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Maris Habitats

Figure 1: The logo of Maris Habitats

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Abstract

Hosted by the Instituto Superior de Engenharia do Porto (ISEP), the European Project Semester (EPS) program facilitates an interdisciplinary environment for engineering students of diverse nationalities. The projects serve as a multidisciplinary platform for the joint acquisition and application of technical skills, specifically oriented toward the lifecycle of a proof-of-concept prototype, from initial design to rigorous testing.

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Glossary

Abbreviation	Description
BBNJ	Biodiversity Beyond National Jurisdiction
BFRP	Basalt Fiber-Reinforced Polymer
C2C	Consumer-to-Consumer
CAC	Customer Acquisition Cost
CAPEX	Capital Expenditure
CPT	Camptothecin
CTD	Conductivity Temperature Depth
DaaS	Data-as-a-Service
DVL	Doppler Velocity Log
EPS	European Project Semester

Abbreviation	Description
ESG	Environmental, Social, and Governance
EU	European Union
GEF	Global Environment Facility
GNSS	Global Navigation Satellite System
HSC	High Strength Concrete
I^2C	Inter-Integrated Circuit
IMU	Inertial Measuring Unit
IoT	Internet of Things
ISEP	Instituto Superior de Engenharia do Porto
KPI	Key Performance Indicator
MPA	Marine Protected Areas
NGOs	Non Governmental Organizations
NRL	Nature Restoration Law
OBC	On Board Computer
PDMS	Polydimethylsiloxane
PMS	Power Management System
RTC	Real Time Clock
SAC	Sulfoaluminate Cement
SD	Secure Digital
SDG	Sustainable Development Goals
SLIPS	Slippery Liquid-Infused Porous Surfaces
SMART	Specific, Measurable, Achievable, Relevant and Time-bound
SWOT	Strengths, Weaknesses, Opportunities and Threats
TDS	Total Dissolved Solids
UN	United Nations
USB	Universal Serial Bus
WBS	Work Breakdown Structure
WWF	World Wide Fund for Nature

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1. Introduction

1.1 Presentation

The 'Divers' team comprises six students from various nations with diverse academic backgrounds. Brought together at ISEP to participate in the EPS, the team objective is to leverage the collective skills to develop a sustainable solution for a real-world challenge.

Table 1: Divers team

Name	Country	Field of Study

Hernán Nieto Marabini	Spain	Biomedical Engineering
Chaehee Kim	South Korea	Industrial Engineering
Ida Schmitt	Germany	Interactive Media
Isak Björk	Finland	Electrical Engineering & Automation
Louis Van Nederkassel	Belgium	Product Development
Oda Kristine Johansen Fossvoll	Norway	Information Technology

1.2 Motivation

The motivation for this project is based on the growing concern about the degradation of marine ecosystems and the decline of natural reef habitats. Coral reefs and other complex seabed structures provide important habitats for many marine species, including fish, invertebrates, and algae. However, many of these ecosystems are currently under pressure due to factors such as climate change, pollution, overfishing, and habitat destruction.

Artificial reefs have been proposed as one possible approach to support marine biodiversity and help restore degraded habitats. By creating structures that mimic the complexity of natural reef environments, artificial reefs may provide shelter, feeding areas, and breeding grounds for marine organisms. Understanding how different materials and structural designs influence these habitats is therefore an important topic in marine environmental research.

1.3 Product

MARIS HABITATS is a modular reef infrastructure and environmental monitoring system designed for underwater environments. The product combines physical reef blocks with a removable smart sensor box, allowing it to provide both structural support and long-term environmental data.

The reef blocks are designed to be placed on the seabed and to create surfaces, cavities, and sheltered spaces that may support habitat formation over time. Instead of claiming immediate biological recovery, the product focuses on providing a physical structure that can be used in marine restoration, research, or environmental monitoring projects.

The smart sensor box collects environmental data from selected locations around the reef structure. This data can help users understand local site conditions and observe how the reef and surrounding marine environment change over time. The monitoring system is designed to operate with low power consumption and store data locally, reducing the need for continuous communication infrastructure.

The final product is intended for organizations such as public institutions, coastal municipalities, research groups, environmental NGOs, port authorities, aquaculture operators, and marine infrastructure companies. These customers may use MARIS HABITATS as part of restoration projects, long-term monitoring programmes, sustainability reporting, or environmental decision-making.

