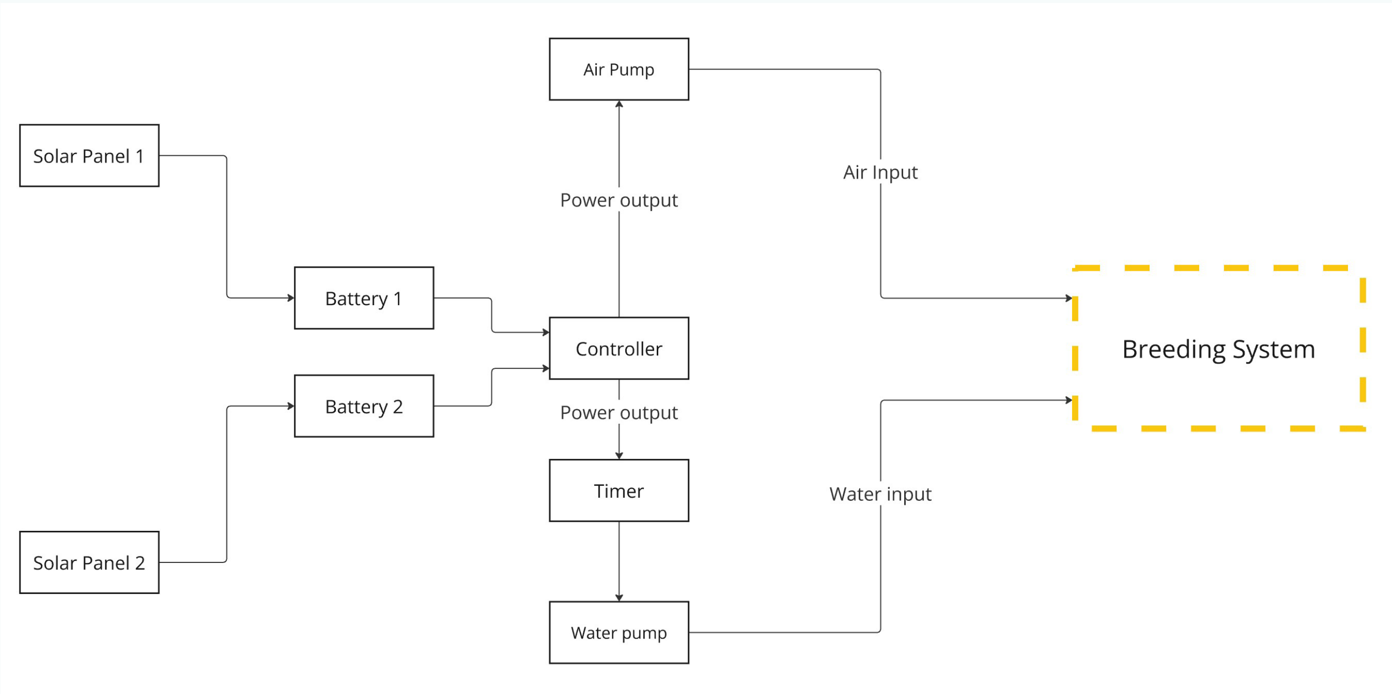


Figure 3.11: Electronics Schematic

3.5 Conclusions

The pilot served as a proof of concept for the system and achieved that goal. The system was shown to work to support fish from eggs to larvae, and scientists were able to collect data during the process. There were some performance issues in regard to user-friendliness and performance in intense weather.

Separating the overall system into three subsystems helps with narrowing the scope into further sections and deciding what the new system needs to do.

From this initial assessment, the subsystem that could benefit the most from a redesign would be the structural system. In the next sections, the system requirements will be defined based on these results as well as the background information.

4

Requirements

After researching the background and assessing the current system, the next step is creating a list of requirements for the new system to guide the design process according to the aim.

The requirements are determined by discussing the ideal scenario and synthesizing the insights from the previous sections.

The goal of this section and the list of requirements is to create a way for the success of the redesign of the product to be assessed. It is also important to lay out the improvements that need to be made to the current system.

4.1 The Ideal Scenario

Moving from the current system to the next version, it is important to identify the ideal functionality. In discussions with Roffa Reefs, the following items were identified as desires for future additions:

Optimized Power-

Currently, the system has a power generation system that uses solar panels and batteries. There is trust that the system will work continuously, but there will be no external checks of battery health or alternative systems if the solar panels fail.

Remote Monitoring-

Currently, there is no remote monitoring on the system. Other than checking the battery health. It would be nice to see how the system operates and the conditions around it.

Microscope Integration-

Monitoring the eggs' development is currently done by hand through microscope observation of daily sample collection. In the future, the goal is to have this done automatically in the system. Additionally, the prelarval stages of many reef fish species have never been documented. With the eventual goal of Roffa Reefs to train an AI to match eggs to their species, collecting lots of microscope images is important.

Withstands all ocean conditions-

The ocean is turbulent and sometimes unpredictable. The system must withstand various conditions while continuing to function and not breaking. The system must operate 24/7, 365, even if it is not accessible to operators due to external conditions.

Accessible for technicians-

It is important that scientists and operators can access and maintain the system. This means the system should be user-friendly, understandable, and flexible for additional scientific experiments.

Supports eggs through larvae stage-

The current system supported the larvae for five days. However, the prelarval and larval phases differ in length for each species. With more scientific studies, the system should be able to support the larvae further along with their development.

Works in a variety of contexts-

The breeding system pilot took place in Bonaire; however, the goal is to use it in various contexts all over the world. The goal of the nature-based system is to help nature heal itself; therefore, there is little artificial input. The biological system should be suitable for pelagic fish globally, and the other systems should be able to withstand and respond to varied conditions.

4.2 Requirements

The following pages will lay out the requirements that define this project. The full list of requirements, how the redesign was performed, and the validation method is available in Appendix A. This information is also available in Chapter 7: Final Design Proposal.

Requirement 1 - Product must create a suitable environment for rearing fish eggs to larvae

A suitable environment is defined as regulated temperature; larvae are provided food from nutrient-rich ocean water, waste is filtered out, flows within the barrels, and protects the eggs and larvae.

Regulating the temperature, providing food, and filtering out waste is done by refreshing the water within the barrel. Therefore, the system needs to have a pump that can ensure the refresh rate within the barrel. This pump needs to have a high enough output and run 24/7.

Protection for the larvae comes from keeping the predators, namely birds and larger marine animals, that could access the system from the top of the system as it floats. Eggs and larvae also cannot have too many physical agitation waves at risk of lowering their survival rate. These requirements were referenced from aquaculture standards, RoffaReefs testing, or a mix of both. When assessing the current product with RoffaReefs, it meets almost all these requirements minus the reduced movement in wavy conditions. This refers to movement within the barrels themselves and reducing

Requirement	Reference	Related Subsystem	Assessment of Current Product*	When Addressed in Project
1.1 Water pump ensures a refresh rate of at least 24 times per day.	3.2: Biological Subsystem	Biological	Green	Integrate system from pilot (Chapter 3)
1.2 Barrel shape must maintain the consistent flow output of the aerator pump with no stagnate areas.	3.2: Biological Subsystem	Biological	Green	Integrate system from pilot (Chapter 3)
1.3 Aerator in system creates flow within barrels.	3.2: Biological Subsystem	Biological	Green	Integrate system from pilot (Chapter 3)
1.4 The system's lid must prevent predator and exterior water entry having no upward facing openings or any openings larger than 10 mm.	3.3 Structural Subsystem	Structural	Green	Embodiment (Chapter 6)
1.5 Reduced movement in wavy conditions	3.3 Structural Subsystem	Structural	Yellow	Concept Development (Chapter 5)
1.6 System needs to be able to generate enough power per day to power pump system.	3.4 Power Subsystem	Power	Green	Integrate system from pilot
1.7 The system must store enough power to sustain continuous operation for at least 24 hours during periods without generated power.	3.4 Power Subsystem	Power	Green	Integrate system from pilot (Chapter 3)

Figure 4.1: Requirements 1.1 - 1.7.

Assessment of the current product was done through communication with the RoffaReefs team.

Green = Meets

Yellow = Partially Meets

Red = Does not Meet

Requirement 2 - Product must be able to withstand ocean conditions.

The system must be able to withstand various ocean and weather conditions. The system must float, be hurricane resistant, withstand long-term exposure to sun and salt water, and keep the electronics water safe.

These requirements are all addressed by the structural subsystem. The ability of the system to float is determined by the material's density and the product's shape. Due to the constant exposure to salt water, the choice of material is very important for extending the lifespan.

As previously stated, the pilot system has had difficulties with hurricane-type conditions. To make the system "hurricane-proof", there are two ways to address it: improving the anchoring and adapting to the wave conditions (see 5.2.2: Technology Map). These are currently not met in the pilot system.

Lastly, protecting electronics from water is important. Working close to the water, the danger of electronics getting wet is almost inevitable. There must be a waterproof container large enough to store these elements and a method of removing water that may get in.

Requirement	Reference	Related Subsystem	Assessment of Current Product*	When Addressed in Project
2.1 The system must float in saltwater with a capacity of 150 kg, including the weight of operators and equipment, without submerging below the water line.	3.3 Structural Subsystem	Structural	🟢	Concept Development (Chapter 5)
2.2 Materials should have no less than "excellent" resistant rating to salt water, according to material database.	3.3 Structural Subsystem	Structural	🟢	Embodiment (Chapter 6)
2.3 Materials should be weldable to create watertight features that are able to withstand for at minimum one year.	3.3 Structural Subsystem	Structural	🟢	Embodiment (Chapter 6)
2.4 The system should have 3 or more possible attachment points for anchors.	3.3 Structural Subsystem	Structural	🔴	Embodiment (Chapter 6)
2.5 System needs to adapt to intense wave conditions.	3.3 Structural Subsystem	Structural	🔴	Concept Development (Chapter 5)
2.6 There must be waterproof container that can contain the batteries and necessary electronic components.	3.4 Power Subsystem	Structural	🟡	Embodiment (Chapter 6)

Figure 4.2: Requirements 2.1 - 2.7.

Requirement 3 - Product must be scalable

The system is adaptable to different contexts and can grow and respond to more demand. For this, the product must be able to fit into different environments while not having site-specific features that limit use in other locations.

Requirement	Reference	Related Subsystem	Assessment of Current Product*	When Addressed in Project
3.1 The product is as simple as possible by using standard pieces whenever possible.	2.6 Nature Based Solutions	Biological	🟡	Concept Development (Chapter 5), Embodiment (Chapter 6)
3.2 System can be scalable by having the option hold more than six species at one time.	4.1 Ideal Scenario	Biological, Structural	🔴	Concept Development (Chapter 5), Embodiment (Chapter 6)
	4.1 Ideal		🔴	Embodiment (Chapter

Figure 4.3: Requirements 3.1 - 3.3.

Requirement 4 - Product must be able to be used for scientific research.

The system should collect data on the surrounding environment and collect microscopic images of the larvae. Operators must be able to take daily samples from the system, and the system overall should not threaten the surrounding environment.

Requirement	Reference	Related Subsystem	Assessment of Current Product*	When Addressed in Project
4.1 System allows for future integration of data collection devices.	4.1 Ideal Scenario	Biological, Power	🔴	Future (Unaddressed)
4.2 Microscopic imaging system must be able to capture a image of the eggs that is readable for AI.	4.1 Ideal Scenario	Biological, Power	🔴	Future (Unaddressed)
4.3 Product has remote monitoring to give operators consistent updates about the status.	4.1 Ideal Scenario	Biological, Power	🔴	Future (Unaddressed)
4.4 There must be space within the system for future elements.	4.1 Ideal Scenario	Structural, Biological	🟡	Embodiment (Chapter 6)
4.5 System must have a platform that surrounds the entire system that allows for operators to stand within arms distance of barrels.	3.3 Structural Subsystem	Structural	🟡	Concept Development (Chapter 5)
4.6 There must be a feature to assist operators on to the platforms.	3.3 Structural Subsystem	Structural	🔴	Embodiment (Chapter 6)
4.7 Removing/Moving the lid for daily samples should not require challenging motions.	3.3 Structural Subsystem	Structural	🔴	Embodiment (Chapter 6)
4.8 System must not be made with any toxic materials.	3.3 Structural Subsystem	Structural	🟢	Embodiment (Chapter 6)

Figure 4.4: Requirements 4.1 - 4.8.

4.3 Project Scope

From this product, several different requirements could turn into thesis topics by themselves. Therefore, taking the time to narrow the scope of this project is important. After assessing the needs of the current product, my expertise, and my available resources, I decided to frame the project around the structural subsystem. For the structural components, the focus is on the stability and accessibility of the system.

This decision puts several items out of scope, such as improvements to the biological subsystem or integration of data collection into the system. The power system will also not be thoroughly addressed as it is highly dependent on the needs of the biological subsystem.

5

Concept Development

This next section follows the design process's second diverging and converging phase. Using the information and insights from the previous sections, the project's scope can be defined.

Various methods were used, from discussions of demands and wishes to beginning ideas. These ideas were assessed, narrowed down, and developed further into concepts.

By the end of the concept development phase, three concepts will have been created and tested. This section aims to narrow down these concepts into one that can be further developed.

5.1 Structural Subsystem Redesign

In the concept development phase, emphasis was placed on the stability and accessibility of the breeding system.

The stability of the breeding system can be handled in two different ways: reduced movement within the barrels and of the total system. In this stage the stability will mainly focus on the entire system stability.

As stated in Chapter 3, accessibility can be addressed in three ways: getting to the system (AKA swimming up to and standing near), standing near, and taking samples and working within the system. In the current system, a floating island was added around the system to provide access. Although it is not currently considered part of the breeding system, it has become essential for the operation. Addressing accessibility will explore ways to incorporate the functionality provided by the floating island into the system.

This segment will address the following requirements:

1.5 Reduced movement in wavy conditions.

2.1 The system must float in saltwater with a capacity of 150 kg, including the weight of operators and equipment, without submerging below the water line.

2.5 System needs to adapt to intense wave conditions.

3.1 Product must be as simple as possible.

3.2 System can be scalable by having the option hold more than six species at one time.

4.5 System must have a platform that surrounds the entire system that allows for operators to stand within arms distance of barrels.

5.2 Explorative Research

Ideation began with explorative research for existing methods, technologies, and inspiration that help address the requirements of the structural subsystem.

5.2.1 Biomimicry as a Source of Inspiration

Biomimicry is a method of designing where one looks to nature to emulate nature to find sustainable and innovative solutions. Here, biomimicry was used as a source of inspiration and learning for the shapes and features of the structural subsystem. The design questions were how does nature...

Create stability in moving water.

Adjust to rough sea conditions

Starting in the context of floating and close to a reef, I researched and observed some creatures of interest.

First, observing fish in the Oceanium at the Rotterdam Zoo, I looked into how fish maintained stability in water. Looking at fish locomotion, as seen in Figure 5.1, typically, a dynamic system is used to maintain this stability. A powered stabilizing system would have to be added to mimic the strategies used by fish.

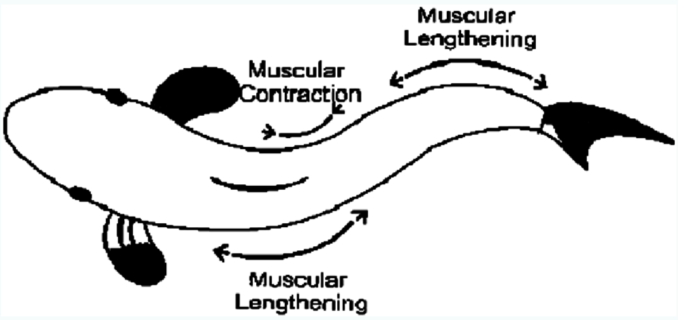


Figure 5.1: Fish Locomotion (Kumar, 2012)

Expanding the research to find more shapes of interest, I looked more at floating creatures as they better represent the context of the use of the product. One species of interest was the Portuguese man of war jellyfish, as seen in Figure 5.2. Like most jellyfish, the man of war has no fins or system of locomotion. Movement and stability are driven from the streamlined shape and long tentacles into the water. The long tentacles help the jellyfish in rough sea conditions by acting like an anchor.

These insights were noted and utilized in the next stage of the ideation process.

Figure 5.2: Portuguese Man of War Jelly Fish (HTO Blog, 2021)

5.2.2 Technology Mapping

Further inspiration for the concept development was looking into technology surrounding floating structures and marine engineering. Based on the requirements, four topics were created: accessibility, stability, hurricane-proofing, and crash prevention. Technologies can be seen below in Figure 5.3.

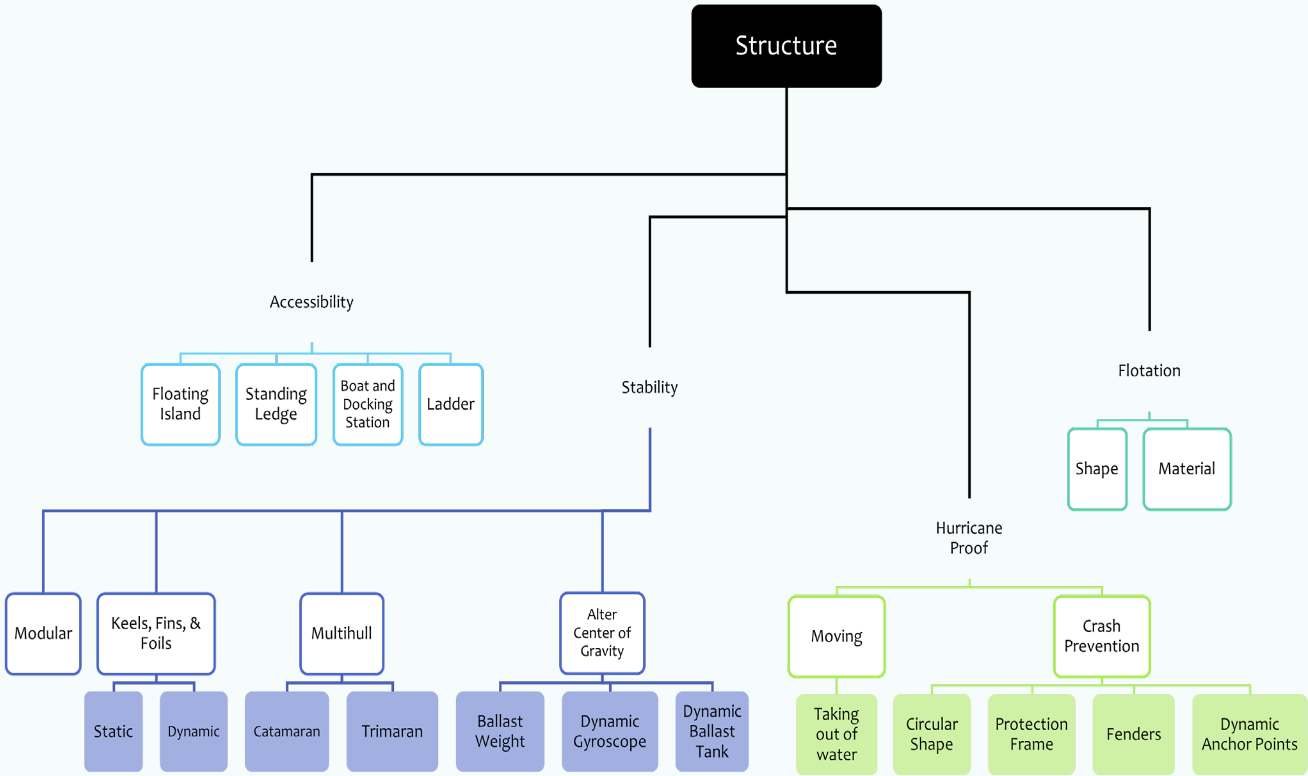


Figure 5.3: Technology Map.

In terms of accessibility, most of the solutions to having operator access to floating structures are forward floating islands, like in the current system, or an integrated standing ledge. Stability research found four main solutions: modular designs, keel features, multi-hull boat designs, and designs or technologies relating to the centre of gravity. Whether an object floats is entirely determined by its density. This affects the design in the shape and the material choice. For hurricane-proofing, there are proactive plans where the system could be removed from the water, but intense conditions are not always predictable. Therefore, the other option is crash prevention which looks at circular or rounded shapes, a protection frame or from boating: fenders and anchoring the system down. Further detail of some of these solutions can be seen in Appendix B.

Figure 5.4: Operators using a standing ledge for maintenance of a buoy (WGAN Radio, 2018).

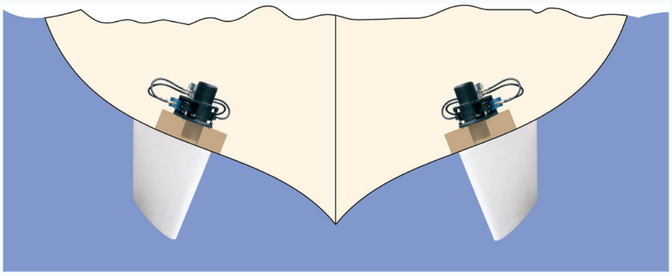


Figure 5.6: Dynamic keel system used in luxury yachts to maintain stability (Pacific Powerboats, 2021).

Figure 5.5: Modular docking system maintaining stability by adapting to waves (StartupSelfie, 2023).

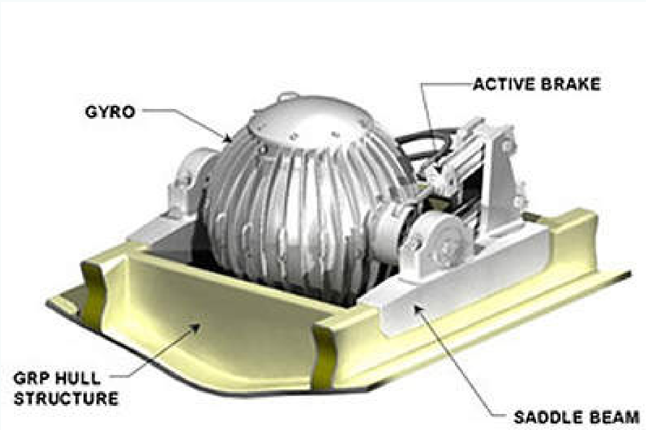


Figure 5.7: Powered gyroscope for a boat to adjust center of gravity to varying conditions (NavalTechnology).

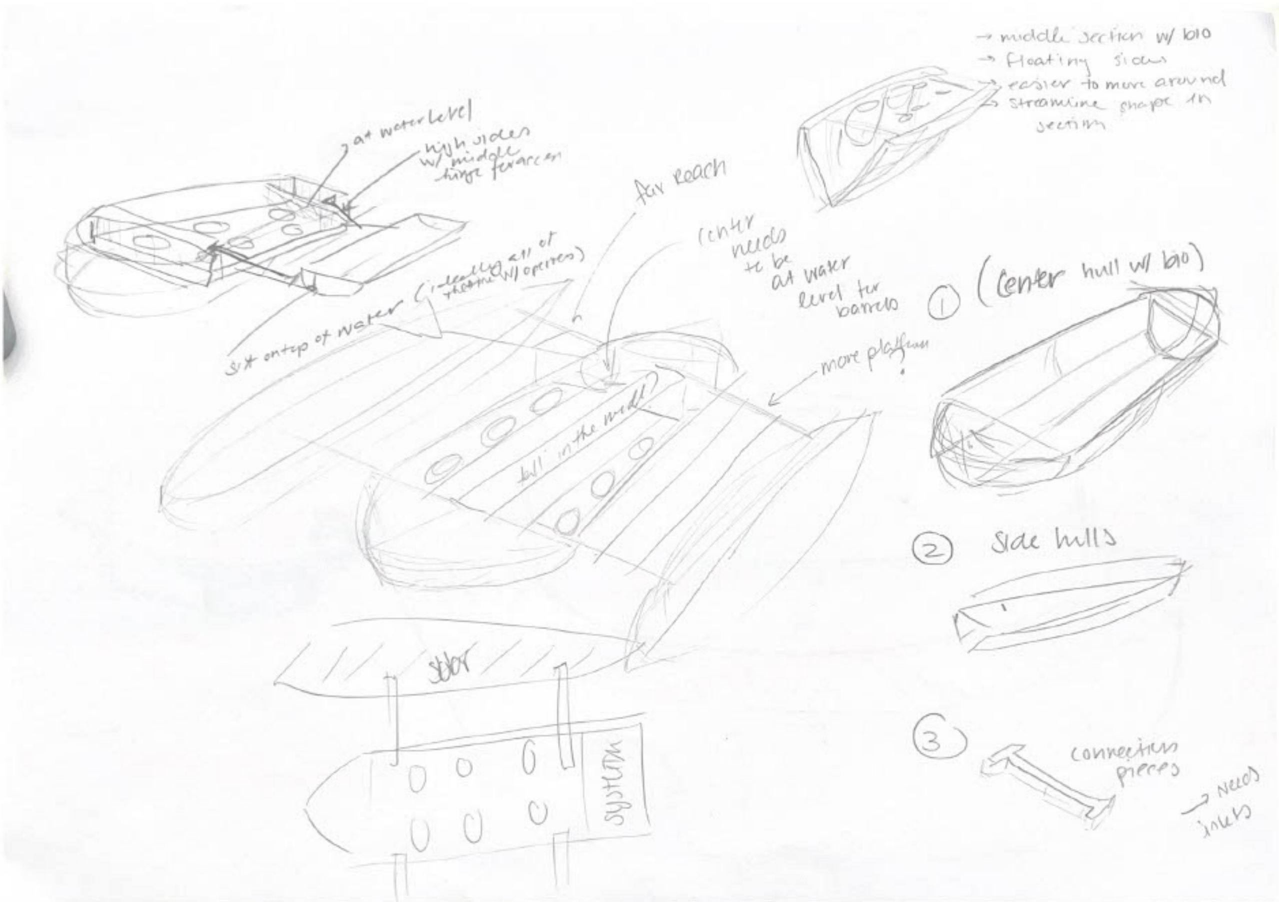
5.3 Ideation

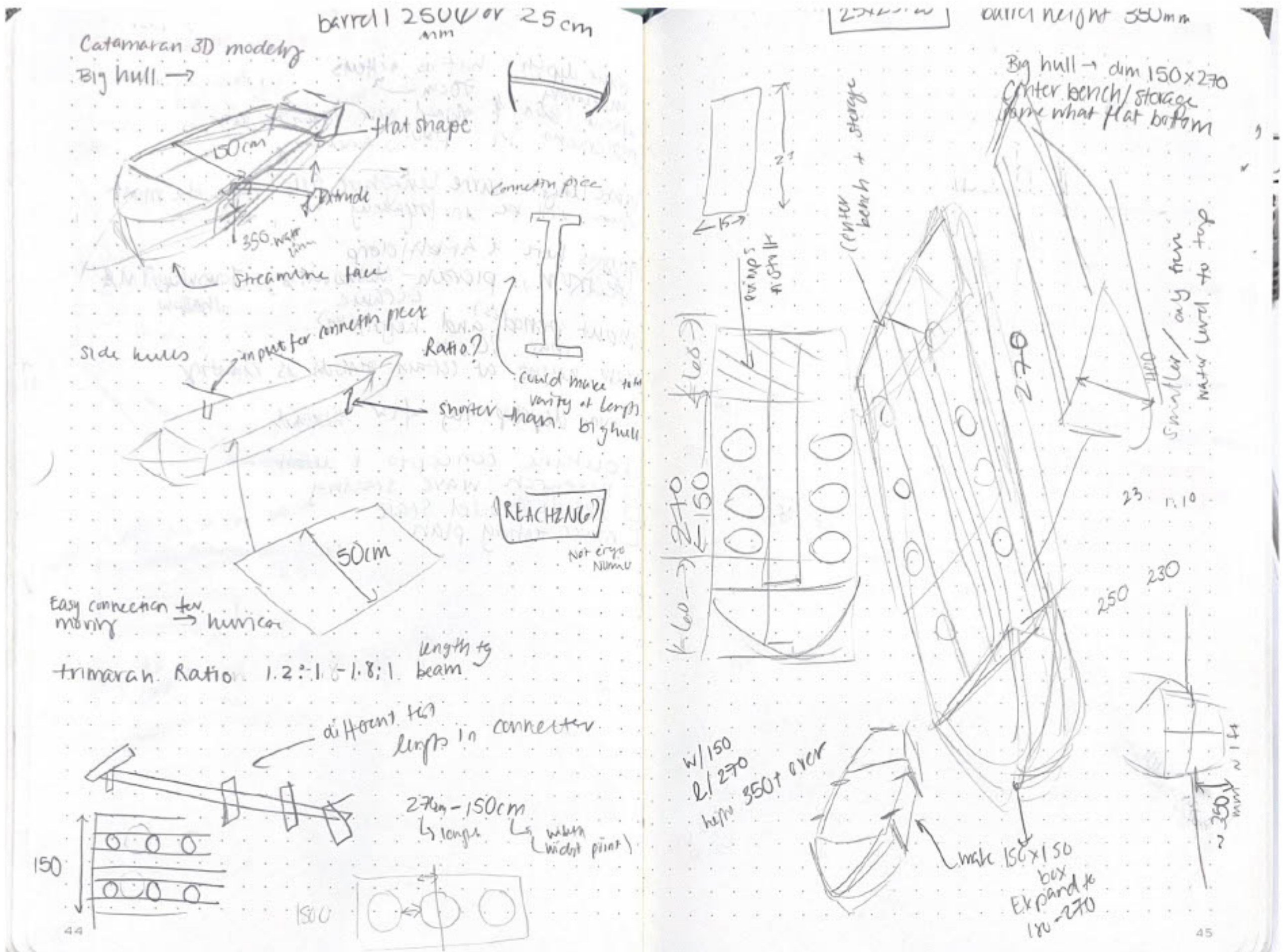
5.3.1 Morphological Chart

Ideation began by using the morphological chart method (van Boeijen, Daalhuizen, & Zijlstra, 2021). In this method specific features and all their solutions are listed. Then the different solutions are mixed and matched to see what ideas emerge. Due to the complexity of the system, it was important to establish what each concept would address so that they were comparable. Therefore, each idea had one of the following elements: shape, stability method, collision protection, and accessibility. No solutions that would require power were considered as the power subsystem has not been addressed yet. The system should be accessible and stable without needing power. The morphological chart can be viewed below as Figure 5.8.

