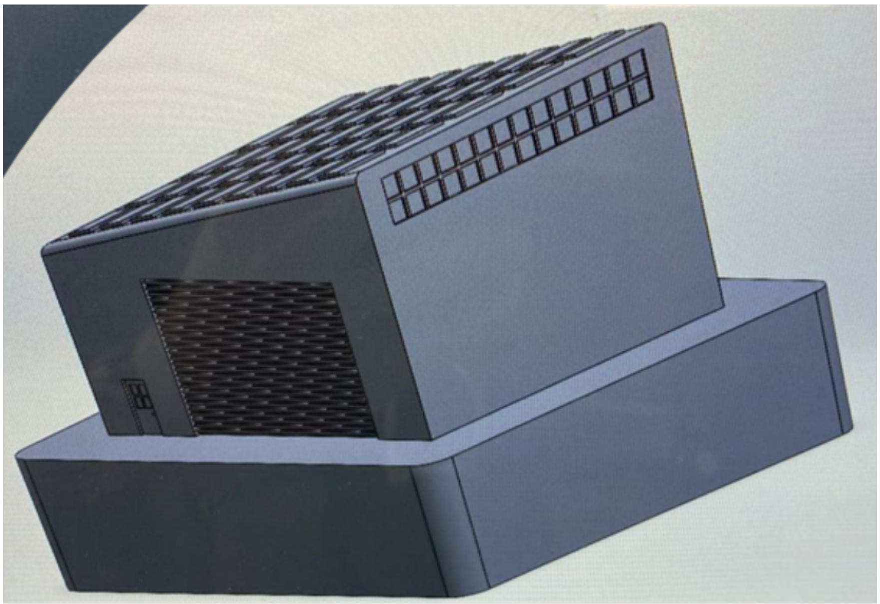

Designing a Sustainable Island for Electric Boat Charging

A Collaboration between Chalmers University of Technology, The Pennsylvania State University and Volvo Penta

Bachelor's Thesis in Engineering

CARL NORSTRÖM BERDENIUS, OLIVIA GREISZ, ALBIN PARMALM, ELINA SKOGLUND, MÄRTHA STAKE

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

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Cover image: A CAD model of one of the modules.

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Abstract

The increase of electric boats has highlighted the necessity for marine charging facilities. With numerous marinas lacking the requisite infrastructure to support a significant influx of electric boats, there is a pressing demand for charging solutions. This project featured the iterative process of creating an self-sustainable island that could facilitate the charging needs of electric boats, as well as attract other visitors. This required extensive research of solutions regarding energy, waste and water management, different facilities that could generate profit and costs related to all parts of the island.

The project involved a comprehensive concept development process, research over current technology and how it could me implemented. Creative methods were used to generate innovative ideas for the modular island. Through the iterative process, a final concept wad defined to meet the demands of Volvo Penta and electrical boat owners. Utilizing CAD models and 3D printing, the team was able to visualize the final concept, ensuring the design could be implemented.

The final island represented a complete off-grid solution for energy supply, water management and waste management, meaning it was independent of external energy sources, water supply and waste management systems.

Sammandrag

Ökningen av elbåtar har visat på behovet av marina laddningsanläggningar. Med många småbåtshamnar som saknar den nödvändiga infrastrukturen för att stödja ett betydande tillflöde av elbåtar, finns det en pressande efterfrågan på laddningslösningar. Detta projekt skulle presentera den iterativa processen att skapa en självförsörjande ö som kunde underlätta laddningsbehoven för elbåtar, samt attrahera andra besökare. Detta krävde omfattande forskning kring lösningar gällande energi-, avfalls- och vattenhantering, olika anläggningar som kunde generera vinst och kostnader relaterade till alla delar av ön.

Projektet innebar en omfattande konceptutvecklingsprocess, forskning kring aktuell teknik och hur den kunde implementeras. Kreativa metoder användes för att skapa innovativa idéer för den modulära ön. Genom den iterativa processen har ett slutgiltigt koncept definierats för att möta kraven från Volvo Penta och elbåtsägare. Med hjälp av CAD-modeller och 3D-utskrift kunde teamet visualisera det slutliga konceptet och säkerställa att designen kunde implementeras.

Den sista ön representerade en komplett off-grid-lösning för energiförsörjning, vattenhantering och avfallshantering, vilket innebar att den är oberoende av externa energikällor, vattenförsörjning och avfallshanteringssystem.

Acknowledgements

Throughout the course of the project, the group has received incredible help from many different parties. We would like to thank everyone who has helped us during this project. Special thanks to the other part of our team, Gustavo Capote, Keyu Chen, Elias Lopez, Ronit Patel, and Chase Watkins from The Pennsylvania State University. Many thanks to our supervisor Mikael who has not only helped us during the course of the project, but also gave us the opportunity to gather the entire team in the United States of America.

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Gothenburg, May 2024

Contents

1 Introduction

This report formed a part of the Department of Industrial and Materials Science at Chalmers University of Technology. The report presented a comprehensive analysis and modeling of an island intended to serve as a charging station for electric boats. The project was the result of a collaboration between Chalmers, Volvo Penta, and Penn State University. With a focus on sustainability and technological innovation, this collaboration aimed to develop a robust and efficient infrastructure for marine charging capabilities.

1.1 Background of the Project

The global desire to find more sustainable solutions to various modes of transportation has spurred significant advancements in electric propulsion technologies, leading to the emergence and growth of the electric boat market. As concerns about environmental impact and climate change have gained prominence, the maritime industry has faced increasing pressure to transition toward cleaner and more energy-efficient alternatives [1].

The widespread adoption of electric boats necessitates a robust charging infrastructure and marine facilities. This would instill confidence in both customers and original equipment manufacturers (OEMs) to transition from combustion-based power systems to electric ones. Unlike already well-established charging networks on land, creating an equivalent maritime charging infrastructure presents unique challenges. Harbors and small to medium sized marinas usually lack both space and necessary grid connection to facilitate charging for a growing population of electric marine mobility (EMOB) [2].

Another challenge faced by the growing EMOB population is the lack of nearby harbors or marinas in many popular boating areas, leading to range anxiety for electric boat users. In these remote archipelagos and long coastal sections boaters rely on being able to carry their own fuel for hundreds of miles. When addressing these challenges an innovative approach is required. Developing a floating island equipped with multiple charging stations, energy storage facilities, vessel-to-grid capabilities, energy production systems, waste management facilities, freshwater sources, restaurants, and other essential services presents an opportunity to address the infrastructure challenges currently faced by electric boats. This initiative could alleviate the strain on existing harbors and marinas. This island would not only open up for significantly more sustainable boating, but also new market opportunities [2].

The project aimed to create a modular design for Penta Island that could be implemented in diverse locations. Weather data and potential locations for the island were adapted to the conditions in Sweden, taking into account that Volvo Penta had its headquarters in the country. This adaptation was made with the intention that if the project proved successful in this environment, it was likely to be applicable worldwide. The challenges Sweden faces, such as the short boating season and the challenging weather conditions, formed a significant part of the consideration for the project.

The project was based on a few requirements. These included that the island would be able to store energy and provide charging service for approximately 50 electric boats, have a life expectancy of 50 years, to have a payback-time of 7 to 12 years and be self sustainable. [2].

1.2 Purpose

The project aimed to design and implement a floating island with the core purpose of charging electric boats. The island should also function as a leisure destination for tourists and accommodate boat owners not in need of charging.

1.3 Objective

The project's main objectives included achieving carbon neutrality, creating a modular design, ensuring safety for visitors and the environment, promoting accessibility, and fostering an inviting atmosphere for exploration, while still being self-sustainable.

1.4 Research Questions

This section presents the questions that were answered by the research carried out during the course of the project. The key questions that were addressed are outlined below:

- Penta Island is going to be a completely energy self-sufficient marina. How can sufficient energy be generated to supply all parts of the island that are capable of charging incoming electric boats?

- The waste generated on the island must be managed effectively. What systems can be put in place to manage this requirement?

- A self-sufficient water management system is needed. The operations of water facilities require a lot of energy, so how can a relative low energy water management system be created that possesses the capability to fulfill the water requirement?

- An essential requirement for the island was to turn a profit. The two underlying questions in regards to this are: How to draw people to the islands and how to make them stay?
- How can sufficient revenue be generated to achieve a payback period of 12 years?
- What measures can be implemented to reduce the environmental impact of the island?

1.5 Scope and Delimitations

Boundaries and limitations were vital to keep the project and ideas within a reasonable scale. It also ensured that there was enough time to complete the report since the designated time only was one semester.

The project was designed to accommodate 50 boats ranging between 25-50 feet, serving as a pivotal scale limiter [2]. An internal minimum of ten $126kWh$ boats charged per day was implemented. Exploration above this size was not implemented since that would strongly affect all other facets of the island, from water and energy consumption to the physical dimensions of the island itself.

Fossil fuels for energy production were not be investigated since the concept of the island was to be entirely self-sustained through green energy, independent of any ties to the central main land energy grid. While it might have been cost-effective to rely on a generator fueled by fossil resources during periods of reduced green energy availability, such as low wind or sunlight, this concept was not pursued.

The construction of the floating base was not developed during this project. Instead it was sourced from a producer that specializes in concrete based pontoons [3]. SF Pontona, the producer in question, was already engaged in collaboration with Volvo Penta. Therefore the exact design of each pontoon were not undertaken.

1.6 Risk Management

Throughout this project, a list of potential risks that could impact the design of the island was generated in order to assess and prevent them. The risk analysis involved potential risks in this project when designing the island, but also potential risks when building the island because of its connection to the designs. The risks were divided into two main categories; internal and external risks.

1. Environmental Risks

    (a) Natural Disasters: Exposure to hurricanes, earthquakes, floods, or other natural disasters can pose significant threats to the infrastructure and sustainability of the island.

    (b) Climate Change: Changing climate patterns may impact the island's ecosystem, affecting agricultural practices, water availability, and overall environmental stability.

2. Financial Risks

    (a) Return on Investment (ROI): There may be uncertainties regarding the financial returns on the investment made in creating the self-sufficient island.

3. Performance Risks

    (a) Power system: If the system does not meet power requirements, it could limit both how often boats could be charged, and the price for how much the boat owners would have to pay. It could also limit the availability for both the jet-skis and the rental boats.

    (b) Freshwater production system: If the system does not meet freshwater requirements, it could result in costumers not receiving any freshwater while being on the island. This would directly affect the experience of visiting the island negatively.

    (c) Waste system: Similar to the freshwater production system, if the waste system does not meet the waste handling requirements the island experience would be affected negatively, e.g. there would be too much trash left on the island.

4. Risks Revolving the Teamwork between the Chalmers and Penn State Students

    (a) Attendance: If not everyone from the team could attend the scheduled time for working on the project.

    (b) Missed deadlines: Failure to regularly review the Gantt chart by the team could lead to overlooking crucial milestones and missing deadlines.

    (c) Scheduled weekly meetings: Cancellation of a meeting between Chalmers and Penn State could potentially postpone progress by one week.

    (d) Different time zones: Because of the 6h time difference, there will be limitations when the students work together.

5. Regulatory and Compliance Risks

    (a) Permitting Issues: Delays or difficulties in obtaining necessary permits for construction and operation can impede progress.

6. Biodiversity and Conservation Risks
    (a) Impact on Ecosystem: The development of the island may pose risks to local biodiversity and ecosystems, requiring careful consideration and conservation measures.

Internal risks: 2, 3, and 4.
External risks: 1, 5, and 6.

Table 1.1 shows these risks with a degree of consequence and probability of the risks occurring. The degrees are numbered 1-10, where 10 is the highest risk level. The consequence and probability are then multiplied to achieve the risk number, which indicates how levels of reward and risk are weighed. Last column contain the strategy of how to minimize the risk numbers.

Table 1.1: Risk Analysis.

Risk	Consequence	Probability	Risk number	Fallback strategy
1a	8	2	16	Placing the island in a secure environment in order to minimize the risk of it being destroyed in a natural disaster.
1b	6	4	24	Supplying the costumers with locally produced food from communities close to the island.
2a	8	7	56	Minimize the costs of the island and creating multiple income streams in order to shorten the payback-time.
3a	10	7	70	Include backup solutions when there are not enough energy production.
3b	8	7	56	For days when the freshwater consumption is higher than the production rate, the island should have a supply of bottled water.
3c	10	5	50	Communication with municipal service boats that could step in when it is needed.

4a	6	10	60	Regular communication between the students to make sure everyone have something to contribute with.
4b	10	5	50	Routinely check the Gantt chart and communicate upcoming deadlines in the team well in advance of the deadline.
4c	10	6	60	Regular communication between the students to make up for the missed time.
4d	5	7	35	Divide work within the team and create internal deadlines for different phases to work against.
5a	10	9	90	Early and continuous communication with local authorities to ensure alignment on project objectives, requirements, and timelines, thereby fostering a collaborative and proactive approach to addressing permitting issues.
6a	8	5	40	Include a research center to closely observe the impacts of the ecosystem due to the island.

2

Methodology

The methodology chapter outlines the systematic approach utilized to design and model the island. The approach is listed and described below, divided into the different parts of the project.

In order to make the process as effective as possible, the project was divided into different parts that make up the island in it's entirety. These parts consisted of energy calculations, water and waste management, creating a business model and concept development, where the Chalmers students collaborated with the Penn State students on each area of interest. The design process of the island depended on feedback from all subgroups, which is why it was based on the collaboration of all parts. Lastly the business model depended on all parts, and the possible solutions were therefore discussed between the parts.

2.1 Island Visitor Capacity Method

A requirement for the island was to have a capacity of 50 25-50 feet boats. Consequently, the energy production had to be sufficient enough to power all charging spots and all of the systems on the island. To accurately dimension all systems, it was necessary to determine the maximum number of people present at any given time. The group made assumptions from personal experience to ascertain the number of visitors arriving by private boat, those utilizing the island's ferry service, and the requisite workforce needed for the island.

2.2 Waste and Water Management Method

The initial phase of waste and water management involved defining the goals and identifying the tasks necessary to achieve it. After identifying what had to be done it lead to a first period of waste and water research that was done in a wide range, and explored the subjects of blackwater processing, waste handling, greywater recycling and fresh water generation. There were no eliminations done in the beginning, the goal was to paint a picture of what was possible and whatnot. Then as the iterative processes went on moments came when it had to be realized what might be suitable for future projects, and what was possible in today's technological development. Different systems and concepts were compared, and pros and cons were weighted against each other with Morphological- and Pugh matrices to figure out what should be eliminated and whatnot. The process was completed upon the development of concepts supporting blackwater processing, waste management, greywater recycling, and freshwater generation, aligning with today's technological capabilities. There were also recommendations and annotations done considering what might be interesting and suitable in 20-50 years.

2.3 Energy Supply method

The development of the microgrid energy system within the energy group commenced with individual research into the field, and the various components that might be required. This research spanned from renewable energy to combustion engines and small nuclear power plants. Following this phase, rough estimations were conducted on the number of boats to be charged daily and the energy consumption required to initiate the concept generation. Concurrently, a Matlab script was developed to simulate the energy demand and production of the microgrid, aiming to obtain a more accurate estimation of its size, efficiency, storage, and the output generated by specific sources within the grid.

2.3.1 Micro Grid design

The design was developed through concept generation phases with Morphological matrix and eliminations with Pugh matrices. Between each elimination continued research was implemented to have a better understanding of the more intricate parts of the systems for next cycle.

2.3.2 Energy Calculations

For energy calculations and system sizing, an energy system model was developed using Matlab. The flowchart implemented to develop the model can be viewed in Figure 7.3. This model was tailored to the envisioned microgrid system, integrating an energy output simulation with random boats of different sizes arriving hourly for charging purposes. Throughout the day, the arrival rate ranges from 2 to 5 boats per hour, while during the night, it varies from 0 to 3 boats per hour. The simulation is run with several different variations on the size of the energy sources and the amount of chargers and their charging speed to find a stable version that works within our payback time and delimitation's.

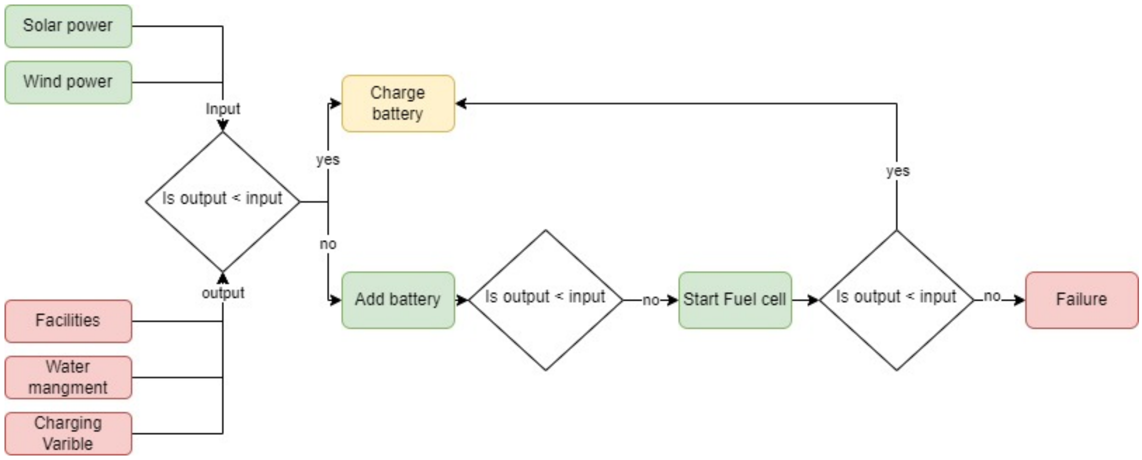

Figure 2.1: *Flowchart used to develop the model.*

2.4 Facilities

Facilities and activities for the island (excluding waste-, water- and energy facilities) were formulated by discussing possibilities, and doing research while applying a creative and open mind. The facilities and activities were divided into required and desired facilities, and later weighted against each other. While choosing the final contestants for the island it depended on how fell the different facilities and activities would work together, and how much revenue it could bring.

2.5 Business Model

The development of the business model followed an iterative approach aimed at enhancing revenue streams while optimizing costs. Throughout this process, brainstorming sessions were conducted to generate a diverse range of ideas regarding service offerings, target customers, revenue generation, cost allocation, distribution channels, and key partnerships. These ideas were evaluated based on their potential to be implemented to the island, but also their impact and feasibility. The business model were adjusted continuously based on insights gathered in the cost analysis.

A canvas of the business model was implemented as a blueprint for the description of the island's network between the revenue streams and the cost allocations. The canvas was divided into nine sections, were the sections on the right side stood for how revenue would be generated and customer relationships, and the sections on the left side stood for costs and crucial relationships with suppliers and manufacturers needed for the island. The nine sections were value propositions, customer segments, channels, customer relationships, revenue streams, key partners, key activities, key resources, and cost structure.