1.4 Problem

The basis for this idea is the global environmental challenge of marine ecosystem degradation. The causes of this problem are multiple; the global warming is raising not only the level of the oceans but the temperature of them. This is altering the conditions of most of the underwater eco-systems, and this evolves in multiple species having to migrate from their original environments to new ones.

Another major issue is the impact of human fishing activities on marine ecosystems. Fishing is practiced worldwide and is regulated by governments and various institutions. However, in some areas, intensive fishing can disturb marine food chains and contribute to the decline of certain fish populations. These changes may also affect other species that depend on balanced marine ecosystems.

The third environmental concern is the decline of marine oxygen production and overall ecosystem balance. Changes in marine fauna can also affect marine flora, including algae and coral reef ecosystems. Coral reefs, such as the Great Barrier Reef, are under pressure from climate change, rising sea temperatures, and other environmental stressors. Their degradation can affect biodiversity, habitat quality, and the stability of marine ecosystems. Therefore, there is a growing need for solutions that support marine restoration and long-term ecosystem monitoring.

1.5 Objectives

This project focuses on developing a sustainable and technically feasible concept for a modular artificial reef system with environmental monitoring functions. The main goal is not to prove immediate biological recovery, but to design a reef structure and a basic sensing system that can support future marine restoration and monitoring projects.

The first objective is to design a modular reef structure that can be adapted to different sites and project sizes. The structure should be made of repeatable blocks that can be combined in several ways. These blocks should provide surfaces, cavities, and sheltered spaces that may support habitat formation over time.

Another important objective is to select materials that are suitable for marine conditions. For the final design, durable and environmentally compatible materials, such as basalt fiber-reinforced concrete, are considered because they can improve resistance to seawater conditions and reduce long-term environmental risks **[1]**, **[2]**.

The project also aims to include a removable monitoring unit. Instead of placing electronics permanently inside the reef structure, the system should use a smart sensor box that can be separated from the main habitat. This makes it easier to check, repair, or replace electronic components without removing the whole reef from the seabed.

A further objective is to collect useful environmental data. In the final system, the intended parameters include temperature, pressure or depth, pH, and conductivity. This data can help users understand the conditions around the installation site and observe how the surrounding marine environment changes over time.

For the prototype, the objective is more limited. The prototype is intended to validate the basic sensing and data logging concept under controlled conditions. Due to budget and component availability, it uses a simplified sensor set, including temperature, pressure, and TDS. The pH and conductivity sensors are reserved for the final product.

Finally, the project aims to reduce unnecessary disturbance to the marine environment. The removable sensor box allows maintenance, battery replacement, and data collection to be carried out without disturbing the main reef structure. This also reduces the risk of leaving failed electronic components underwater.

1.6 Requirements

This section defines the main requirements of the MARIS HABITATS system. The requirements are divided into functional and non-functional categories. Functional requirements describe what the system should do, while non-functional requirements define the conditions needed for safe and reliable operation in a marine environment.

Because the project separates the final product from the prototype, the requirements are also considered at two levels. The final product is intended for long-term marine deployment, while the prototype is designed to validate the basic sensing and data logging concept under controlled conditions.

1.6.1 Functional Requirements

The final system must collect environmental data at predefined time intervals. The intended final measurement parameters include water temperature, pressure/depth, pH, and conductivity.

The prototype uses a simplified sensor set due to budget and component availability. For prototype testing, the measured parameters include temperature, pressure, and Total Dissolved Solids (TDS). The pH and conductivity sensors are reserved for the final product.

The collected data must be stored locally using a data storage unit such as a Secure Digital (SD) card. This allows long-term operation without relying on external communication infrastructure or real-time underwater data transmission.

Energy consumption must be minimized to extend the operational lifetime of the monitoring system. This is achieved through low-power operation, where the system remains active only during short measurement cycles.

The system must perform measurements periodically, typically once per hour. During each cycle, the system remains active only for the time required to stabilize sensor readings and store the data.

The smart sensor box must be removable so that battery replacement, sensor inspection, maintenance, and data retrieval can be carried out without removing the whole reef structure from the seabed.