Shape	Circular	Square	Stream Profile	Hexagons
Stability	Modular	Keels/Fins/Foil	Catamaran/Trimaran	Lower Center of Gravity
Collison Protection	Circular Shape	Protection Frame	Fenders	Dynamic Anchor Points
Accessibility	Floating Island	Standing Ledge	Docking Station	Ladder

Figure 5.8: Morphological Chart


→ middle section w/ bio
→ floating sides
→ easier to move around
→ streamline shape in section
at water level
high sides w/ middle hinge features
far reach
center needs to be at water level for barrels
① (center hull w/ bio)
more platform
② side hulls
③ connection pieces
→ needs inlets
system


barrell 250 mm or 25 cm
Catamaran 3D modeling
Big hull →
flat shape
150cm
streamline face
connection piece
Ratio?
side hulls
input for connection piece
shorter than big hull
could make variety of lengths
REACHING?
50cm
Easy connection for mooring → hurricane
trimaran Ratio 1.2:1 - 1.8:1 length to beam
different size lengths in connector
270cm - 150cm
150
44
barrel height 350mm
Big hull → dim 150 x 270
Center bench/storage
Some what flat bottom
center bench + storage
270
smaller/ary their water level to top
w/150
l/270
h/350+ over
make 150x150 box Expand to 150-270
45

5.3.2 Initial Ideas and Selection

The “PMI” method (van Boeijen, Daalhuizen, & Zijlstra, 2021) was used to assess the different ideas. In this method, each idea is reviewed, and the pluses (+), minuses(-), and interesting points(?) are identified. The ideas were discussed with the RoffaReefs team, and the results are based on their expert input and personal research. After reviewing, it was decided to go forward with ideas one, three, and four. Five was eliminated due to the high risks of managing samples close to the water line with little to no added ergonomic or performance benefit. Six was similar to the current system, so it was deemed not helpful to develop further and test again. Two was deemed not suitable for this context due to the more turbulent wave conditions near the shore.

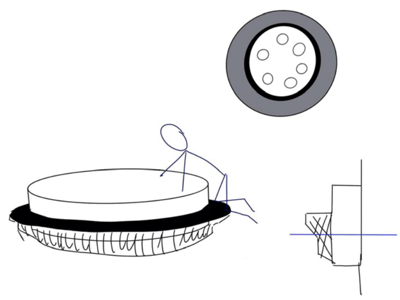
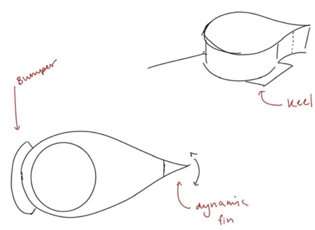
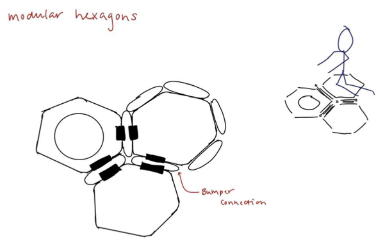
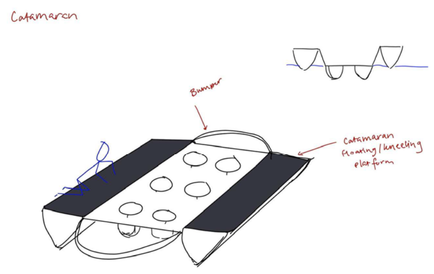
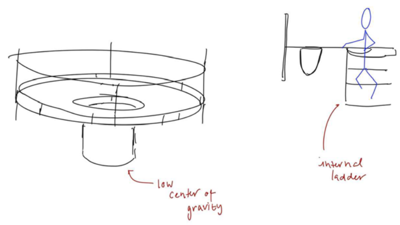
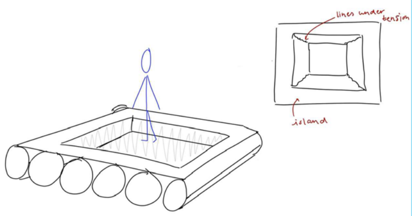
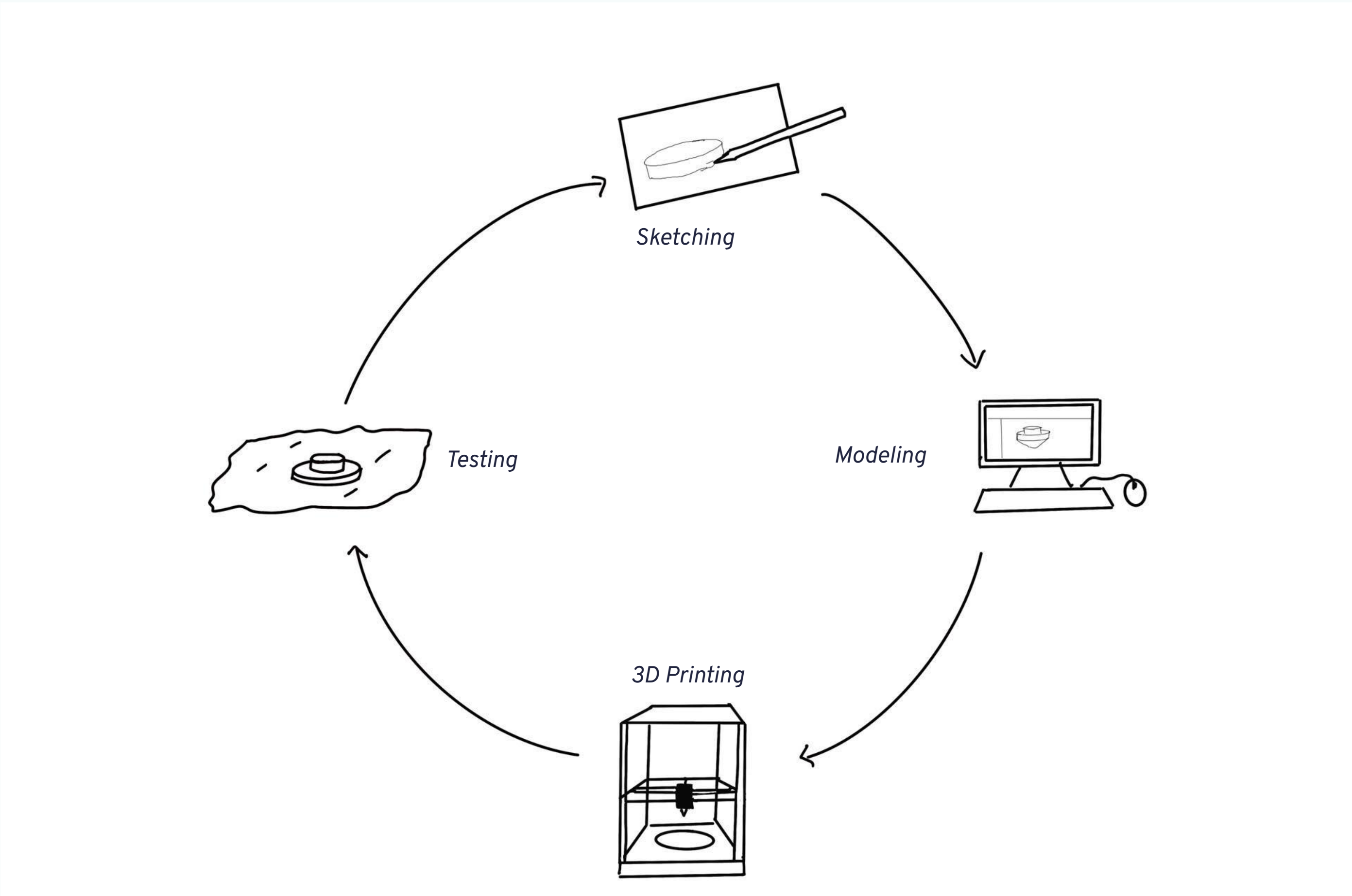
	Idea One	Idea Two	Idea Three
Concept Sketch			
Shape	Circular	Streamline	Hexagons
Stability	Lower Centre of Gravity	Fin and keel	Modular
Crash Resistance	Protection Frame, Circular Shape	Bumper to support critical points	Bumper connections
Accessibility	Standing Ledge	Floating Island	Floating Island Module
Inspiration	Current system	Biomimicry	Modular Dock
Description	For idea one I wanted to look at the original design but see how to integrate the functionality of the floating island. In this idea, the system remains circular but has a kneeling ledge around the exterior. This ledge would also be used as a protection frame and lower the centre of gravity, where it is designed to take a hit without damaging the internal systems.	Inspired by observations made in the biomimicry research, this design used a streamline or raindrop shape. The stability mechanism was a dynamic but not power fin as well as keels along the base. Bumpers would be placed over critical or vulnerable points. This design would still need to be accessed using the floating island.	Roffa Reefs is interested in how to make the breeding system scalable and the clearest way to do this is through a modular design. Hexagon shape was chosen to have more connection opportunities. The connection between modules has a gap to allow for movement and has the addition of bumpers to avoid crashing. For accessibility, some modules will act as floating islands spread throughout.
PMI	+ Similar to current system + Simple design +Barrels are assembled in the same way as a current system +Does not require floating island - May experience similar issues as current design ? Using different materials for bumper system	+ Bioinspired - Waves close to shore come from different directions - Currently requires floating island - May require powered steering or stabilizing - Complicated anchor points ? Save for later version behind a boat	+ Modular + Add more power as needed + Only need to put the amount of barrels being used - Complicated electrical connections - Complicated microscope integration - Continuous manufacturing - Flexible connection method needed to connect ? Connection to existing floating dock blocks
Continue?	**Yes**	**No**	**Yes**

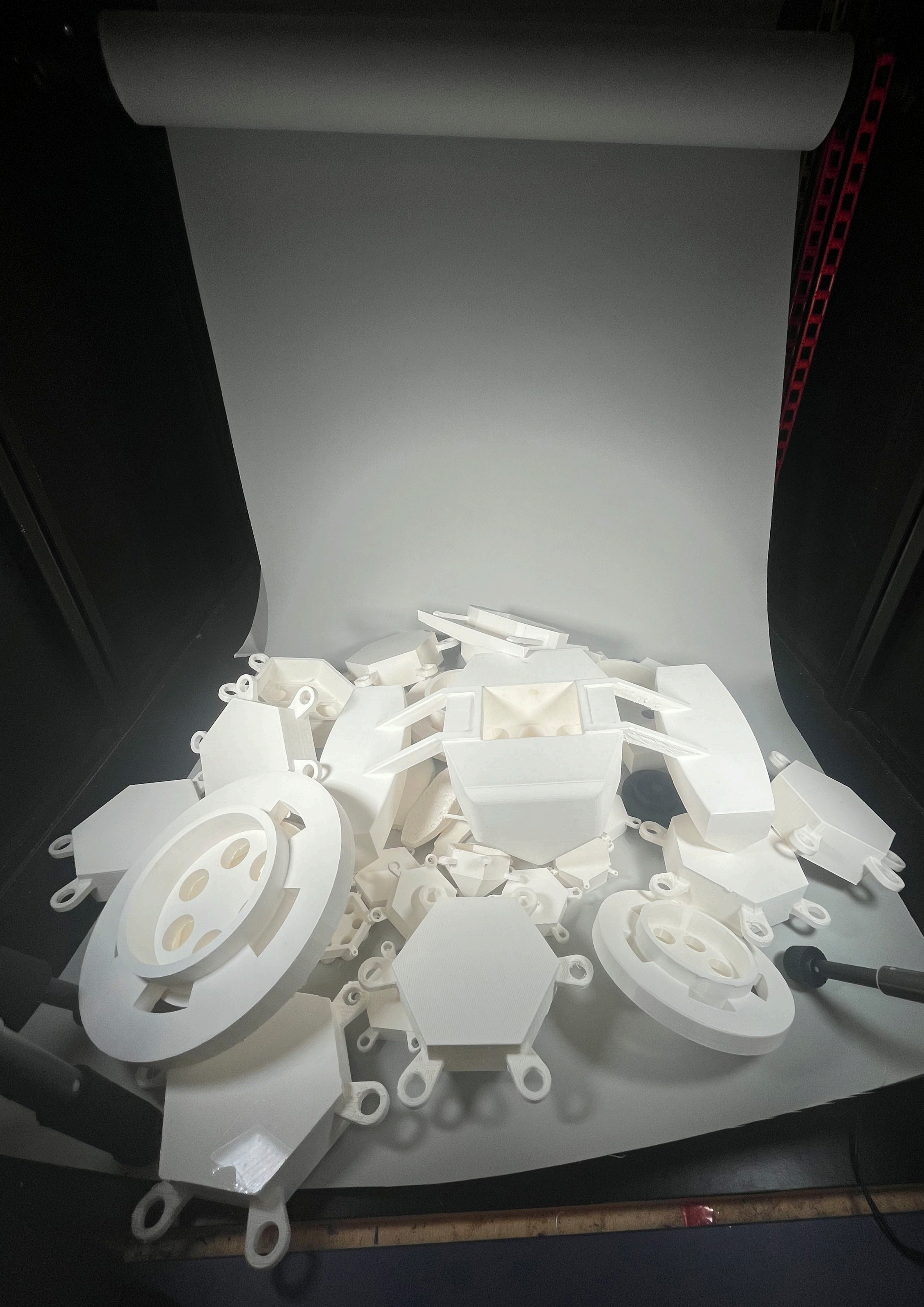
Figure 5.9: Ideas evaluated with PMI Method

Idea Four	Idea Five	Idea Six
		
Square	Circular	Square
Catamaran	Stability	Lower centre of gravity
Bumper	Circular Shape	Dynamic Anchoring
Standing/Kneeling Platform	Ladder in middle	Integrated with floating island
Catamaran/Trimaran	Buoy	Floating Docks
From the technology tree research, catamarans are designed for stability. For the accessibility the two outrigger hulls of the catamaran can be used as a standing or kneeling platform. The central section where the biological elements will be protected by a bumper or fender.	Currently, sometimes a boat is not available for bringing the operators to the system. In these cases, the operators swim out to the system. This system has a lower centre of gravity in the centre that also works as a ladder for the operators to stand and work from. In this situation the operators could work at a comfortable waist level rather than bending down or kneeling. It is also circular to reduce the impacts of crashes.	Idea six is inspired by floating dock and works to integrate the floating island with the system. The system would have a lower centre of gravity. The system would have modular lid so operators could walk across the entire system. For crash prevention, there would four anchor points where there is not enough tension to crash into the sides.
+ Accessible kneeling platform + "Drivable" can be towed to new locations + Applying proved design + Possible easier microscope integration - Catamaran technology may only create added stability under movement - Operators would have to reach over gap to access	+ Lower centre of gravity easy to implement + Operator working at more comfortable level - Limits operators to those who can swim well - Would not be comfortable in colder water - Risky with sample in the water - More difficult to lift sample up ? Adding a lower gravity point can be implemented into most designs	+ Similar to existing system - Projected similar issues to existing system - Already tested ? Flat lid can be implemented in other systems
Yes	**No**	**No**

5.4 Concepts

The chosen ideas were detailed into concepts. This was done through sketching, modeling, 3D printing, testing, gaining insights, and detailing the concepts further.





5.4.1 - Concept One: Circular Frame

Concept One is the building of the first idea and most closely matches the current system. There are a lot of elements from the current system that work well this allows for easier manufacturing and transition. However, there is the risk of bringing the same issues from the current system into the next edition.

This concept integrates the floating island into the rest of the system. Operators can kneel or stand on the platform that surrounds the internal biological components. This is the smallest of the three concepts as well. A comparison to the final figure can be seen in Figure 5.11. The different iterations can be seen in Figure 5.13. Time allowed for another iteration, the kneeling platform would have extended for the test model as currently it is quite a tight fit. This would then make the overall size similar to the next two concepts.

The gaps between the kneeling platform and the centre system allow for future measurement devices to be included. Further development would have to include the placement of the power system. There could also be a different material selected for the outside platform to help cushion crashes in extreme weather.

Figure 5.13: Iterations of concept one, first two at around 5-6% scale while the final at 10%.

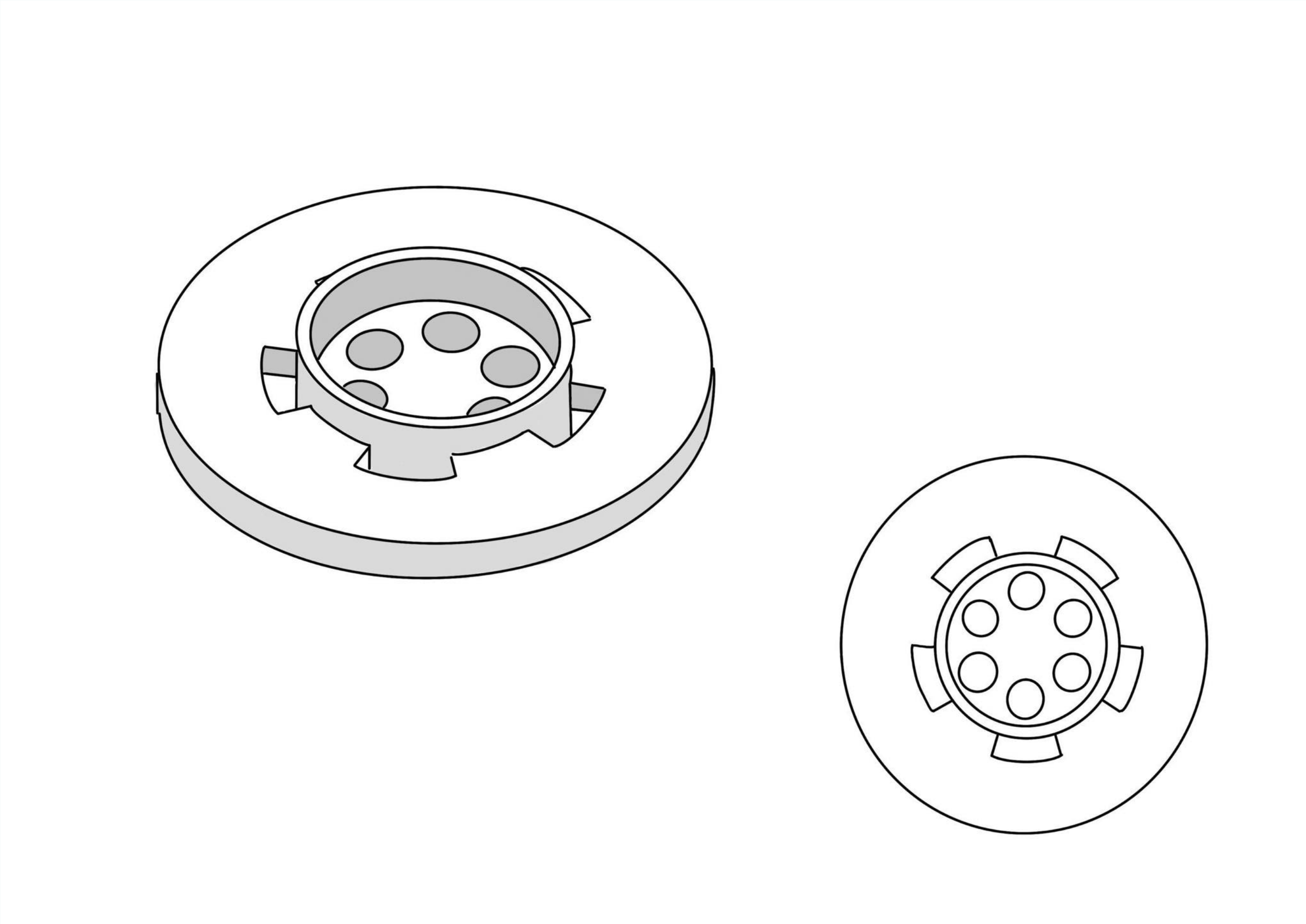


Figure 5.10: Concept One Sketch.

Figure 5.11: Model created at 10% scale with figure to demonstrate size.

Figure 5.12: Every iteration went through a float test to get a basic idea of the performance.

5.4.2- Concept Two: Modular Hexagons

Concept Two detailed the modular hexagon design. This concept features two types of modules: biological and float.

The biological module holds all of the necessary components of the biological subsystem. The floating modules serve the same purpose as the floating island by providing access to the internal systems for operators.

The modules are designed with a gap between each so the whole system can flex and provide more stability by “riding the waves”. The attachment system is inspired by what is currently used on the floating island with pins; see Figure 5.15. Further development after this concept phase is needed in the pins and their attachments to ensure strength.

The choice of a hexagonal shape is to give more attachment points for upscaling. Later detailing would have storage modules to contain the necessary components for the power and biological subsystems.

Figure 5.17: Iterations of Concept Two

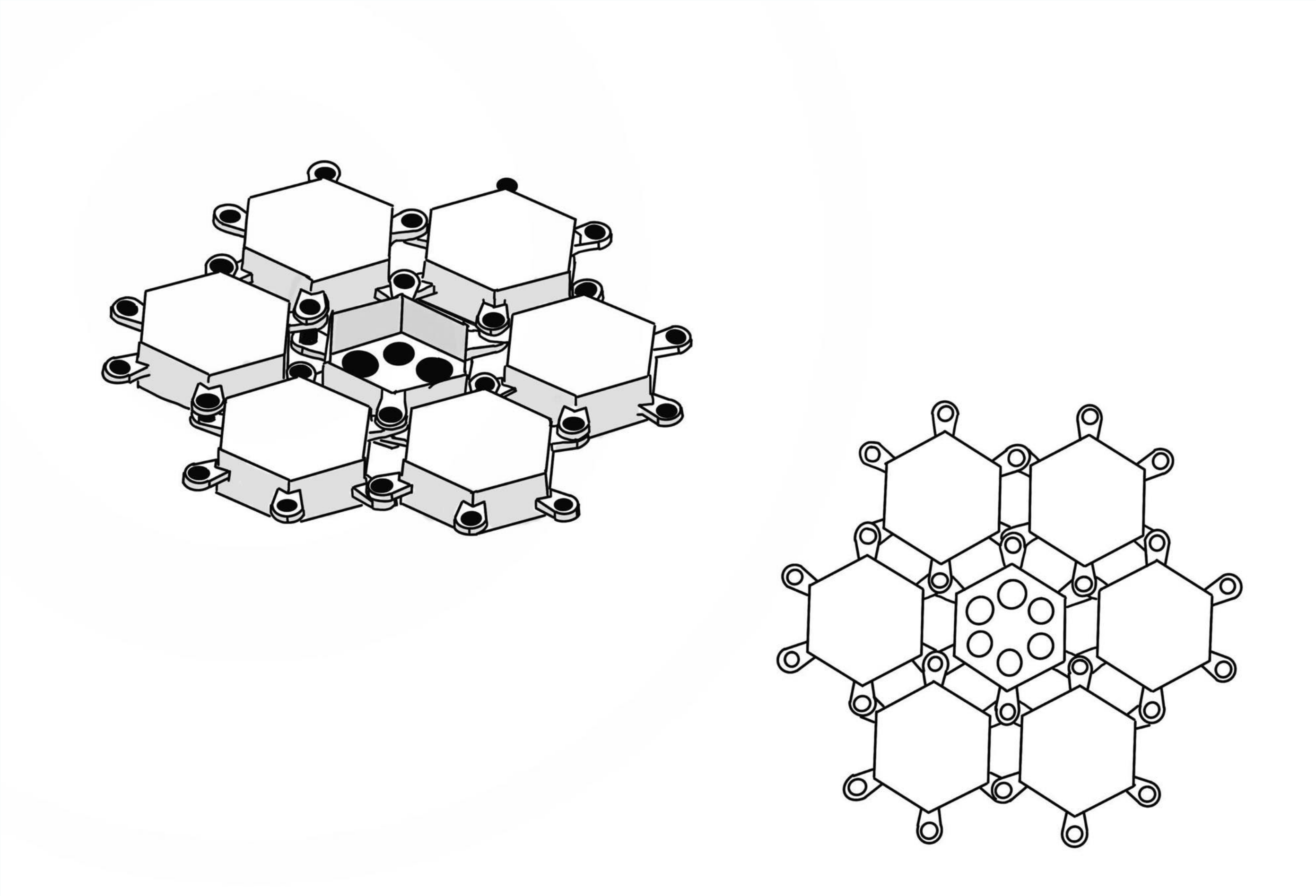


Figure 5.14: Sketch of concept 2.

Figure 5.15: Floating Dock Inspiration (StartupSelfie, 2023)

Figure 5.15: 10% Scale model with figure.

Figure 5.16: Float test of final test model.

5.4.3 - Concept Three: Trimaran

Concept Three builds off of the catamaran idea presented in the previous section. The decision was to move towards a trimaran set-up as it was important that the internal biological system had more structure for additional protection.

Dimensioning for the central hull was based on maritime design standards. The length-to-beam ratio is the total length of hulls vs the widest part. Typically, on a trimaran, this is between 1.2:1 to 1.8:1 (Length to beam ratios for multihulls, 2011). The barrels of the breeding system will remain at the water level like in the current system. Due to the similar boat design, this concept can be towed and brought to another location in case of a hurricane.

Operators can stand or kneel on both the outriggers and central hull to be able to access the breeding system. The outriggers have to be wide to help balance the system, so reaching across would be impossible for operators. Many catamarans and trimarans have additional platforms between the hulls for passengers, which can also be considered.