2.6 Generation of Design Concepts and Solutions

Throughout the project, a cyclic iterative process was implemented. The iteration begun with an idea generation phase where creative concepts are generated, which then were refined by research dedicated to exploring possible solutions. The next phase contained combining the different potential concepts that were generated in the idea phase into new conceptual ideas. The last phase involved the elimination stage, where the ideas are reviewed and removed according to the specified criterion's in the boundary section, but also the criterion's.

The elimination phase was critical to implement at the end of each iteration process since it was a necessity to limit the work, and prioritize the aspects that would benefit the island the most. At the same time, it was important to avoid choosing only the best options, therefore the mindset applied was to eliminate the worst ones or the ones the least fitting.

After conducting the initial inquiry, the necessary components to create the island were identified. This included water management, waste management and energy solutions and a business model. However, additional facilities are also necessary to generate profit. These additional needs are referred to as *desires*, as they do not constitute mandatory requirements for the system's functionality.

2.6.1 Method Behind Generating Design Concepts

The design phase of this project was executed with a systematic approach by integrating creative methods. By implementing different creative methods when generating design concepts, the likelihood of multiple different concepts increases [4].

- Brainstorming: In the early stages of creating concepts for Penta Island, brainstorming was adapted to design generation and the researching stages.
- Brainwriting: Similar to brainstorming, brainwriting is a technique to generate ideas. The difference is that it is an individual contribution where the participants generate ideas individually, often in a written format. Once the initial ideas are created, they are passed on to the rest of the group [5].

The geometric approach played a vital role in ensuring the island's effectiveness. The shapes, forms and spatial arrangement defined the impression of the finalized structure. These decisions was based on the visualization of both design and functionality, which provided a comprehensive understanding of the interaction between aesthetics and utility.

To visualize and refine the design, a CAD-model was utilized. The CAD-model was essential when creating a visual representation of the structure and aiding the exploration of different design possibilities.

2.6.2 Method Behind Generating Concepts Based on the Requirements

The starting point, when creating the concepts that included essential elements, was to create a list of requirements that contained both desires and necessary requirements. The list served as a reference point used to verify that solutions for all requirements had been identified. In addition, it enabled a comprehensive summary of all requirements and wishes in a central location.

Based on this list, the desired objectives was entered into two pairwise matrices, where they were weighted to enable prioritization. The objectives that shared common elements were incorporated into one of the matrices, while the remaining ones were placed into the second matrix. When implementing a pairwise matrix, the objectives were compared based on their ability to attain profit as well as how desirable it would be to visitors.

When creating the concepts consisting of requirements, the process begun by reviewing all the requirements in the requirement list and conducting further research to identify different solutions. A morphological matrix was then carried out to summarize all potential solutions and investigate the possibility of combinations, with the exception of the environmental aspects.

The different solutions were evaluated against the research conducted to determine their effectiveness, and if they were unfeasible or that could not be implemented at the present time, resulting in the elimination of less suitable alternatives trough Pugh matrices. This was determined to enable the preparation of a matrix where all proposed solutions could be combined to create different concepts. These concepts were then compared in another round of Pugh matrices.

2.7 Data collection

When collecting data, it involves a systematic gathering of information for analysis and interpretation. The data collection followed a structured process to ensure accuracy, reliability, and relevance.

3

Background Research of Current Technology

This chapter aims to provide an introduction to the research endeavor by contextualizing its relevance and objectives. By offering a comprehensive overview, it aims to establish a detailed understanding of the research's significance to the project.

3.1 Waste Management

An off-grid structure such as the Penta Island demands efficient solutions regarding sewage treatment and trash handling. Appliances need to be as efficient as possible since fresh water and energy will always be scarce on the island.

The goal is to make the island as self sufficient as possible, but there will always be some build up of waste on the island that needs to be transported away. To minimize environmental impact and energy consumption, it is imperative to minimize waste generation.

3.1.1 Blackwater

Blackwater is a term used to refer to contaminated water. Blackwater includes wastewater from bathrooms, which may contain urine or fecal matter, as well as water from the kitchen and dishwasher, which may contain grease [6]. The common denominator is that water from these sources may contain pathogens that can be harmful if not treated properly.

3.1.2 Sewage Treatment

Utilizing a membrane bio reactor (MBR) is an energy and space efficient way to process blackwater. The MBR houses suspended biomass and membrane filtration modules [7]. Wastewater is introduced into the MBR, where the biomass breaks down the organic matter it contains through oxidation. This makes sure the water does not contain excess nutrients that can cause eutrophication. Additionally, viruses and bacteria are removed from the water through filtration. When this process is done, the water is clean enough to be released into the sea.

3.1.3 Biogas Production

Biogas primarily consists of methane and carbon dioxide and is a flammable gas that can be used as a fuel for a combustion engine [8]. The gas is generated in anaerobic conditions within a biogas chamber. Biodigesters, which are airtight tanks, facilitate the digestion of biomass by microorganisms, resulting in the production of biogas. Biogas can med upgraded to biomethane through separation. Biomethane, nearly pure methane, possesses a higher energy content compared to regular biogas, making it a more efficient fuel.

3.2 Water Management

The island is to be self-sustainable which means that all the consumed water has to be recycled or generated on site, in this case Reverse Osmosis (RO) and Rainwater Harvesting (RWH) is used to generate fresh water and greywater recycling to recycle waste water.

3.2.1 Reverse Osmosis

The membrane desalination technology called reverse osmosis creates fresh potable water from the sea water, by using external pressure to push the desalinated water and its molecules through a semi-permeable membrane, while the ions and similar particles are discarded on the feed side [9]. See Figure 3.1 for a visual representation of the RO-process.

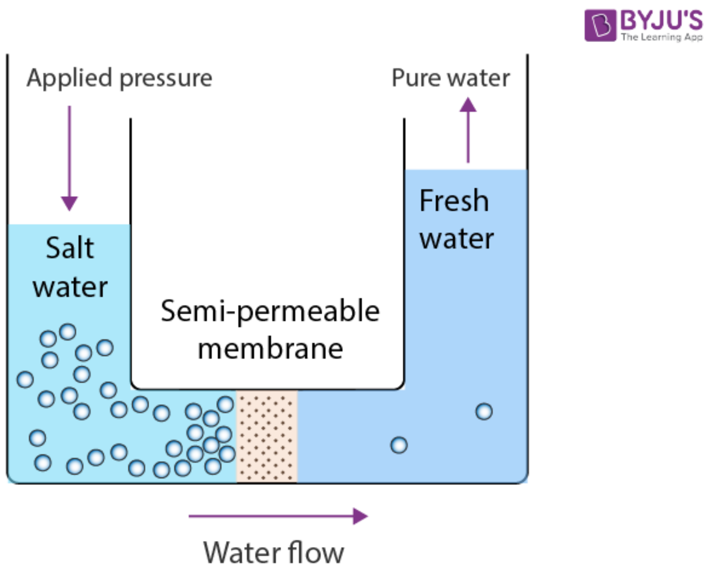

Figure 3.1: *Visualization of the reverse osmosis process [10].*

There are several benefits that follows RO and to name a few it effectively eliminates water contaminants, is environmentally friendly and improves taste and odor while also providing high quality water[11; 12].

3.2.2 Rainwater Harvesting

The RWH typically consists of concentration, collection, storage and lastly treatment [13]. The treatment process needed for creating potable water often consists of pre-storage filtration, slow sand filtration, UV-lights et cetera. On the subject it is also very important to keep up the maintenance for the different water tanks, gutters, catchment surface and filters while also inspecting points of entry for insects and similar pests.

Rainwater harvesting is a proven concept with both environmental and financial benefits, and to name a few it reduced surface runoff and provides an ability of clean water [14]. It is a concept that is suitable for a future society where climate change is expected to have impacted freshwater resources, RWH reduces reliance on groundwater resources and it helps mitigate the impact of droughts, floods and other extreme weather events that follows climate change [15].

3.2.3 Greywater recycling

Greywater recycling is a concept where wastewater (excluding wastewater from toilets) generated in buildings is collected and transformed to what is usually called greywater [16; 17]. Greywater recycling systems can result up to 40% in water savings. The general process of greywater recycling can be seen in the Figure 3.2. The greywater travels through filtration, a treatment tank where water is oxygenated and then through microfiltration via membrane filtration to at last be transported and gathered in a clean water tank [18].

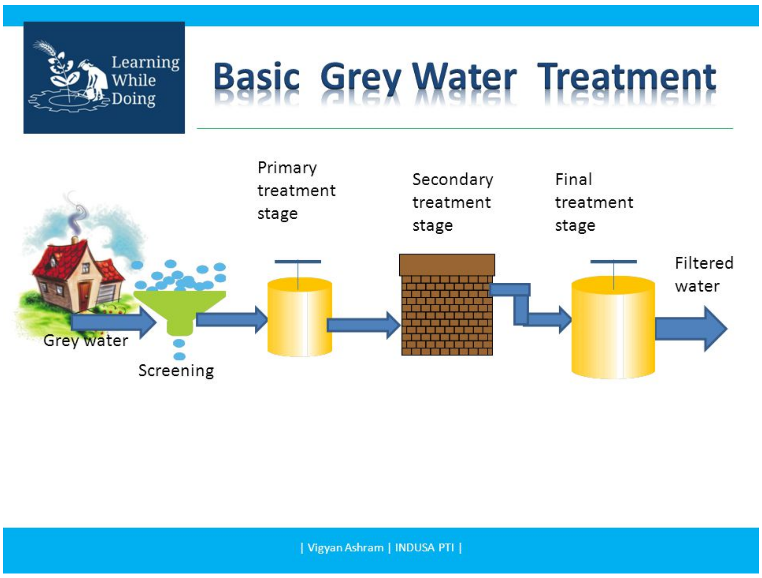

Figure 3.2: *Visualization of an possible layout for greywater recycling process [19].*

Benefits that follows greywater recycling are reduced water consumption, it reduces the amount of wastewater that reaches the drainage work, that in itself results in a reduced risk of sewer overflow into rivers and seas which leads to environmental benefits [18].

3.2.4 Requirements Water Quality

The requirements for potable drinking water in Sweden are formed and decided by Livsmedelsverket, an Swedish state administrative authority. Livsmedelsverket have created guideline values that are based on technical, aesthetic and health-vise coded matters [20]. The technical coded parameter looks at if the water can destroy fresh water systems or household appliances via corrosion or similar issues, the aesthetic side looks at issues such as if the water is considered repulsive because it smells or tastes bad, is brown et cetera; finally the health-coded parameter examines if there are microorganisms or chemical substances in the water that could be considered dangerous health wise.

3.3 Energy System

Penta Island will be completely of grid and self sufficient on renewable energy sources. This means that the energy production and distribution will happen on a closed of micro grid with several renewable energy sources and energy storage. The energy sources is gonna produce enough to support charging and all the facilities on the marina during the whole year with all its different seasons. Since the goal of the marina is to be completely green energy fossil fuels solutions wore avoided. While looking in to different renewable sources that would work out on the ocean its clear most are unreliable because their source is weather based examples like sunlight, wind or waves [21]. Because of this uncertainty where no source could be producing energy at certain times energy storage was added to the concept that could be charged when there is excess energy. For a final fail safe if both the renewable energy isn't producing and the batteries are empty a combustion engine or fuel cell can supplement the shortages.

3.3.1 Energy Demand

The energy demand of the whole operation have meany different variables that could effect the yearly energy consumption a broad calculation is made for the energy demand. This is so that the concept can be continued to be developed even if the numbers are estimations. Example of that needs this is business plan since a estimated cost for the system is needed witch needs energy demand for its dimensions. (trying to develop a mathematical model to calculate energy demand per hour day month and yearly)

The yearly estimated energy demand was $525,600 kWh/year$, this was calculated using broad estimations. A commercial Swedish electric boat has a batteries capacity of $126 kWh$ [22]. The marina will be able to fully charge 10 boats of this capacity each day witch then gives a yearly demand of $459,900 kWh/year$ for charging. The island will also have facility's that consume energy like restaurant and hotel services. The yearly energy demand for a restaurant is $45,000 kWh/year$ and a small hotel is $24,000 kWh/year$ [23; 24]. Adding this together gives a estimated yearly energy demand to estimate energy grid size and requirements.

3.3.2 Solar Energy

Solar energy is derived from the sun's radiant energy emitted and undergoes a process of capture and conversion into practical forms of energy, chiefly electricity and heat [25]. This process centers on photovoltaic (PV) cells, constituting the core of solar panels. These cells comprise semiconductor materials, typically silicon, distinguished by their capacity to directly convert solar radiation into electrical energy via the photovoltaic effect.

When sunlight strikes the surface of a solar panel, it initiates a sequence of events within the semiconductor material, leading to generation of an electric current [25; 26]. Initially manifesting as direct current (DC). Cooling and angle is essential for maintaining the efficiency, performance, and reliability of solar cells, especially in environments with high temperatures or intense sunlight exposure. Various cooling techniques, such as passive cooling through design optimization or active cooling using fans or liquid cooling systems, can be employed to manage the temperature of solar cells and keeping 30° angle south when in Sweden maximize their energy output.

Several types of PV-cells exist, each with its own unique characteristics and performance attributes.

- Monocrystalline Solar Cells: Monocrystalline silicon cells are made from single-crystal silicon, which is produced by growing a single crystal ingot [27]. These cells are highly efficient and offer excellent performance in converting sunlight into electricity during direct sunlight and no clouds. They have a uniform dark color and are easily recognizable by their rounded edges. Monocrystalline cells are known for their higher space-efficiency, longevity and cost, making them popular for residential and commercial applications.
- Polycrystalline Solar Cells: Polycrystalline silicon cells are manufactured using silicon crystal fragments melted together [27]. They have a distinctive speckled blue appearance due to the presence of multiple crystals. While polycrystalline cells are generally less efficient than monocrystalline cells and also need direct sun light, they are more cost-effective to produce. Polycrystalline solar panels are commonly used in utility-scale solar farms and other large-scale installations where cost is a primary consideration.
- Thin-Film Solar Cells: Thin-film solar cells are made by depositing thin layers of photovoltaic material onto a substrate, such as glass, plastic, or metal [28]. Thin-film solar cells are lightweight, flexible, and can be manufactured using less material than crystalline silicon cells. They are less effective and more costly than the above, but when its cloudy thin-film solar cells are the most effective solution out of the ones presented. This makes them suitable for applications where weight, flexibility and weather are important factors, such as building-integrated photovoltaics (BIPV) and portable electronics.

3.3.3 Wind Power

Wind power harnesses the kinetic energy in moving air to generate electricity. It revolves around wind turbines, complex structures equipped with various components like blades, a rotor, gearbox, generator, and controller[29]. These turbines are strategically positioned in areas with consistent wind, like open plains, coastlines, or elevated terrains. When the wind blows, the rotor blades spin, capturing the wind's kinetic energy. The rotating blades turn the rotor, connected to a gearbox, which amplifies rotational speed to optimize the generator's performance. Control systems monitor wind speed and direction, adjusting blade pitch to optimize and ensuring turbine safety during extreme weather conditions. Generated electricity is typically alternating current (AC)[29; 30].

The two most common turbines are horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) [29]. HAWTs have a horizontal rotor shaft with curved blades rotating around a vertical axis, perpendicular to the ground. They excel in converting wind energy into electricity, with a wide capture range and higher efficiency, making HAWTs the most used turbine. VAWTs, on the other hand, have a vertical rotor shaft with blades rotating around a horizontal axis, parallel to the ground. Their blade designs vary from straight to helical or curved shapes, arranged vertically. VAWTs are omnidirectional, capable of capturing wind from any direction. They perform well in low wind speeds and turbulence, making them more suitable for areas with varying wind patterns of lower speeds.

3.3.4 Fuel Cells

Fuel cells are devices designed to convert chemical energy directly into electrical energy [31]. They rely on two primary components: a fuel source and oxygen usually derived from the air. Within the fuel cell, the fuel, often hydrogen, reacts with oxygen with the aid of a catalyst. This reaction yields electricity, water, and heat as outputs. The resulting flow of electrons constitutes an DC capable of powering various devices. Fuel cells can maintain continuous operation as long as a steady supply of fuel and oxygen is available.

3.3.5 Energy Storage

Incorporating energy storage mechanisms, notably battery systems, to amass excess electricity during periods of peak generation, and subsequent utilization during low generation conditions or grid disruptions increases energy system reliability [32].

Lithium batteries use lithium ions to create electricity. During charging, ions move from one electrode to another through an electrolyte. When discharging, they move back, generating electricity. This process enables efficient energy storage and release for various applications[33]. Batteries have a C-rating witch measures the rate at which a battery is charged or discharged relative to its capacity. It's expressed as a multiple of the battery's capacity, with 1C representing a charge or discharge rate equal to the battery's capacity is 1h, 0.5C is 2h and 2C equals 0.5h[34].

When storing larger amounts of energy in several batteries an easy way of doing it is in battery containers to protect battery components. They shield them from environmental factors like moisture and physical damage[35]. Inside the containers the batteries are installed in battery racks, battery racks provide structural support and organization for multiple batteries. These racks ensure that batteries are properly spaced and positioned within the container for easy maintenance[36].

3.3.6 Electrical Boat Charging

Electrical boat chargers are a developing field where no universal standard have been implemented yet. Just within the EU 3 different standards exists, International Electrotechnical Commission (IEC), Society of Automotive Engineers (SAE) and CHAdeMO [37]. All these have a varying efficiency with DC charging for slower speeds and AC for fast charging.

3.3.7 Microgrids

Microgrids function as localized electricity systems, capable of operating independently or in conjunction with the larger electrical grid [32]. They integrate diverse distributed energy resources, including renewable sources like solar and wind, alongside energy storage systems such as batteries [38]. Occasionally, traditional fossil fuel generators are also part of the mix. These energy sources contribute to a distribution network, which includes power lines and transformers, facilitating the delivery of electricity to various loads within the microgrid's reach.

There are several distinctions between different types of microgrids, with a major differentiation being between AC or DC bus systems [38]. The contrast between AC and DC buses lies in their electrical architectures and the types of components utilized for power distribution and conversion.

Microgrids with AC buses rely on alternating current for power distribution. AC power is well-suited for long-distance transmission and distribution due to its ability to easily change voltage levels using transformers [38]. Generators, loads, inverters, and transformers within AC microgrids are designed to handle AC power. AC generators produce AC power directly, while AC loads operate on AC power without needing additional conversion. Inverters are employed to convert DC power from sources like solar panels or batteries into AC power for compatibility with the grid.