The physical reef structure must include cavities, textured surfaces, and sheltered spaces that may support the attachment and growth of marine organisms over time **[3]**.

1.6.2 Non-Functional Requirements

In addition to functional capabilities, the system must satisfy several non-functional requirements to ensure safe and reliable operation in marine environments. Since the structure is deployed underwater and interacts directly with marine ecosystems, material selection, structural stability, waterproofing, and maintenance access are critical.

To avoid environmental risks, the structure must be made from durable, non-toxic, and environmentally compatible materials that do not release harmful substances into the marine environment. Poorly selected artificial reef materials can create long-term environmental problems, as shown by previous failed reef projects such as Osborne Reef **[4]**.

For the final product, basalt fiber-reinforced concrete is considered as the main structural material because basalt fibers are known for corrosion resistance and chemical stability in marine environments **[5]**.

The structure must be designed to remain stable under expected currents and wave conditions without displacement. Artificial reef guidelines emphasize that reef materials should be stable and remain at the intended deployment site **[6]**.

All electronic components, including sensors, batteries, and storage units, must be enclosed in a waterproof housing with at least IP68 protection to prevent water ingress and support underwater operation **[7]**.

The monitoring unit must be designed to reduce the risk of leakage, corrosion, and internal moisture. Moisture-absorbing materials may be used inside the enclosure to help control condensation.

The design must allow access for maintenance, battery replacement, and data retrieval. This is especially important because the system stores data locally and requires scheduled retrieval.

The prototype does not need to meet the same marine-grade requirements as the final product. It is intended for controlled testing and should be clearly presented as a simplified validation model rather than a final deployable system.

1.7 Tests

The main objective of testing the prototype is to verify that the MARIS HABITATS concept functions as intended under controlled conditions. Since the prototype is a simplified validation model, the tests will focus on the basic operation of the sensor system, the structural stability of the habitat module, and the protection of the electronic components. The final product is intended for long-term marine deployment, while the prototype is mainly used to validate temperature, pressure, and TDS measurements in a controlled environment.

1.8 Report Structure

Chapter	**Description**
1. Introduction	Introduction to the project and the report
2. Background and related work	Previous similar projects with common useful knowledge
3. Project management	Distribution and important aspects about the project itself
4. Marketing plan	Analysis of the market and economical feasibility
5. Eco-efficiency Measures for Sustainability	Sustainable responsibilities in different aspects
6. Ethical and Deontological Concerns	Different ethical points of view for the project
7. Project development	Evolution from the design to the prototype

Chapter	Description
8. Conclusions	Final ideas of the outcomes achieved and next steps
9. Bibliography	Information sources

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2. Background and Related Work

2.1 Introduction

This chapter establishes the technical and scientific foundation for the MARIS HABITATS project by situating it within the broader context of artificial reef design and underwater environmental monitoring. Traditional artificial reefs are usually passive structures that provide physical habitat support, while marine monitoring systems are often treated as separate technical equipment.

MARIS HABITATS aims to connect these two areas by combining modular reef infrastructure with a removable smart sensor box. Instead of focusing on real-time data transmission, the system is designed for long-term local data logging. This approach reduces technical complexity and makes the concept more realistic for a low-power underwater system.

The chapter reviews artificial reef concepts, existing companies, material options, sensor placement challenges, and biological and geographical factors. This background helps justify the project direction: a modular reef block system supported by environmental data collection rather than a fully live underwater IoT platform.

2.2 Concepts

Artificial marine habitats can be designed in several ways to help restore marine ecosystems and support endangered fish species. One approach is the use of 3D-printed reef corals, which can be made from materials such as ceramic, limestone, or eco-concrete. These materials are durable and suitable for marine environments. Examples of projects using this approach include Reef Design Lab in Australia, which develops 3D-printed reef structures for marine habitat restoration, and SECORE coral restoration projects, which focus on rebuilding damaged coral reefs by supporting coral growth and reef recovery **[8]**, **[9]**.

Another commonly used solution is reef balls. These are concrete dome structures with holes that mimic natural reef caves. Because of their simple design they are easy to mass produce and very stable when placed on the seabed. The holes and cavities provide immediate shelter for fish and other marine animals, allowing the structures to quickly function as protective habitats **[10]**, **[11]**.