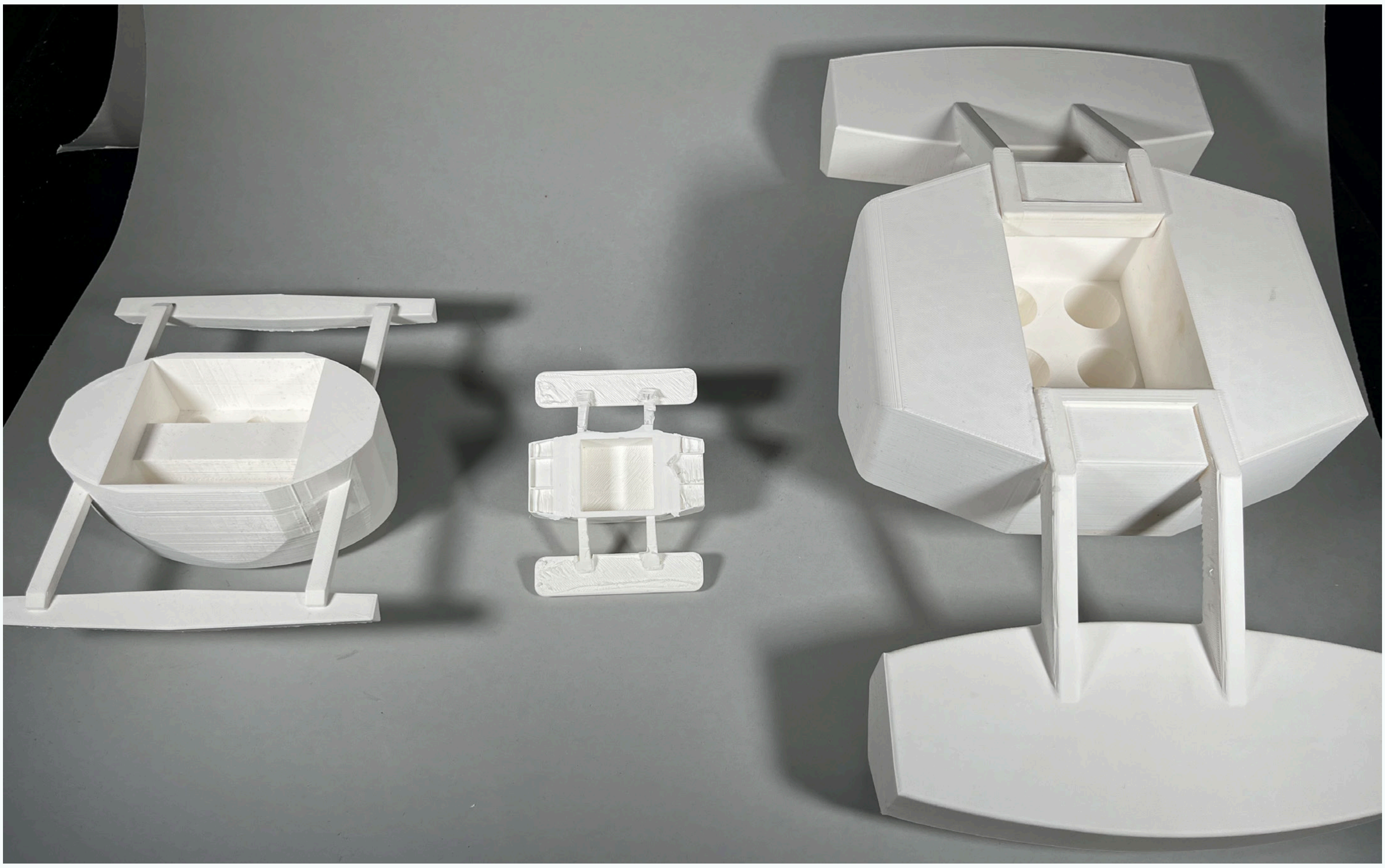


Figure 5.22: Prototyping iterations with insights gained from float test.

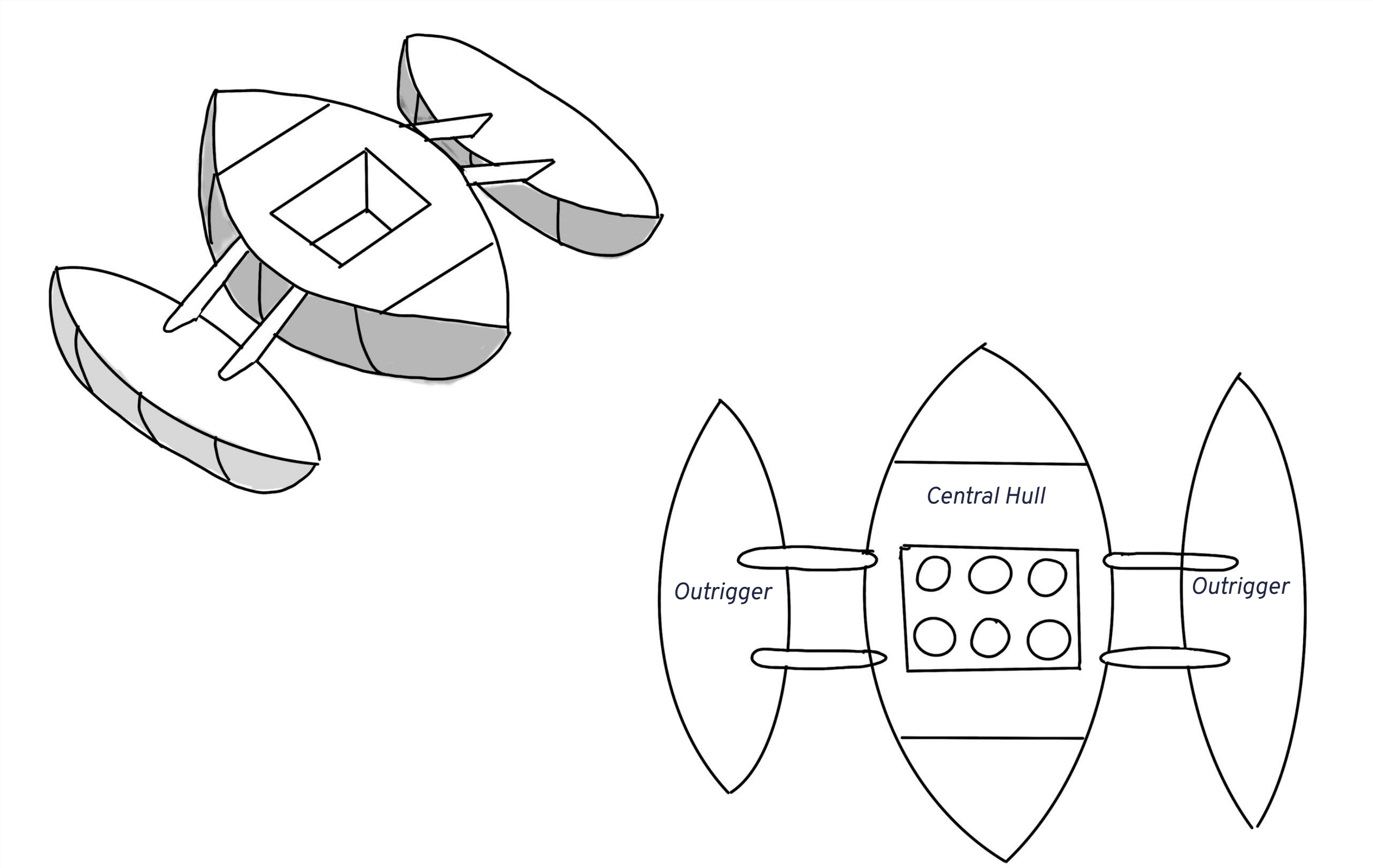


Figure 5.18: Trimaran concept sketch

Figure 5.19: Trimaran as inspiration

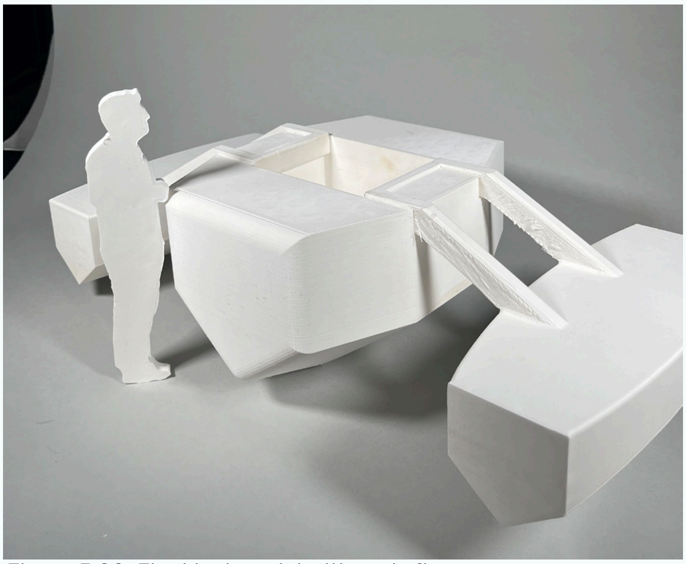


Figure 5.20: Final test model with scale figure.

Figure 5.21: Float Tests of the test models of concept one and three.

5.5 Testing

In order to assess the different concepts against the requirements, the stability had to be tested. For this, scale models were tested in a wave flume.

5.5.1 Background

The goal of creating a stable system is that it has as little movement as possible, even in wavy conditions. Each concept has been designed with a stability method in mind. However, with a combination of accessibility and crash prevention, it is important to understand how these concepts perform. There are four research questions for this study:

1. How does each concept's movement compare to each other?

2. How does the movement change from typical to intense waves?

3. How do the different shape/accessibility/crash prevention features affect the movement of the concept under wavy conditions?

4. What other factors lead to different behaviour?

5.5.2 Testing Set Up

Each concept will be tested under two conditions: "typical" and "intense" waves. These conditions will be simulated using data from Bonaire. On the island of Bonaire, there is a lee or sheltered and windward sides. The current system is placed on the lee side, where typically, waves are less than one meter in height (Frade et al.). However, the ocean is always at risk of a storm, so it is important to the behaviour under "intense conditions" or about twice the typical wave height. For this test, the typical wave height was chosen to be 75 cm, and the intense wave height was 150cm.

The testing was completed at the wave flume at the RDM Aqualab. The flume is 10 meters by 20 meters and has a depth of 70cm. The maximum wave height that can be produced is 30cm. The maximum wave height and depth of the pool are both limiting factors in the size of the model that can be tested and concepts and wave heights have to be scaled as a result. The concepts were all 3D printed out of PLA at low infill densities.

For this trial, everything was done on a 10% scale.

	Wave Height (cm)	*Period (s)*	*Wave Length (m)*
Typical	7.5	1.46	3
Intense	15	.98	1.5

Each concept was anchored to the bottom of the flume using two mooring lines and weights see Figure 5.24.

Each concept went through at least six tests, three typical and three intense. Each test was stopped after 40 seconds. In the wave flume, after a period of time, the waves start to bounce back and create inconsistent conditions. 40 seconds allows for the waves to fully develop and observe the wave effects before there is the "bounce back" effect.

The trials were filmed from a top and side view. They were observed by myself, the experts at RoffaReefs, and the marine engineer at RDM. These observations were noted down.

Figure 5.23: Concept Test Models.

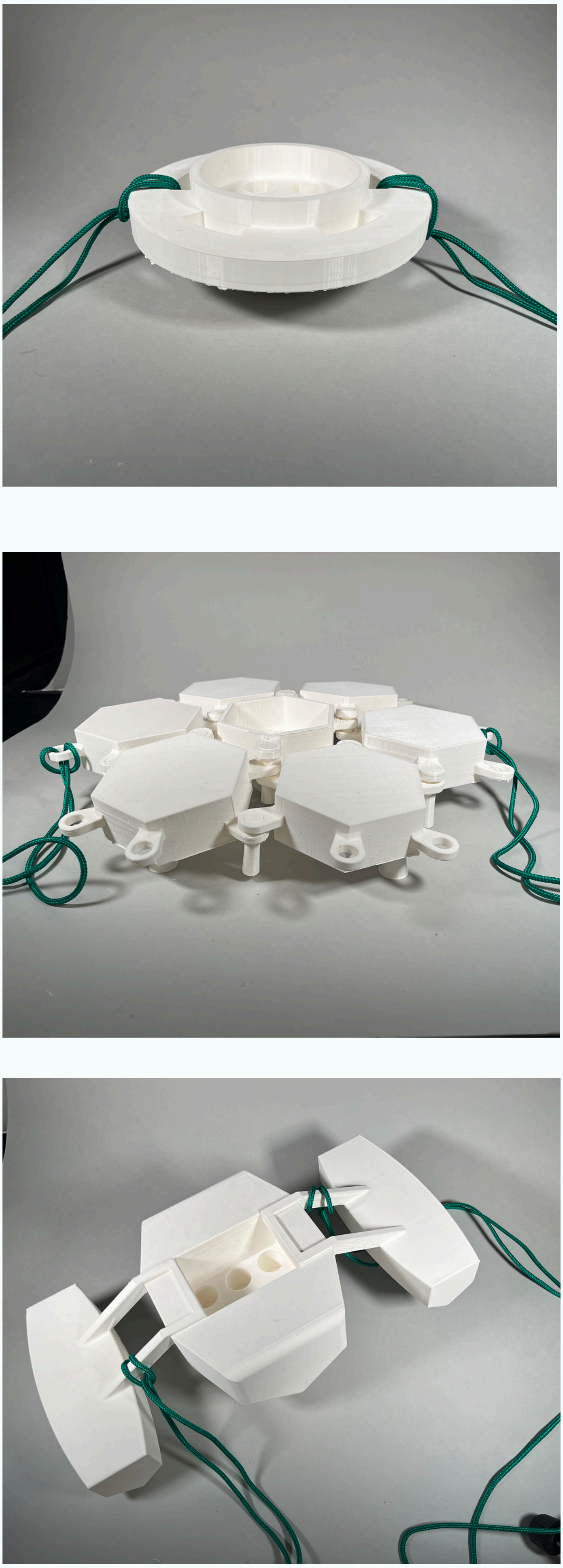


Figure 5.24: Anchoring attachment points on each concept.

5.5.3 Results & Discussion

Concept One

Figure 5.25: Test 1: Circular Frame stable before waves

Figure 5.26: Test 1: Circular Frame at maximum displacement

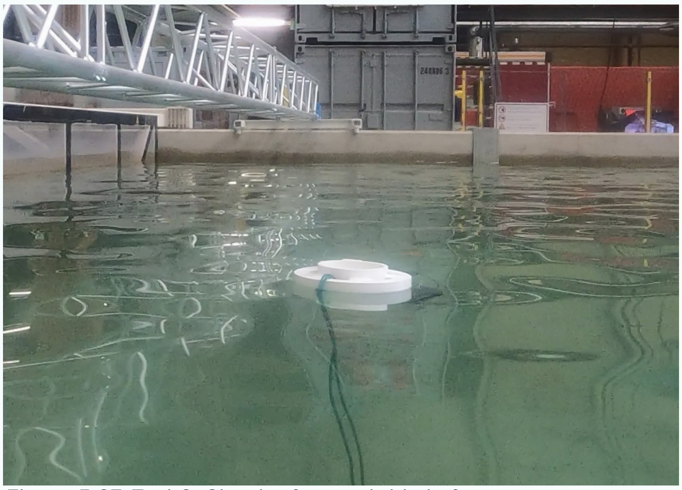


Figure 5.27: Test 2: Circular frame stable before waves

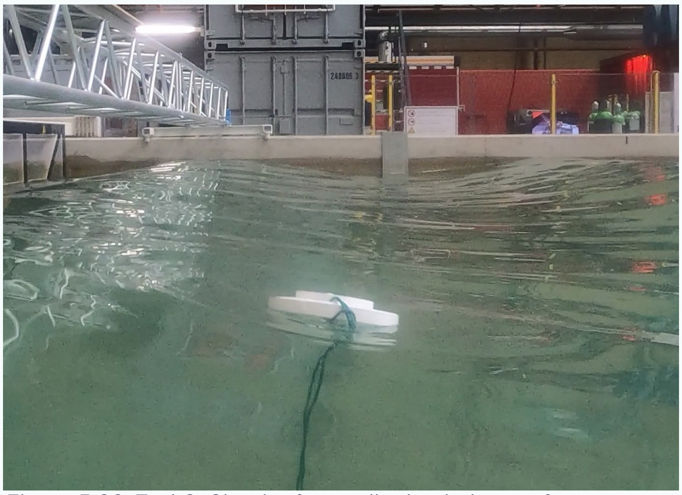


Figure 5.28: Test 2: Circular frame dipping below surface

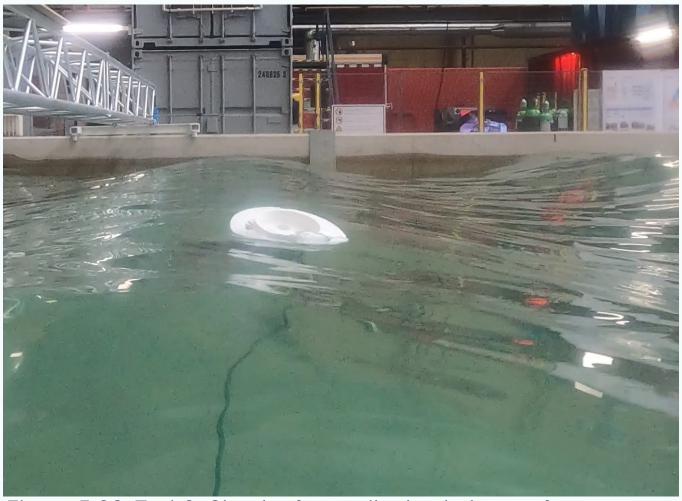


Figure 5.29: Test 2: Circular frame dipping below surface

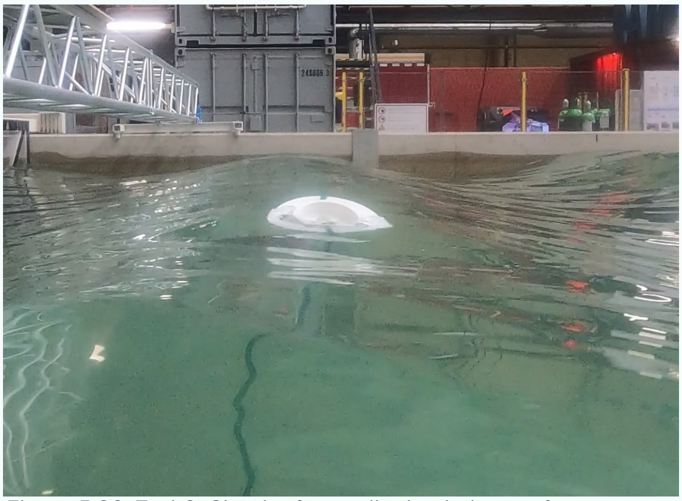


Figure 5.30: Test 2: Circular frame dipping below surface

Experimental Results:

In the typical wave test, the circular frame stayed mostly stable. Comparing Figure 5.25 and Figure 5.26, the maximum displacement of the system can be seen as not greatly affecting the internal system. The angular displacement is present but not significant to the operation. The standing platform does dip below the water line, but the internal system does not.

Test two, however, saw significant displacement. The internal system dips below the surface multiple times in the intense waves, as seen in Figures 5.28-5.30. Additionally, the displacement between stable systems is shown in Figure 5.27.

Discussion:

In these results, multiple factors lead to the instability. The mooring lines affect the stability significantly due to the creation of moment arms in the system. In Figure 5.34, the distribution of the forces on the system can be seen. As the force of the wave, Fwave, is applied it is opposed by the drag force of the standing water, Fwater, as well as a tension force from the moorings, Fmoor. The mooring force will always only become under tension as the wave force overcomes the drag force. The mooring force will always be at an angle and may want to pull the system below the water line, as seen in Figures 5.29 and 5.30. There are two ways to oppose this: first, by resisting the downward mooring force. The buoyancy force, Fb, is opposing this. Increasing the buoyancy force would mean the vertical mooring force and lessening the possible instability in the system.

The other way to avoid these conditions is to decrease the lever arm effect on the concept. Rarely, if ever, will both mooring lines be under tension. Therefore, one will always act as a pivot point, and the distance between the anchor points acts as a lever arm. Decreasing the distance between the two points or adding more pivot points would decrease this lever arm effect.

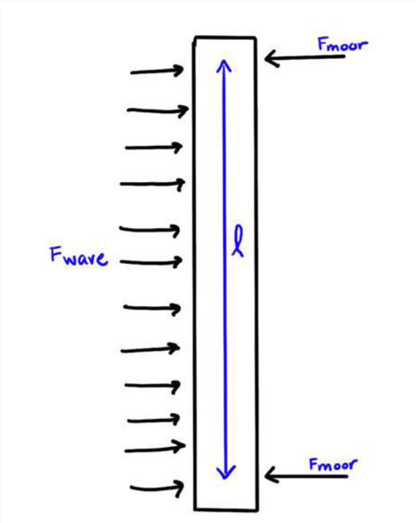


Figure 5.31: Simplified moment arm diagram where l is the distance between the two mooring points.

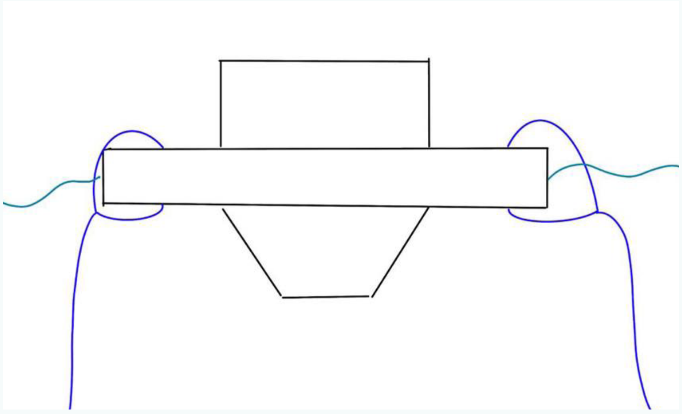


Figure 5.32: Mooring on concept one

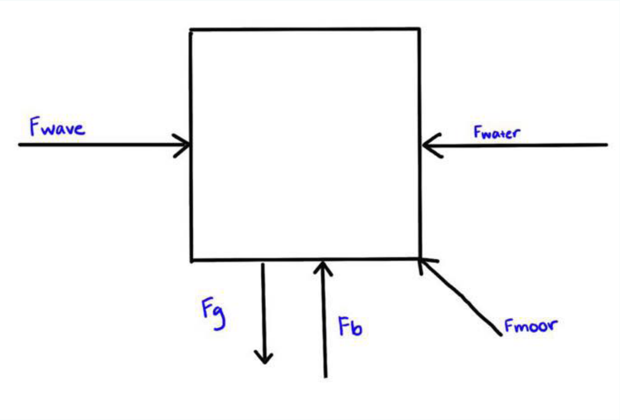


Figure 5.34: Free body diagram of forces on concept where F_{wave} is the applied force from the wave, F_{water} is the drag created by the standing water, F_g is the gravitational force, F_b is the buoyancy force, and F_{moor} is the opposing force of the moorings.

Concept Two

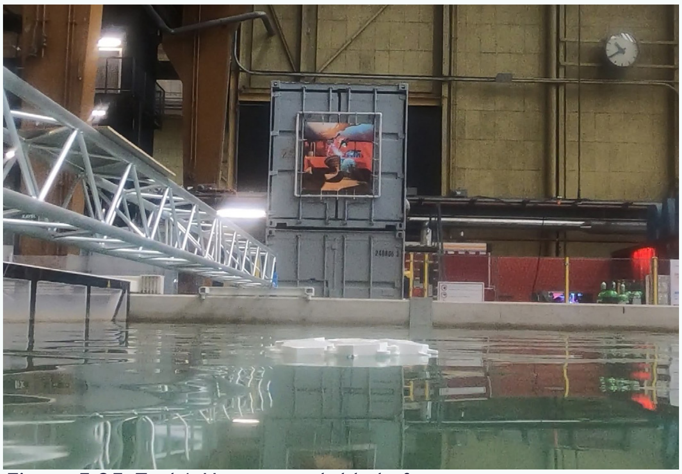


Figure 5.35: Test 1: Hexagons stable before waves

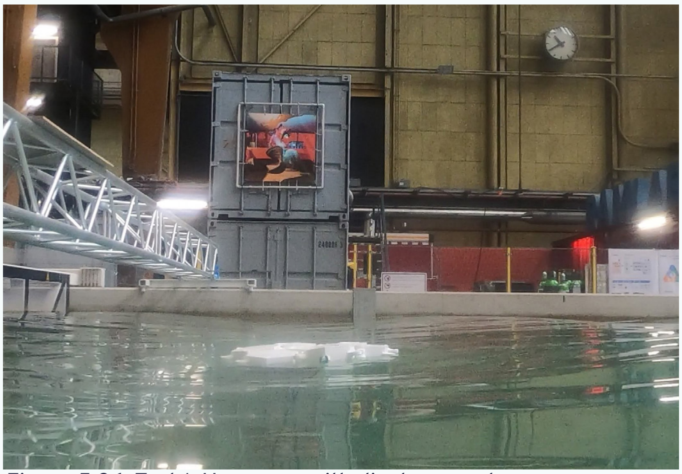


Figure 5.36: Test 1: Hexagons with displacement

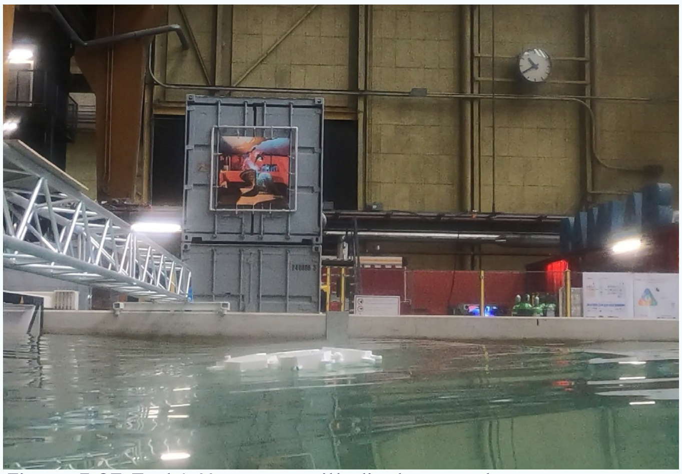


Figure 5.37: Test 1: Hexagons with displacement

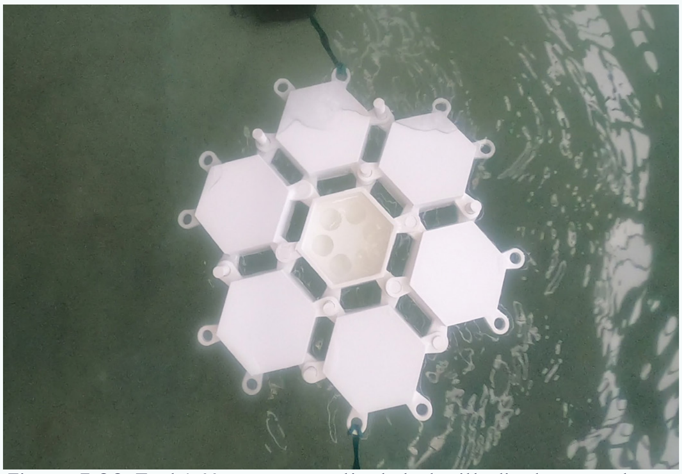


Figure 5.38: Test 1: Hexagons vertical shot with displacement

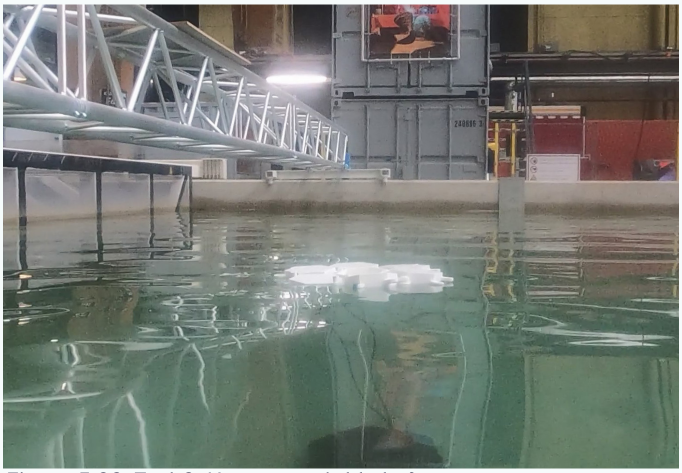


Figure 5.39: Test 2: Hexagons stable before waves

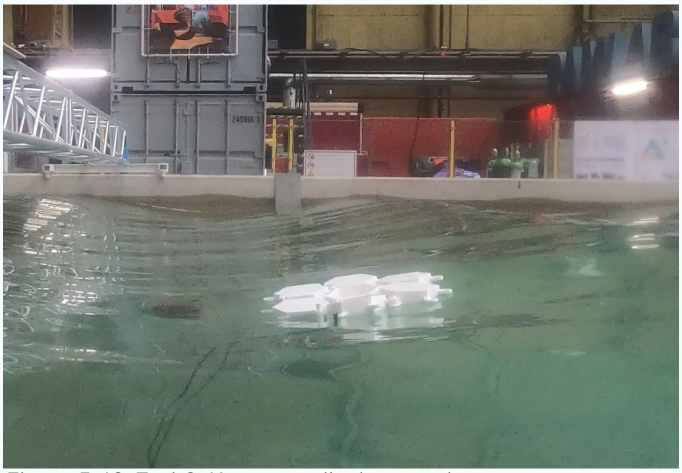


Figure 5.40: Test 2: Hexagons displacement

Results:

In the typical wave test, Concept Two did not show significant movement or displacement. The separate modules moved individually to adapt to the waves, and the central biological module moved less. In Figure 5.38, it can be seen how the exterior modules are adapting to the waves, but the central biological module remains stable. In the intense waves, the system moved more as a single body but did not show significant angular displacement or movement, especially in the central module.