On the other hand, DC microgrids employ direct current for distributing power. DC power maintains a steady voltage level, making it suitable for specific types of loads and devices [38]. Components such as solar panels, batteries, and certain electronic devices naturally generate or operate on DC power. DC generators, such as solar panels or fuel cells, directly produce DC power without the need for conversion. Converters play a vital role in DC microgrids by transforming AC power from sources like wind turbines into DC power, ensuring compatibility with the microgrid. DC microgrids may offer enhanced efficiency compared to AC counterparts, particularly when incorporating DC-native sources like solar panels and batteries. They involve fewer conversion stages, thus reducing energy losses associated with AC-DC and DC-AC conversion. However, managing voltage levels and safeguarding against faults are crucial for ensuring the safe and reliable operation of DC microgrids.

4

Concept Development

This chapter presents the outcomes of the concept generation process. It delineates the various concepts devised to address the requirements and objectives outlined in the earlier phases of the project. Through systematic analysis and synthesis, a range of conceptual solutions were developed, aiming to meet the specified criteria while fostering innovation and sustainability. This section highlights the key concepts, their attributes, and their alignment with project objectives, providing valuable insights into the conceptualization phase of the project.

4.1 Island Capacity and Dimension Specifications with Impact on Concept Development

From personal experience, the average number of people per boat is four. Even if a 50 foot boat is classified for 12 people, it is very rare to see that many people on one boat. This meant that the island was dimensioned to facilitate around 140 people from private boats, 60 visitors via the ferry and 20 people that worked on the island. This made the total dimensional maximum number 220 people. Since the island would have rental boats included in the 50 boats requirement, the estimated amount of visitors became 140 people.

Based on these assessments, along with the potential locations where the island could be placed in terms of boat traffic, environmental protection and accessible facilities for up to 220 people, the area of the island was determined to be approximately 125 by 120 meters. This effected both the design concepts and the concepts based on the specified requirements regarding limitations.

4.2 Resulting Requirement List

Based on the need to identify the desires, a list of requirements was drawn up which included specification of criteria, assessment of whether it was a requirement or a desire, as well as different solutions for the identified components. This list is shown below in figure (4.1).

Category	Req.	Crit. spec.	Req. / Desire	Comments	Suggestions
Performance	Life span	50 years	R	Told from Volvo and project outcome	
	Energy Supply	Energy source	R	Implement a self-sustaining energy solution using sustainable energy sources	Solar pannels Biogas Wind power Ammonia Hydrogen gas
		Effective Energy Production	R		
		Energy storage units to enable charging even during periods of low energy production	R	Necessary, told from Bjorn	
	Boat capacity	Floating enclosures	R		
		Mooring facilities	R		
		50 boats, 20-50 ft	R	Information from Volvo Penta	
	Technological Innovation	Technical solutions to monitor and optimize charging processes	D		
		Provide digital platforms for user interactions, booking of charging spots, and real-time information on availability	R	Helps be current with day to day technology, need to find a way to allow widespread attention	
	Charging infrastructure	Provide at least 50 reliable and efficient charging stations for electric boats	R	Told from Volvo and project outcome	
		Charging Interface outlet CCS1 & CCS2&NACS (depending on region).	R	Björn stresses	
		Fast charging	D	Not as necessary but if feasible would be great	
		Normal charging	R		
		Slow charging	D	Not desired, need to consider people's time	
	S...e Dime...s	100m...ngth and...eters in...	D	...n discu...ce estab...our con...	

Figure 4.1: *Partial Figure of the Resulting Requirement List.*

4.3 Pairwise Comparison Matrix

After generating the requirement list, including the desired objectives, two pairwise comparison matrices was performed to determine which of the desired objectives could be eliminated. The desired objectives were divided into two different matrices to simplify the comparison process.

The first matrix in figure 4.2 compared the different desires related to facilities that could be implemented. The matrix produced a clear result showing that rental services, convenience store and restaurant were the facilities that should be prioritized in terms of the business model.

	Crit.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	Sum	Rank.
Valet	A		0	0,5	0	0	0	0	0	0	0	1	0	1	0	0	0	0	**2,5**	**14**
Resturant	B	1		1	0,5	1	1	0	0,5	1	1	1	1	1	1	1	1	1	**14**	**3**
Casino	C	0,5	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0,5**	**17**
Convenience Store	D	1	0,5	1		1	1	0	1	1	1	1	1	1	1	1	1	1	**14,5**	**2**
Boat School	E	1	0	1	0		1	0	0	1	0	1	0	1	0	0	1	0	**7**	**10**
Boat Club	F	1	0	1	0	0		0	0	1	0,5	1	1	0	0,5	0	1	0	**7**	**10**
Rentals (Boats and Water Scooters)	G	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	**16**	**1**
Overnight Stay	H	1	0,5	1	0	1	1	0		1	1	1	1	1	1	1	1	0	**12,5**	**4**
Cafe	I	1	0	1	0	0	0	0	0		0	1	0	1	0	0	0	0	**4**	**13**
Swimming School	J	1	0	1	0	1	0,5	0	0	1		1	1	1	0	0,5	1	0	**9**	**7**
Water Polo	K	0	0	1	0	0	0	0	0	0	0		0	0	0	0	0	0	**1**	**16**
Island Tours	L	1	0	1	0	1	0	0	0	1	0	1		1	0,5	0,5	1	1	**9**	**7**
Tours of the Island in Itself	M	0	0	1	0	0	0	0	0	0	0	1	0		0	0	0	0	**2**	**15**
Library	N	1	0	1	0	1	0,5	0	0	1	1	1	0,5	1		1	1	0	**10**	**6**
Gym	O	1	0	1	0	1	1	0	0	1	0,5	1	0,5	1	0		0	0,5	**8,5**	**9**
Rental Kitchen/Grills	P	1	0	1	0	1	0	0	0	0	0	1	0	1	1	0		0	**6**	**12**
Pool	Q	1	0	1	0	1	1	0	1	1	1	1	0	1	1	0,5	1		**11,5**	**5**

Figure 4.2: *The Pairwise Comparison Matrix of Desired Facilities.*

The second matrix in figure 4.3 carried out a more in-depth comparison of technical solutions related to the self-sufficiency of the island. Based on this matrix, it was clear that optimization of the loading process had a higher priority than, for example, the dimensions of the island. However, it was clear that the dimensions, together with the island capacity, would affect the number of facilities that could be implemented according to the matrix above, even if its rank was low.

	Crit.	A	B	C	D	E	F	G	H	I	J	K	Sum	Rank.
Technical solutions to monitor and optimize charging processes	A		1	1	1	1	1	1	1	1	1		**9**	**1**
Offer various charging capacities (fast/normal/slow charging)	B	0		1	1	1	1	1	1	1	1		**8**	**2**
100m in length and 60 meters in width	C	0	0		0	0	0	0	0	0	0		**0**	**10**
Have recycling-machines	D	0	0	1		0,5	0	0	1	0	0		**2,5**	**7**
Microplastic Treatments	E	0	0	1	0,5		0,5	0	0	0	0		**2**	**9**
Wind Blowing debris	F	0	0	1	1	0,5		0	0	0	0		**2,5**	**7**
Trash compactor	G	0	0	1	1	1	1		1	1	0,5		**6,5**	**3**
The island should be appealing to visitors	H	0	0	1	0	1	1	0		1	1		**5**	**5**
Enable easy costomization of charging stations for different types of boats and charging needs	I	0	0	1	1	1	1	0	0		0		**4**	**6**
Possible to collaborate with local communities	J	0	0	1	1	1	1	0,5	0	1			**5,5**	**4**

Figure 4.3: *The Pairwise Comparison Matrix of the Technical Solutions.*

It is important to note that the matrices do not represent definitive solutions, but served as an indication of the elements that should be prioritized in the examination of facility costs. For example, a boat club could be suggested as a concept even though it was ranked low in the matrix.

4.4 Concept Generation

Based on the pairwise matrix of desires and the list of requirements, several solutions were developed that met all specified requirements. By analyzing and comparing desires with the specified requirements, it can create a clear understanding of which specific features and functions must be integrated into the solutions.

4.4.1 The Result of Using Creative Methods

The group used brainstorming to discuss ideas and thoughts, which led to new ideas that were combinations of the previous ideas.

The brainwriting method was used when generating design ideas for the island. Each member of the group created visual designs and ideas for the island that was presented before the entire group. Figure 4.4 includes the visual design sketches that contributed to the final design of the island.

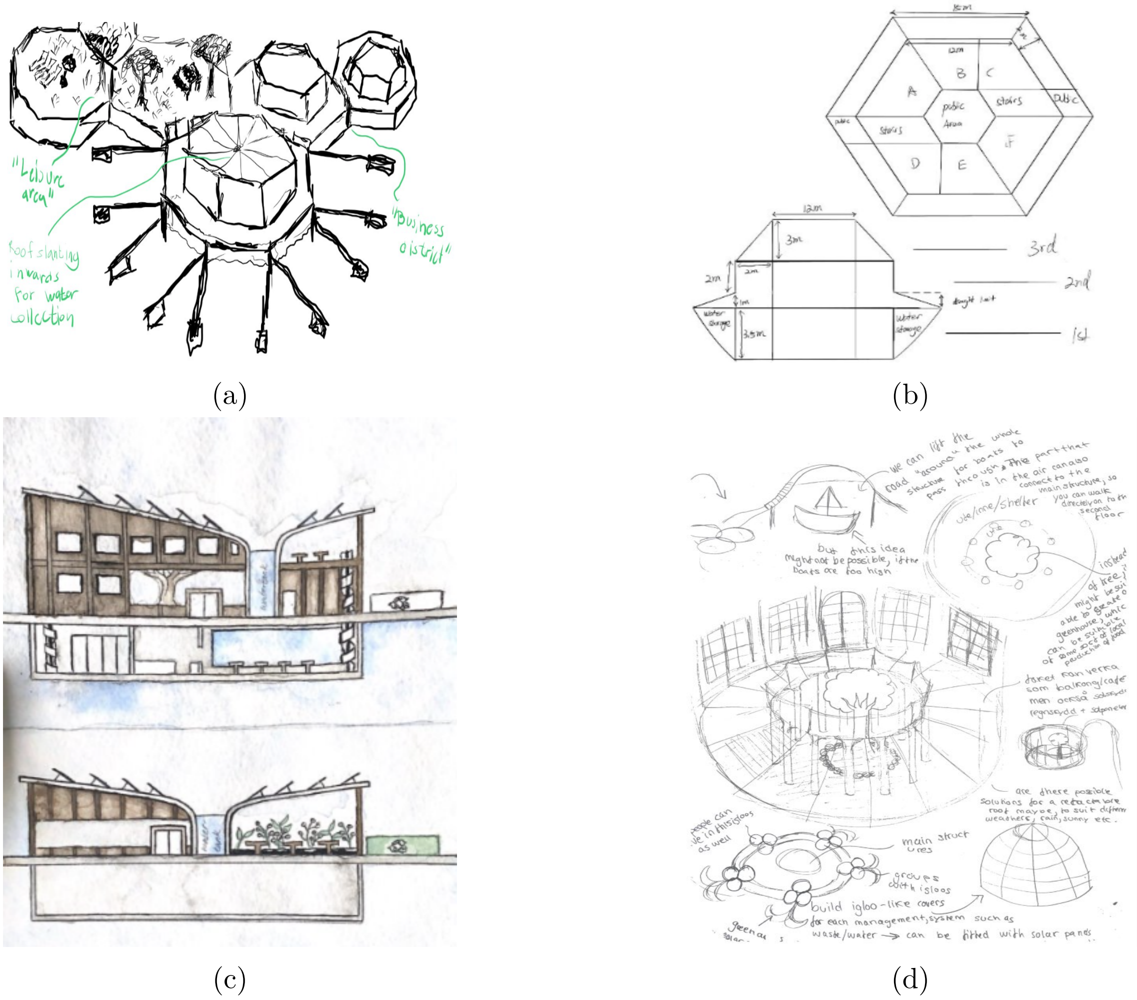

Figure 4.4: *A Compilation of the Early Sketched Design Concepts.*

The proposed designs, such as hexagonal shapes and levels underwater, offered creative options. However, the financial consideration was a limiting factor for the implementation of such ideas, as they would involve significant costs.

The presented ideas were compared and from these designs, as well as the financial consideration, two new designs were created, whereof one was created by the Chalmers University students and one by the Penn State University students.

4.4.2 Design Concept Rendering

The two concepts were drawn up by hand as well created in both AutoCad and Solid Works. The design concept from Chalmers was more futuristic and was deemed not feasible at present time, while the concept from the students at Penn State University was judged as feasible at the current stage. Therefore, the latter concept was chosen for focus and a 3D model of it was created. The final design can be seen in figure (8.2, 8.3, 8.4).

4.4.3 Implementation of Morphological Matrix on Generated Ideas

Various combined solutions were created based on the solutions, shown in the partial figure (4.5) below. The solutions were developed during the multiple research phases. From this matrix, 16 different concepts were developed, which were unique to enable the evaluation of the different combined solutions. In figure (4.5) below are the first Pugh matrices, which were used to eliminate various subsystems and enable the creation of the resulting combined matrix, presented in figure (4.8).

	Problem / Number	1	2	3	4	5	6	7	8	9
Energy Supply	Energy for boats	Solar energy	Wind turbine	Ammonia	Hydrogen engine	Diesel engine	Biogas	CorPower Ocean's C4 Wave Energy Converter (Tidal Power)	Coal plant	Nuclear plant
	Energy for facilities	Solar energy	Wind turbine	Ammonia	Hydrogen engine	Diesel engine	Biogas	CorPower Ocean's C4 Wave Energy Converter (Tidal Power)	Coal plant	Nuclear plant
	Energy Storage Units	Battery containers								
Boat Capacity	Mooring Facilities/Floating enclosures	Asssisted docking system - Volvo Penta	Beams	SeaPen (dry-docking system)	Floating dock systems	Bouys	Submerged lines	"Wooden Docking"	Boat lift	Drive-On Docks
Safety	Wave Breakers	Integrated in the islands shape	External wavebreakers	No wavebreakers						
	Clear Signage	High Visibility	Signs to prep for night	Green/Yellow Reflecting						
	Good Lightning	Floor lightning	Lamp-post							
	Emergency equipment	Rafts	Inflateable rafts	Lifejackets	First help kit	Heart starter	Rescuerunner	Fire extinguisher	VHF radio	Sprinkler system
	Fences around the island and	Fences that extend after pressing a button (retractable fence)	No Fences	Fences around the island at all time						
	Anchoring the island	Multi-point mooring	Dynamic positioning	Fixed concrete foundation	Motors and GPS positioning	Just floating with the winds and currents				
	Defence against hackers	Firewall	Password quality checks	Backup devices	Educate the staff (most crucial)	Encrypt the data	Follow PCI Security Standards	Jailbreak and Root detection		
Environment	Use sustainable construction materials, aviod chemical pollutants and addtional environmental benefits	Automatic trash in water remover	Sea bins	Floating wetlands	Plants on the island	Algae based microplastic reduction	Bioplastic production	Manure production	Environmental conscious awareness	Cement substitutes
Water Management	Recycle fresh water	Greywater recycling	Rainwater Harvesting (with solar panels)	Atmospheric Water Generators	Hydropanels	No fresh water	Tertiary RO (wastewater to cleaned greywater)			
	Sea to fresh water (desalination)	Collected engine heat	Solar still Technology	Distillation - Thermal desalination technology	Reverse osmosis membrane desalination technology	Utilizing seawater (flush toilets etc.)	Buy water and pump to island/buy bottled water/via a boat with pump	Don't offer water	Photovoltaic Desalination	Wind power desalination (RO

Figure 4.5: *Partial Figure of the Morphological Matrix.*

4.4.4 Elimination Phase of the Combined Solutions trough Pugh Matrices

The first 16 concepts were compared in four Pugh matrices. These matrices compared energy supply, safety regulations, environment, water and waste management, costumer satisfaction and the sustainability of the system.