A different method is the creation of Bio-Rock or electric reefs. These reefs consist of metal structures through which a small electrical current is passed. This current causes minerals from seawater to deposit onto the structure, gradually forming a limestone-like coating. This process helps corals grow much faster than under normal conditions, and fish rapidly colonize these artificial reefs. This technique is known as Bio-Rock technology **[12]**.

Artificial habitats can also be designed as modular “fish cities”. These structures include holes of different sizes so that multiple fish species can use them for shelter. Vertical elements are often incorporated to mimic natural reef cliffs, and the modules can be interconnected to create more complex ecosystems that support a greater diversity of marine life **[13]**.

Another concept is the development of living seawalls. These are harbor walls or seawalls designed with textured panels and cavities so that marine organisms can attach to them and live on them. Instead of smooth concrete surfaces that support little life, these modified structures create habitats for algae, small invertebrates, and fish **[14]**.

Several endangered fish species can benefit from these types of artificial habitats, including the Humphead wrasse, Nassau grouper, Atlantic Goliath Grouper, Smalltooth Sawfish, and the European eel. Although many of these species grow quite large, the habitats are especially important for juvenile fish. Young fish can use the structures as shelter and breeding areas, increasing their chances of survival. When more juvenile fish survive, adult populations can recover and thrive. Larger predators may also benefit by hunting around these habitats.

In habitat design, the shape of the structure is often more important than the material used. It is important to include many holes and cavities in different sizes so that different fish species can find suitable shelter. Vertical structures are also important because they mimic natural reef cliffs. In addition, rough surface textures help corals and algae attach and grow on the structures. Finally, ensuring good water flow around the habitat is essential, as it brings nutrients and oxygen that support marine life.

2.3 Comparative Analysis

The selected companies and solutions are evaluated based on criteria such as reef structure, modularity, material approach, monitoring capability, data collection method, maintenance, and suitability for long-term environmental observation.

Since MARIS HABITATS is designed to observe how an artificial reef and the surrounding marine conditions change over time, the comparison looks beyond ecological enhancement. It also considers whether each solution can collect, store, and retrieve environmental data for later analysis.

Table 2: Comparative overview of selected artificial reef and marine infrastructure companies and the proposed MARIS HABITATS system

Criteria	**ECOncrete**	**Reef Design Lab**	**IntelliReefs**	**rrreefs**	**MARIS HABITATS**
Main business focus	Bio-enhancing concrete for marine and coastal infrastructure	Designed and 3D-printed reef structures	Oceanite-based artificial reef restoration	3D-printed modular clay reef restoration	Modular reef infrastructure and environmental data
Product type	Eco-engineered concrete infrastructure units	Modular reef modules and design services	Artificial reef modules made with Oceanite marine substrate	Interlocking 3D-printed clay reef modules	Reef blocks with a removable smart sensor box

Criteria	ECOncrete	Reef Design Lab	IntelliReefs	rrreefs	MARIS HABITATS
Main application	Ports, seawalls, shoreline protection, offshore assets, and subsea cable protection	Reef restoration and marine habitat construction	Coral reef restoration and marine habitat support	Coral reef regeneration and habitat creation	Reef installation, environmental monitoring, and long-term site observation
Modularity	Moderate	High	High	High	High
Ecological design focus	High	High	High	High	Moderate to high
Material / design approach	Bio-enhancing concrete composition, surface texture, and macro-design	Ceramic 3D-printed modular reef structures	Oceanite bio-enhancing marine substrate	3D-printed clay modules inspired by natural reef structures	Basalt fiber-reinforced concrete blocks and removable sensor housing
Integrated sensors	No clear indication as a core product feature	No clear indication	No clear indication	No clear indication	Yes
Real-time data transmission	No clear indication	Not specified	Not specified	Not specified	No
Long-term local data logging	No clear indication as a core product feature	Not specified	Not specified	Not specified	Yes
Data retrieval method	Not specified	Not specified	Not specified	Not specified	SD card / scheduled annual retrieval
Service model	Project-based marine infrastructure solution	Design and project-based reef solution	Restoration project-based solution	Impact-driven reef restoration projects with local partners	Reef modules with optional monitoring and data service
Main differentiation	Ecological concrete material and infrastructure integration	Complex modular reef design	Alternative Oceanite-based reef material	3D-printed clay reef modules and local restoration partnerships	Removable sensor box and long-term environmental data

The comparison presented in Table 2 is based on publicly available information from company websites, project descriptions, and related documentation. The selected companies represent different approaches to artificial reef and marine infrastructure development. ECOncrete focuses on bio-enhancing concrete for marine and coastal infrastructure, while Reef Design Lab focuses on designed and 3D-printed modular reef structures. IntelliReefs uses Oceanite-based artificial reef structures for reef restoration, and rrreefs develops 3D-printed clay modules for coral reef regeneration.