Discussion:

The modular design of this concept led to its success in the trials. Due to the flexibility of the connections between the modules, this lessens the lever arm effect as described in the previous concept testing. This is due to there being more pivot points throughout the concept, therefore decreasing the lever arm length. The buoyancy force is also increased as there is a large volume and surface area of the system. The distribution of forces across the system was not uniform, as can be seen in Figure 5.39, the modules do not all float on the same plane even at stable. This is due to a few factors within the prototype. First, the pins used to connect the modules were tapered in the middle for ease of assembly. The 3D printed pieces were also not watertight and absorbed water over the course of the testing, which made their density inconsistent. As Test Two was done after Test One, there was more time for the prototype to absorb water.

Despite these irregularities, the modular design faired well in both the typical and intense waves.

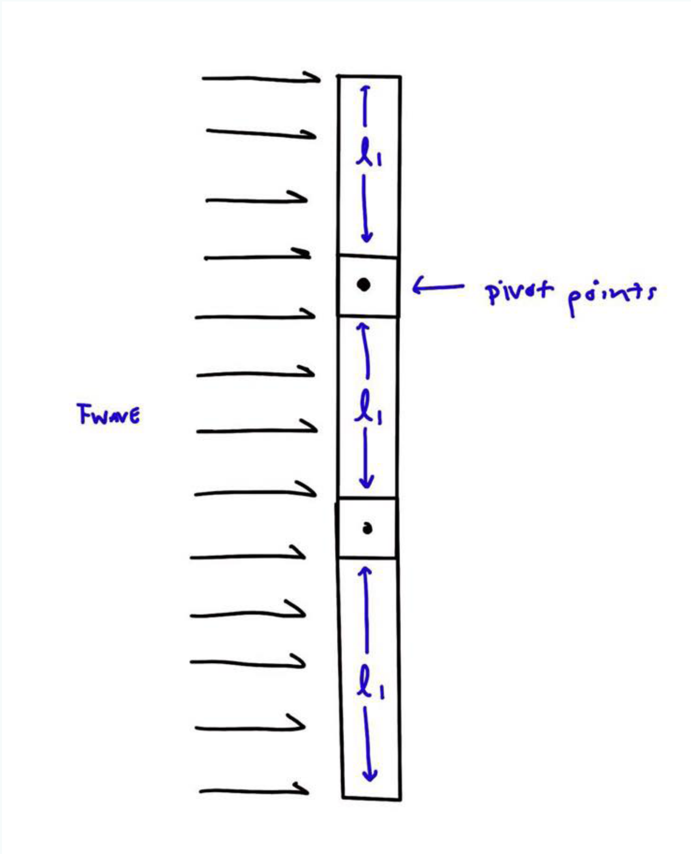


Figure 5.41: Simplified moment arm diagram. Due to the length being shortened compared to concept one, the lever arm effect is less.

Concept Three

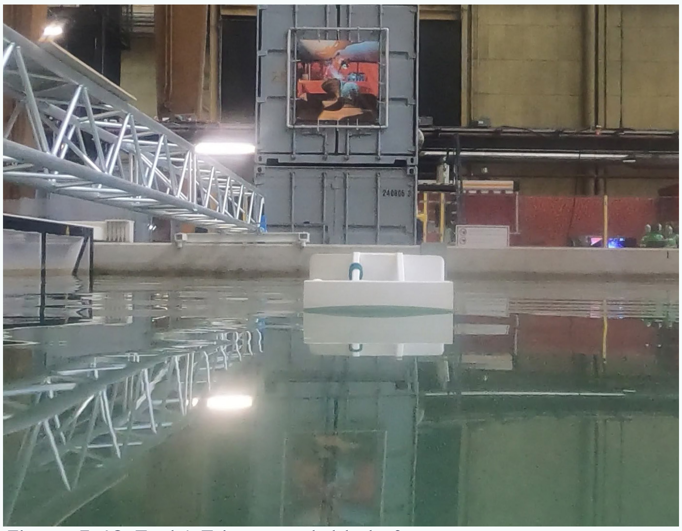


Figure 5.42: Test 1: Trimaran stable before waves

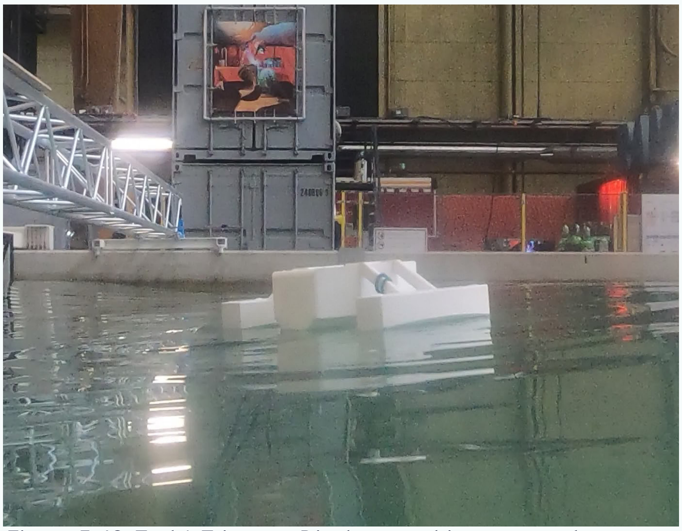


Figure 5.43: Test 1: Trimaran Displacement in movement

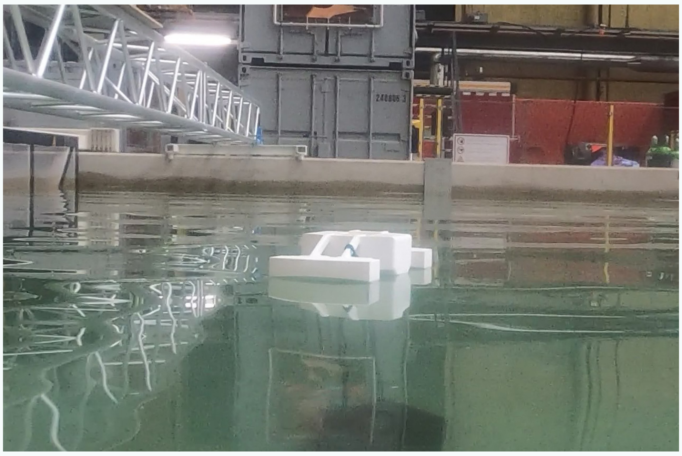


Figure 5.44: Test 2: Trimaran stable before waves

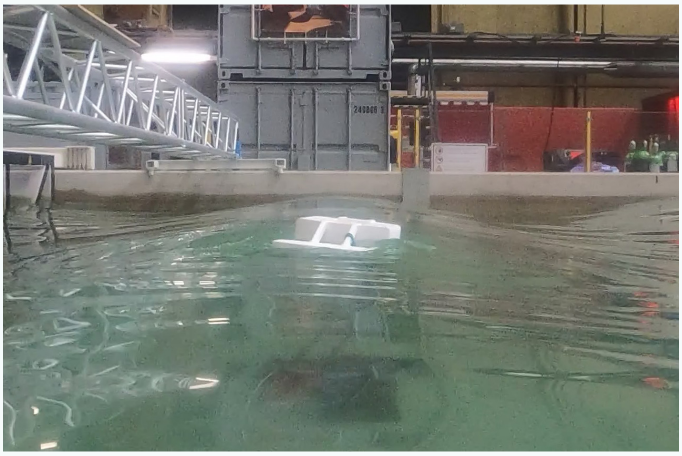


Figure 5.45: Test 2: Trimaran Displacement

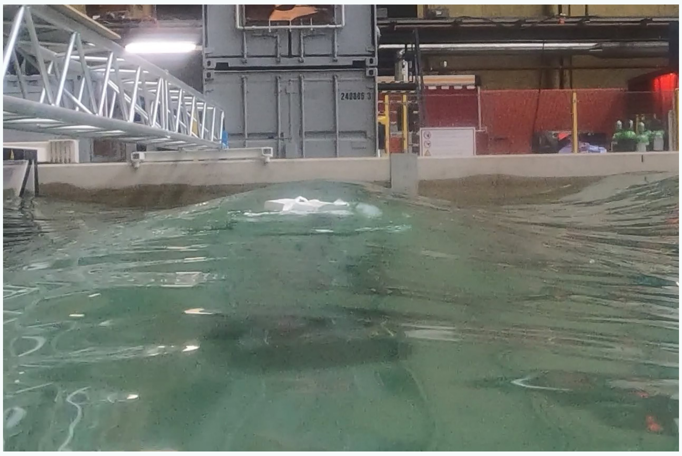


Figure 5.46: Test 2: Trimaran Under the Water

Results:

In the typical water test, Concept Three had a lot of horizontal movement. As seen in Figure 5.42 compared to Figure 5.43, the system would move back and forth in the horizontal direction throughout the waves. There was little angular displacement in the typical wave test. In the intense waves, concept three saw significant movement. The system moved both in the horizontal direction, like the typical test, as well as dipping below the surface. At points in the intense wave testing, Concept Three dipped almost completely below the surface, as seen in Figure

Discussion:

Concept Three also suffers from effects similar to those of Concept One. The placement of the mooring points has a significant effect on the performance. The flat faces of the trimaran also absorbed much more wave energy than the other two concepts. This impact could be lessened in future development if the trimaran was a more streamlined shape. However, in reality, the waves do not just come from one direction, so changing the shape may not necessarily improve the performance. The combination of the less-than-the-ideal mooring methods and these flat faces caused the concept to perform the worst of the three.

5.5.4 Testing Conclusion

To revisit the study questions, the following conclusions can be made:

1. How does each concept's movement compare to each other?

Following all of the trials, the concept that had the best results was Concept Two, followed by Concept One, and last, Concept Three. Concepts One and Three were highly affected by the mooring position. This could be improved in a future iteration; however, Concept Two stayed the most stable among the three. The modular design showed to adapt to the incoming waves.

2. How does the movement change from typical to intense waves?

Concepts One and Three became more unstable in the intense waves, with moments where parts or the whole system dropped below the waterline. Concept 2 did not have as dramatic of a change between the two tests; however, the flexible movement of the modular design that was observed in Test One was decreased.

3. How do the different shape/accessibility/crash prevention features affect the movement of the concept under wavy conditions?

For shape, two affecting factors were the horizontal surface area and the overall volume. As seen in Concept Three, the flat faces meant that the force applied by the waves created more pressure. The overall volume affects the buoyancy force.

4. What other factors lead to different behaviour?

The mooring affected the stability of the system overall. The system is currently moored with just two anchor points, but this can create instability overall. It would be interesting to do further testing with a third anchor point and see the effects.

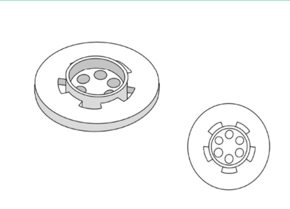
For the testing, the 3D-printed models also affected the results. As stated in Concept Two's results, the models are porous and absorb water throughout the testing. This caused a change in the behaviour, so it is important to note irregularities.

5.6 Concept Selection

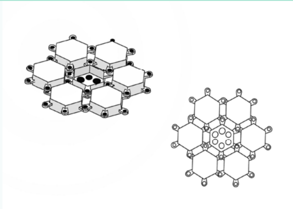
To select between the concepts, a Harris profile (van Boeijen, Daalhuizen, & Zijlstra, 2021) was used. In this method, the concepts are compared to the requirements.

The concept that rated the best was concept two the modular hexagon design. Therefore, this concept will be chosen to detail further into the final design.

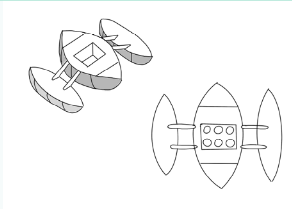
Concept One



Concept Two



Concept Three



	Concept One				Concept Two				Concept Three				
	--	-	+	++	--	-	+	++	--	-	+	++	
Stability (Req 1.5 & 2.5)		■						■	■				As seen in the testing, concept two performed the best in the stability test. Concept one performed similarly to the current version and concept three performed worse.
Flotation (2.1)			■				■				■		As seen in the testing all of the concepts can float above the reef. It is not possible to say if one floats better than the current version since the models are not fully detailed.
Simplicity (3.1)				■		■				■			Concept one is the most simple as it is the most similar to the current pilot. Concept two and three both have their own challenges which lead to complexity.
Scalable (3.2)		■						■		■			Concept two is by far more scalable. It is designed so that more modules can be attached and grow if more storage or floating is needed.
Accessibility 4.5)				■				■			■		All of the concepts are accessible as they have been specifically designed with a place for the operators to stand near without the floating island. However concept three may require the operators to reach over a gap to access the barrels.

5.7 Conclusion

In the conclusion of this concept development section, one concept has been selected. Through ideation, testing, and rating of concepts, a modular, hexagonal concept was selected for further development. It is projected to meet the product requirements best. In the next section, this concept will be detailed and embodied into a competing product that will be able to meet much more of the product requirements as well as assessed against the current system.

6

Embodiment Design

This next section describes the embodiment design process, which details the concept in the final product. Working alongside the RoffaReefs team and an engineer at a plastic manufacturer, the new breeding system comes together.

The final stability of the new system is also completed to compare with the pilot. Overall, this section addresses the final requirements before the full concept proposal is finalized for this project.

6.1 Scope of Embodiment Design

The embodiment of the final design involved taking the concept tested in the previous section to a manufacturable product. Several iterations were done to design each module and segment. Throughout the designing process feedback was provided from the RoffaReefs team and Hessel Luiten, the engineer at Kemeling Kunstoffen who will be manufacturing the final product. After giving the final design to Kemeling, a codesign process took place to detail the design for manufacturing. Overall this section will address the following requirements:

1.4 Lid on system does not allow for predators to enter.

2.2 Materials should have “excellent”resistant to salt water.

2.3 Materials should be weldable to create watertight features.

2.4 Material must be suitable for marine environments.

2.5 Product must have more than two anchor points.

2.7 System must have a water proof container that can contain the batteries and necessary electronic components.

3.1 The product is as simple as possible.

3.2 System can hold more than just six fish species.

3.3 System can grow other marine life.

4.4 There must be space within the system for future elements.

4.7 Removing/Moving the lid for daily samples should not require challenging motions.

4.8 System must not be made with any toxic materials.

6.2 Material Choice

The pilot and the new system are both manufactured using high-density polyethylene (HDPE). HDPE plastic is a typical choice for marine contexts due to its manufacturing ability and resistance to fresh and salt water. There are downsides in terms of end-of-life and repairability in low-context settings. This material choice was confirmed by using the Granta software. The list of materials was limited to the following parameters:

- “Excellent” rating for resistance to salt water (Requirement 2.2)

- 4 or higher rating for weldability (Requirement 2.3)

- “Excellent” rating for use in marine atmosphere (Requirement 2.4)

- System must not be made with any toxic materials (Requirement 4.8)

The remaining materials were charted on embodied energy vs cost, and after filtering some additional materials that did not make sense for the application (ex, soda lime glass), PE still came out as the best option. There may be newer materials that would be more sustainable to use but commercial availability and cost are limiting factors. The full materials chart is featured in Appendix E.

6.3 Biological Module

The embodiment of the biological module involved integrating the new changes into the existing elements from the pilot. Overall, here are the elements that kept the same and those that were changed:

Kept The Same	Changed Elements	New Elements
Main Body	Lid	Attachments
Floating Plate	Keel	Coral Grid Mounting

Kept The Same

Although in earlier concepts, the biological module was hexagonal like the other modules but this was quickly changed in the embodiment design phase after first discussions with Kemeling. In the pilot, the biological subsystem performed well, so there is no significant need to change it. After confirming that the new attachment points could be welded onto the existing design, it was decided to keep the main body and floating plate within the same.

New Elements

Other than the new attachments (addressed in 6.7), a coral grid mounting was added to the interior of the biological module. In addressing requirement 3.3, RoffaReefs has been in discussions with other scientists on how to use the system also to grow coral. This still needs to be researched more, but they do know it would look like installing a grid below the floating plate. For this design, a ledge, see Figure 6.1, was added for grids that could be affixed later.

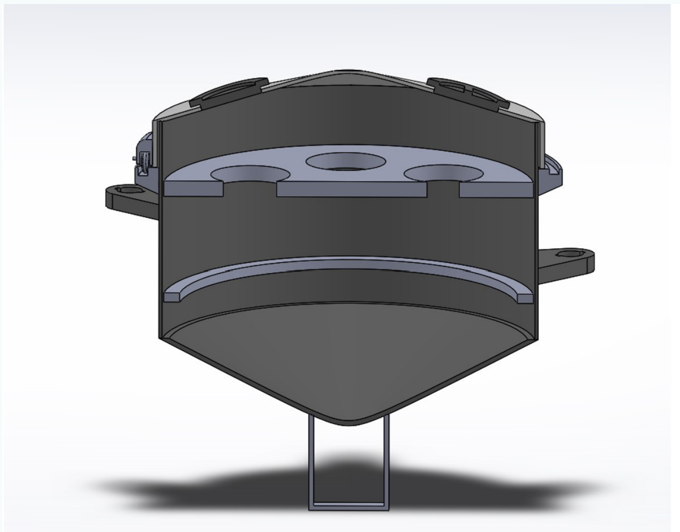


Figure 6.1: Coral Grid Mounting

Changed Elements

The lid of the biological system was one of the biggest concerns the RoffaReefs team raised when taking daily samples. This was important to address in the embodiment design. There were three main iterations where, in between, there was feedback from either the RoffaReefs team or the engineers at Kemeling.

The first iteration was a “puzzle piece” design, see Figure 6.2, where only one-quarter of the lid would need to be removed at a time. Concerns were raised by the RoffaReefs team that the puzzle pieces may not be as watertight as needed. This led to the creation of requirement 1.4. The current lid does fulfil this requirement but does not meet requirement 4.7. This led to efforts to improve the usability of the current lid. This led to the second iteration, see Figure 6.3. This added smaller access ports that could be rotated using a rail and roller system to access the barrels. There was an additional pin-locking system that would keep the lid from rotating when not needed. After consulting on this design with Kemeling, the rail and roller system was deemed unnecessary as the lid could spin without it. Therefore, the final lid design was the lid for the pilot system, which had an additional access port and a lid locking system on the attachment points of the module. Handles were also added so that the operators could easily rotate the lid.

The changes made to the keel were much more simple. The drain pipe remained the same but the system around it was replaced by a larger tube to reduce manufacturing costs.

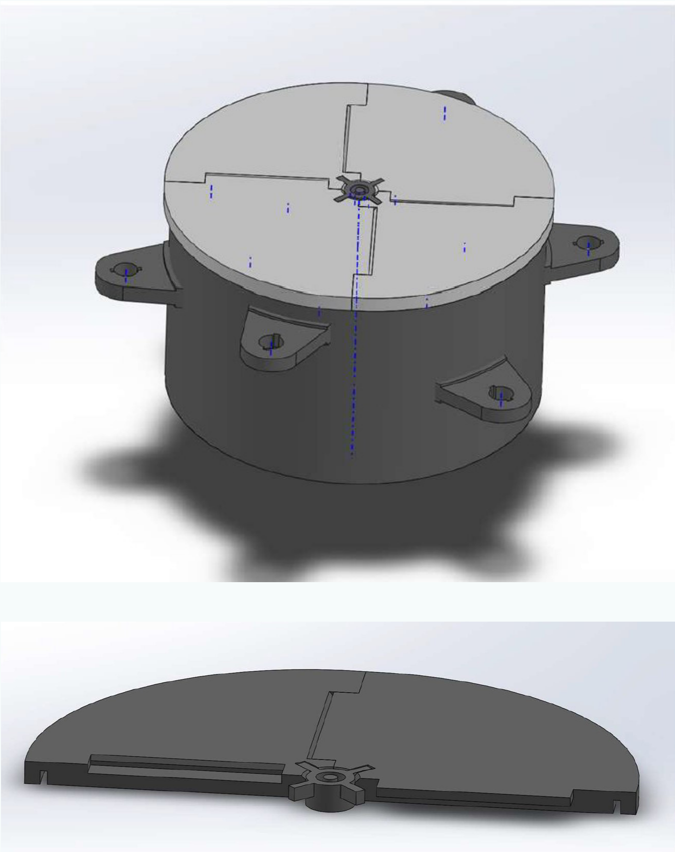


Figure 6.2: First Lid

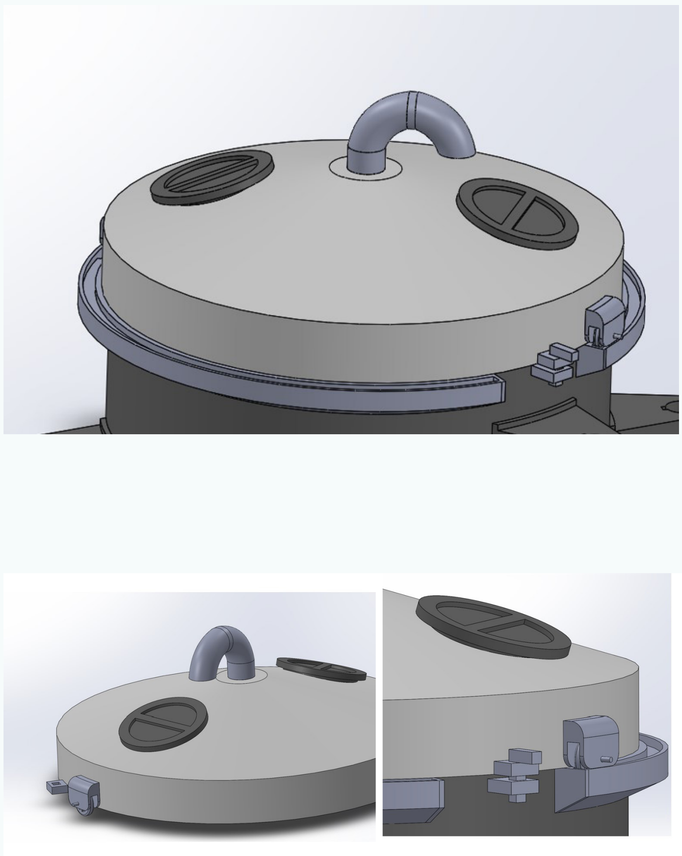


Figure 6.3: Second Lid

6.4 Storage Module

The storage module must hold the necessary electronic components and connect to the biological modules, see Figure 6.4. There also must be some internal support features so that operators can stand on top of the modules without the system breaking or deforming. Due to this, the modules will have a storage box rather than the entire inside being open. Additionally, when securing the electronics, drilling into the structure would risk the flotation of the module.

The lids are the same type as those used in the current system. They were first designed to be 500mm across so there would be no risk of items being unable to fit in the system. However, 500mm is nearly twice the size of the largest available standardized piece. Using an additional customized piece would be expensive and possibly make repairs difficult. Therefore, the lid was changed to the largest available and what is used in the current system. Kemeling added the final support pieces within according to their knowledge of the material, see Figure 6.5.

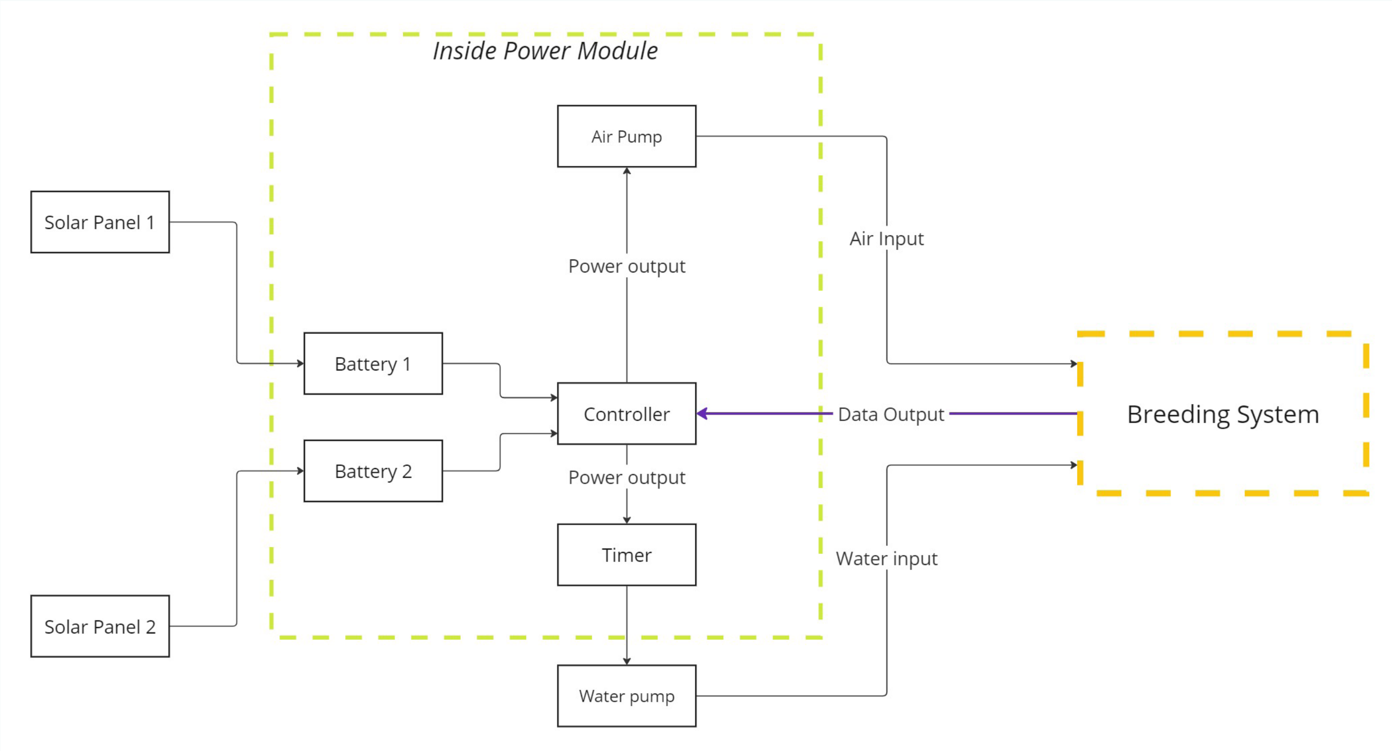


Figure 6.4: Electronics Schematic

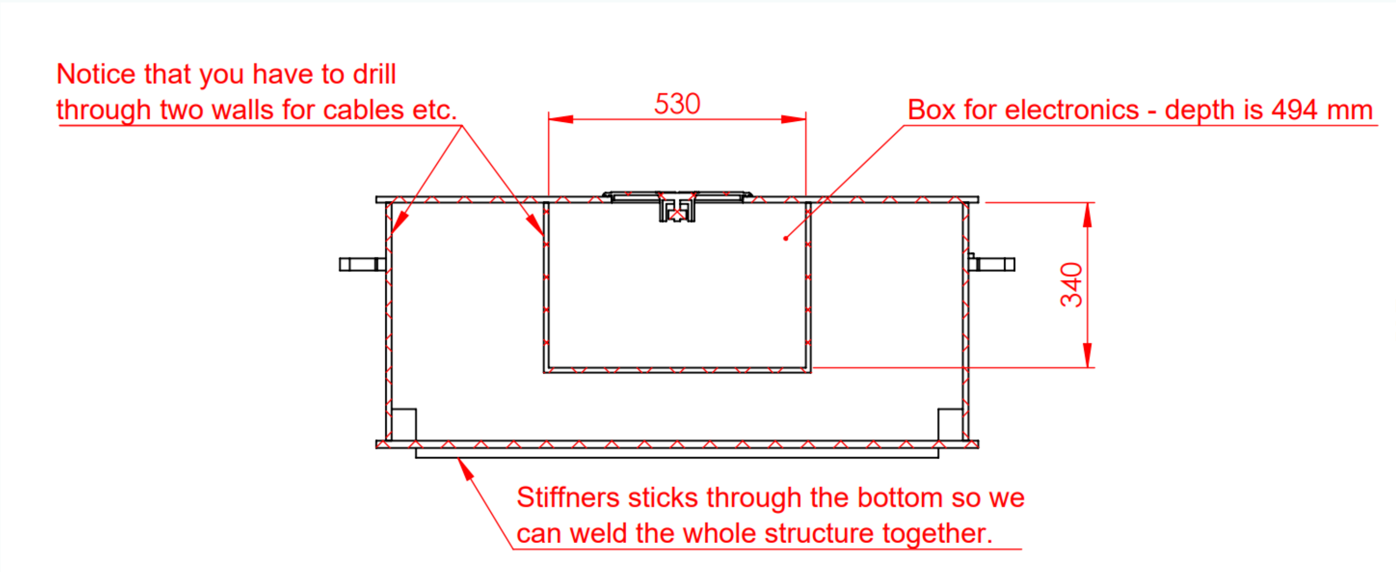


Figure 6.5: Internal Structure as directed by Kemeling.