Concept	Energy Supply	Boat Capacity	Safety		Environment	Water Management		Waste Management		Activities	
1	Solar + Wind + Hydrogen engine	Beams	Integrated in the islands shape	Multi-point mooring + dynamic positioning	Algae based microplastic reduction/Bioplastic production	Greywater recycling/Rainwater Harvesting (with solar panels)	Reverse osmosis membrane desalination technology	Reverse vending machines/Recycling stations/municipal services	Septic tanks/Biogas chamber/Membrane bio reacto	Resort	Just visitors
2	Solar + Wind + Hydrogen engine	Beams + Rentals on land during winter	Integrated in the islands shape	Multi-point mooring	Floating wetlands/Plants on island	Greywater recycling/Rainwater Harvesting (with solar panels)	seawater reverse osmosis + photovoltaic cells	Reverse vending machines/Recycling stations/Trash compactor/modular service boat	Septic tanks/Membrane bio reactor	Resort + Underwater	Visitors + Service ferries (electrical)
3	Solar + Wind + Diesel engine	Beams + Rentals on land during winter	Integrated in the islands shape + External wavebreakers	Multi-point mooring	Floating wetlands/Plants on island	seawater reverse osmosis + photovoltaic cells	Greywater recycling/Rainwater Harvesting (with solar panels)	Reverse vending machines/Recycling stations/Trash compactor/modular service boat	Septic tanks/Membrane bio reactor	Resort + Underwater	Visitors + Service ferries (electrical)
4	Wind + Solar + Biogas	SubmergedLines+JetPort+Sea Pen	External wavebreakers	Multi-point mooring	Environmental conscious awareness/Divers against ghost nets	Greywater recycling/Atmospheric Water Generators	Solar Thermal Desalination + Multi-stage flash distilaltion (MSF)	Biogas chamber/Reverse vending machines/Recycling stations/Trash compactor/modular service boats	Septic tanks/Biogas chamber/Membrane bio reacto	Bed & Breakfast	Visitors + Service ferries (electrical)
5	Solar + Wind + Diesel engine	Beams + Rentals on land during winter	Integrated in the islands shape + External wavebreakers	Multi-point mooring + dynamic positioning	Algae based microplastic reduction/Bioplastic production	Greywater recycling/Atmospheric Water Generators	seawater reverse osmosis + photovoltaic cells	Reverse vending machines/Recycling stations/municipal services	Septic tanks/Membrane bio reactor	Bed & Breakfast + Underwater	Visitors + Service ferries (electrical)
6	Wind + Solar + Biogas	Beams + Rentals on land during winter	Integrated in the islands shape	Multi-point mooring	Floating wetlands/Plants on island	Greywater recycling/Rainwater Harvesting (with solar panels)	seawater reverse osmosis + photovoltaic cells	Reverse vending machines/Recycling stations/Trash compactor/modular service boat	Septic tanks/Membrane bio reactor	Resort + Underwater	Visitors + Service ferries (electrical)
7	Tidal Power + Biogas + Wind	Wooden docking	No	Dynamic positioning	Cement substitutes/Recycled aggregate	Tertiary RO (wastewater to cleaned greywater)	Solar still Technology	Trash bins/municipal services	Septic tanks	Hostel	Visitors + septic tank
8	Biogas + Diesel engine + Hydrogen engin	Beams + JetPort	Integrated in the islands shape + External wavebreakers	Dynamic positioning	Environmental conscious awareness/Divers against ghost nets	Greywater recycling/Hydropanels/Rainwater Harvesting	Vapour compression evaporaiton (VC) + Multi-effect distillation (MED)	Trash compactor/Trash bins/use municipal services	Septic tanks/Tertiary RO/Membrane bio reactor	Bed & Breakfast	Visitors + septic tank
9	Solar Panel + Diesel Engine	Beams + Rentals on land during winter	Integrated in the islands shape	Multi-point mooring	Floating wetlands/Plants on island	Greywater recycling/Rainwater Harvesting (with solar panels)	seawater reverse osmosis + photovoltaic cells	Reverse vending machines/Recycling stations/Trash compactor/modular service boat	Septic tanks/Membrane bio reactor	Resort + Underwater	Visitors + Service ferries (electrical)
10	Diesel Engine + Wind	Beams+JetPort+BoatLift/FloatingDocks	No	Dynamic positioning	Cement substitutes/Recycled aggregate	Greywater recycling	Buy water and pump to island + buy bottled water	Biogas chamber/Reverse vending machines/Recycling stations/municipal services	Septic tanks/Simple on-site filtration	Hostel	visitors + service ferries + water pump
11	Solar+wind + diesel engine	Beams + JetPort + Drive-on-docks	Integrated in the islands shape + External wavebreakers	Multi-point mooring + dynamic positioning	Floating wetlands/Plants on island	Greywater recycling/Rainwater Harvesting (with solar panels)	adsorption desalination driven by Collected engine heat + solar energy	Reverse vending machines/Recycling stations/Trash compactor/modular service boat	Septic tanks/Tertiary RO/Membrane bio reactor	Bed & Breakfast	Visitors + Service ferries (electrical)
12	Solar + Wind + Diesel engine	Beams + Rentals on land during winter	Integrated in the islands shape	Multi-point mooring + dynamic positioning	Floating wetlands/Plants on island	Greywater recycling/Rainwater Harvesting (with solar panels)	seawater reverse osmosis + photovoltaic cells	Reverse vending machines/Recycling stations/Trash compactor/modular service boat	Septic tanks/Biogas chamber/Membrane bio reactor	Resort + Underwater	Just visitors
13	Solar + Wind + Fuel cells	Beams + Rentals on land during winter	Integrated in the islands shape	Multi-point mooring	Algae based microplastic reduction/Bioplastic production	Greywater recycling/Rainwater Harvesting (with solar panels)	Reverse osmosis membrane desalination technology	Reverse vending machines/Recycling stations/municipal services	Septic tanks/Tertiary RO/Membrane bio reactor	Resort + Underwater	Visitors + septic tank
14	Solar + Wind + Fuel cells	Beams + JetPort + Drive-on-docks	Integrated in the islands shape	Multi-point mooring	Floating wetlands/Plants on island	Greywater recycling/Atmospheric Water Generators	seawater reverse osmosis + photovoltaic cells	Reverse vending machines/Recycling stations/Trash compactor/modular service boat	Septic tanks/Biogas chamber/Membrane bio reacto	Bed & Breakfast + Underwater	Visitors + Service ferries (electrical)
15	Solar + Wind + Fuel cells	Submerged lines + Rentals on land during winter	Integrated in the islands shape + External wavebreakers	Multi-point mooring + dynamic positioning	Algae based microplastic reduction/Bioplastic production	Greywater recycling/Hydropanels/Rainwater Harvesting	Adsorption desalination driven by Collected engine heat + solar energy	Biogas chamber/Reverse vending machines/Recycling stations/Trash compactor/modular service boats	Septic tanks/Membrane bio reactor	Resort + Underwater	Just visitors
16	Solar + Wind + Fuel cells	Beams + Rentals on land during winter	Integrated in the islands shape	Multi-point mooring + dynamic positioning	Floating wetlands/Plants on island	Greywater recycling/Rainwater Harvesting (with solar panels)	seawater reverse osmosis + photovoltaic cells	Reverse vending machines/Recycling stations/Trash compactor/modular service boats	Septic tanks/Biogas chamber/Membrane bio reacto	Resort + Underwater	Just visitors

Figure 4.6: *The First 16 Developed Concepts.*

The resulting Pugh matrices from the first concepts.

	Fulfillment of requirement specification								
Concept	Energy supply	Water for 220 people	Waste for 220 people	Safety regulations	Environment improvements	Maintenance\Risk	Costumer satisfaction	Sustainable system	Result
1	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
2	0	/+	/+	/-	0	/-	0	/-	-1
3	/+	/+	/+	/-	0	/-	0	/-	0
4	/-	/-	/+	/-	/+	/-	/-	0	-2
5	/+	/-	/-	/-	0	/-	0	/-	-4
6	/+	/+	/+	/-	0	/-	0	/-	0
7	/-	/-	/-	/-	/-	/-	/-	/-	-8
8	/+	/-	/-	/-	/+	/-	/-	/-	-4
9	/-	/+	/+	/-	0	/+	0	/-	0
10	/-	/-	/-	/-	/-	0	/-	/-	-7
11	/+	0	/+	/-	0	/-	/-	/-	-4
12	/+	/+	/+	0	/+	/+	/+	/-	5
13	/+	0	/-	/-	0	/-	/+	/-	-2
14	/+	/-	/+	/-	/+	/-	/+	/+	2
15	/+	/-	/-	/-	0	/-	/+	/-	-3
16	/+	/+	/+	0	/+	/+	/+	/-	4

(a)

	Fulfillment of requirement specification								
Concept	Energy supply	Water for 220 people	Waste for 220 people	Safety regulations	Environment improvements	Maintenance\Risk	Costumer satisfaction	Sustainable system	Result
1	0	/-	/-	/+	0	/+	0	/+	1
2	reference	reference	reference	reference	reference	reference	reference	reference	reference
3	/+	0	0	/-	0	/+	0	/-	0
4	/-	/-	/+	/-	/-	/-	0	/+	-3
5	0	0	/-	/-	0	/-	0	/-	-4
6	/-	0	0	0	0	/+	0	/-	-1
7	/-	/-	/-	/-	/-	/-	/-	/-	-8
8	/-	/-	/-	/-	/-	/-	/+	/-	-7
9	/-	0	0	0	0	/+	0	/-	-7
10	/-	/-	/-	/-	/-	/+	/-	/-	-7
11	0	/-	/+	/-	0	/+	/-	/-	-2
12	/+	0	/+	/+	0	/+	/+	0	5
13	/+	/-	/+	0	0	0	0	/-	0
14	/+	/-	/+	0	0	/+	/-	/+	2
15	/+	/-	0	/-	0	/-	/+	/-	-2
16	/+	0	/+	/+	0	/+	/+	/+	6

(b)

	Fulfillment of requirement specification								
Concept	Energy supply	Water for 220 people	Waste for 220 people	Safety regulations	Environment improvements	Maintenance\Risk	Costumer satisfaction	Sustainable system	Result
1	/-	/-	/-	/+	0	/+	0	+/	0
2	/-	0	0	/+	0	/-	0	/+	0
3	reference	reference	reference	reference	reference	reference	reference	reference	reference
4	/-	/-	/-	/-	/-	/-	/-	/+	-6
5	0	/-	/-	/+	/-	/-	/-	0	-4
6	/-	0	0	0	0	0	0	/+	0
7	/-	/-	/-	/-	/-	/-	/-	/+	-6
8	/-	/-	/-	/-	/-	/-	/-	/-	-8
9	/-	0	0	/+	0	/+	0	0	1
10	/-	/-	/-	/-	/-	/+	/-	/-	-6
11	/-	/-	/+	/+	0	0	/-	/-	-2
12	0	0	/+	/+	0	/+	/+	/+	5
13	/+	/-	/+	/+	0	/-	0	/+	2
14	/+	/-	/+	/+	0	0	/-	/+	2
15	/+	/-	0	0	0	/-	/+	/-	-1
16	/+	0	/+	/+	0	/+	/+	/+	6

(c)

	Fulfillment of requirement specification								
Concept	Energy supply	Water for 220 people	Waste for 220 people	Safety regulations	Environment improvements	Maintenance\Risk	Costumer satisfaction	Sustainable system	Result
1	/-	/+	/+	/+	0	/+	0	/+	4
2	0	0	/+	/+	0	/+	0	/+	4
3	/+	/+	/+	/-	/+	/+	/+	0	5
4	/-	/-	/+	0	/+	/+	/-	/+	1
5	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
6	/-	/+	/+	0	/+	/+	/+	/+	5
7	/-	/-	/-	/-	/-	/+	/-	/+	-4
8	/-	/-	0	/-	/+	/+	/-	/-	-2
9	/-	/+	/+	0	/+	/+	/+	0	4
10	/-	/-	/+	/-	/-	/+	/-	/-	-4
11	/-	/-	/+	0	/+	/+	/-	/-	-1
12	0	/+	/+	/+	/+	/+	/+	/+	7
13	/+	/-	/+	/+	0	/+	/+	/+	6
14	/+	0	/+	/+	0	/+	0	/+	5
15	/+	/-	/+	0	0	/+	/+	/-	2
16	/+	/+	/+	/+	/+	/+	/+	/+	8

(d)

Figure 4.7: *A Compilation of the First Pugh Matrices Performed.*

Based on these comparisons, the concepts and their subsystems that were ranked as least favorable were eliminated. In figure 4.8 is the matrix that was established after the elimination phase.

The matrix contains the final requirement concepts that were possible to implement in the current situation. This matrix comprises 16 concepts which were compared through Pugh matrices and the focus was specifically on energy systems, maintenance, safety, water and waste management as well as sustainability based on these factors, and payback time for the concepts.

Concept	Energy Supply	Maintenance	Safety	Water Management	Water Management	Waste Management	Waste Management	Sustainability	Payback-time
1	Solar + Wind + Diesel engine	Mediocre maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Higher sustainability	Mediocre payback-time
2	Solar + Wind + Diesel engine	Higher maintenance	External Wavebreakers	Greywater recycling + Atmospheric Water Generators	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Mediocre sustainability	Higher payback-time
3	Solar + Wind + Diesel engine	Mediocre maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Seawater reverse osmosis + Photovoltaic cells	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Higher sustainability	Higher payback-time
4	Solar + Wind + Diesel engine	Higher maintenance	External Wavebreakers	Greywater recycling + Atmospheric Water Generators	Seawater reverse osmosis + Photovoltaic cells	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Mediocre sustainability	Highest payback-time
5	Solar + Wind + Diesel engine	Lower maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations+ Municipal services	Biogas chamber + Membrane bio reactor + Septic tanks	Mediocre sustainability	Lower payback-time
6	Solar + Wind + Diesel engine	Mediocre maintenance	External Wavebreakers	Greywater recycling + Atmospheric Water Generators	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations+ Municipal services	Biogas chamber + Membrane bio reactor + Septic tanks	Lower sustainability	Mediocre payback-time
7	Solar + Wind + Diesel engine	Lower maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Seawater reverse osmosis + Photovoltaic cells	Reverse vending machines + Recycling stations+ Municipal services	Biogas chamber + Membrane bio reactor + Septic tanks	Mediocre sustainability	Mediocre payback-time
8	Solar + Wind + Diesel engine	Mediocre maintenance	External Wavebreakers	Greywater recycling + Atmospheric Water Generators	Seawater reverse osmosis + Photovoltaic cells	Reverse vending machines + Recycling stations+ Municipal services	Biogas chamber + Membrane bio reactor + Septic tanks	Lower sustainability	Higher payback-time
9	Solar + Wind + Fuel cells	Mediocre maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Highest sustainability	Lower payback-time
10	Solar + Wind + Fuel cells	Higher maintenance	External Wavebreakers	Greywater recycling + Atmospheric Water Generators	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Higher sustainability	Mediocre payback-time
11	Solar + Wind + Fuel cells	Mediocre maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Seawater reverse osmosis + Photovoltaic cells	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Highest sustainability	Mediocre payback-time
12	Solar + Wind + Fuel cells	Higher maintenance	External Wavebreakers	Greywater recycling + Atmospheric Water Generators	Seawater reverse osmosis + Photovoltaic cells	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Higher sustainability	Higher payback-time
13	Solar + Wind + Fuel cells	Lower maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations+ Municipal services	Biogas chamber + Membrane bio reactor + Septic tanks	Higher sustainability	Lowest payback-time
14	Solar + Wind + Fuel cells	Mediocre maintenance	External Wavebreakers	Greywater recycling + Atmospheric Water Generators	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations+ Municipal services	Biogas chamber + Membrane bio reactor + Septic tanks	Mediocre sustainability	Lower payback-time
15	Solar + Wind + Fuel cells	Lower maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Seawater reverse osmosis + Photovoltaic cells	Reverse vending machines + Recycling stations+ Municipal services	Biogas chamber + Membrane bio reactor + Septic tanks	Higher sustainability	Lower payback-time
16	Solar + Wind + Fuel cells	Mediocre maintenance	External Wavebreakers	Greywater recycling + Atmospheric Water Generators	Seawater reverse osmosis + Photovoltaic cells	Reverse vending machines + Recycling stations+ Municipal services	Biogas chamber + Membrane bio reactor + Septic tanks	Mediocre sustainability	Mediocre payback-time

Figure 4.8: *Final concepts summarized in a matrix.*

4.4.5 Final Pugh Matrices

16 concepts became the result of combining all the different solutions from the morphological matrix. These concepts were then compared to each other in three Pugh Matrices that are shown in figures (4.9, 4.10, 4.11).

Typically, Pugh matrices are compared to an existing reference. As this project was based on an idea and does not currently exist, there is no existing reference available. Therefore, one concept was adopted as a reference, namely concept number 13, which would probably give the best possible results, and the other concepts were weighed against this. From the original matrix, four other concepts emerged that showed the same results as the reference. Thus, one of these four concepts was chosen that differed the most from the reference, which in this case was concept 10.

After the second weighting, a concept emerged that outperformed the reference, which was concept number 9. This concept was then adopted as the new reference to ensure the reliability of the results. The resulting matrix indicated that only the original reference, concept number 13, was comparable to concept number 9.

Fulfillment of requirement specification								
Concept	Energy supply	Maintenance\Risk	Safety regulations	Water management	Waste management	Sustainable system	Payback-time (7-12 years)	Result
1	0	-1	0	0	1	0	-1	-1
2	0	-1	0	1	1	-1	-1	-3
3	0	-1	0	0	1	0	-1	-1
4	0	-1	0	1	1	-1	-1	-1
5	0	0	0	0	0	-1	-1	-2
6	0	-1	0	1	0	-1	-1	-2
7	0	0	0	0	0	-1	-1	-2
8	0	-1	0	1	0	-1	-1	-2
9	0	-1	0	0	1	1	-1	0
10	0	-1	0	1	1	0	-1	0
11	0	-1	0	0	1	1	-1	0
12	0	-1	0	1	1	0	-1	0
13	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**
14	0	-1	0	1	0	-1	-1	-2
15	0	0	0	0	0	0	-1	-1
16	0	-1	0	1	0	-1	-1	-3

Figure 4.9: *First Pugh Matrix of Final Concepts.*

Fulfillment of requirement specification								
Concept	Energy supply	Maintenance\Risk	Safety regulations	Water management	Waste management	Sustainable system	Payback-time (7-12 years)	Result
1	0	1	0	-1	0	0	0	0
2	0	0	0	0	0	-1	-1	-2
3	0	1	0	-1	0	0	-1	-1
4	0	0	0	0	0	-1	-1	-2
5	0	1	0	-1	-1	-1	1	-1
6	0	1	0	0	-1	-1	0	-1
7	0	1	0	-1	-1	-1	0	-2
8	0	1	0	0	-1	-1	-1	-2
9	0	1	0	-1	0	1	1	2
10	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**
11	0	1	0	-1	0	1	0	1
12	0	0	0	0	0	0	-1	-1
13	0	1	0	-1	-1	0	1	0
14	0	1	0	0	-1	-1	1	0
15	0	1	0	-1	-1	0	1	0
16	0	1	0	0	-1	-1	0	-1

Figure 4.10: *Second Pugh Matrix of Final Concepts.*

Fulfillment of requirement specification								
Concept	Energy supply	Maintenance\Risk	Safety regulations	Water management	Waste management	Sustainable system	Payback-time (7-12 years)	Result
1	0	0	0	0	0	-1	-1	-2
2	0	-1	0	1	0	-1	-1	-2
3	0	0	0	0	0	-1	-1	-2
4	0	-1	0	1	0	-1	-1	-2
5	0	1	0	0	-1	-1	0	-1
6	0	0	0	1	-1	-1	-1	-2
7	0	1	0	0	-1	-1	-1	-2
8	0	0	0	1	-1	-1	-1	-2
9	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**	**Reference**
10	0	-1	0	1	0	-1	-1	-2
11	0	0	0	0	0	0	-1	-1
12	0	-1	0	1	0	-1	-1	-2
13	0	1	0	0	-1	-1	1	0
14	0	0	0	1	-1	-1	0	-1
15	0	1	0	0	-1	-1	0	-1
16	0	0	0	1	-1	-1	-1	-2

Figure 4.11: *Third Pugh Matrix of Final Concept.*

5
Water and Waste Results

This chapter addresses results concerning water and waste system that are to be applied for Penta Island. These system are based on assumptions, expected values and knowledge gathered from 3.1 3.2.

5.1 Water Management Results

On the premises of Chalmers University of Technology there are multiple projects conducted via the HSB Living Lab, a place for students to live where experiments are conducted on students living situation with greywater recycling et cetera [39]. A similar way of thinking needs to be applied to the island since it is supposed to be entirely self-sustainable, and the water resources are going to be scarce. Therefore it is expected to apply low-flowing faucets and other water saving products for washbasins, kitchen faucets and showers to reach the end goal of saving energy, chemicals and money [40]. These water saving measures can save up to 30% in todays' current technological competence. Usually greywater is only used for irrigation and outside water needs, but similar to the HSB Living Lab it is going to have a wider range of usage for the island.