Compared with these companies, MARIS HABITATS is positioned as a modular reef infrastructure and environmental data solution. The project does not focus only on ecological design or reef structure, but also on collecting environmental data around the reef over time. The main difference is the removable smart sensor box, which stores data locally and allows scheduled retrieval during annual maintenance.

2.4 Companies

This section reviews selected companies related to artificial reef systems and marine habitat infrastructure. The aim is to understand how existing companies approach reef structure, material choice, modularity, and ecological design.

The review also considers whether these solutions include monitoring or environmental data collection as a core feature. This helps identify the position of MARIS HABITATS as a modular reef infrastructure system with a removable smart sensor box and long-term local data logging.

ECOncrete

ECOncrete is a company that develops bio-enhancing concrete technologies for coastal, marine, and offshore infrastructure. Its solutions are designed to improve the ecological performance of concrete structures while still maintaining their engineering function. The company's approach is applied in infrastructure such as ports, seawalls, coastal protection systems, offshore assets, and subsea cable protection.

The main idea of ECOncrete is to make marine infrastructure less biologically poor than conventional smooth concrete structures. This is achieved through changes in concrete composition, surface texture, and structural design. According to the Living Ports project, ECOncrete's rough and irregular surfaces, gaps, and swim-through holes can create habitats, shelter, and breeding spaces for marine organisms **[15]**.

One example of ECOncrete's application is the Living Ports Project at the Port of Vigo. In this project, ECOncrete Coastalocks and ecologically enhanced seawalls were used to create nature-inclusive port infrastructure. As shown in Figure 2, marine growth can develop on these concrete elements over time, showing how infrastructure can maintain its coastal protection function while also supporting ecological value.

However, ECOncrete is different from MARIS HABITATS in its main focus. Based on the available product descriptions, ECOncrete mainly provides bio-enhancing concrete infrastructure rather than a modular reef system with a removable sensor box. There is also no clear indication that long-term local data logging is included as a core product feature. Therefore, ECOncrete is a useful benchmark for ecological concrete design, while MARIS HABITATS aims to add environmental data collection through a removable smart monitoring unit.

Figure 2: ECOncrete bio-enhancing coastal protection units used in the Living Ports Project at the Port of Vigo **[16]**

Reef Design Lab

Reef Design Lab is an Australian design and fabrication company that develops artificial reef and marine habitat solutions. The company describes its work as the design, prototyping, and manufacturing of coastal solutions, with a focus on improving ecological performance in artificial reefs and coastal habitat infrastructure **[17]**.

One of its well-known systems is MARS, which stands for Modular Artificial Reef Structure. MARS is a ceramic 3D-printed modular system designed to construct reef habitat without the need for heavy-duty equipment. The system can be deployed from small boats and assembled by divers, making it suitable for reef restoration projects in locations where large marine construction equipment may be difficult to use **[18]**.

Reef Design Lab is relevant to MARIS HABITATS because both projects use modular reef structures and focus on creating physical habitat infrastructure in underwater environments. The use of repeated modular units also makes Reef Design Lab a useful benchmark for comparing scalability, deployment, and structural complexity.

However, Reef Design Lab differs from MARIS HABITATS in its main focus. Based on the available product descriptions, Reef Design Lab mainly focuses on reef design, 3D-printed structures, and project-based marine habitat solutions. There is no clear indication that a removable sensor box or long-term local environmental data logging is included as a core product feature. Therefore, Reef Design Lab is useful as a benchmark for modular reef design, while MARIS HABITATS aims to combine modular reef blocks with a removable smart monitoring unit for long-term environmental observation.