6.5 Float Module

The float module is designed for operators to stand on the modules and access the biological module. In the first iteration, the module was designed to minimize the material needed by simplifying the internal support structure. After discussions with RoffaReefs, this was changed so that the float modules were just storage modules without a lid. This would simplify the manufacturing process and make adding more storage easier.

6.6 Attachments

The design of the attachments between the modules had two questions to address: How will the modules connect to each other and what will the pin mechanism look like.

The first question had been addressed in the previous concepts but changed in the embodiment phase. In these concepts, the attachment points were at three different heights to make three-point connections possible at the corners of the module. The connection did work, but the assembly was a bit complicated. The engineer at Kemeling raised concerns about the risk of assembly error when having to hand weld these attachments at three different heights, as well as issues with creating large force concentrations. Due to this, on the advice of the engineer, these attachments were changed to two-point attachments at only two heights and the biological module would sit on top, see Figure 6.6. This helps reduce the force concentrations as the float modules can support the biological module more. Adding a two-point attachment point also allows for more opportunities for anchoring.

In designing the pins to hold the system together, some consideration was given to using standardized bolts or fasteners to simplify. Unfortunately, metal fasteners do not fair well in salt water and, according to Kemeling, HDPE does not hold threads well. Due to this, the pin was designed with a locking tab, see Figure 6.7. In the final design, Kemeling adjusted these pins to be a more appropriate size.

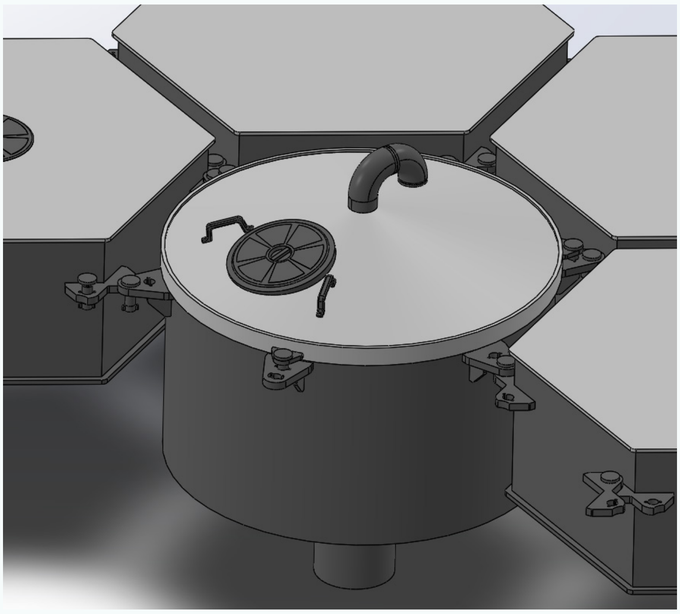


Figure 6.6: Module Connection

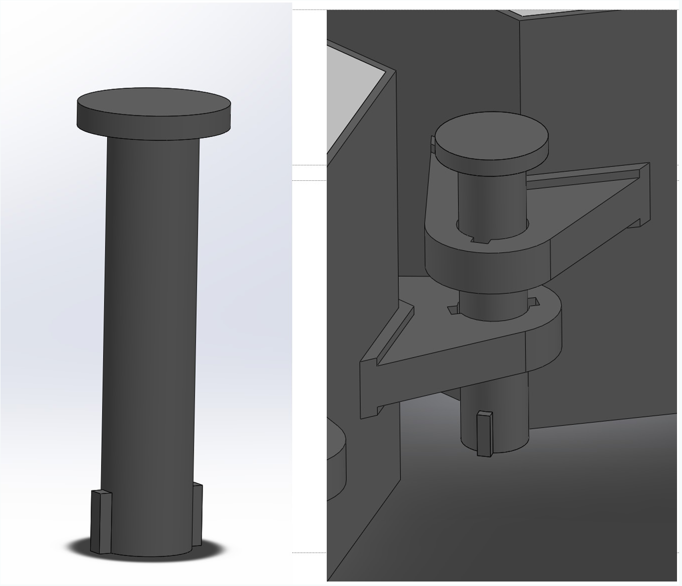


Figure 6.7: Locking Pins from iteration two.

6.7 Testing Design

6.7.1 Testing Set Up and Goals

Additional stability testing took place to show an improvement in performance for the new system. This testing had the same experimental set-up as the testing that took place in the concept development phase (full set-up details in Ch.5.5.2). Again, a 10% scale 3D printed models in typical and intense wave conditions. The main goal of this study is to assess the stability of the new concept and compare this to the pilot system.

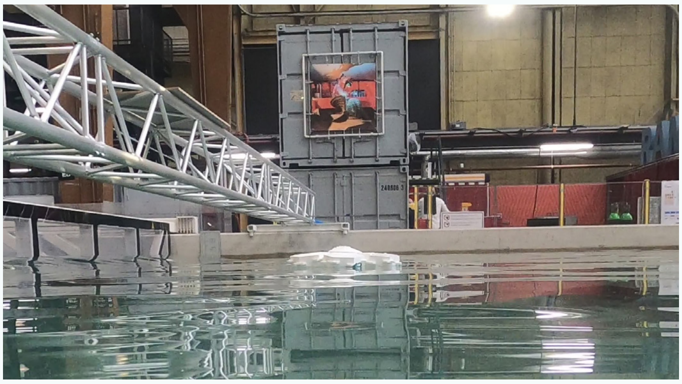


Figure 6.10: New system a stable before intense waves

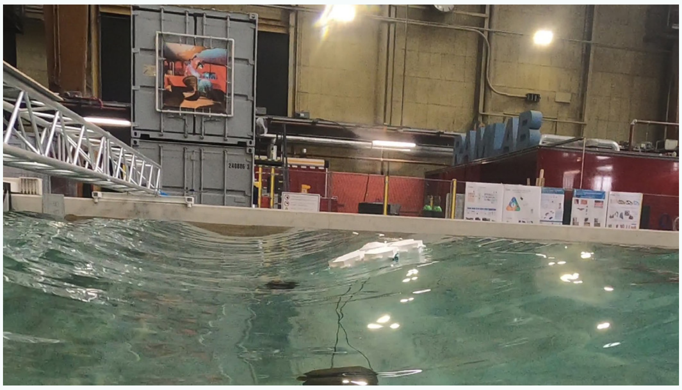


Figure 6.11: New system at significant displacement in trial

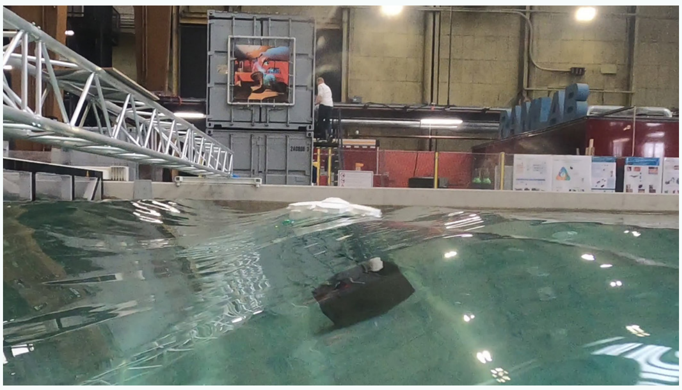


Figure 6.12 New system showing flexing in intense waves.

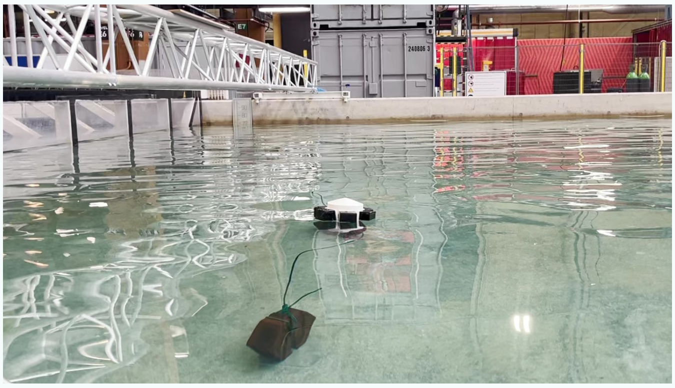


Figure 6.13: Pilot system stable before waves

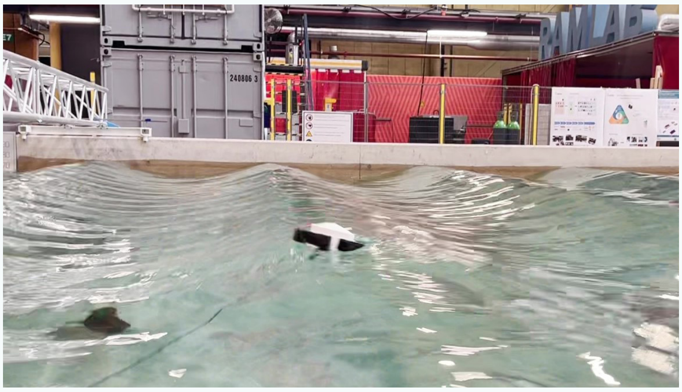


Figure 6.14: Pilot system at significant displacement

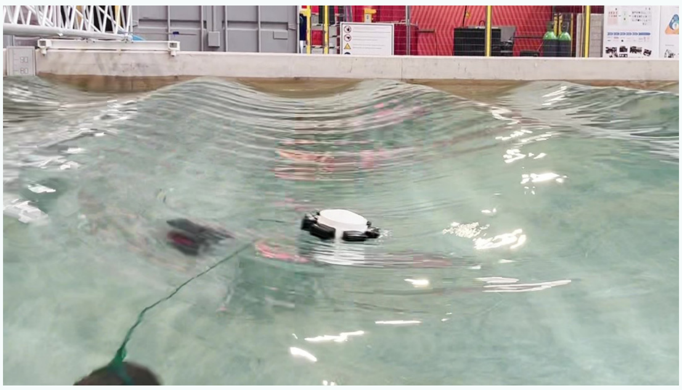


Figure 6.15: Pilot system at significant displacement.

6.7.2 Results and Discussion

In the results of the testing, the pilot and new system performed similarly in the typical wave conditions. These results are shown in testing appendix D. Comparing the intense waves is when there is more significant differences.

While observing the stability trials, significant angular displacement times were noted, especially in the central biological module. The pilot system saw significant angular displacement in the intense wave testing, as seen in Figures 6.14 and 6.15. Throughout the test, the pilot system model pulled on the mooring points, causing it to dip below the surface, including the biological subsystem. After pulling on the mooring lines the system would jerk to right itself.

The new system was not as affected by the intense waves. As seen in Figure 6.11, even when the system was at significant displacement, no part dipped below the surface. The flexible connections between the modules led to its success. When the system pulls on the mooring points, it only affects the float modules, while the central biological module can remain stable. This can be seen in Figure 6.12, where the system can be seen to have a slight flex at the wave peak.

This can also be seen as the system is scaled up. Two and three systems were also tested under typical and intense wave conditions. As seen in Figure 6.16, with two systems, the modules can adapt to the wavy conditions.

Overall, the new system is more stable in wavy conditions than the pilot system.

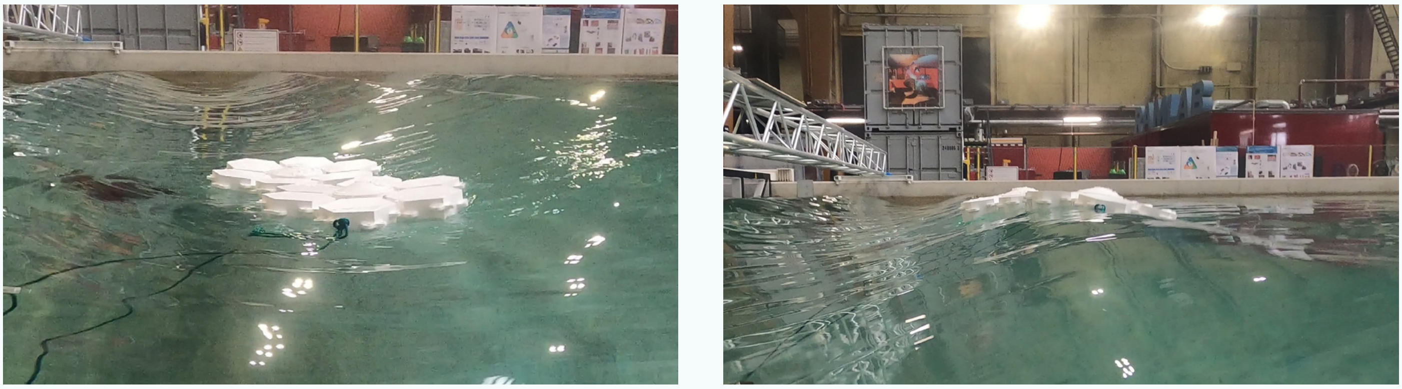


Figure 6.16: Scaled up version of the system.

6.8 Conclusion

The new system concept was detailed into a manufacturable product through iterations in the embodiment design process. The decision to keep some elements the same as the pilot was able to make this process more efficient. Ultimately, the biological subsystem looks very similar to the pilot version, but the added modularity and access for operators increases the performance. Based on the designs given and discussions with the Kemeling engineer, there are manufacturing plans for the system. The system iterations and final design plans can be seen in Appendix F.

This design process has also concluded the final diverging and converging phase. This culminates in the creation of the design proposal in the next section.

7

Design Proposal

7.1 Concept Design Proposal

7.1.1 Overview

The final design comprises seven modules: one biological, three storage, and three floats. Each module has a diameter or width of 1200mm. The float and storage modules are 500mm in height.

The modules are connected through pins and attachment pieces. The pins are made of hand-milled solid HDPE. They are created with notches so they can lock in place on the attachment pieces. Twelve pins are needed to connect the entire system. Every float and storage module has six attachment elements with two holes for pins. These attachment points can also serve as the place for fixing mooring lines. The current layout has the storage modules connected. This allows for easier wiring between modules. It is not projected to cause the system to be misaligned or off balance due to the size of the modules. This can be changed, and weights can be added to the system if needed.

The entire system is made out of 12mm thickness HDPE. The majority of the system is made out of black as it is cheaper and more accessible, but the tops of all modules are white. This is to reduce the heat absorbed from the sun.

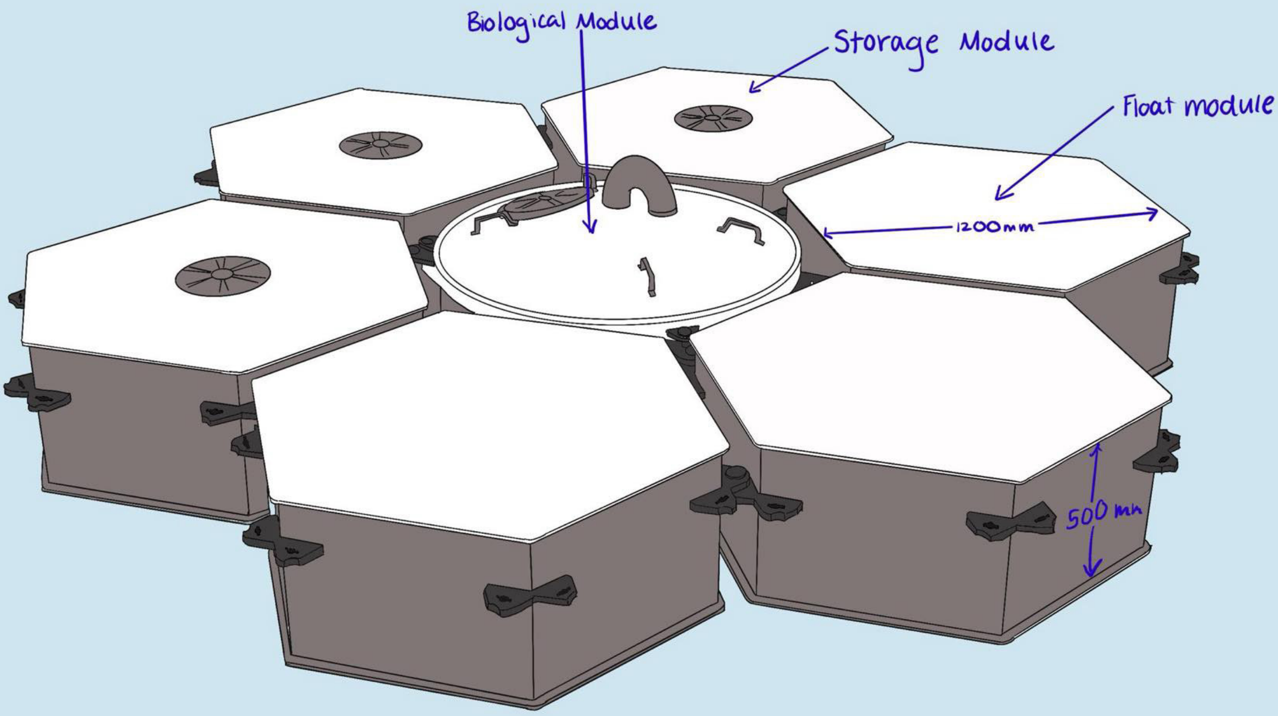


Figure 7.1: System Overview

7.1.2 Biological Module

The biological module is made out of several components. The main body is a large cylindrical piece with a cone at the base. These elements are bent and rolled from large sheets of HDPE and welded together. Inside the module contains the floating plate and the coral grid mounting. The floating plate is the same design as the pilot system and can hold 6 barrels for fish eggs. The coral grid mounting is 40mm in width and welded to the interior of the main body. More testing needs to be done to determine how to grow coral within the system, but this will allow for a future grid to be fastened here. At the base of the cone of the main body is an open pipe, which allows the system to fill with water as well as output the water filtered from the barrels. This pipe is surrounded by a larger cylindrical pipe piece, which can also act as a keel and a stand when out of the water.

The lid of the system is based on the pilot. There is a large pipe in the centre. This allows air into the system but has a gird at the end which does not allow birds or other predators into the system. To provide the operators access to the system, there is a smaller lid port where operators can access the barrels without removing the entire lid. There are handles on the lid to rotate to access all barrels as well as help remove the entire lid as needed. The whole lid will still need to be removed to clean the barrels between species or utilize the coral grid. Smaller pins of the attachment elements lock the rotational motion of the lid.

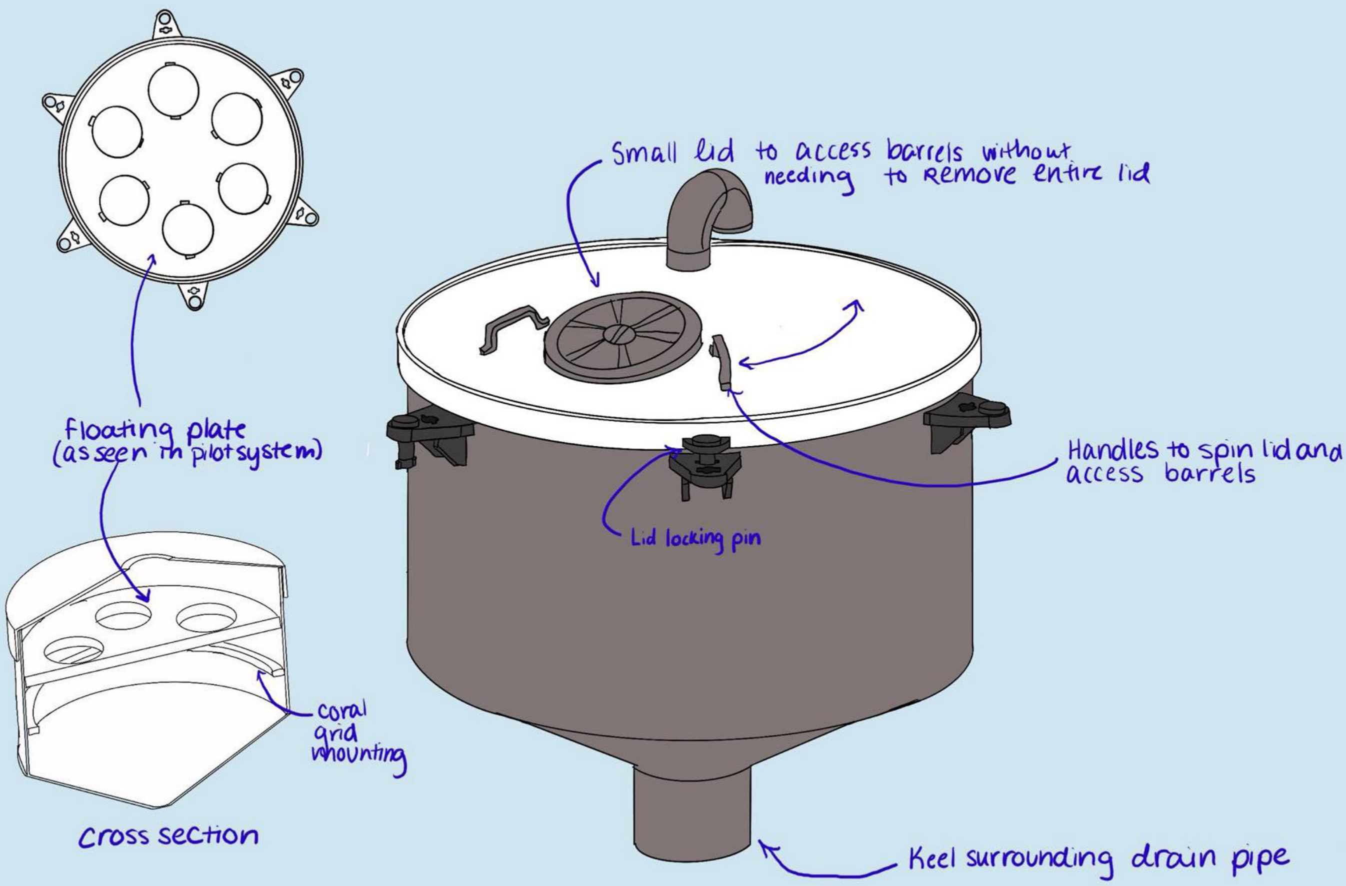


Figure 7.2: Biological Module

7.1.3 Storage Module

The storage module is a large hexagonal box which is mostly hollow. Inside the storage module is a compartment to hold the electronics and other components. The internal storage box is 530mm by 530mm by 340mm depth. This will store the components necessary for the current system and allow these components to change. To prevent water buildup in this compartment, any water that could enter can be drained to the rest of the module outside of the compartment. Two holes will need to be drilled through the compartment and main body wall to wire connections to the biological module or other storage modules. This will help prevent water from accumulating on electronic components. The lid on the module is the same type which is on the storage boxes on the pilot system and has a 270mm diameter. This lid size is the largest standardized lid available from the manufacturer. Since the element is standardized, the manufacturing is easier, quicker, and cheaper.

There is an internal support structure which makes the modules more sturdy and supports operators standing on them. The professional engineers at Kemeling manufacturing determined these support structures.

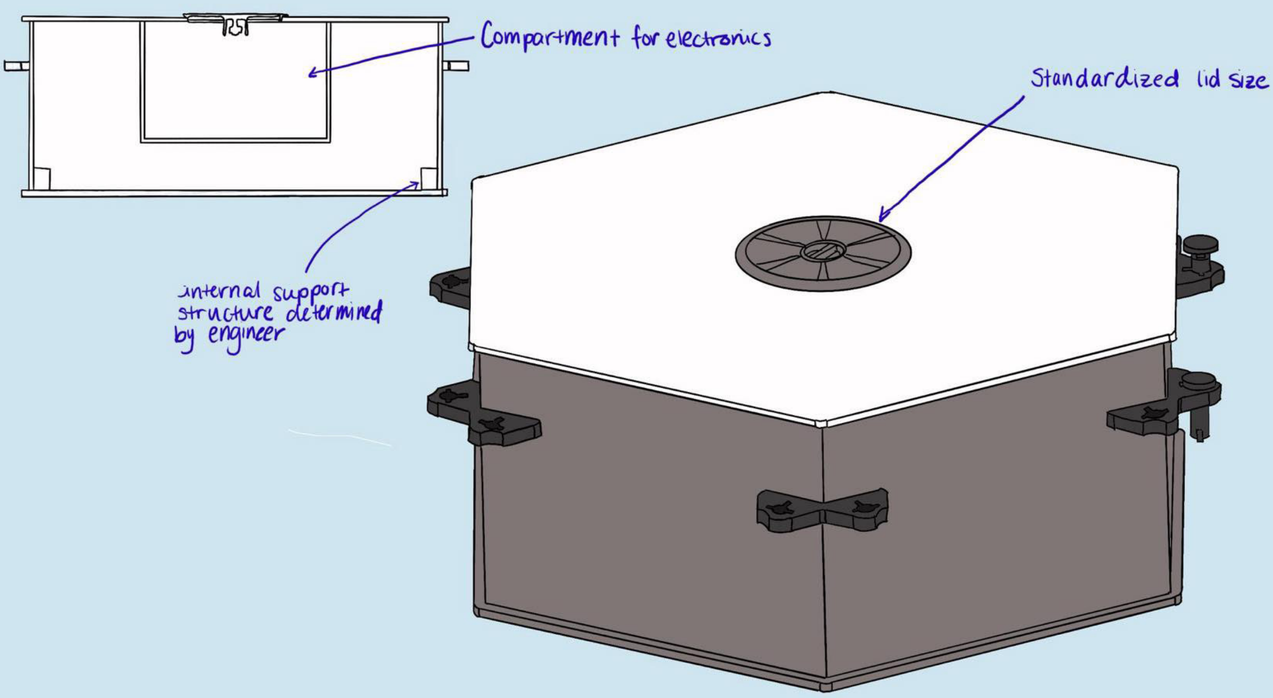


Figure 7.3: Storage Module

7.1.4 Float Module

The float module comprises the same internal components as the storage module; the only thing missing is the lid to access the electronics compartment. This is so if more storage is needed in the future, it will not be difficult to add. The float module can be present to give the operators access to all sides of the biological module. The float module would also be the placement of the solar panels. In this new concept, a switch to semi-flexible, marine-grade solar panels is recommended. These solar panels can support people walking on top of them and would fit atop the module.