The water management is expected to produce fresh water and greywater, and when producing fresh water the sea or the rain are used as water sources. To create systems that could work for the island it had to be grasped how much water, and of which type that was needed for each sub-section of the island and sources were used to estimate a reasonable number for an island dimensioned for 220 people. The fresh water is expected to be used for drinking water, in the restaurant and for washing your hands while greywater is used for flushing toilets, showers and cleaning equipment etc.

5.1.1 Expected Water Usage

As said in table 5.1 generated potable freshwater is going to be used for drinking water, in the restaurant for cooking and for washing hands. Greywater however is not potable or drinkable but is expected to be used for flushing toilets, showers, irrigation and for washing boats and things of similar character. Table 5.1 gave an indication of what the different water needs were, and how large the systems needed to be.

Table 5.1: Calculated Water Need per Day, and of what Water Type. The Values were Based on Information Gathered Information about Water Needs [41; 42; 43; 44; 45].

	Flushing toilets	Showers	Washing hands	Restaurant	Drinking water	Amount people
Visitors via ferry/not overnight stay	4*20	No showers	3*20			20
Visitors via ferry/overnight stay	7*40	160*40	10*40			40
Visitors via boats	3*140		4*140			140
Workers	5*20	No showers	5*20			20
Type of water	Grey-water	Grey-water	Fresh water	Fresh water	Fresh water	Σ
Liters of water	5280	6400	2090	700	704	15 174
Tot type of water	Grey-water	Fresh water				
	11 680	3494				

Worth to mention is that the general use of greywater has not covered showers in such a wide range, since the general opinion is that most users do not want to use greywater for activities that involves personal contact [46]. For the island the resources are scarce and such an decision has been made, and similar to HSB Living Lab it is considered a necessity to use greywater for showers. Since the water resources are scarce there are going to be limits for the showers. The showers in the overnight stay rooms will have a time limit for 10 min, and the limit were used to form an understanding of the expected water usage for showers each day as can be seen in Table 5.1. The data in Table 5.1 about the specifics for how many people that shower, and the distribution of how many times people for example washes their hands at home and at the island is made out of assumptions.

5.1.2 Water Quality

Table 5.2 gives an indication of the expected composition of drinking water in Gothenburg, but it is difficult to gather data touching required water quality for showering (with recycled greywater). There are however systems applied in the HSB Living Lab that makes the option possible, where one of them is called Graytec which cleans the greywater to potable quality [47; 48]. There are also showers from Orbital Systems used, where the water used while showering is circulating and cleaned during the shower cycle, the process saves heat and amount of used water [49; 50]. By using the showers from Orbital Systems it is possible to save up to 90% water and 80% energy.

Table 5.2: Composition for Fresh Drinking Water in Gothenburg. These Values are Within the Limits that Livsmedelsverket has Formated [51].

Water hardness (considered soft water)	pH-level	Alakinity	Iron content	Chlorine level	Aluminium level	Floride level
20-24 mg Ca/l	approx. 8.0	approx. 1,0 mmol/l	<0,01 mg/l	0,05-0,25 mg/l	<0,02 mg/l	<0,02 mg/l

5.1.3 Fresh Water Generation

Here the presented fresh water generation systems for the island are presented, there are also systems on the market supplied that fits the concept of Penta Island and its requirements.

Reverse Osmosis

Based on conducted research the RO-desalination is suited for small-scale operations in remote areas which supports the relatively small floating island [52]. There have also been research done and studies where it is apparent that combination of wind-powered RO and photovoltaic-powered RO is promising and a good option for renewable energy, which truly fits the idea of the island [17]. In this sense for small-scale RO-systems there is a high capital cost (per kW) and it is therefore necessary that the system is very energy efficient, which have been proven possible by conducted research but often lands in recovering the mechanical energy from the brine stream which is then returned to the feed flow.

When researching available systems on the market that could handle the necessary dimensions presented in Table 5.1, a system manufactured by ZONESUN was chosen as a representative. It is called ZS-WP500L and produces 500L/H, with dimensions of (Length x Width x Height) 1550x900x1820 mm [53]. An RO-system that has a filter process that contains multiple filters, and to name a few: quartz sand-filter, activated carbon filter and a primary reverse osmosis filter. For the system it is necessary to have at least two water tanks, which in this case consists of a Raw Water Tank and a Pure Water Tank.

Rainwater Harvesting

Combined with the reverse osmosis is the idea of generating fresh potable water from rainwater harvesting, which can be harvested from surfaces on the island covered by solar panels. See Figure 5.1 for an already existing concept of the idea.

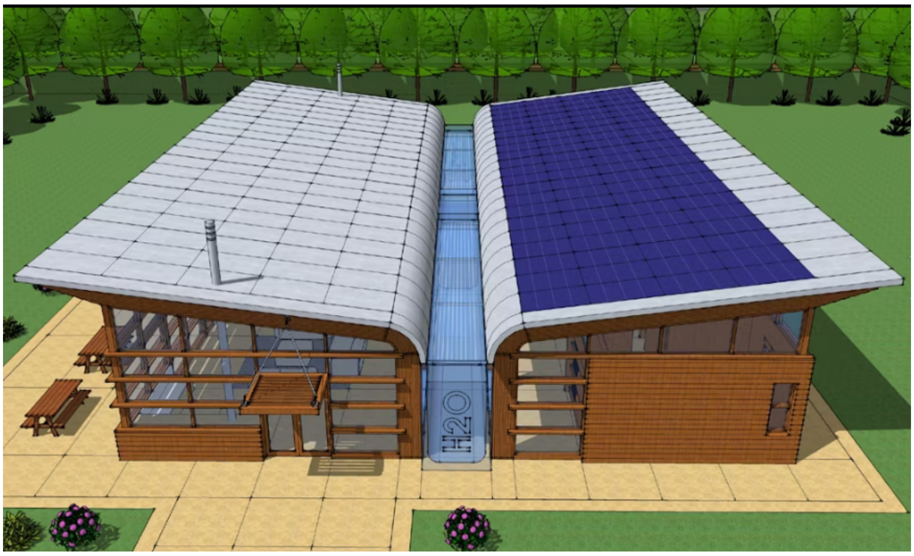

Figure 5.1: Rainwater and Solar Power Power Harvesting System [54].

As stated before the RWH from the island is mainly conducted from solar panel runoff, the idea is environmentally sound and suitable for rural and dry areas [13]. However when harvesting rainwater from Photo Voltaic-modules it is critical that there are no cracks or that similar delamination occurs. The phenomena is usually a result of modules nearing the end of its lifespan where toxicants and metals might leach [55]. But since rainwater harvesting is such an effective way of harvesting fresh water compared to extracting water from air it seems reasonable to apply the idea and avoid the leaching by upholding a keen eye on the upkeep of the panels. There are numerous projects where the water used for cleaning the solar panels (to uphold the efficiency) have been recycled and later used again [56; 57].

The capacity of possible harvested rainwater varies during the year and location, from the location in Gothenburg's archipelago representative values were gathered from SMHI. And the chosen relevant location for data collection were Vinga A. Below are the expected monthly rainfall for Vinga A, with translates to how much rainwater that can be expected to be harvested per m^2 each month.

Table 5.3: Monthly precipitation values (mm) put together from data gathered from January 1961 - December 2020 [58].

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
mm	49	35	33.8	36.5	41.7	59.6	58.9	73.1	55.5	64.7	56.3	54.4	618.9

When scanning the market for suitable disinfection systems for RWH the "RainFlo (Double) 10 GPM Complete UV Disinfection System" seemed fitting [59]. It is an UV-disinfecting system that utilizes sediment filtration to clean and disinfect rainwater for indoor potable usage, and fulfills the expected needs. Similar to the reverse osmosis there is a need for two water tanks here, one for the untreated and one for the treated potable water.

5.1.4 Greywater recycling

In the waste section it was mentioned how MBR can be used to process blackwater (from toilets), but for greywater recycling the greywater are to be collected from showers, sinks and waste water from the restaurant et cetera. Since there is no requirement that the water used for flushing toilets need to have the quality of potable water (is often the norm when flushing in Sweden) it is not necessary for it to be fresh water, and therefore greywater recycling is an excellent procedure [60]. The greywater used for flushing toilet are going to be generated via the so called greywater recycling, but also with help from the waste side and the MBR. This will ensure the need that you can always flush the toilets.

For the greywater recycling system INTEWA's AL-GW10800 seemed fitting, with an capacity to treat 10,800 l/day which supports the expected dimensions in Table 5.1 [61].

5.2 Sewage Production

Having an effective sewage treatment system on the Penta Island is crucial to limit the islands environmental impact and to reduce the use of freshwater. Given that the maximum capacity of the island at any given moment is 220 people, the sewage system must be sufficient to handle the load. During a 24-hour period, the average human produces two liters of urine and 0.3 L of feces, which are typically flushed down toilets eight times [62; 63]. A high efficiency toilet uses six liters of water per flush [42]. This makes the daily maximum locally produced blackwater 13332 L per day.

The option to empty septic tanks on the island will be available for visiting boats. In the range of boat sizes that the Penta Island will cater for, the size of the septic tanks equipped on different boats vary. The Fairline Squadron 50 and the Yamarin 88 DC represent the extremes in boat sizes that the Penta Island serves, providing valuable insights into the sizing requirements for septic tanks. The Fairline Sqaudron 50 comes equipped with a 110 L septic tank and the Yamarin 88 DC comes with a 30 L septic tank [64; 65]. This makes the average septic tank size 70 L, which makes the maximum daily emptied blackwater 3500 L per day.

The total amount of blackwater is obtained by adding the quantity from emptied septic tanks to the locally produced amount. This adds up to 16832 L, which is approximately 17 m^3/day. Given the criticality of waste management, a safety factor of 1.25 is applied to the maximum sewage capacity to prevent any possibility of overflow. This sizes the maximum blackwater to 21040 L/day, approximately 21 m^3/day.

5.2.1 Membrane Bio Reactor

To effectively handle the maximum load, an EVAC MBR 22K system will be used for processing the blackwater. This system can process up to 22 m^3 of blackwater per day. The MBR boasts a space-efficient design with a compact footprint of approximately 2.5 meters in all directions. Additionally, it effectively recycles water, allowing for reuse of up to 99 % of the water that passes through the system [7]. The treated water meets the required standards for discharge into the sea and can also be utilized for toilet flushing or for cleaning boats and docks on the platform.

5.3 Waste Handling

There will be an expected need to handle waste produced on the island and brought by visiting boats on the island. In Sweden, the average person generates 1.3 kg of waste per day [66]. At maximum capacity, the Penta Island will produce 546 kg of waste per day. There will be trash collection points on the island that encourage visitors to recycle their waste and promote reducing their consumption of items that become litter.

5.3.1 Trash Compactor

Untreated waste occupies a considerable amount of space. A trash compactor makes waste handling more space-efficient. The density of uncompressed waste is approximately 390 kg/m^3, while compressed waste has a density of around 710 kg/m^3 [67]. The compressed waste takes up 45 % less space than the non-compressed waste. The trash compactor enhances waste management efficiency, reducing the frequency of waste transportation from the island and saves space on the island.

5.3.2 Reverse Vending Machine

Recycling PET bottles and aluminum cans using a reverse vending machine is not only space-efficient and sustainable but also addresses one of the major sources of waste from visiting boats on Penta Island. Based on personal observation, cans and bottles are frequently brought items for boat trips and are also commonly purchased at convenience stores visited by boat. In Sweden, 87 % of all containers included in the deposit system are recycled, and adding another possibility of recycling in a remote location like the Penta Island can help increase this number [68].

5.3.3 Service Boat

To accommodate for the water and waste needs on the Penta Island, a service boat is required. The boat needs to be able to handle frequent waste disposals, use an electric powertrain and fit the image of the Penta Island. During discussions at the Gothenburg Boat Show 2024, conversations were held with an individual working for the company Alukin about utilizing their biggest model, CWA 850, as a service boat. Alukin makes sturdy aluminum boats that comes with the option to be equipped with electric outboard engines. With additions to optimize waste handling the Alukin CWA 850 can be used as a service boat in all types of weather, all seasons.

5.4 Biogas Chamber

The human waste collected in the MBR can be used as substrate for biogas production in a biogas chamber. The calorific value of biogas is estimated at 6 kWh/m3 [69]. Considering a maximum daily input of 60 kg of human feces (calculated as 220 individuals producing 0.3 kg of feces per day each), with each kilogram of feces having a potential biogas yield of at least 28 L/kg makes the maximum biogas production 1680 L/day [70]. Assuming the biogas generator operates with an efficiency of approximately 0.35, this corresponds to an energy output of approximately 3.528 kWh/day. This is equivalent to about 6 % of the charging capacity for a single X Shore 1 electric boat [22].

However, it is important to acknowledge that these calculations represent best-case scenarios, real-world conditions may result in lower biogas yields. Nevertheless, using biogas for energy generation could offer supplementary power for onsite facilities, such as a restaurant or to power lamps, contributing to the overall sustainability goals of the island.

6

Research and Results for Facilities and Activities

Islands are and have always been fascinating and mysterious places [71]. That is the mindset that has been applied to the island from the beginning, the desired outcome has been to create the same fascination and ambiance for this artificial island and by that attract visitors.

While working with different activities and facilities, excluding waste, water and energy, for the island, the facilities were divided into required and desired facilities to keep apart what would be required for the island and what would be regarded as a way to raise the interest of traveling to the island. A list of the suitable required facilities is shown in table 6.1 and the desired facilities in table 6.2.

6.1 Required Facilities

Required facilities covers things that seemed non-negotiable, these concepts were mostly based on the given assignment and facilities that the island would be non-functional without. In table 6.1 a list of required facilities is shown.

Table 6.1: Presentation of Required Facilities for Penta Island.

Required Facilities				
Floating enclosures /Mooring	Shuttle Services	Anchoring Facilities	Wave Breakers	Fences around island

6.1.1 Floating Enclosures and Mooring Facilities

When designing the island the requirement to moor different vehicles followed, which in this case includes mostly boats in the scale of 25-50 feet and some electrical jet-ski rentals. The most suitable floating enclosures was considered to be the Y-beams because of their simplicity and durability, but also since they are quite customizable and not too expensive. The beams used for the island, and later on in the business model were beams produced by a subcontractor for SF-Pontona [72]. The fitting mooring facilities for the jet-skis were the JetPort Plus from dockmarine-europe, the JetPort does a great job at protecting and securing the jet-skis as well as being easy to anchor [73]. For the winter season on the Swedish West Coast there are also plans to keep the boat rentals on land during the off-season, in a rented spot for storage to minimize the risk of damages, but also to have the flexibility to retrieve the boats.

6.1.2 Safety for island

Safety for the island that arises as an result of a floating structure at sea, the points works to create a more stable and safe environment.

Anchoring facilities

Since Penta Island is a floating island it was necessary to anchor it, and while researching this matter multi-point mooring and dynamic positioning surfaced. Multi-point mooring fastens the floating structures with steel chains in multiple points, this type of mooring provides a stable fixation of the structure and is typical for fastening pontoons [74]. Dynamic positioning is a motion controlled fixation of the floating structure, and is often used for submarine vessels and is a eco-friendly alternative. The two different kinds have been realized to work well in combination, where improvements in stability and safety have been displayed.

Wave Breakers

Something that also was deemed necessary was wave breakers that reduces the wave insensitivity and protects the infrastructure against erosion and damage. Since the physical structure were based on the floating concrete platforms from SF Pontona, it seemed obvious that it was their product that should be used. To create an seamless and suitable designed it was the wave breaker from the SF500-serie that were deemed most fitting [75].

6.1.3 Shuttle Services

Transporting people that do not own a boat to the island were a part of the idea that was formulated for this project, and since there generally is an perceived gap on the market it made sense to use a shuttle service via electrical ferries. The function for these ferries are to transport visitors to and from the island, and the boat model in mind has been the Candela P-12 in the shuttle variant. This boat is fast, electric and made for commuting while having an capacity to carry 30 passengers at a time while having 1 driver [76]. This model of Candela-boats have a battery size of 252 kWh, and a charging speed of 175 kW DC. This model is also suited for wheelchair users, to ensure availability for everyone on the island. The plan is for the shuttle ferry to make round trips a couple times a day, with an increased intensity during weekends and peak season.

6.2 Desired Facilities

The desired facilities in table 6.2 presents activities and facilities that would enhance the profit by creating a attractive scenery and ambiance that makes visitors drawn to the island and makes them wanting to visit more than once.

Table 6.2: Presentation of Desired Facilities for Penta Island.

Desired Facilities			
Boat Rentals /Jet Skis/Diving Gear	Restaurant	Convenience Store	Shelter from sun, rain etc.
Boat Club/Boat School	Library	Tours of The Island	Collaboration with local communities
Overnight Stay	Local Food Production/Vegetation	Cafe	ev. Fences Around the Island

6.2.1 Rentals

Rentals serve as an effective means to attract visitors to Penta Island, generate income, and cultivate a positive reputation for the island. Primarily a revenue-generating business, this endeavor also has the potential to enhance people's appreciation of the archipelago and the sea.

Boat Rentals

The island will offer the possibility to rent an electric boat. Three X Shore 1s will be available. These electric boats have a 126 kWh lithium-ion battery and a range of 50 NM [22]. To hire a boat, a boating license is required to minimize the risk for accidents and injuries. Individuals lacking a license can still rent a boat, albeit with a capped maximum speed of 5 knots. This is to further the interest in boating in the general public and promote the use of electrical powertrains in marine environments.

Jet Skis

To ensure that the island is an attractive leisure platform, it will offer rental of four Taiga Orca electric jet-skis to the visiting customers. The Taiga Orca jet-skis have an estimated range up to 2h, which makes it good enough for shorter water activities [77]. In Sweden, to rent a jet-ski it is required for the costumer to be over 15 years old and have a jet-ski license [78].

Diving Gear

Another way to involve more people in water activities on the island is to provide a service of renting a package of diving gear, masks and snorkels to the customers.

6.2.2 Restaurant

The restaurant is one of the facilities on the island that is expected to bring forth a significant revenue each year. In combination with the goal of creating an exclusive feel for the island, it seemed apt to have a high end restaurant that could serve 70 people per night. It was appropriate for the restaurant to be seafood centered, to enhance the experience and feeling of the sea. A restaurant taken as reference is Långedrag Värdshus, a restaurant based in Långedrag, Gothenburg which specializes in seafood [79]. The restaurant could also work well and bring in revenue year round, when the boating season is not at its peak it could still be in operation and being transformed into fitting themes such as Christmas buffets.

The restaurant would also function as a room that transforms into a lunch hall for visitors and workers, as well as working as an suitable space for conferences as well as being available for rentals during slow seasons and such.