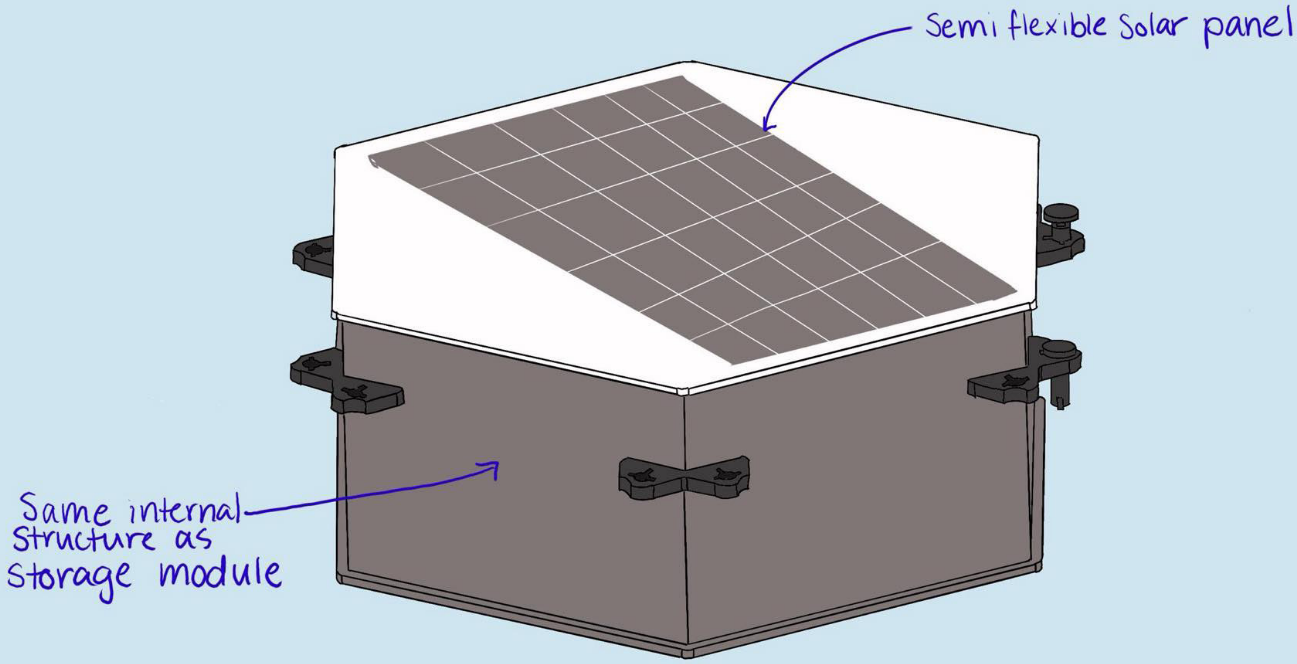
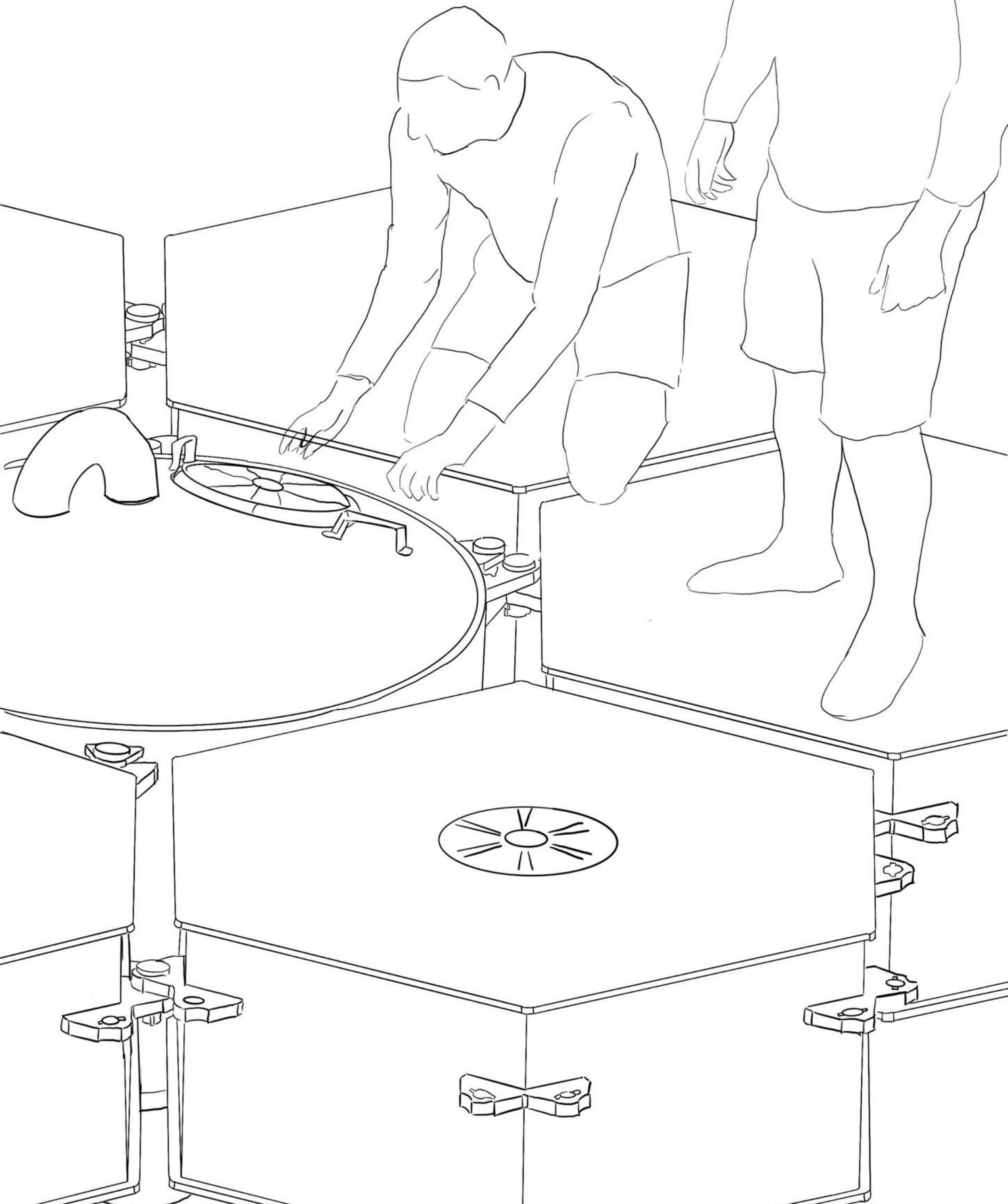
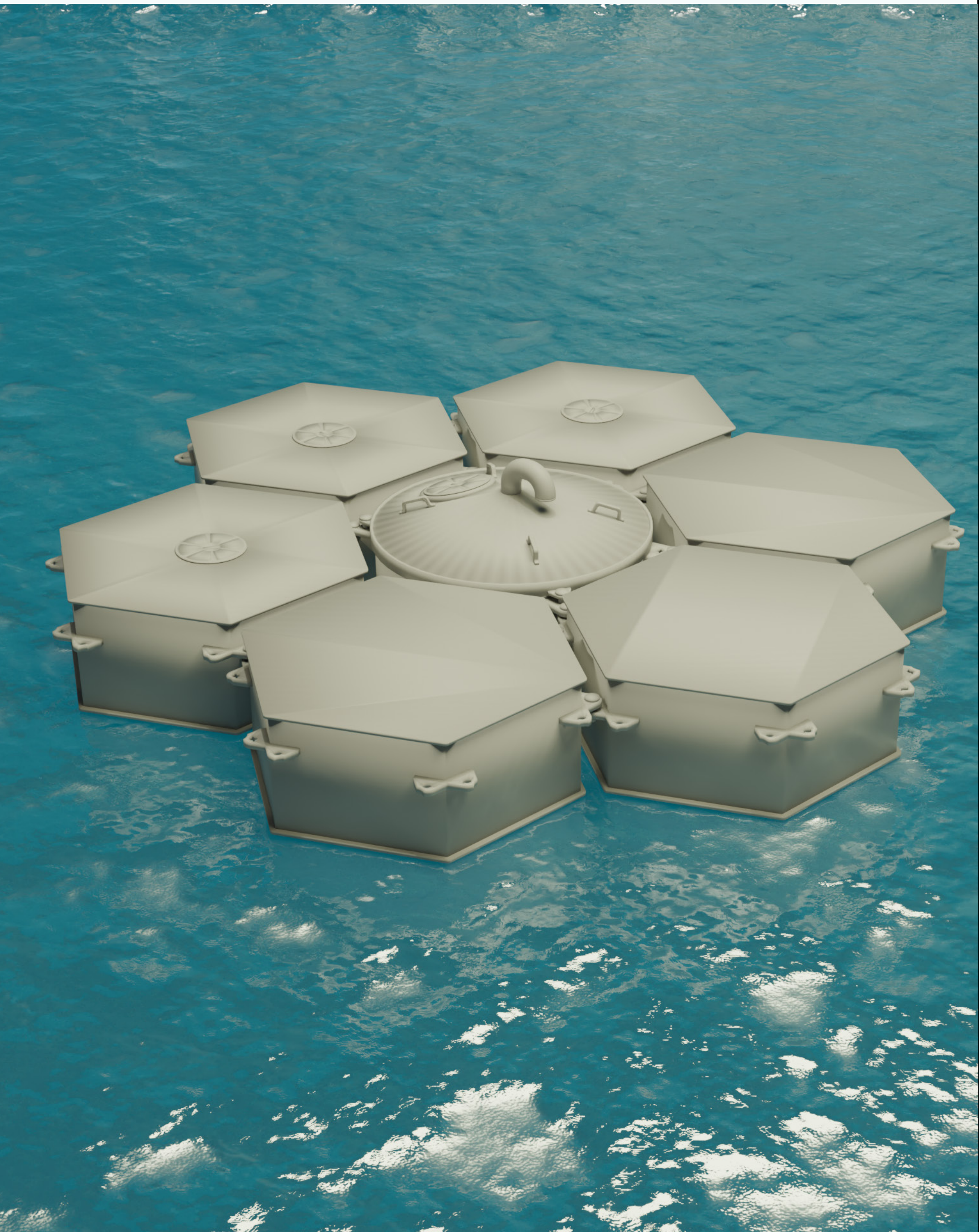


Figure 7.4: Float Module





7.2 Requirements Assessment

For a successful redesign, improvement must be shown from the current product. Using the requirements, as established in Chapter 3, the new system can be assessed. This information can be seen in Figure 7.5 as well as Appendix A.

Overall, the new design can meet more requirements than the current version. The notable improvements are in stability, scalability, and accessibility. The new design still only partially meets requirements 3.1, 3.3, and 4.3 regarding simplicity, growing other marine life, and space for future elements.

In terms of simplicity, the modular design leads to a more complicated product in many ways. More parts are needed, many of which are not standardized. This could be improved in a future version. Regarding the 3.3 and 4.3, the new system has addressed these partially but more research needs to be done on how to complete them fully.

7.3 Product Assessment

Typically, a successful product must be shown to be desirable, feasible, and viable.

7.3.1 Desirability

The new design has been shown to be desirable to the RoffaReefs team. It has been shown to other experts and funders of the project to help gain further investment. A video from the testing was shown at the European Union of Aquarium Curators conference to help show progress in the RoffaReefs project overall.

7.3.2 Feasibility

The feasibility of this product has been approved by the engineer who helped with the embodiment. Final drawings and manufacturing plans have been made they are just awaiting funds to create it. Where the product struggles in feasibility is the high cost associated. The final estimate for the manufacturing was around €50.000, a barrier for RoffaReefs. The high cost is associated with the amount of material needed and the hand-machined and welded elements. There are ways to reduce costs, which must be examined in a future study.

7.3.3 Viability

The product will be viable against the contextual and environmental effects due to the material choice and construction. The new system can also be adapted to future scenarios. The viability could be improved by manufacturing. It is pretty complex and must be done in the Netherlands before being shipped to Bonaire. To improve its viability, it should be more easily manufacturable and repairable on-site.

Roffa Reef Goals	Requirement	Related Subsystem	Assessment of Current Product*	Assessment of Final Design	Validation Method
1. Product must create a suitable environment for larvae	1.1 Water pump ensures a refresh rate of at least 24 times per day.	Biological	Green	Green	RoffaReefs Feedback
	1.2 Barrel shape must maintain the consistent flow output of the aerator pump with no stagnant areas.	Biological	Green	Green	RoffaReefs Feedback
	1.3 Aerator in system creates flow within barrels.	Biological	Green	Green	RoffaReefs Feedback
	1.4 The system's lid must prevent predator and exterior water entry having no upward facing openings or any openings larger than 10 mm.	Structural	Green	Green	RoffaReefs Feedback, Kemeling Engineer Feedback
	1.5 Reduced movement in wavy conditions	Structural	Yellow	Green	**Testing (Ch 6.8)**
	1.6 System needs to be able to generate enough power per day to power pump system.	Power	Green	Green	RoffaReefs Feedback
	1.7 The system must store enough power to sustain continuous operation for at least 24 hours during periods without generated power.	Power	Green	Green	RoffaReefs Feedback
2. Product needs to withstand all potential ocean conditions	2.1 The system must float in saltwater with a capacity of 150 kg, including the weight of operators and equipment, without submerging below the water line.	Structural	Green	Green	Kemeling Engineer Feedback
	2.2 Materials should have no less than "excellent" resistant rating to salt water, according to material database.	Structural	Green	Green	Granta Material Database
	2.3 Materials should be weldable to create water tight features that are able to withstand for at minimum one year.	Structural	Green	Green	Granta Material Database
	2.4 The system should have 3 or more possible attachment points for anchors.	Structural	Red	Green	RoffaReefs Feedback
	2.5 System needs to adapt to intense wave conditions.	Structural	Red	Green	**Testing (Ch 6.8)**
	2.6 There must be waterproof container that can contain the batteries and necessary electronic components.	Structural	Yellow	Green	RoffaReefs Feedback
3. Product is scalable	3.1 The product is as simple as possible by using standard pieces whenever possible.	Biological	Yellow	Yellow	RoffaReefs Feedback, Kemeling Engineer Feedback
	3.2 System can be scalable by having the option hold more than six species at one time.	Biological, Structural	Red	Green	RoffaReefs Feedback, **Testing (Ch 6.8)**
	3.3 System can grow other marine life	Biological	Red	Yellow	RoffaReefs Feedback
4. Product must be able to be used for scientific research	4.1 System allows for future integration of data collection devices.	Biological, Power	Red	Red	
	4.2 Microscopic imaging system must be able to capture a image of the eggs that is readable for AI.	Biological, Power	Red	Red	
	4.3 Product has remote monitoring to give operators consistent updates about the status.	Biological, Power	Red	Red	
	4.4 There must be space within the system for future elements.	Structural, Biological	Yellow	Yellow	RoffaReefs Feedback
	4.5 System must have a platform that surrounds the entire system that allows for operators to stand within arms distance of barrels.	Structural	Yellow	Green	RoffaReefs Feedback
	4.6 There must be a feature to assist operators on to the platforms.	Structural	Red	Green	RoffaReefs Feedback
	4.7 Removing/Moving the lid for daily samples does not require challenging motions.	Structural	Red	Green	RoffaReefs Feedback
	4.8 System must not be made with any toxic materials.	Structural	Green	Green	Granta Material Database

Figure 7.5: Requirements Assessment

Green = Meets

Yellow = Partially Meets

Red = Does not Meet

Assessment of the current product was done through communication with the RoffaReefs team.

7.4 Recommendations

There are several recommendations for the next steps of the system and further redesign.

Price reduction -

The final cost of the system manufacturing was too much for RoffaReefs' funding at this time. There are definitely ways to reduce the costs. Further research should be done into moulding or other forms of plastic manufacturing or looking at reducing the size of the modules to decrease material costs.

Full-Scale Testing -

Once the system has been manufactured, testing should be conducted to validate the requirements further. The system should be tested to see how it resists the environmental conditions and waves. With the full-scale testing, the assembly will also be essential to see. This redesign did not address how the wiring between the modules would look, and the full-scale model would have to be decided upon.

Additional accessibility -

More accessibility for the system could be added to the float or storage modules to help the operators who are approaching by swimming. Adding a handle to the module or a ladder would help them climb on board.

On-site manufacturing and materials -

Further study into how the system or elements could be manufactured in lower resource settings would help the project overall. It would be even better if certain elements could be made out of sustainable or natural materials.

End of life and Repairability-

Like with every product, there should be an end-of-life plan. Due to the choice of material and the permanent connections needed for working in the marine environment, recycling and end of life is complicated. Additionally, it should be ensured that the product can be repairable with available materials and skilled labor. Future studies should be done to see how to improve repairability to extend life and what will be done in the end.

7.5 Conclusion

The redesigned system, featuring a modular design with biological, storage, and float components, improves both accessibility and scalability. Initial tests have demonstrated enhanced stability in challenging marine conditions, paving the way for full-scale implementation and testing. The next version of the system is now ready for manufacturing, bringing it one step closer to supporting global coral reef restoration efforts.

This design is based in the literature and research done by RoffaReefs and is projected to help restore the Coral Reef ecosystem in the southern Caribbean and beyond. Further research and adjustments should be made to reduce costs and repairability.

In personal reflection, at the end of this project, I am very happy with the results. I am proud of all the hard work that I have put into this redesign and I am looking forward to seeing how the full scale model will preform if or when it is built. I learned a lot throughout the process, especially in the concept development phase. I was also happy to practice my engineering side in the embodiment phase. There is not a lot of things I regret doing or would change during the design process, I would only do more if the time allowed.

If you got this far, thank you again for your support!

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Appendices

A - Detailed List of Requirements
B - Technology Tree Details
C - Idea Sketches
D- Testing Videos
E - Granta Chart
F - Embodiment Iterations
H - Project Brief and Planning

Appendix A: Detailed List of Requirements

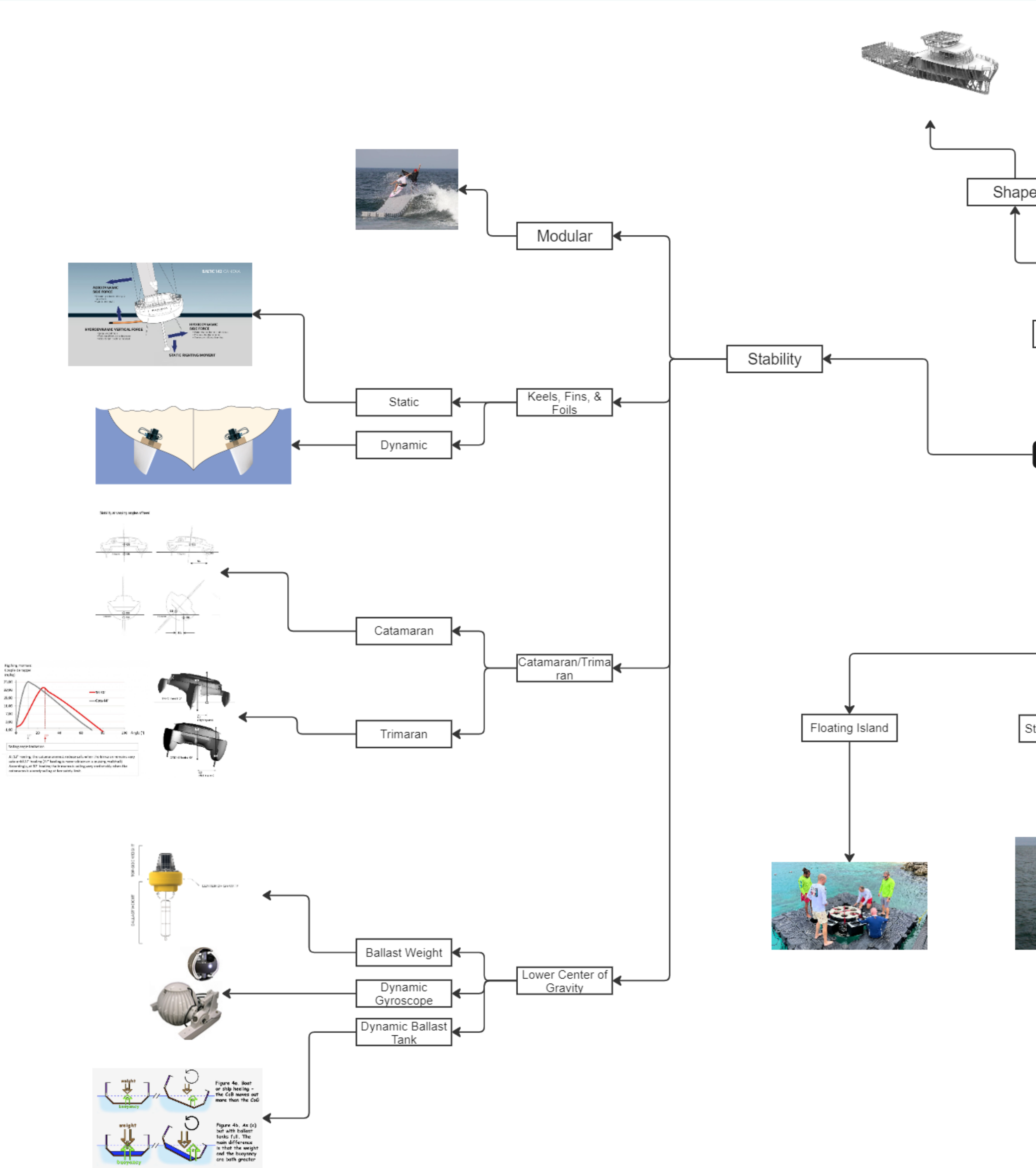
Roffa Reef Goals	Description	Requirement	Requiremen
1. Product must create a suitable environment for larvae	A suitable environment is defined as regulated temperature, larvae is provided food from nutrient rich ocean water, waste is filtered out, flow within the barrels, and provide protection for the eggs and larvae. Regulating the temperature, providing food, and filtering out waste is done through refreshing water withing the barrel. Therefore, the system needs to have a pump that can ensure the refresh rate within the barrel. This pump needs to have a high enough output and run 24/7. Protection for the larvae comes from keeping the predators namely birds and larger marine animals that could access the system from the top of the system as it floats. Eggs and larvae also cannot have too much physical agitation waves at risk of lowering their survival rate.	1.1 Water pump ensures a refresh rate of at least 24 times per day.	3.2: Biologica
		1.2 Barrel shape must maintain the consistent flow output of the aerator pump with no stagnant areas.	3.2: Biologica
		1.3 Aerator in system creates flow within barrels.	3.2: Biologica
		1.4 The system's lid must prevent predator and exterior water entry having no upward facing openings or any openings larger than 10 mm.	3.3 Structura
		1.5 Reduced movement in wavy conditions	3.3 Structura
		1.6 System needs to be able to generate enough power per day to power pump system.	3.4 Power Su
		1.7 The system must store enough power to sustain continuous operation for at least 24 hours during periods without generated power.	3.4 Power Su
2. Product needs to withstand all potential ocean conditions	With the ocean conditions, the product needs to float, be hurricane resistant, withstand long-term exposure to sun and salt water, and keep the electronics water safe.	2.1 The system must float in saltwater with a capacity of 150 kg, including the weight of operators and equipment, without submerging below the water line.	3.3 Structura
		2.2 Materials should have no less than "excellent" resistant rating to salt water, according to material database.	3.3 Structura
		2.3 Materials should be weldable to create water tight features that are able to withstand for at minimum one year.	3.3 Structura
		2.4 The system should have 3 or more possible attachment points for anchors.	5.2.2 Techno
		2.5 System needs to adapt to intense wave conditions.	3.3 Structura
		2.6 There must be waterproof container that can contain the batteries and necessary electronic components.	3.4 Power Su
3. Product is scalable	The system is adaptable to different contexts and system can grow and respond to more demand. For this the product must be able to fit into different environments while not having site specific features that limit use in other locations.	3.1 The product is as simple as possible by using standard pieces whenever possible.	2.6 Nature B
		3.2 System can be scalable by having the option hold more than six species at one time.	4.1 Ideal Sce
		3.3 System can grow other marine life	4.1 Ideal Sce
4. Product must be able to be used for scientific research	The system should collect data on surrounding environment and collect microscopic images of the larvae, operators must be able to take daily samples from the system, and the system overall should not threaten the surrounding environment.	4.1 System allows for future integration of data collection devices.	4.1 Ideal Sce
		4.2 Microscopic imaging system must be able to capture a image of the eggs that is readable for AI.	4.1 Ideal Sce
		4.3 Product has remote monitoring to give operators consistent updates about the status.	4.1 Ideal Sce
		4.4 There must be space within the system for future elements.	4.1 Ideal Sce
		4.5 System must have a platform that surrounds the entire system that allows for operators to stand within arms distance of barrels.	3.3 Structura
		4.6 There must be a feature to assist operators on to the platforms.	3.3 Structura
		4.7 Removing/Moving the lid for daily samples does not require challenging motions.	3.3 Structura
		4.8 System must not be made with any toxic materials.	3.3 Structura

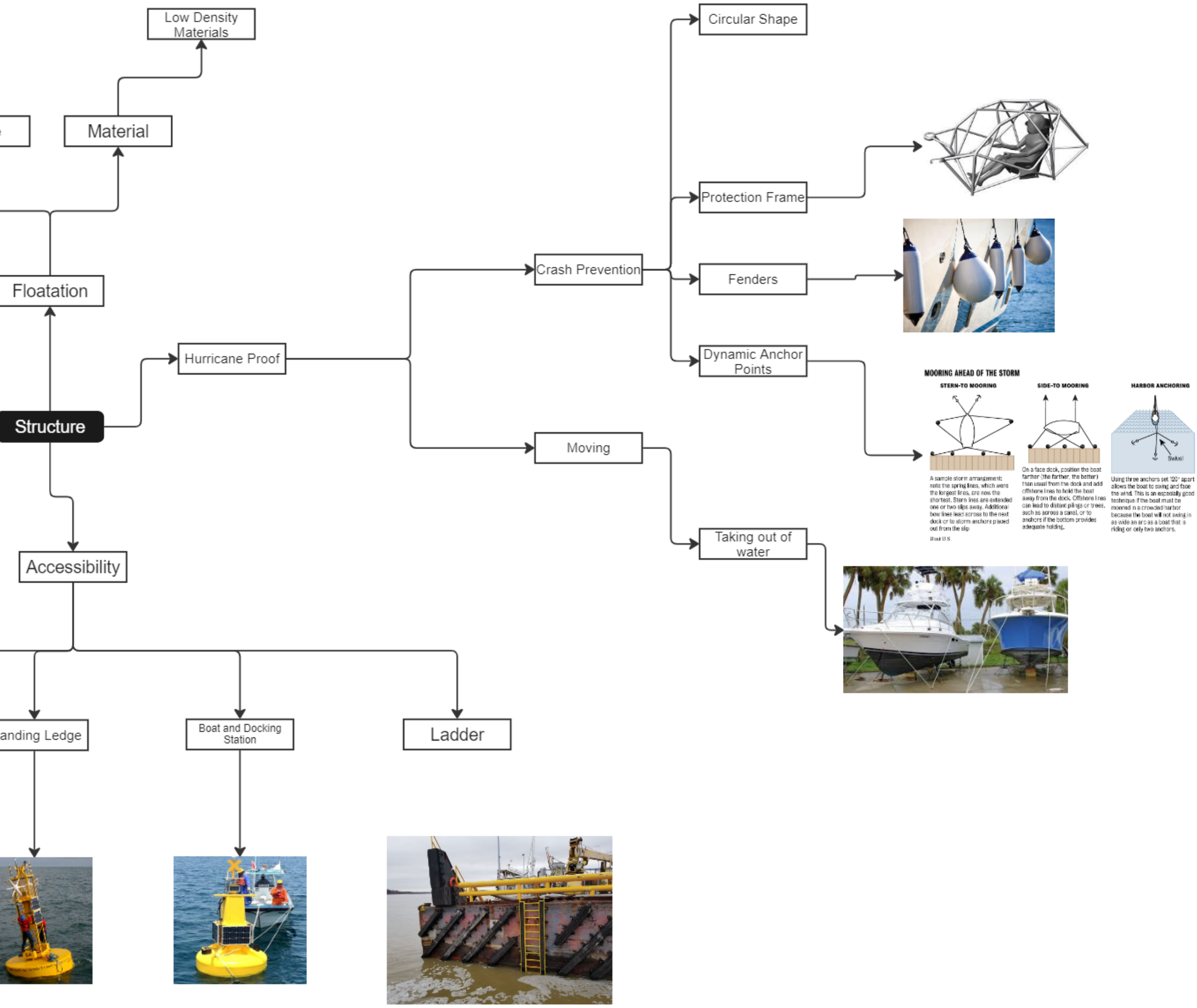
t Reference	Related Subsystem	Assessment of Current Product*	When Addressed in Project	Assessment of Final Design	Validation Method
al Subsystem	Biological		Integrate system from pilot (Chapter 3)		RoffaReefs Feedback
al Subsystem	Biological		Integrate system from pilot (Chapter 3)		RoffaReefs Feedback
al Subsystem	Biological		Integrate system from pilot (Chapter 3)		RoffaReefs Feedback
al Subsystem	Structural		Embodiment (Chapter 6)		RoffaReefs Feedback, Kemeling Engineer Feedback
al Subsystem	Structural		Concept Development (Chapter 5)		**Testing (Ch 6.8)**
ubsystem	Power		Integrate system from pilot (Chapter 3)		RoffaReefs Feedback
ubsystem	Power		Integrate system from pilot (Chapter 3)		RoffaReefs Feedback
al Subsystem	Structural		Concept Development (Chapter 5)		Kemeling Engineer Feedback
al Subsystem	Structural		Embodiment (Chapter 6)		Granta Material Database
al Subsystem	Structural		Embodiment (Chapter 6)		Granta Material Database
ology Mapping	Structural		Embodiment (Chapter 6)		RoffaReefs Feedback
al Subsystem	Structural		Concept Development (Chapter 5)		**Testing (Ch 6.8)**
ubsystem	Structural		Embodiment (Chapter 6)		RoffaReefs Feedback
ased Solutions	Biological		Concept Development (Chapter 5), Embodiment (Chapter 6)		RoffaReefs Feedback, Kemeling Engineer Feedback
enario	Biological, Structural		Concept Development (Chapter 5), Embodiment (Chapter 6)		RoffaReefs Feedback, **Testing (Ch 6.8)**
enario	Biological		Embodiment (Chapter 6)		RoffaReefs Feedback
enario	Biological, Power		Future (Unaddressed)		
enario	Biological, Power		Future (Unaddressed)		
enario	Biological, Power		Future (Unaddressed)		
enario	Structural, Biological		Embodiment (Chapter 6)		RoffaReefs Feedback
al Subsystem	Structural		Concept Development (Chapter 5)		RoffaReefs Feedback
al Subsystem	Structural		Embodiment (Chapter 6)		RoffaReefs Feedback
al Subsystem	Structural		Embodiment (Chapter 6)		RoffaReefs Feedback
al Subsystem	Structural		Embodiment (Chapter 6)		Granta Material Database

* Assessment of current product was done through communication with the RoffaReefs team

Green = Meets Req, Yellow = Partially Meets, Red = Does not meet

Appendix B: Detailed Technology Tree




Low Density Materials
Material
Floatation
Structure
Hurricane Proof
Accessibility
anding Ledge
Boat and Docking Station
Ladder
Crash Prevention
Moving
Circular Shape
Protection Frame
Fenders
Dynamic Anchor Points
Taking out of water
MOORING AHEAD OF THE STORM
STERN-TO MOORING
SIDE-TO MOORING
HARBOR ANCHORING

Stability -
Modular

Modular floating structures are used in variety of contexts from small scale dock to large offshore wind farms.

Roffa Reefs currently use a modular docking system as the floating island. These floating docking systems have been shown to withstand against wavy and ocean conditions.

Keels, Fins, & Foils

Keels, fins, and foils are the substructures of boats that aid with stability and movement through the water. The keels work by opposing the aerodynamic forces above the surface.

Luxury yachts and large cruise ships have powered fins to help with maintain stability.

Affecting Center of Gravity

The stability of a floating structure is determined by the locations of the center of gravity and center of buoyancy and their relation to each other. In wavy conditions, the center of buoyancy can move as the waves rock the structure. To reduce this rocking or instability, these structures should be designed to either be less affected by these conditions or recover quickly from being unstable.

Static systems like a large ballast weight can lower the center of gravity and make these structures less affected by wavy conditions.

Dynamic systems can respond to the current conditions and help aid in a fast recovery time in wavy conditions. Ballast chambers have been in use in cargo shipping for centuries. Once a ship delivers its cargo, weight, typically in the form of water, would be added in order keep the center of gravity low.

To help the boat recover from instability, some have powered gyroscopic systems that can change the center of gravity in response to the center of buoyancy.

Catamaran/Trimaran

Catamarans are designed so the center of buoyancy will not moves as much as in a traditional boat.

Flotation -

To ensure that a product floats, the only thing that matters is its density. The density can generally be affect by the material or shape choice. Low density materials need to have a density lower than water in order to float this can include common manufacturing materials like wood or some plastics. However, how most floating structures are design by shape. Creating hollow structures even out of high density materials can help them float. The product needs to weigh less than the amount of water it displaces in order to float.

Hurricane Proof -

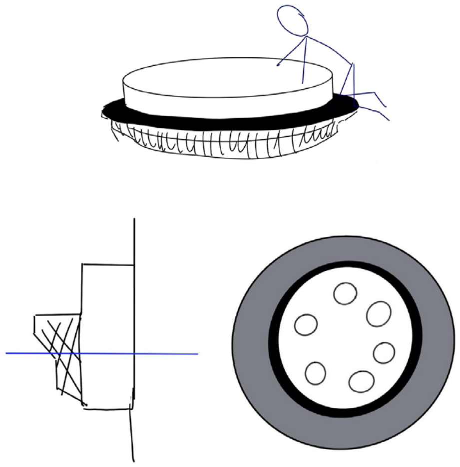
Hurricanes and big storms are definitely a risk when working on the ocean. They can bring extreme winds, large waves, and strong currants. The most likely and worst risks that could come with a storm is the system becoming lose from anchoring and either flipping or crashing into sometime else in the sea.

Typically, hurricane are tracked and there is time to prepare. Preparations can look like adding additional mooring lines, adding fenders, or pulling the system out of the water.

Collision protection can take inspiration from the automotive industry with bumper and roll cages. These can help distribute the forces and protect internal structures.

Appendix C: Idea Sketches

1. Crash frame kneeling platform



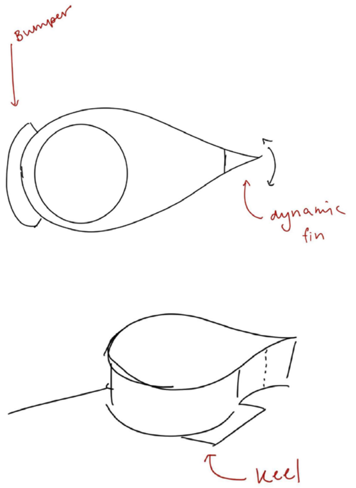
Shape: Circular

Stability: Circular to help maintain stability

Crash resistant: Bumper/cage to absorb force

Accessibility: Kneeling platform for operator access

2. Raindrop with fin



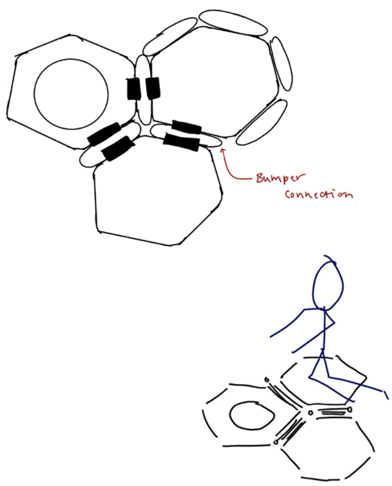
Shape: Streamline/Raindrop

Stability: Streamline shape, dynamic fin to reposition, keel

Crash resistant: Bumper to support critical points

Accessibility: Needs floating island

3. Modular hexagons



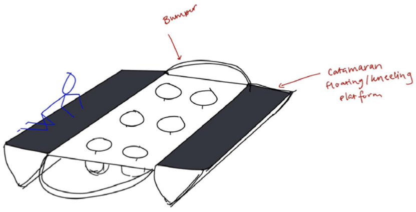
Shape: Modular hexagons

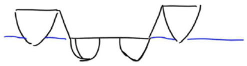
Stability: Flexible connection to "ride the waves"

Crash resistant: Hexagons connected with fenders

Accessibility: Hexagons serve different purposes including a kneeling platform

4. Catamaran





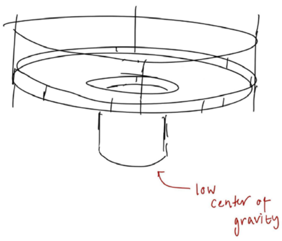
Shape: Square

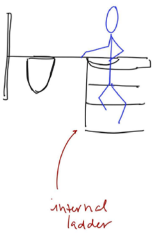
Stability: Catamaran shape

Crash resistant: Bumper to protect internal systems

Accessibility: Kneeling platform on catamaran structure

5. Central Ladder





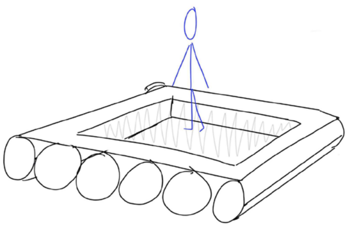
Shape: Donut shape with hole in the middle

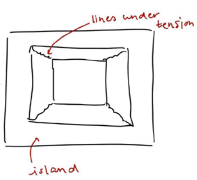
Stability: Circular and lower center of gravity

Crash resistant: Circular shape

Accessibility: Hole in the middle also has a ladder accessible by diving or standing while working

6. Floating dock





Shape: Square

Stability: Four-point connection to floating island

Crash resistant: Four point connection to floating island

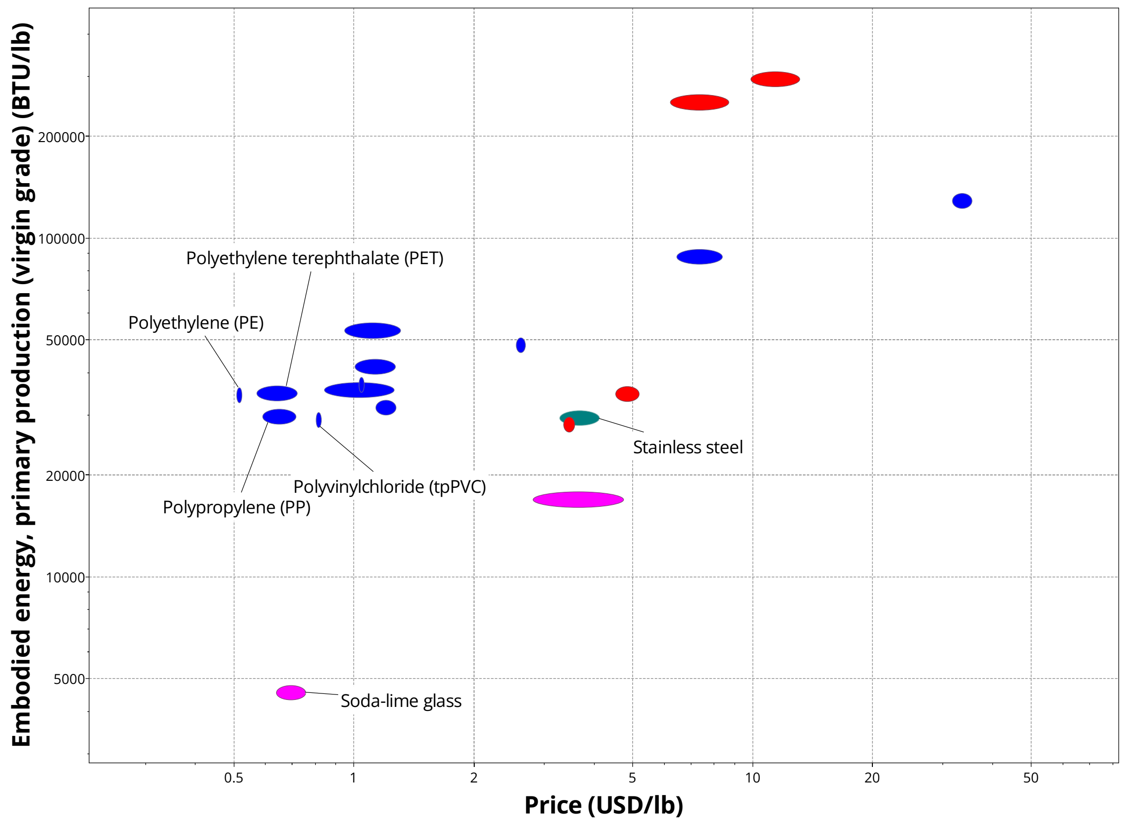
Accessibility: Completely flat on top and walkable, lid removes in sections

Appendix D: Testing Videos

https://www.youtube.com/watch?v=vdEHiSkYVGQ

Appendix E: Materials Chart

Stage 2: Embodied energy, primary production (virgin grade) (BTU/lb) vs. Price (USD/lb)



Appendix F: Embodiment Design Iterations

System Iteration 1 - 16/7

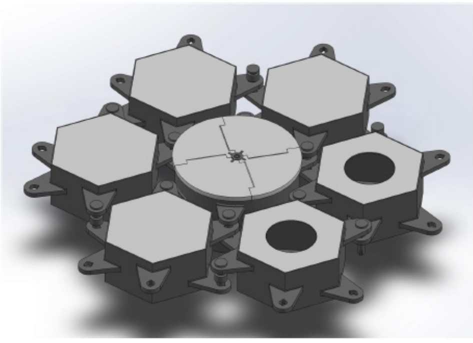
Roffa Reefs
System Assembly

16/07/2024

Overall System

Four Key Elements –

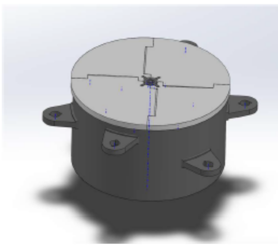
- Biology module
- Power/Storage module
- Float Module
- Pins and spacers

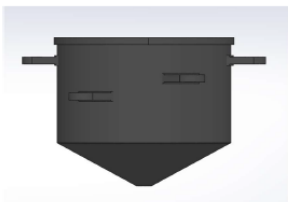


Biological module

Components-

- Main body
- Conical base
- Floating Plate
- Attachment points
- Lid subassembly



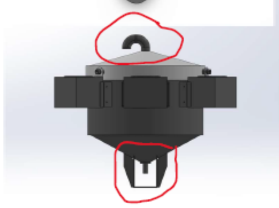


Main body, conical base, and floating plate:

All dimensions taken from the current system. The overall diameter is 1200 mm.

The plate has additional locking elements to keep the barrels/vessels in place. I haven't modelled these, but they should be included.

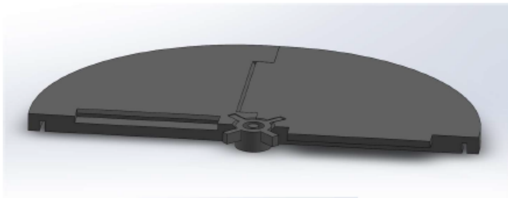
The current system has an additional substructure in the conical base that has not been included in my model. There is no venting like on the current system, but this can be added.

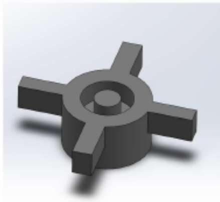


Lid is made up of 4 overlapping pieces that are secured all together with a pin in the middle. The lids hang over the outside of the main body of the biological module.

The lid should balance between minimizing tolerances so it's more watertight and making sure it's still easy to assemble.

Handles should/could be added to make them easier to remove.



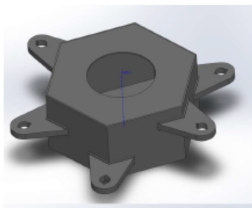


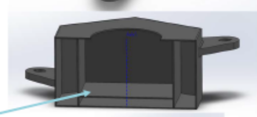
Power/Storage Module

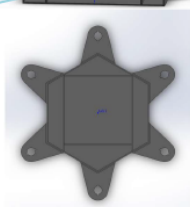
Overall structure is 1000mm across.

Internal structures so that it can support people standing on top of it. Currently, the actual storage area is around 600mm x 600mm.

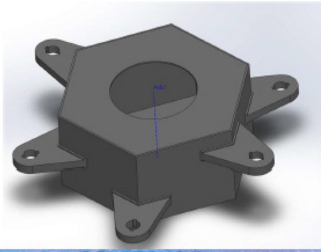
Adding an additional plate a bit off the base so that you don't have to drill into the actual main body if anything needs to be fastened in with bolts. Additionally, the electronics won't be sitting in water if some does get in. I am not sure if this plate should be welded to the other supports on have legs like a table.







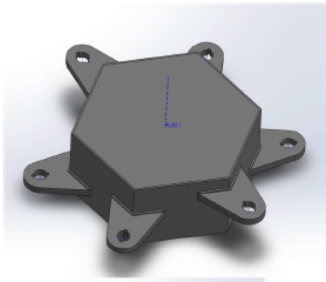
Current plan for lid is to use the same as on the storage boxes of the current system. It is possible to have an additional bar so that it can support people walking or standing on it. Currently the opening is modelled to be 500mm diameter.

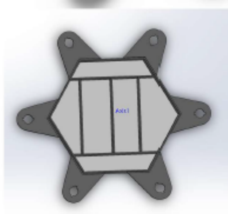


Float Module

Float module uses the same outside structure and attachment points as the storage module.

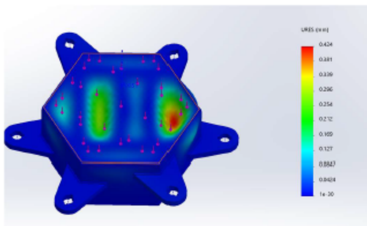
Module has an internal support structure so that it can support people standing on it.

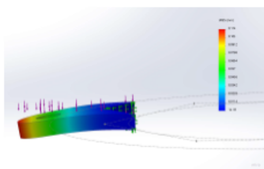




To determine the support structures, need in both power and storage modules simple FEA was done. 200kg force was applied to mimic one person standing on the module with a factor of safety. The support structure could be reduced to lower weight and material use.

The hexagonal attachment pieces were verified by simple FEA but could be reduced if necessary.

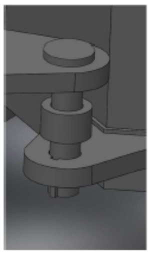


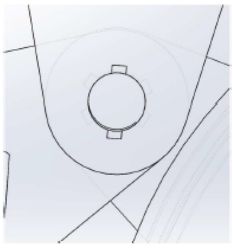


Pins and spacers

Pin holes have notches to lock in place. Pin will have to be rotated to go through each segment.

Currently, the pins have a large diameter of 75mm, not including the notch pieces. The spacers used will have a larger internal diameter than the notches and pin diameter.





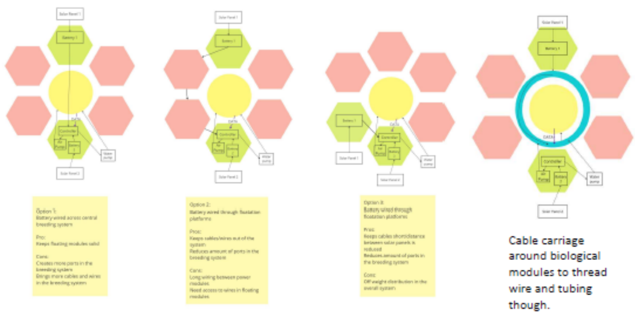
Wiring between modules

The wiring method differs according to the layout of the different modules. These are the questions that need to be answered:

Is it necessary that the power modules are opposite each other to distribute the weight more evenly?

Should there be access to the float modules so that tubing/wires can be through?

What are the drawbacks of how the current system is wired together and what needs to be improved?

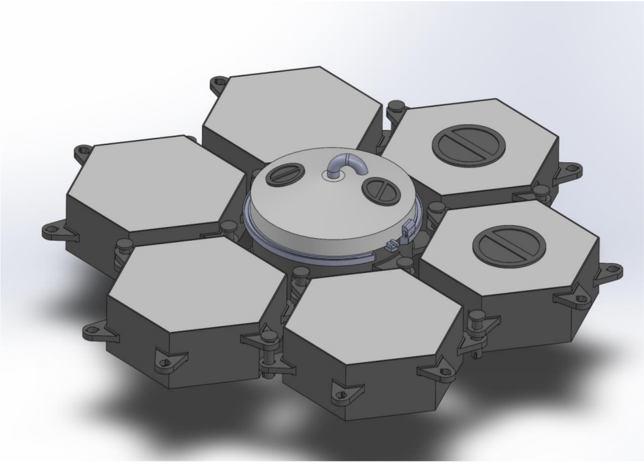


Cable carriage around biological modules to thread wire and tubing though.

System Iteration 2 - 23/7

Roffa Reefs System

Biology Module
Storage Module (x2)
Float Module (x4)
Pins (x12)



Bio Module

Components the same as the current system:

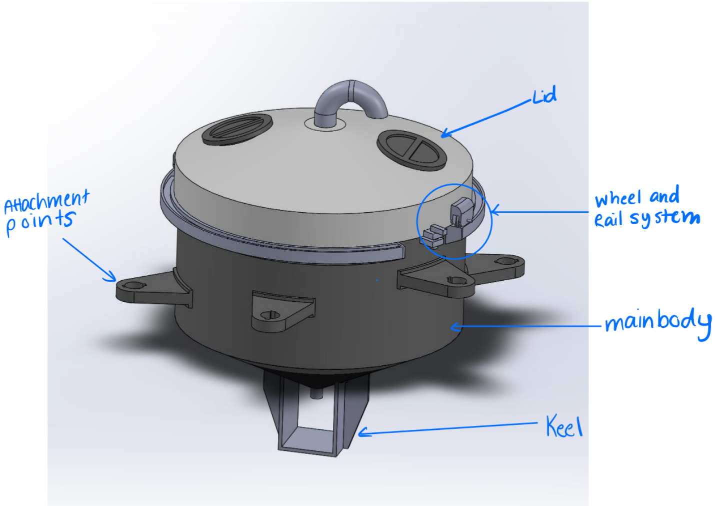
- Main body
- Floating Plate
- Keel system

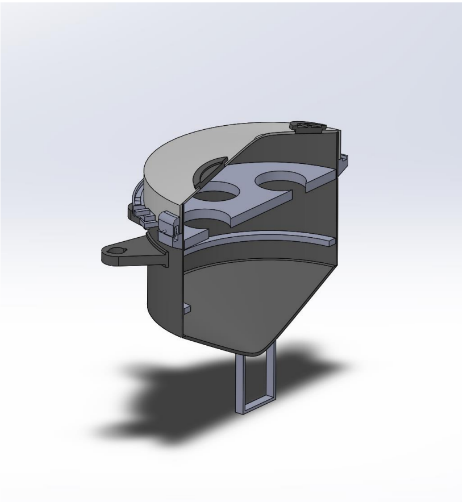
Existing Components that have changed from current:

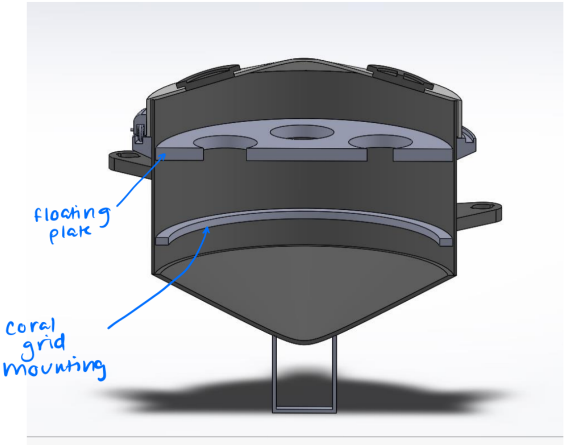
- Lid

New Elements:

- Attachment points
- Wheel and rail system for lid
- Coral Grid mounting







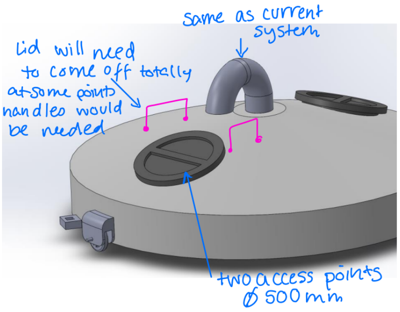
Lid Assembly

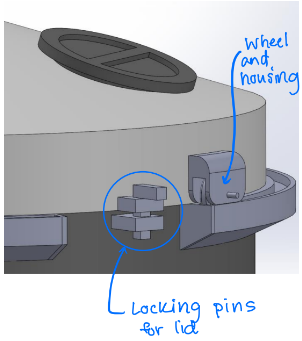
Same lid as current system except with additional entry points

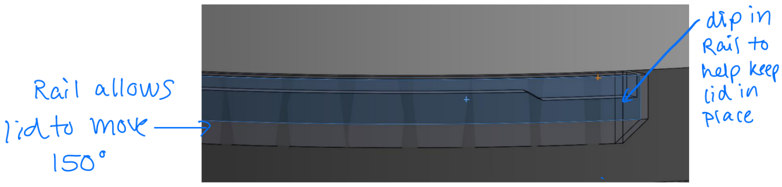
Wheel roller

Locking pin

Rail on main body

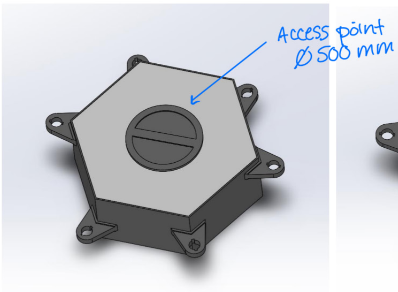


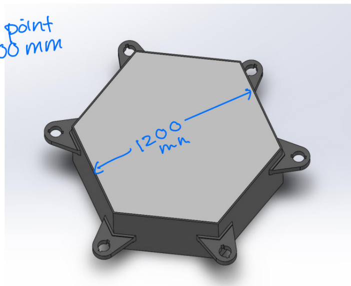


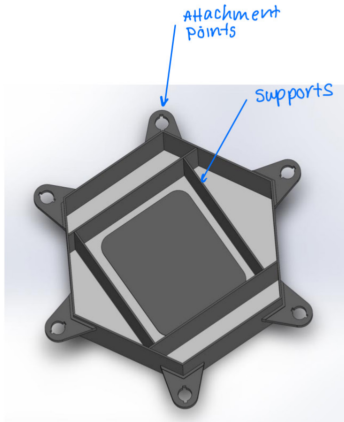


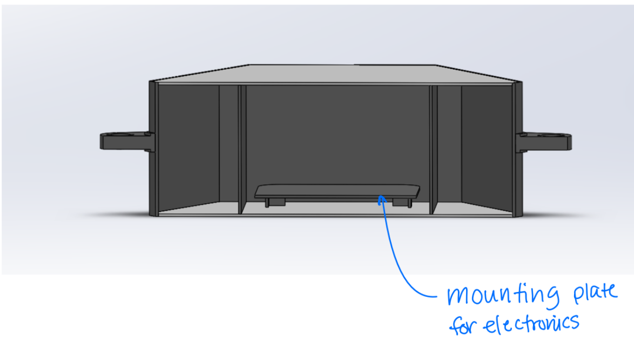
Float & Storage Modules

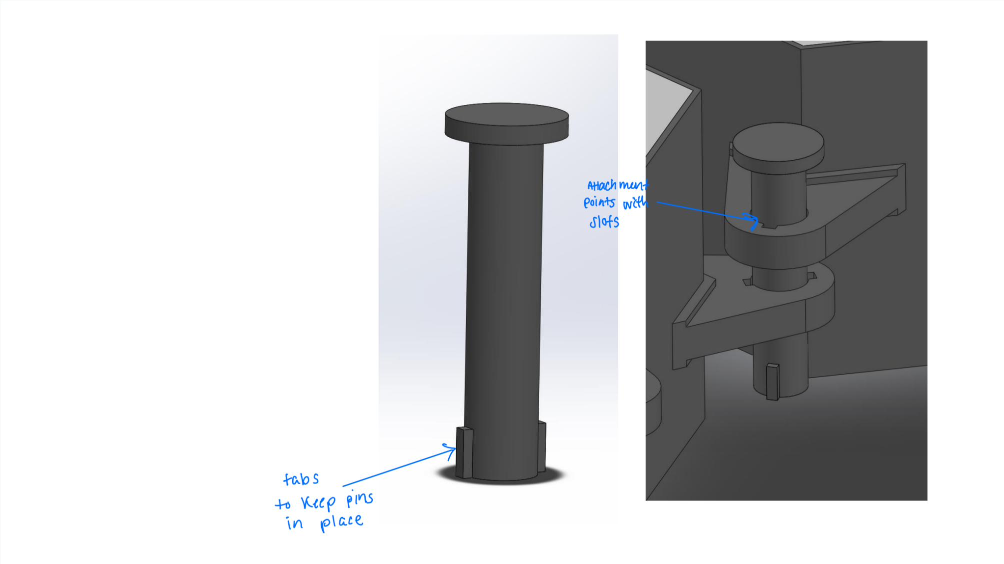
Float and store modules are the same on the inside, so if future expansion is needed, it is easier to integrate. The only difference is that the storage modules have a lid and are accessible.