6.2.3 Overnight Stay

An important part for making the island functional is to provide some sort of overnight stay accommodations for guests that want to stay. For this part the accommodations have resulted in 10 rooms with an exclusive 3-star standard feel. Concepts in collaboration between the overnight stay and boating club would preside, so the customers could rent a boat and book a room with meals for their stay.

6.2.4 Convenience Store

Since the primary focus of the island has from the beginning circulated around energy and charging of electrical boats. Something almost mandatory for a charging station would be a convenience store, where necessities such as hygiene products, food and beverages are provided. Therefore there is going to be a module of the island intended for the convenience store. The format of the store is going to be extended hours, open 24h a day, with the concept of the Swedish self-service store Lilla Landet [80] in mind. A self service store minimizes the need of personnel for the store and is therefore a way to save up on costs while still generating revenue.

6.2.5 Other Activities and Facilities

An section of activities and facilities that really do not fit under any other title.

Boat Club

Boat clubs are a well known concept, but the exclusivity and benefits that follows varies. For the island, the boat club will work as a way for easier access to the island, and also to provide with rental subscriptions where the customer can rent a boat or jet-ski in advance for specific dates.

The boat club will also provide the possibility of attending a boat school that for example is suitable for visitors to travel to the island with the electric ferry. It works towards the goal of making boating accessible for people with all backgrounds. Since there are licenses required before renting the boats and jet-skis, there would be an opportunity to have courses available on the island where this is provided.

Library/Cafe

To enhance the visitor experience thoughts have been put into what activities that could provide an overall better experience. Some ideas for this is to have a sort of lounge experience, that simultaneously works as an library and quiet place that the customers can wind down in. At last in addition to the restaurant of the island an additional cafe seemed fitting. Lighter food, snacks and beverages such as coffee is sold on the boating deck, for example ice cream that could be enjoyed in the sun or the boat ride home.

Tours of the Island

The island is an almost entirely self-sustainable island, and people working in applied sciences for the island are expected to want to see how everything works since it is quite innovative in its concept. When customers visits the island an interest might spark for the island's structure, therefore guided tours on the island showing the logistics and workings of different waste, water and energy facilities will be conducted. These tours are expected to be charged, or in a package deal through the boat club.

6.2.6 Sustainability

When the island is introduced to an environment it will inevitably impact the local ecosystem. To mitigate this and to make the island a net positive over its lifetime several different solutions can be integrated in the island. Implementing extra measures to make sure the island is as sustainable as possible will benefit the environment and contribute to the public perception of the platform.

Shelter from sun and rain

The island is supposed to convey the feeling of an open space, and fitting for that experience is an shelter from sun and rain without walls that follows the experience of an open space. These shelters works in combination with the energy sources by having the roof consisting of solar panels converting solar energy into electrical energy.

Vegetation

There will be vegetation on the platform for several reasons. Urban vegetation is known for having several health benefits on humans [81]. People usually prefer spending time in close proximity to nature rather than in an urban environment. Grass lawns provide relaxation areas and social gathering spaces, which are conducive to relaxation and socializing. The plants help regulate the local climate by absorbing heat from the sun and reducing heat islands, making the island more enjoyable during hot weather. An island abundant with vegetation also has positive environmental implications. The plants create habitats and play a crucial role in preserving and supporting local ecosystems. They serve as habitats and resources for insects, while also enhancing air quality on the island.

Floating Treatment Wetlands

Floating treatment wetlands (FTW) are artificial biological structures designed to naturally purify water and enhance ecosystems. FTW are primarily employed to purify stormwater in stormwater ponds or mitigate eutrophication in freshwater lakes and rivers, although they can also be adapted for use in saltwater environments [82]. It is an efficient way to reduce a large variety of pollutants, from nutrients to pesticides [83]. The island will cater mostly to electric boats, however, boats with combustion engines will not be prohibited from visiting the island. Leisure boats with combustion engines emit an array of pollutants that contribute to eutrophication [84]. Having FTW around the island is a way to mitigate these risks.

Local Food Production

The island is supposed to be self sustainable to the greatest extent possible, and for this concepts such as mussel farming, algae cultivation and hydroponic farming has been researched. Hydroponic farming has proven to be an promising concept, by growing plants in a water-based nutrient instead of soil [85]. Worth mentioning is that some local harvesting could be done at the island as well, as part of the vegetation area. Mussel farming is good for the environment as well as by acting as a large filter, and works as an cheap source of high-quality protein [57].

Collaboration with Environmental Initiatives

To strengthen the island's positive impact on the environment, opportunities for collaboration with local environmental programs or scientific initiatives will be available. Depending on the platform's location, various types of collaborative partners may be suitable. In regions with short leisure boating seasons, the island could serve scientific purposes throughout the rest of the year.

Fences on island/Safety

For certain parts of the island fences felt needed, to create certain safety barriers and security perimeters. The different fences that seemed suitable, where the thought was that the design could be changed depending on the cause of the fence. Some possible designs were composite fences [86], tempered glass fences [87], aluminum fences or posts [88], stainless steel fences or posts and at last cables. The aluminum and stainless steel posts could also be combined with cables or to keep the tempered glass in place.

7

Energy and Business Model Results

This chapter addresses results concerning Energy system, code and business model that are to be applied for Penta Island. These system are based on assumptions, expected values and knowledge gathered from 3.

7.1 Energy Results

Initially, the yearly estimated energy demand stood at 525, 600, kWh/year, derived from broad estimations. The X-shore commercial electric boat boasts a battery capacity of 126, kWh [22]. The marina aims to produce enough energy to fully charge 10 boats daily, resulting in an annual demand of 459, 900, kWh/year for charging alone. Additionally, the island will host facilities such as restaurants and hotels, each with their own energy consumption needs. The yearly energy demand for a restaurant amounts to 45, 000, kWh/year, while for a small hotel, it is 24, 000, kWh/year [23; 24]. Summing these requirements provides an estimated yearly energy demand, pivotal for gauging the size and specifications of the energy grid. This preliminary estimate served as a benchmark for setting simulation goals and determining the initial size of the grid.

7.2 Micro Grid Design

The microgrid's design transforms it into a commercial hybrid energy system (shown below in fig 7.1), incorporating three energy sources: solar, wind, and fuel cell, along with battery storage to ensure reliability during peak loads [32]. It operates as a standalone system, featuring a DC power system and a radial configuration depicted below in figure 7.2. The DC power system minimizes the necessity for DC/AC converters, thereby diminishing losses within the grid since all sources of energy is DC except wind turbine[38]. The radial configuration simplifies grid deployment, offering cost-efficient solutions.

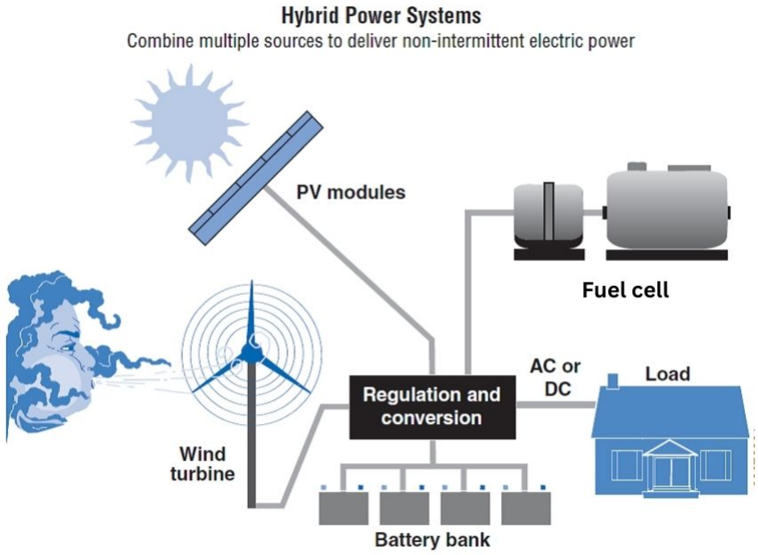

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Figure 7.1: *Hybrid standaloner micro grid [89].*

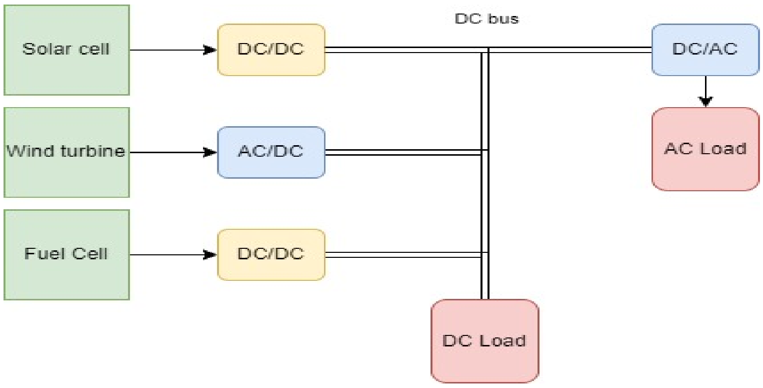

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Figure 7.2: *DC powerd Microgrid.*

Thin film solar cells are strong for their ability to maintain consistent energy production even under cloudy conditions and their adaptability to the varying sizes and structures of the floating marina. They are accompanied by a DC/DC converter to safeguard the cells [28]. The wind turbines are configured as small HAWT to ensure stable energy generation, capable of withstanding high wind speeds common in ocean environments where the marina is situated [90; 29]. The fuel cell chosen is a low-temperature fuel cell with a hydrogen catalyst, providing a reliable and renewable energy source [31]. Energy storage is facilitated by lithium battery racks housed in a battery container with a C-rating of 3C, ensuring convenient storage without compromising the grid's ability to access sufficient energy during periods of low energy input from other sources [36; 35].

7.3 Microgrid Simulation

The Matlab script simulated a year's worth of activity, covering the boating season from May to September, as well as the off-season when private boating isn't active.

The simulation was build on data gathered on efficiency of the different energy systems. The solar data points was taken from PVWatts and Climate-data.org [91; 92]. The wind turbine efficiency data was taken from The Swedish energy authority's book on small scale wind turbines and Smhi local wind speeds at the light tower Vinga A is all shown in table 7.1 [93; 90]. And the different charging standards data was taken from from Damilare Oyediran master thesis Electrification of marinas for charging of electric recreational boats in table 7.2 [37].

Table 7.1: Table with Sun and Wind Energy Data Points for Simulation.

Month	$kWh/m^2/day$	Sun hours/month	Wind speed (m/s)
January	0.46	2.5	8.6
February	1.05	3.6	7.4
March	2.47	5.8	7.3
April	4.20	8.6	6.5
May	5.82	10.5	6.0
June	5.71	11.2	6.2
July	5.81	10.7	6.4
August	4.63	9.3	6.6
September	3.41	7	8.2
October	1.90	4.5	8.7
November	0.66	2.9	9.4
December	0.38	2.3	9.0

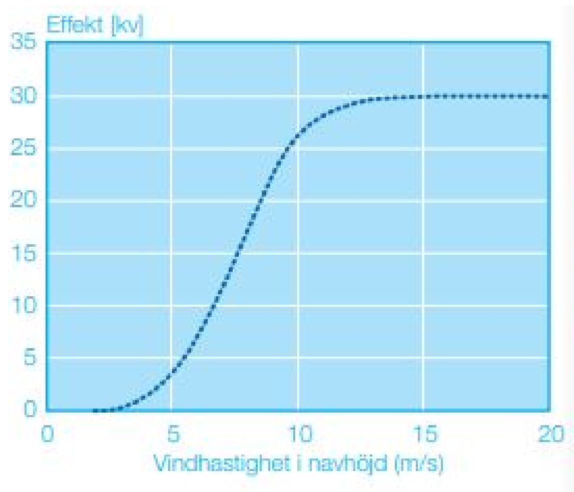
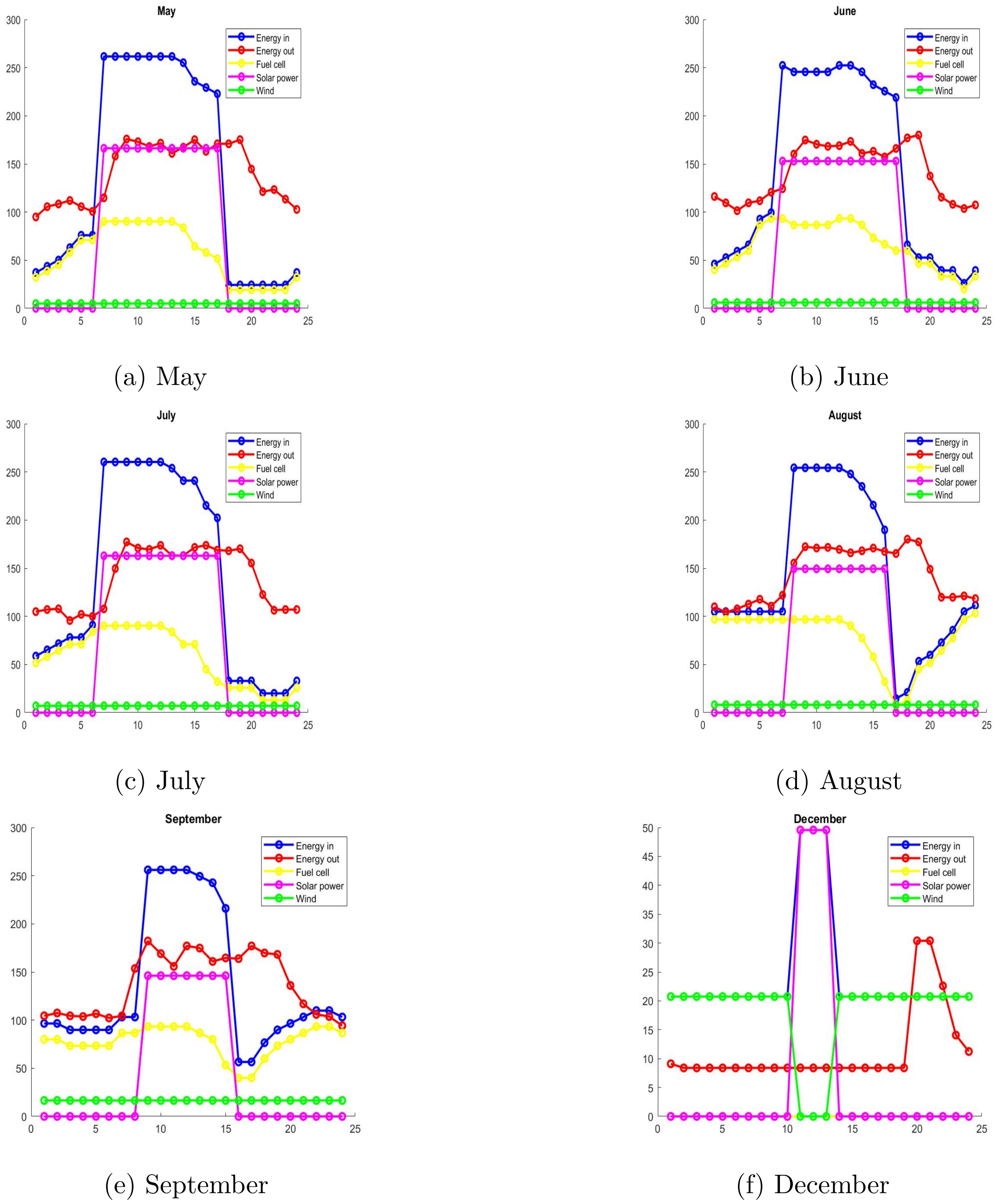


Figure 7.3: *Wind turbine efficiency per m/s [93].*

Table 7.2: Charging Levels and Maximum Ratings [37].

Levels	**Maximum power rating [kW]**	**Maximum current rating [A]**
SAE Standard		
DC Charging		
Level 1	90	80
Level 2	up to 400	400
AC Charging		
Level 1	2	16
Level 2	20	80
Level 3	Above 20	Above 80
CHAdeMO		
DC Fast Charging	400	400
IEC Standard		
DC Charging	100-200	400
AC Charging		
Level 1	4-7.5	16
Level 2	8-15	32
Level 3	60-120	250

With the data points gathered the code was developed according to figure 2.1 where the different energy sources complements each other. After ruining several different setups with stability, cost reduction and are limitation in mind and using a trial and error method. A stable system emerged with 15 chargers with a max charging output of 12kW when chargers are full, then increased based amount of boats charging below 15 to a max charging speed of 22kW. These parameter created a yearly total energy output of 571380kWh per year. The energy sources are 100kW low temp fuel cell, $300m^2$ Solar cells (about 46kW) and 1 30kW HWAT turbine. The battery container has a storage capacity of 4000kWh to be able to supplement more than 24h of no renewable energy or the fuel cell needs repairs/maintenance. With this setup the yearly input became 622800kWh per year. The graphs in Figure 7.4 display the average energy output for each month of the boating season and December, which represents the off-season months with the lowest energy production. These graphs depict the energy balance, emphasizing occasions when power output surpasses input, with the battery intervening to bridge the gap or when fuel cell supplement a discharged battery. Given the minimal energy demand during the non-boating season, the graphs for these months exhibit striking similarity. However, December, with its lowest energy input, demonstrates its capacity to manage the reduced energy demand effectively.



(a) May

(b) June

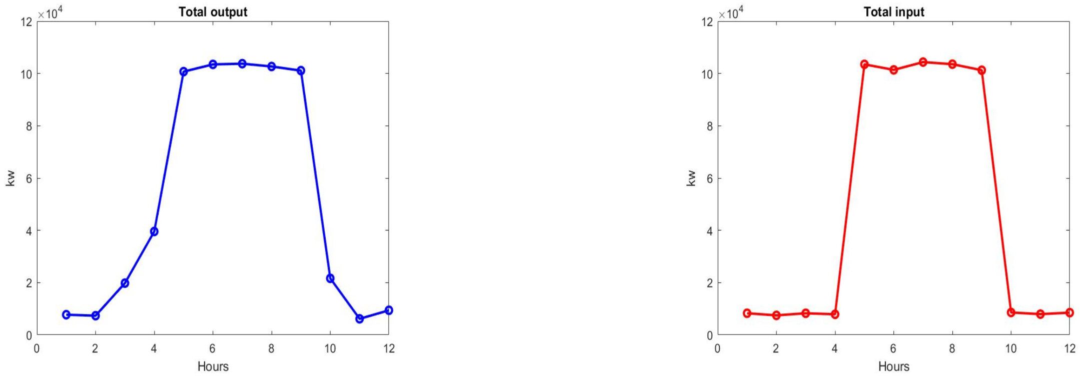
(c) July

(d) August

(e) September

(f) December

Figure 7.4: *Monthly average energy out/input (kw/h).*



(a) Output (b) Input

Figure 7.5: *Yearly in/output kWh/month.*

7.4 Business Model

In order to understand the operational framework and revenue generation strategies of the island, it is essential to delve into its business model. This model encapsulates the various components and activities that drive its functionality and success. The business model shown in figure 7.6 illustrates the combination of costs and revenues within this frame of network.