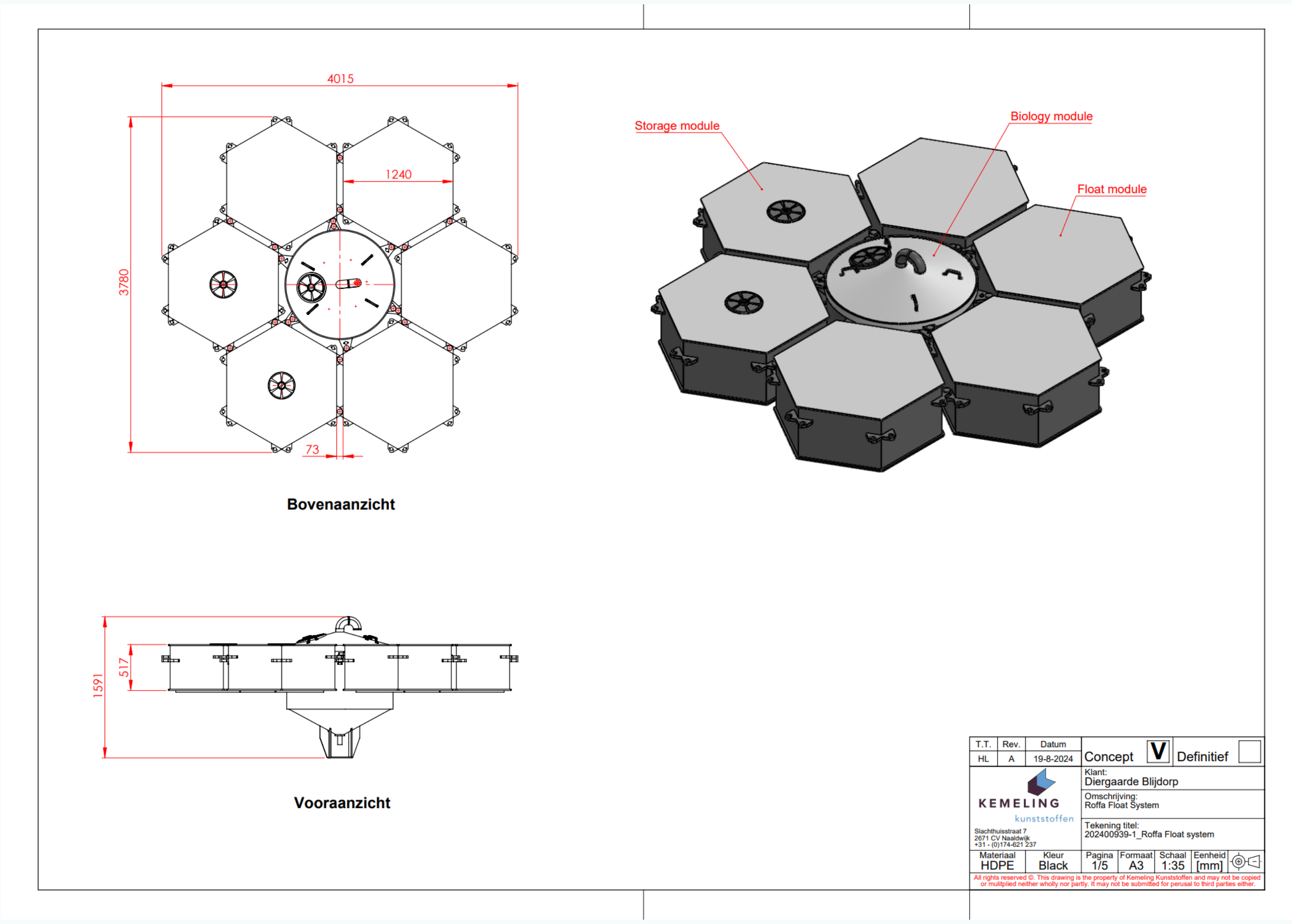


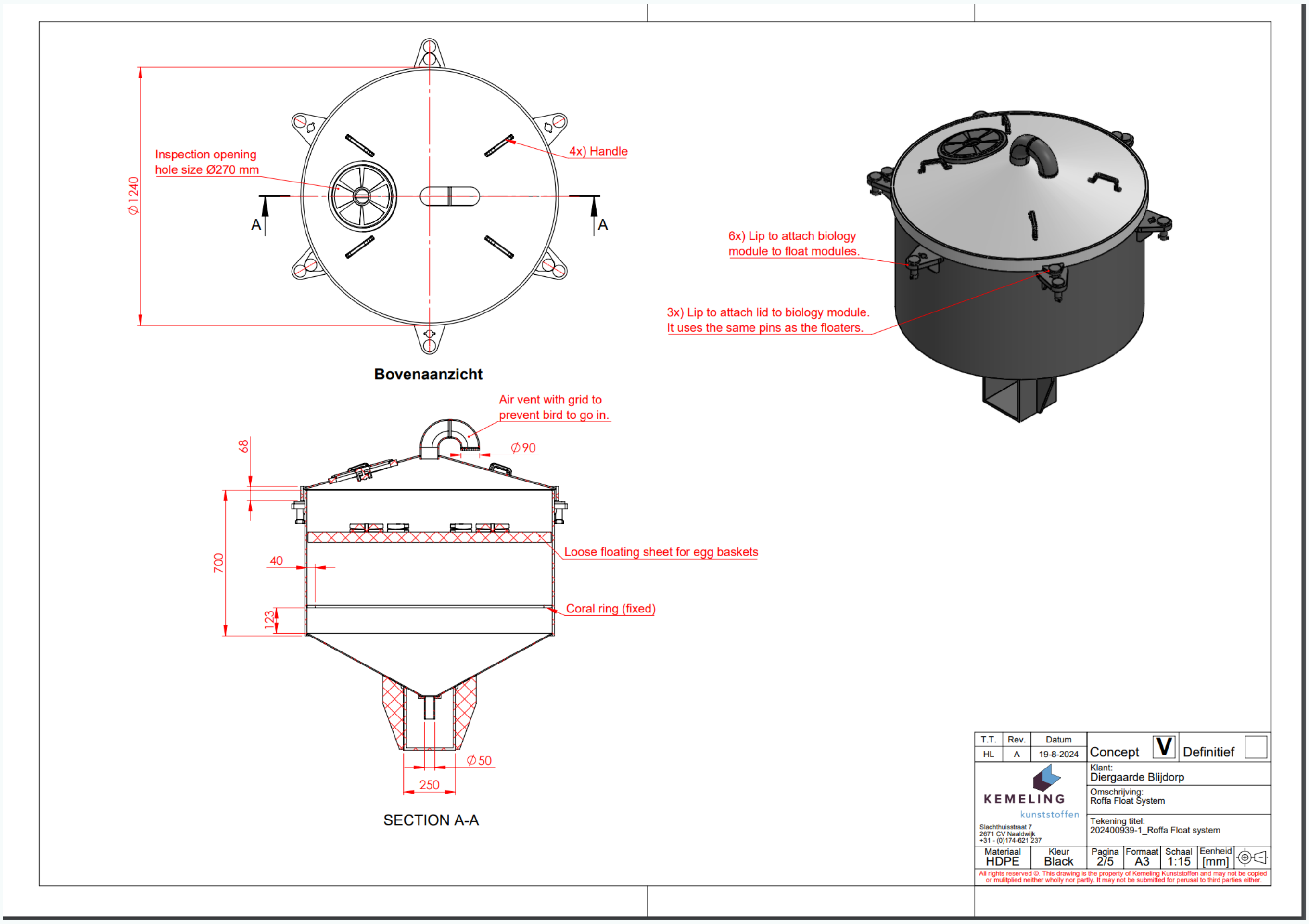


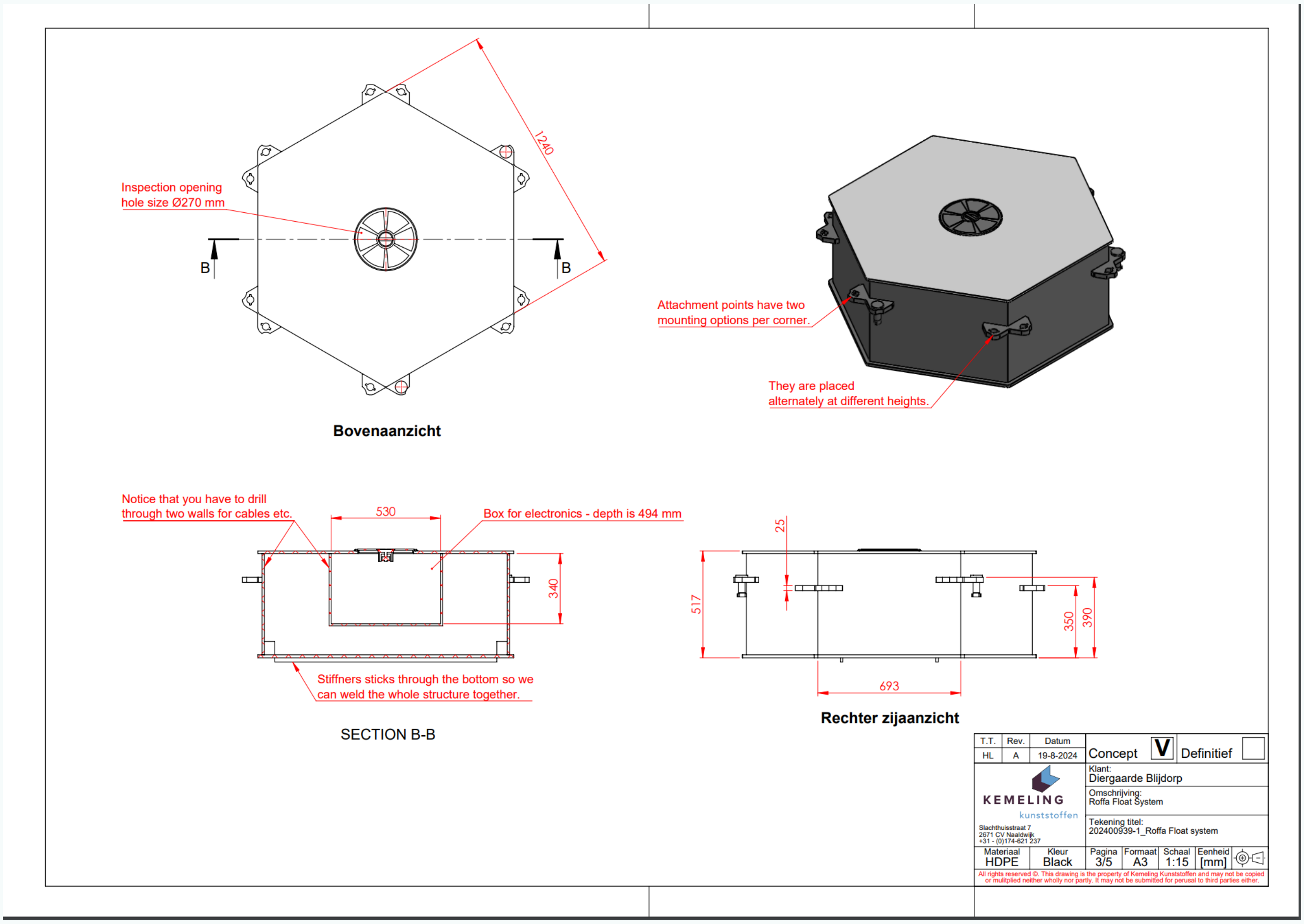


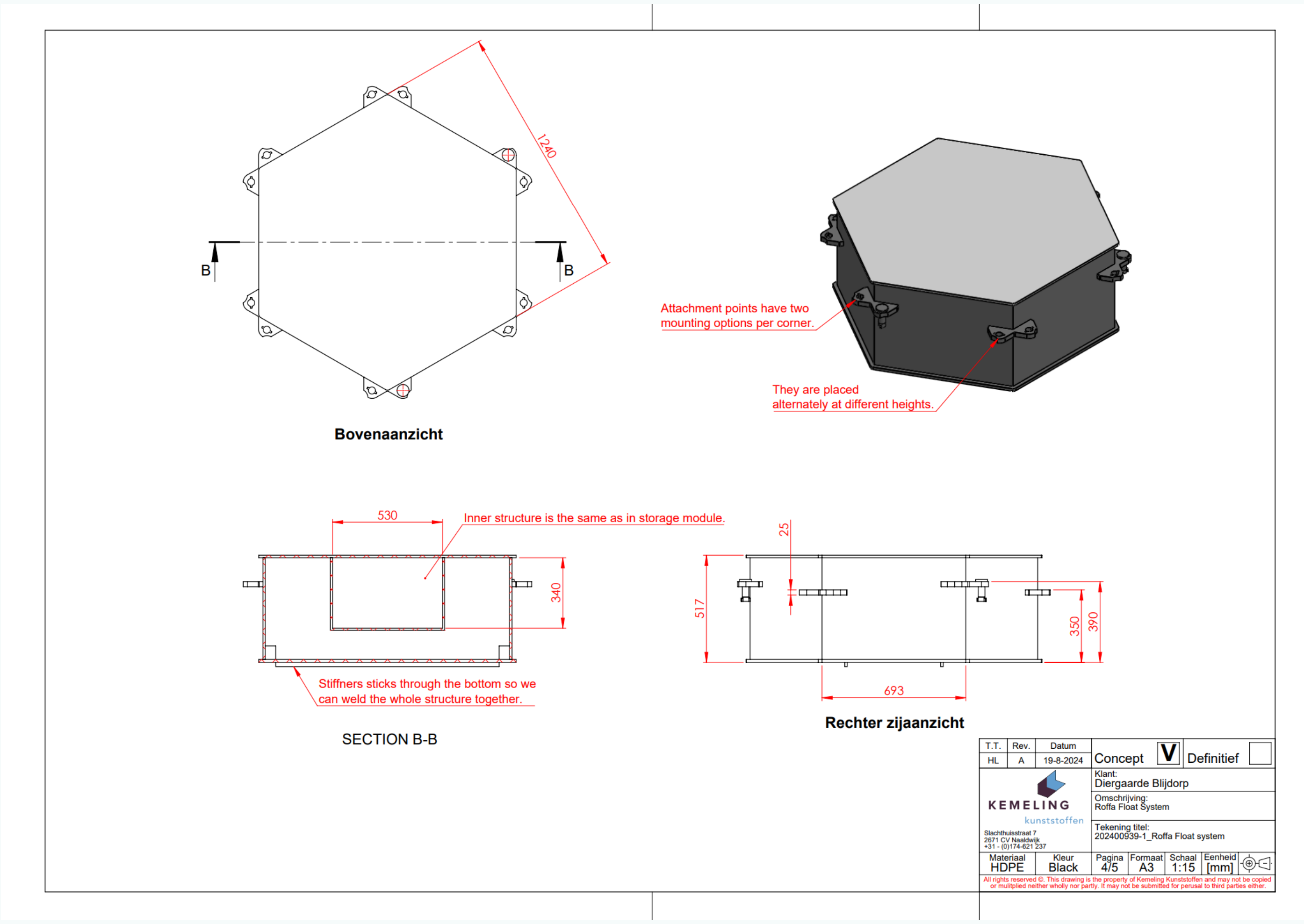


Kemeling Iteration




Inspection opening
hole size Ø270 mm
4x) Handle
Ø1240
A
A
Bovenaanzicht
6x) Lip to attach biology
module to float modules.
3x) Lip to attach lid to biology module.
It uses the same pins as the floaters.
Air vent with grid to
prevent bird to go in.
Ø90
68
700
40
123
Loose floating sheet for egg baskets
Coral ring (fixed)
Ø50
250
SECTION A-A
T.T.
Rev.
Datum
HL
A
19-8-2024
Concept
V
Definitief
Klant:
Diergaarde Blijdorp
Omschrijving:
Roffa Float System
Tekening titel:
202400939-1_Roffa Float system
KEMELING
kunststoffen
Materiaal
HDPE
Kleur
Black
Pagina
2/5
Formaat
A3
Schaal
1:15
Eenheid
[mm]


1240
Inspection opening
hole size Ø270 mm
B
B
Bovenaanzicht
Attachment points have two
mounting options per corner.
They are placed
alternately at different heights.
Notice that you have to drill
through two walls for cables etc.
530
Box for electronics - depth is 494 mm
340
Stiffners sticks through the bottom so we
can weld the whole structure together.
SECTION B-B
25
517
350
390
693
Rechter zijaanzicht
T.T.
Rev.
Datum
HL
A
19-8-2024
Concept
V
Definitief
Klant:
Diergaarde Blijdorp
Omschrijving:
Roffa Float System
Tekening titel:
202400939-1_Roffa Float system
KEMELING
kunststoffen
Materiaal
HDPE
Kleur
Black
Pagina
3/5
Formaat
A3
Schaal
1:15
Eenheid
[mm]


1240
B
B
Bovenaanzicht
Attachment points have two mounting options per corner.
They are placed alternately at different heights.
530
Inner structure is the same as in storage module.
340
Stiffners sticks through the bottom so we can weld the whole structure together.
SECTION B-B
25
517
350
390
693
Rechter zijaanzicht
T.T. Rev. Datum
HL A 19-8-2024
Concept V Definitief
Klant: Diergaarde Blijdorp
Omschrijving: Roffa Float System
Tekening titel: 202400939-1_Roffa Float system
KEMELING kunststoffen
Slachthuisstraat 7
2671 CV Naaldwijk
+31 - (0)174-621 237
Materiaal HDPE
Kleur Black
Pagina 4/5
Formaat A3
Schaal 1:15
Eenheid [mm]
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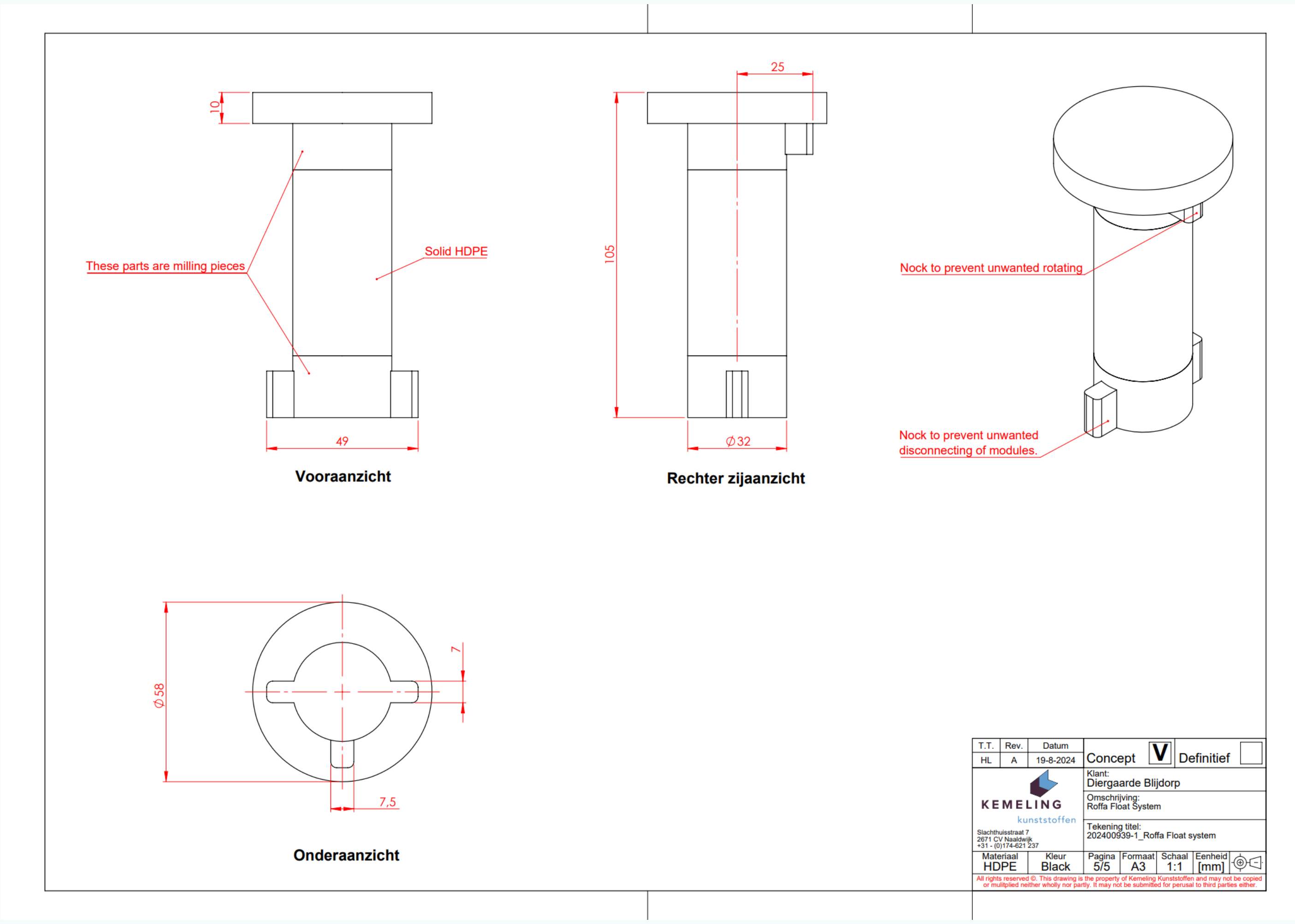
10
These parts are milling pieces
Solid HDPE
49
Vooraanzicht
25
105
Ø32
Rechter zijaanzicht
Nock to prevent unwanted rotating
Nock to prevent unwanted disconnecting of modules.
Ø58
7
7,5
Onderaanzicht
T.T. Rev. Datum
HL A 19-8-2024
Concept V Definitief
Klant: Diergaarde Blijdorp
Omschrijving: Roffa Float System
Tekening titel: 202400939-1_Roffa Float system
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Kleur Black
Pagina 5/5
Formaat A3
Schaal 1:1
Eenheid [mm]
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Appendix H: Project Brief

TU Delft

DESIGN FOR our future

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Murphy 7173	IDE master(s)	IPD ✔ / DfI ☐ / SPD ☐
Initials	M.D.	2nd non-IDE master	
Given name	Mairéad	Individual programme *(date of approval)*	
Student number	5691109	Medisign	☐
		HPM	☐

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Dr. Joana Martins	dept./section	SDE: Mechatronics
mentor	Natassia Jacobs	dept./section	HCD: Design Aesthetics
2nd mentor	Tim van Wagensveld		
client:	Roffa Reefs		
city:	Rotterdam	country:	Netherlands
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Joana Soares de Oliveira Martins

Digitally signed by Joana Soares de Oliveira Martins
Date: 2024.05.17 13:19:34 +02'00'

Name Joana Martins Date 17 May 2024 Signature

CHECK ON STUDY PROGRESS

To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ______ EC

Of which, taking conditional requirements into account, can be part of the exam programme ______ EC

★	YES	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Rik Ledoux Digitally signed by Rik Ledoux Date: 2024.05.23 09:37:28 +02'00'

Name Rik Ledoux Date 23 May 2024 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Monique von Morgen Digitally signed by Monique von Morgen Date: 2024.05.23 10:01:04 +02'00'

Name Monique von Morgen Date 23 May 2024 Signature

TU Delft

DESIGN FOR our future

Personal Project Brief – IDE Master Graduation Project

Name student Mairéad Murphy

Student number 5911009

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Improved Floating Fish Breeding System for Roffa Reefs

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Coral reef ecosystems are an essential part of the ocean environment that is extremely threatened due to climate change.

The loss of coral reefs not only affects marine biodiversity but also has negative impacts on food security, coastal protection,

and tourism. Restoring coral reefs is, therefore, critical to ensure the well-being of both marine and human communities.

Currently, there is a significant amount of projects into restoring the coral itself but it is important to also target the whole

ecosystem. RoffaReefs is a research initiative led by the Diergaarde Blijdorp to develop a floating fish breeding system to

strengthen the natural reef fish population and support coral reef restoration with the pilot taking place in Bonaire. A nature-based breeding system increased the survival rate of fish larvae and supported studies of the reproductive behavior of fish within their natural habitat. The fish breeding system provides a safe, encapsulated environment for endangered species to grow bigger and increase their chance of survival.

The RoffaReefs initiative has many partners including the World Wildlife Fund and the TU Delft Green Village. Local

collaborators include the PISKABON (fisheries of Bonaire), Dive Friends Bonaire, and Stichting Nationale Parken (STINAPA).

→ *space available for images / figures on next page*

introduction (continued): space for images

image / figure 1 Current Bonaire Pilot

image / figure 2

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

"Headstarting" in conservation is when endangered species are raised in a protected environment to then be released back into nature to help give them a better chance at survival. This is what is being done with fish larvae in the RoffaReefs system. RoffaReefs is currently working to design the next version of their breeding system. In discussions with the team, there are some challenges they are facing with the current system that they would like to tackle in the next version such as ensuring stability in wavy conditions, ergonomic issues with the operation, data collection integration, and creating opportutnities for upscaling.
For my project, I want to assess the current product and redesign the breeding system in order to improve the performance.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Redesign the floating fish breeding system for improve performance for Roffa Reefs.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

I am taking a research through design approach where the design direction drives the necessary research topics. I envision three major design iteration phases.

1. The first iteration focuses on narrowing the project scope. Understanding the system and necessary requirements by talking with experts. By the end off this phase I will be deciding on a more specific direction for this redesign.
2. The second phase is concept development with the focus on one design direction. Ideas will be prototyped and tested at scale as they are developed. This phase will see the development of three concepts and will end with one being chosen.
3. The third phase is detailing the chosen concept with the building and testing of a full scale prototype.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	29 Apr 2024
Mid-term evaluation	21/06/2024
Green light meeting	06/09/2024
Graduation ceremony	04/10/2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

Personally, ocean sustainability is something that I am extremely passionate about. I grew up in a small coastal community in the US where many people earn their living on the ocean through fishing. In my life, I have seen the way climate change is affecting the ocean. I want to be able to protect the ocean as well as make sure coastal communities are still able to have sustainable futures.
Additionally, coming from a mechanical engineering bachelor's, I want a project that combines both engineering and design. This project falls into the realm of embodiment design, I think this is a great way to practice and display both my educations.
My learning goals for this project are -
Strengthen my practical engineering and design skills - I am most excited about working on a functional product, being able to try many solutions, and working through problems as they come up.
Individual project management - I expect that individually executing a project for 20 weeks is the largest challenge. I have been learning and practicing project management skills throughout the MSc programme that I will need to employ.

IDE Thesis Project

Mairéad Murphy

Company: Roffa Reefs

Project start date: 4/29/2024