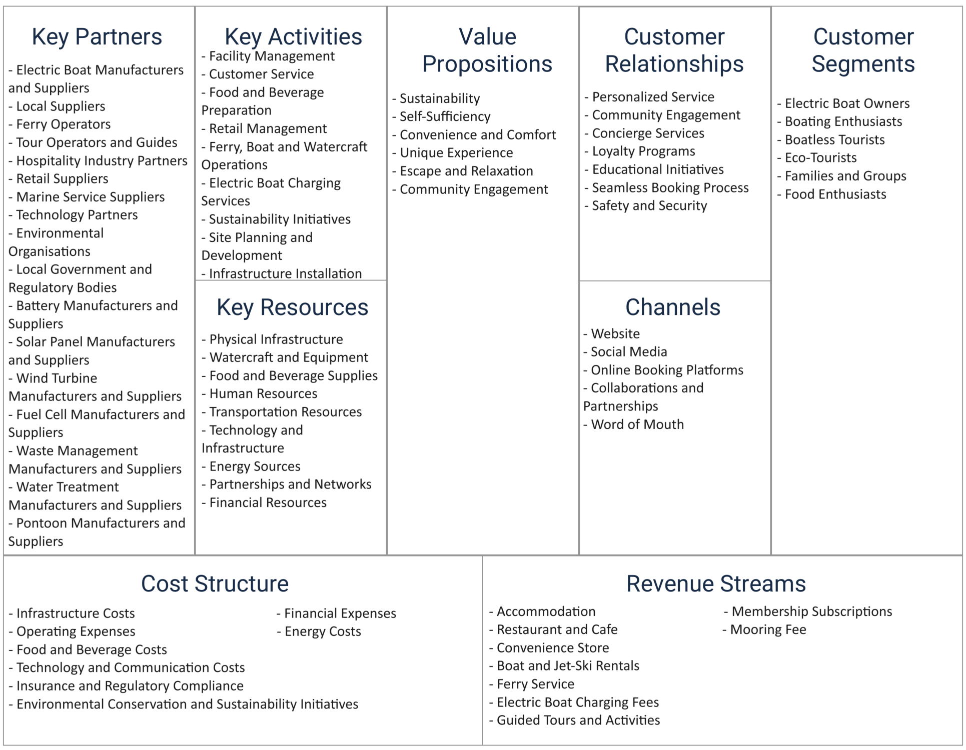


Figure 7.6: *A Comprehensive Framework of the Business Model for the Island.*

7.4.1 Customer Segments

The primary audience for the island is the electric boat owners, but since these small groups, as of today, will not generate enough revenue to the island, there must be a wider audience in order to attract more people. Non-electric boat owners and boating enthusiasts would therefore be a potential segment to target, expanding the island's reach and revenue streams.

This combined customer audience would be able to eat, sleep and take a break on the island, but the second group may have to pay a higher price for some of these services. The electric boat owners would be offered benefits for using the charging service. Finally, due to the island's accessibility to those willing to pay for the island experience, tourists without boats would need to be transported to the island, preferably via an electric ferry.

7.4.2 Value propositions

At the heart of the business model are the value propositions that are offered to the customers. These propositions encompass a green and environmentally friendly charging solution for electric boats, aligning with eco-conscious values and contributing to reducing carbon emissions in waterway transportation. This commitment to sustainability resonates with environmentally conscious travelers, attracting them to the island as a primary destination.

By providing convenience and comfort for visitors through a one-stop destination with amenities such as a restaurant, cafe, and convenience store, it addresses the common inconvenience of visitors needing to return to the mainland for food and beverages. By simultaneously offer a unique experience, it would appeal to both families and groups of all sizes, and foster a sense of community among all visitors and residents alike. This approach not only encourages social interaction but also facilitates the sharing of experiences, thereby creating a vibrant atmosphere and numerous opportunities for meaningful connections.

7.4.3 Channels

Maintaining an informative website allows for showcases of the island's features, amenities, activities, booking options, and contact information while still being cost efficient. Similarly when establishing a presence on social media platforms allows for sharing engaging content, photos, videos, promotions, and updates about the island as well as being cost efficient and still being able to reach the customers.

Partnering with online booking platforms and travel websites would potentially result in reaching a wider customer audience of potential visitors. While simultaneously collaborating with local businesses, hotels, and tour operators, it would create a win-win situation for both parties and at the same time expand reach through mutual referrals.

7.4.4 Customer Relationships

Strong customer relationships are refined through personalized service, community engagement, concierge services, loyalty programs, educational initiatives, seamless booking processes, and safety and security measures. These elements will together encourage trust and loyalty among the customers, ensuring a positive and memorable experience during their visit.

7.4.5 Revenue Streams

Because of the island's variety of contents, the revenue streams are widespread, which not only ensures financial stability but also mitigates risks associated with reliance on a single revenue stream. Additionally, the diverse revenue streams enable the island to adapt to changing market conditions and cater to the varying preferences and needs of visitors, thereby fostering resilience and long-term sustainability.

7.4.6 Key Partners

To reduce the risks and uncertainties of the cost related parts are collaboration with key partners such as electric boat manufacturers and suppliers, local suppliers, ferry operators, tour operators and guides, hospitality industry partners, retail suppliers, marine service suppliers, and so on essential. The collaborations with the key partners could also assist in keeping the costs down with potential long-term contracts of services or investments.

7.4.7 Key Resources

In order for customer relationships to be successful, key resources are needed. The reliance placed on the key resources are physical infrastructure, watercraft and equipment, food and beverage supplies, human resources, transportation resources, technology and infrastructure, energy sources, environmental resources, partnerships and networks, and financial resources.

7.4.8 Key Activities

The activities needed for the island to generate revenue, and the customer relationships to be successful are facility management, customer service, food and beverage preparation, retail management, boat and watercraft operations, ferry operations, e-boat charging services, event coordination, tourism and recreation facilitation, sustainability initiatives, and marketing and promotion.

7.4.9 Cost Structure

The most important costs included in the island are the infrastructure costs, operating expenses, food and beverage costs, transportation expenses, technology and communication costs, energy costs, marketing and promotion expenses, insurance and regulatory compliance costs, financial expenses, and miscellaneous expenses. The initial costs for the infrastructure and power grid are supposedly the most expensive key activities as well as key resources.

7.5 Cost Analysis and Calculations

Based on the business model shown in the previous section, an easier understanding of how the structure of the network between the revenues and costs were organized and how the cost analysis would be implemented.

A breakdown of the costs of the island is implemented in figure 7.3, which contains the required facilities, desired facilities, energy, water treatment, waste management, and infrastructure costs. The costs for the Alukin boat and electric motor were mentioned during discussions at the Gothenburg Boat Show 2024, when conversations were held with an individual working for the company Alukin.

Cost type	Description	Item	One-time cost	Amount	Cost per usage	Overall cost (first year)	Overall cost (after the first year)
Required facilities	Electrical ferries	Candela	$1,819,000	1		$1,819,000	
Required facilities/ Waste	Service ferry	Alukin CWA 850 with electric propulsior	$200,000	1	$5,000	$205,000	$5,000
Required facilities	Mooring facilities	JetPort Plus	$2,579	4		$10,315	
Required facilities	Floating enclosures	Y-boom	$822	50		$41,096	
Required facilities	Rentals on land ($/ year)			3	$925	$2,775	$2,775
Desired facilities	Electric Boat	X Shore 1	$133,750	3		$441,375	$40,125.0
Desired facilities	Jet-skis	Taiga Orca Electric Motor	$17,490	4		$79,996	
Desired facilities	Diving Gear, Masks, Fins, Snorkel	Value Mask Fin and Snorkel Package	$100	10	$999.50	$1,000	
Desired facilities	Restaurant	Permits, equipment, furniture, POS system, food and beverages, and salaries	$150,250	1	$810,000	$960,250	$810,000
Desired facilities	Convenience store	Licenses, inventory, equipment, POS system, goods, and salaries	$262,000	1	$480,000	$742,000	$480,000
Desired facilities	Hydroponics	Installation, equipment, and permissions	$15,000			$15,000	
Desired facilities	Overnight stay (per room)	3-star standard for the rooms	$200,000	10		$2,000,000	
Desired facilities	Cafe		$3,000	1		$3,000	
Energy	Battery container, Solar, Wind, Fuel cell		$810,748		$2,504,432	$3,315,180	$2,504,432
Waste	Membrane bio reactor		$200,000	1		$200,000	
Waste	Biogas Chamber		$4,000	1		$4,000	
Waste	Reverse Vending Machine		$10,000	1		$10,000	
Waste	Trash Compactor		$20,000	1		$20,000	
Water	Greywater recycling	ALGW10800	$15,000	1	$670	$15,670	$670
Water	Rainwater harvesting		$2,235	1	$224	$2,459	$224
Water	Reverse Osmosis	ZS-WP500L	$4,600	1	$580	$5,180	$580
Infrastructure costs	Pontoon plateau	4 m x 18 m	$182,648	120		$21,917,760	
Total costs						$31,811,055.50	$3,843,806

Table 7.3: *Breakdown of Operational Expenses[76; 94; 75; 95; 22; 96; 97; 77; 98**?** ; 99; 100; 101; 102; 103; 104; 105; 106; 107; 108; 109]*

As can be viewed in the breakdown cost table, the highest costs are associated with infrastructure and energy costs, but also the ferry boat in required facilities as well as the overnight stay for desired facilities. Another thing that can be observed from the figure is that the initial investment is about 828% larger than the yearly estimated costs, which mainly consists of maintenance costs.

In figure 7.4 is the breakdown of the island's income streams presented. The revenues were based on mostly the facilities, but also on the usage of the charging system.

Revenue stream	Prices	Generated revenue (per year)
Charging fee	6.5 $/kWh	$3,207,646
Rental boat fee	70 $/h	$204,960
Jet-ski fee	65 $/h	$126,880
Restaurant	$/year	$1,928,000
Covenience store	$/year	$95,000
Cafe	$/year	$160,000
Diving Gear package	50 $/day	$61,000
Mooring fee (basic)	100 $/night	$427,000
Mooring fee (charge spot)	200 $/night	$195,200
Overnight stay	300 $/night	$36,600
		$6,442,286

Table 7.4: *Breakdown of Income Streams [110; 111; 112].*

From personal experience the cost of renting a boat varies with factors such as size, model, location and demand. To promote electric boating in Sweden and make it available to as many people as possible and still make it economically viable, the price of 70$/h is reasonable.
As can be observed in the breakdown of the income streams, the revenue generated from the restaurant and chargers were the largest income streams. The restaurant revenue was based on the generated revenue of Långedrags Värdshus because of the similar offerings. Lilla Landet was the reference for the revenue of the convenience store.

Based on the total costs and total revenue generated, the payback time for the island became approximately 12 years with an energy cost of 6.5 $/kWh.

8

Final Concept

This part of the report presents detailed specifications of the concept. A detailed description of the concept, its final subsystem components, the model of the island and finalize the development of the Penta Island.

8.1 Final Concept Specification

From the iterative process of research and concept development, concept nine was presented as the final concept. An amalgamation of solar and wind power, combined with fuel cells, had the capacity to produce enough energy to power the island's required and desirable facilities.

In terms of water supply, greywater recycling proved to be energy efficient and could provide enough water to flush toilets, use showers and possibly clean boats, to name a few uses. Through a combination of rainwater harvesting and reverse osmosis membrane technology, sufficient amounts of water will be able to be generated for drinking water, hand washing and for use in the potential restaurant.

By integrating reverse vending machines and recycling stations along with garbage compactors, the island is capable to store the waste until a medium-sized service boat can pick it up. An additional facility for managing the waste is a biogas reactor that converts human waste into biogas. A septic tank, that stores black water, together with an MBR, which converts black water into service water, creates a system that cleans enough service water to reuse in other systems, while the excess is clean enough to be released into the ocean.

9	Solar + Wind + Fuel cells	Mediocre maintenance	External Wavebreakers	Greywater recycling + Rainwater Harvesting	Reverse osmosis membrane desalination technology	Reverse vending machines + Recycling stations + Trash compactor + Modular service boat	Biogas chamber + Membrane bio reactor + Septic tanks	Highest sustainability	Lower payback-time

Figure 8.1: *Representation of the Parts that Made Up the Final Concept*

The final concept also incorporated desired facilities, such as boat rental, restaurant and convenience store, among others. All desired activities and facilities can be found in section (6.2). The business model includes revenue from some of the desired facilities, indicating that facilities were necessary implementations. In addition, one of the goals for the island was to attract visitors, something that the desired facilities and activities ensured.

8.2 Physical Model of the Final Concept

A primary 3D model was constructed and followed by a 3D print of the model for the final concept. This model reflected a modular structure for the island, consisting of a platform with an associated building.

As shown in the figures (8.2, 8.3) below, the 3D models only represent two structures. To illustrate the entire island there would have been 20 more modules printed. One of the modules is shown in the figure (8.4) below.

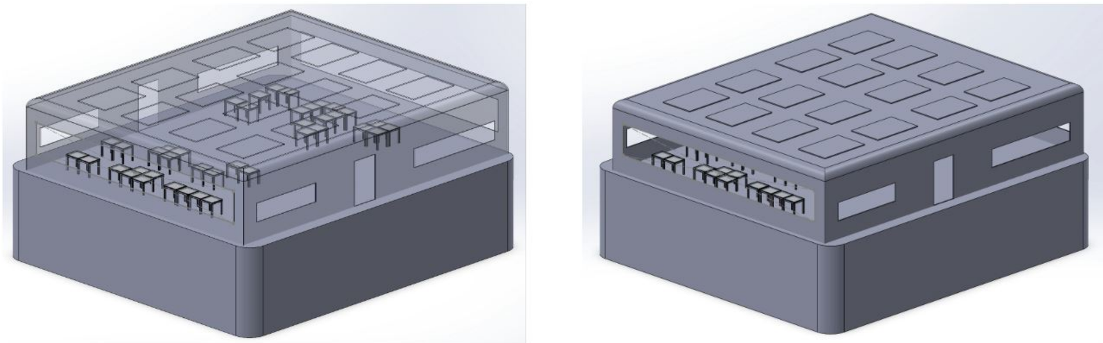


Figure 8.2: *CAD Model of a Sheltered Area Module.*

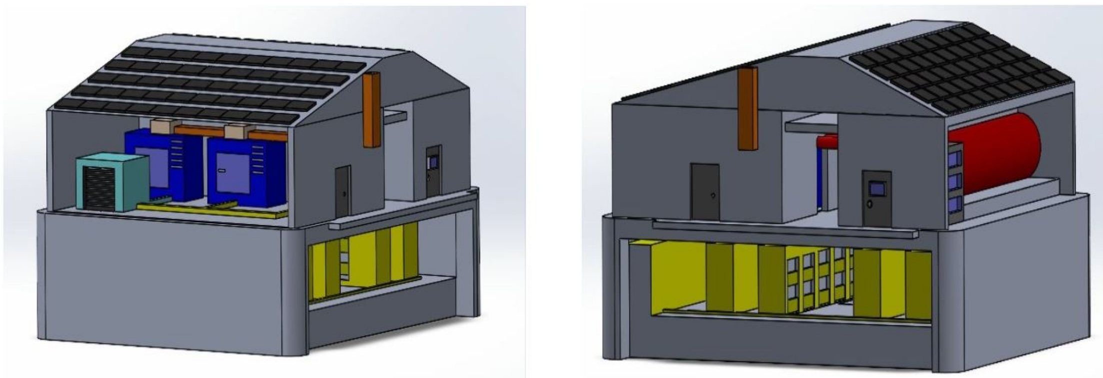


Figure 8.3: *CAD Model of a Storage Module.*

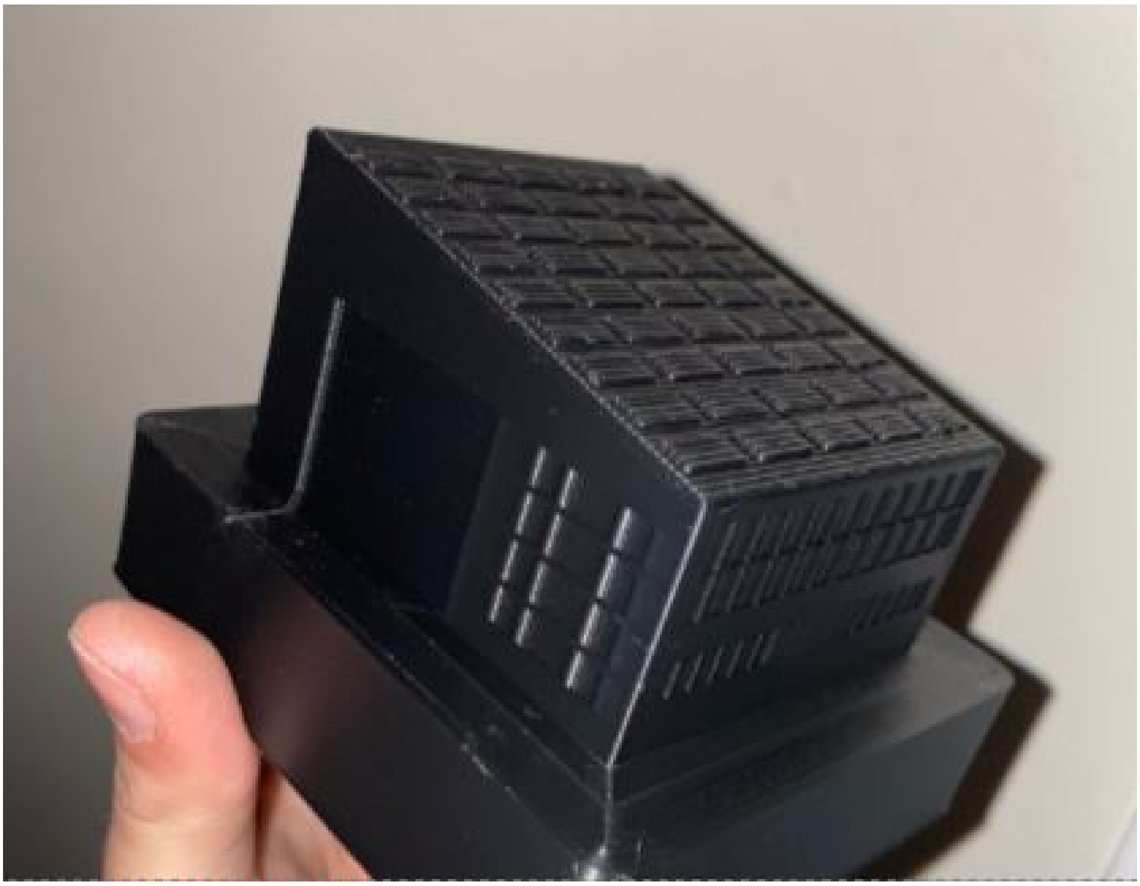


Figure 8.4: *3D Printed Model of One of the Modules.*

9
Discussion

The purpose of this chapter is to discuss all the parts that have been raised during the process of creating Penta Island. The chapter aims to clarify and reflect over the different methods and results.

9.1 Discussion on Waste and Water for Penta Island

As can be seen throughout the project waste and water often goes hand in hand, the water intake leads to waste and therefore the two different areas often works together. And with that in mind the question about if the collaboration can be more seamless arises, how is it actually when flushing toilets; is it necessary to have both greywater from the MBR and the greywater recycling, or could costs and energy be saved if that were not the case.

The biggest issue when designing and modeling the water management system was to figure out how much water was needed. Numbers that varies in a prominent way from person to person and alongside with variants all over the world. If Penta Island were located in the Mediterranean or alongside the Gulf of Mexico where the temperature generally is higher than on the Swedish west cost, it will probably lead to a higher daily water intake. As a result of things like people sweating more. The needed water amount is also affected by the division of men and women on the island, since the male water intake per day is a bigger amount than women's. And while shaping the water systems there have been an expected distribution of 50/50 for men and women on Penta Island, is this truthful and does it correspond to reality? To not produce too much water things such as buying beverages in the convenience store such as sodas have to be taken into consideration, after all the younger generations nowadays daily liquid intake often consists of some sort of non-water drink. To present a truthful predicted amount of water these kinds of factors have to be taken into consideration, but there will always be things that are unexpected.

From personal experience, the most common item brought and bought while boating are bottled drinks. Since the Penta Island utilizes RO and RWH, which produces water suitable for drinking, visitors can refill their bottles for free instead of buying more. The trash collection points will all promote recycling, featuring reverse vending machines. Additionally, informative signs discussing waste in an environmental context could be mounted at these locations to increase the visitors consciousness.

One point when working with the two areas is that it is experienced as difficult to set limits, for example how hard can the restraints be when taking a shower, how much water are you allowed to use and so on. This dilemma becomes even more obvious when it comes to luxury and creating an exclusive environment, after all it usually works in a way that if you have got the money you can do whatever you want. Therefore who is to say that you can only shower for 10 minutes, or even less when that is not the norm for you. To eliminates such conflicts should the showers be disposed of or should the scarce water situation be made very clear.

Also in today's society where the segregation in cities and globally can go to such extremes, is it even something that should be promoted to have an luxury island. Or maybe it is, and it can be seen as an way to create self sustainable facilities for water and waste that can be applied in underdeveloped counties where clean water and waste management are not an obvious or crystal clear access. Maybe such projects that aims for the rich in later years bring such positive outcomes that it is worth it...

The approach to waste management and water production on Penta Island has been developed with environmental and ecosystem considerations in mind throughout the entire process.The impact on ecosystems from the sewage system should be minimal, as the MBR effectively eliminates pathogens, nutrients and other pollutants from the water. The waste should also have minimal environmental impact on the Penta Island, as recycling and reuse are promoted. The waste generated on the island would likely have been produced elsewhere regardless, but now it is properly sorted. The transport of waste to the mainland is by an electric service boat, which also have very little environmental impact.

9.2 Discussion Regarding Energy and Micro Grids

The micro grid design was developed through the iterative idea generation and there fore ended in a well motivated setup. Since the scope of the project the functions and complexity of the grid was narrowed down to fit the project in the designated time frame of the thesis. The grid could be further developed with the help of the Pugh matrices to chose the exact components of each renewable source and the same with grid structure, power system and grid control. Instead the components was chosen on information gathered and personal weighing the options. Grid control was never explored because of time limitation.

9.3 Discussion of the Matlab Script and Possible Improvements

While developing the script to simulate the micro grid and its efficiency the group was doing active researching, this made the modeling a lot harder since new data and understanding was occurring simultaneous. Also the limited experience with modeling and simulations within the group made it difficult to developed a functioning script that gave any reliable data. Because of these short comings the script was not fully completed and the simplifications makes the result given by the simulation unreliable, and should be used with caution.

Because of this the script have a lot of simplifications to function that can give big margins of error. Examples of this is time steps was set to hours, for simplicity, for the development. The consequence of this choice is that in the simulation we lose things that takes less than a hour. If the fast charging is studied where a possible charging rate of 86kW, that could charge a Candela boat with capacity of 40 kWh in less than 30 minuets, but the boat would be counted as charged after 60 minutes[76; 22]. This also affects energy sources that would turn off at certain times like the fuel cell, when the battery is charged, or solar power that is based on sun minutes per day. The responses in the system is slower witch adds to the total input and output over a year.

The way the simulation used the data for renewable energy was also a very rough simplification to make it easier to model. Wind data was the average m/s per month between 1961-1990 [90], and as a result the simulation used this data as constant wind speed. A more sophisticated solution could be creating a random wind speed each day witch when taken the sum of all days per month creates the given data point. Solar power had also a similar simplification with the sun always shining equal hours each day during a month, instead of increasing slowly each day. All these simplifications add up to create larger inconsistencies in the simulation.

Since the model was not finished using it to get the most optimize size wasn't achievable, it only helped achieve the size for a stable system. The trial and error method was used to accomplish this stable system, and it's energy results. But since it is not optimized, and is missing functions to reduce unnecessary energy generation it created 51420kWh of unused energy, see Figure 7.5. An easy fix to this could have been creating a load based on surplus, for example hydrogen production, to the fuel cell for fuel.

The reason the chargers was set to a maximum of 22kWh was because stability of the system was compromised, when adding fast charger. This gave way to big spikes in energy output, and to a big increase in the output, per year for the system to function without stability concerns. This could be amended, but the cost for increasing the size of system would inflate to much to fulfill the limitation concerning the payback time.

The Matlab script and model leaves much to desire in functionality, and optimization options. It gives a good estimate for the required energy output when charging several different kinds of electrical boats, during longer periods of time. This could be used for other areas of the thesis, where energy input and output are relevant like the business plan and payback time.

9.4 Discussion of Activities and Facilities for Penta Island

As said in the facilities chapter, the Penta Island experience is supposed to bring forth an exclusive feel for the affluent people. As well as creating that atmosphere the overall concept and systems on the island is an unique thing, there really are no similar floating islands on the market as for now. Penta Island can be seen as a investment for the growing electrical boat market. A result of this is a expected acceleration to the pace, which it is growing since there are facilities and structures that supports the cause. In time with new technologies that take up lesser space, more space will be available for facilities and activities that makes Penta Island fun. Penta Island is a future concept, and with the right facilities and activities it is possible to enhance loyal support for visitors for the self-sustainable island, and by that spread the concept of this island globally.

While trying to identify which activities and facilities that could enhance the visitor experience it would have been more beneficial to think about the space and area that the different things would need. And that so things did not have to be eliminated depending on that, and on the same thought more things that could work in combination with each other and work as a synergy.

Something that there have not been time for in this project is looking at possible collaborations with other companies, that in some way could contribute to the Penta Island experience. To play at the seasonal activities maybe it could be arranged to in collaboration with organizations and companies present theme-based activities, maybe there could be a star gazing night for example. These kinds of activities would need an engaging team that constantly reaches out, and creates a presence in modern society. Since it is an self-sustainable island it is a prime location for sustainable initiatives for a better climate, and minimizing climate change et cetera.

These different activities are probably not all going to be successfully, therefore moderating what plays well and whatnot is critical. Conduct investigations that asks the public what they would appreciate, and be very observant of what performs admirably.

For the facility side, things that are part of collaborations between the different facilities and activities could be explored to a greater extent. For example subscriptions and packages that would result in lower costs could be explored to a greater extent, that supports the notion that a loyal customer to Penta Island gets advantages and lower prices in different areas.

9.5 Discussion of the Cost Analysis

Even though the project reached it's goal of having a payback time of at most 12 years, the charging price was set to an unfeasible price range of 6.5 $/kWh. Since the price range that had to be implemented in the cost analysis was quite high, the target group became the costumers comfortable money wise. There were many potential revenue streams that were not researched which could potentially have increased the revenue and therefore decreased the charging fee. This was to implement a boat club which could offer subscriptions that would give the customer a lower price for the rentals and a fixed revenue for the island. Also a boat school with possibilities of having an instructor for customers wanting to learn how to swim, as well as having qualified instructors for educating customers on how to use a boat. Giving the possibility of customers to do training and getting the required licenses for using the rentals could also be a source of income.

Another way of increasing the income to the island would be to increase the number of rentals since they are paid off quite fast and are a large income stream. To increase the amount of rentals, the amount of charging spots have to be increased since the rentals would occupy the spots used by the customer's boats. This could potentially increase the costs much more.

Since the cost analysis was based on estimated costs and revenues of similar products and services, it may not be applicable in reality when referring to generated revenue since these are based on estimations of maximum usage. A more dynamic model of the revenue streams would probably give a more righteous picture of the payback time too.

Potential investors and collaborations to the self-sustainable island would also be a way to shorten the payback time or to decrease to more feasible charging fees. On the same area things that should have earned more time, and research but at the time was seen as meager expenses were not taken into consideration, such as fences since the level of details were too high. Therefore it would probably have an impact on the final business model and revenue in the end.

9.6 Discussion of Concept Development

A crucial part of this project was the concept development process. The initial stages of brainstorming and brainwriting were important to generate design concepts. There were also subsequent brainstorming sessions later in the concept design process, which proved to be highly effective. With this in mind, if the creative methods had been applied to more stages of the work, it might have been possible to generate more design concepts and solution proposals that could have further developed the work. In general, additional iterative processes could have been implemented to ensure a even more deliberate outcome.

The project was divided into different sections. These were water- and waste management, energy supply, facilities, business model, concept development. By breaking down the work into smaller sections, the collaboration between the students from Chalmers and Penn State improved. This method also gave the group as a whole an increased opportunity to explore area-specific solutions that would otherwise not have been possible if everyone had focused on a single track.

The concept of modular design was introduced early in the project. By creating different modules, adaptations of the island were made possible regarding the placement and implementation of facilities. This also resulted in the generation of a variety of design ideas. In addition, the modular design facilitated the handling of the different sub-problems the group investigated, as different facilities related to these sub-problems could be applied to different modules.

A further development of the morphological matrix could have involved an exploration of more complex combinations of solutions. Despite this, the matrix presented various proposals for solutions/subsystems for both energy combinations, water and waste management. These concepts and subsystems were also evaluated during the final stages of the concept development process, and the solution proposals were still considered to be optimal after the end of the research phase.

The pairwise comparison of the desired facilities were divided into two parts. By making these comparisons in two matrices, it enabled a systematic and comparative assessment of their relative importance and performance.

Volvo Penta gave the group the opportunity to work independently and encouraged them to explore their own solutions and exercise creativity. This resulted in the group generating a variety of solutions. However, if the project would have been narrowed down to include fewer details, it is possible that the solutions could have delved into more thoroughly.

The 3D-printed model produced was not very detailed and printed in a small scale. Additional resources could have been devoted to enriching this part of the work, given sufficient time. One method to improve the model could have been to include different material choices to enhance the visual representation. This would also have allowed for a discussion of material choices for the island itself, beyond the materials used for its platforms. However, the model did create an understanding of how the island could potentially look.

9.7 Discussion of Concept Elimination Process

In the first phase of concept generation, the team conducted a concept elimination to determine the most viable options for further development. However, the comparison criteria used in the first Pugh matrices (7.4) could have been changed to ensure the elimination process was optimized. To improve the elimination process, further discussion of the criteria was held, which led to other comparison criteria were used in the final Pugh matrices. In despite of this change, this improvement should have been implemented in the earlier stages of elimination. Furthermore, the selection of the concepts for elimination was done in the early stages of research and had possible areas for improvement. If more time had been available for the project, the team could have spent more time improving the first round of concepts. As a result, the focus ended up on the subsystems that preformed best in the first round of elimination which led to the creation of 16 new concepts, believed to have greater potential.

A further improvement to the concept elimination could have been to implement Kesselring matrices after each round of Pugh matrices. This method would have allowed a more detailed evaluation of each concept by clearly identifying its strengths and weaknesses within different criteria. By integrating Kesselring matrices into the process, the decision-makers would have had a more complete picture of each concept's potential and potential shortcomings, which would have facilitated the final decision-making process. Despite the constrained timeline and possible improvements, all concepts were either developed or amalgamated to a certain degree.

9.8 Discussion of Future Concept

In the future, advancements in technology will likely lead to the development of new and more cost-effective techniques, enabling better solutions for most aspects of the Penta Island project. Also, not all avenues of research could be explored due to the time constraints of the project.

A few ideas the group discussed proved to be unfeasible at this time due to being to expensive. One such future possibility included introducing levels to the island to house facilities such as an underwater restaurant or storage areas for septic tanks. The shape of the modules that makes up the island could have been in the shapes of a pentagons or hexagons, which would open up for interesting design choices. Regardless, the cost of implementing such a design would make it challenging for the island to generate a profit in this day and age.

In the future, there will be advancements in efficiency and the creation of better energy storage options. An example of this is utilizing surplus energy to produce hydrogen fuel cells. This would be a more sustainable and cost-effective way to store all of the energy created and not waste any excess energy.

9.9 Discussion of Ethical Dilemmas of Penta Island

With the type of large structure the island has, a series of environmental concerns arose. The structure, once anchored in place, is anticipated to remain a fixture within the ecosystem for a span of fifty years. An examination of the potential implications of this long-term presence on the local ecosystems is a critical aspect of the analysis. If the Penta Island is constructed with this in mind, it could be beneficial for the marine life in the way artificial reefs are. The prolonged presence of the Penta Island also provides a unique opportunity for research initiatives and potentially deepening the understanding of the long-term effects that marine structures can have on the ecosystem.

In the area where the Penta Island is placed boat traffic will increase. An expanded boat traffic is expected to disrupt marine life in the vicinity, with a concurrent rise in water pollution since boats with combustion engines will also be visiting the island. It may also lead to overcrowding and an increase in traffic on land close to where the ferry docks and the private boats moor. Residents in close proximity may be adversely affected by this and find it to be disruptive. The island may however lead to reduced traffic in nearby island communities and harbors since it generates its own electricity, it decreases the strain on the local electricity network.

The island is constructed mainly from concrete. The usage of concrete brings several environmental concerns, such as greenhouse gas emissions, resource depletion, habitat destruction and construction waste generation. In light of these challenges, the project will implement sustainable construction practices when possible. There are ways to minimize the impact concrete production have on the environment with the use of alternative cement materials and recycled concrete as aggregate [113; 114].

Electric boats are expensive. There are only a few alternatives available now, and the second hand market is very limited to non-existing. This means it will be hard for people who are not wealthy to participate in the island. If the Penta Island also caters to people coming with ferry and offers mooring spaces for boats with combustion engines, it will be more inclusive. There is a possibility that the island will offer boat rental, which will also lower the financial threshold. The services on the island creates jobs which in turn creates more opportunities for the individual. This would entail a positive impact for society.

When the Penta Island is introduced into the environment it will contribute to light pollution, regardless of its location. Light pollution at sea can cause problems for the ecosystems. Artificial lights can shine with the same or stronger intensity than the moon at full moon, which can disrupt the life cycles of a wide range of organisms [115]. However, there are possible measures to minimize light pollution. Implementing a light system controlled by motion sensors at night time could be an alternative that reduces light pollution and does not compromise safety for the visitors.

Enjoying boating is often easier for individuals who have unimpeded mobility, as they have fewer accessibility challenges. From personal experience, the accessibility in marinas in the Gothenburg archipelago are subpar. Persons in wheelchairs would have a hard time accessing the docks. Most leisure boats are not wheelchair accessible, and reaching the Penta Island by personal boat would be a challenge for disabled people. Therefore, it is important that the ferry to the island and that the facilities on the island are is easily accessible for people in wheelchair.

10

Conclusion and Recommendations

This chapter provides the project's conclusive findings while conveying the outlined research questions. Additionally, recommendations are be provided to enhance the final design of the island, while taking into account potential avenues for future development.

10.1 Conclusions

The aims of this thesis project was to create a self-sustainable island, that could provide charging for electric boats, whilst being an attractive place that people would want to visit. The team managed to address the research questions, stated in section (1.4), during the course of the project. By involving research of current technology and concept generation, the team created different solutions that fulfilled the requirements for the island.

The project involved research of current technology, concept generation and concept elimination, which all led to the final concept of Penta Island. The final concept was partially visualized as both CAD models and a small 3D model. The final design was made up by different modules that could be adapted to different locations. Furthermore, the islands dimensions was capable to facilitate the set requirement of 50 boats.

Regarding the research questions about achieving enough energy and water to sustain the island, as well as how to effectively handle the waste, the final concept accomplished this. It concludes that the island could be self-sustainable regarding these aspects.

The final conclusion of the project is that Penta Island could be implemented. However, some assumption were made during the course of the project, in the absence of source material. Which had an impact on the final results. Additionally, the possibility of implementing the island is highly dependent on the different revenues, and thereby the set costs for the different activities and charging capabilities on the island.

10.2 Future Recommendations

There are a lot of possibilities for the future of Penta Island. The team generated several interesting ideas that had the potential to be implemented, however some of them were limited by cost aspects and some were considered unrealistic to implement with the current available resources and circumstances. An example of this was the design concept to include levels below the surface of the island, for storage or for an underwater restaurant. Although such ideas have previously been implemented in various contexts, there was not enough time for the group to carry out the necessary investigations regarding both physical and financial aspects.

Another future prospect is the development of current technology. With developed technical solutions the effectiveness of the implemented systems could possibly increase, and thereby generate more output. This includes energy production and the amount of water produced. It could also make the systems more energy efficient. The greatest possibility with future technology is that it could create new systems, with far greater benefits than the current systems.

If this project were executed once more, there are many development opportunities. In order to increase the depth of the research, the project should have more limitations to enable a more extensive investigation. This would have resulted in more detailed solutions and results.

Furthermore, the possibility of implementing Penta Island in other locations should be investigated more closely. The attraction targets for visitors vary between countries, and geographical locations. It is likely that the implementation of Penta Island would be more feasible in places with higher tourism, better weather conditions and less regulations.

To summarize, further investigation into the possibilities of Penta Island is recommended. This includes refining the design, exploring adaptation options for different locations and conducting a more detailed cost analysis. Penta Island's potential for further development is promising and could in the future take shape.

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