Figure 3: Reef Design Lab's MARS system, a ceramic 3D-printed modular artificial reef structure **[19]**

IntelliReefs

IntelliReefs is a reef restoration initiative and technology platform connected to Reef Life Foundation. It focuses on engineered artificial reef structures made from Oceanite, a bio-enhancing marine substrate designed to mimic natural ocean mineral compounds. According to IntelliReefs, Oceanite can be customized according to site, species, and function, and is used to create reef modules that support coral, seaweed, kelp, and other marine organisms **[20]**.

The main idea of IntelliReefs is to combine material science with reef design. Its Oceanite material is described as a complex mineral matrix held together by a proprietary nanobinder, developed to support diverse species growth and integration into local ecosystems **[21]**. The structures are designed with textured and porous surfaces, as well as small spaces where marine organisms can attach, be protected, and grow over time.

As shown in Figure 4, IntelliReefs uses modular reef units that can be arranged to create complex underwater habitats. These structures are relevant to MARIS HABITATS because both concepts use modular reef elements and aim to create underwater infrastructure that can interact with the surrounding marine environment.

However, IntelliReefs differs from MARIS HABITATS in its main focus. Based on the available information, IntelliReefs mainly focuses on Oceanite-based artificial reef structures and marine restoration solutions. There is no clear indication that a removable smart sensor box or long-term local environmental data logging is included as a core product feature. Therefore, IntelliReefs is a useful benchmark for alternative reef materials and ecological reef design, while MARIS HABITATS aims to combine modular reef blocks with removable sensor-based monitoring for long-term environmental observation.

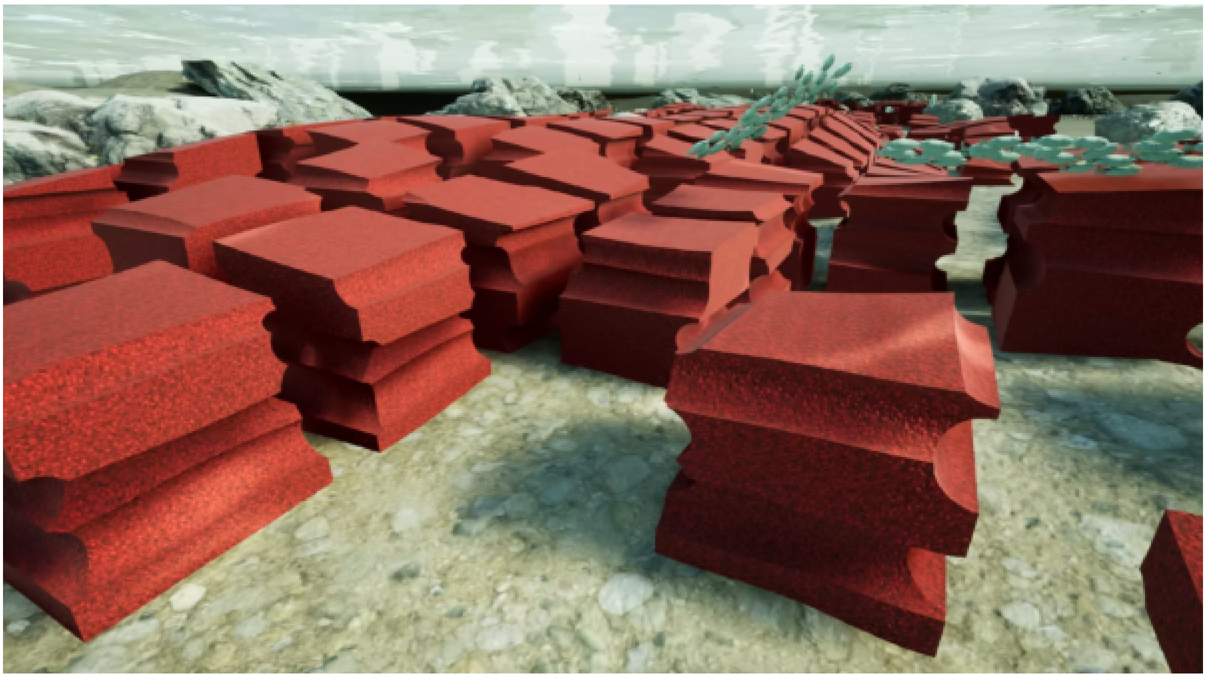

Figure 4: IntelliReefs modular artificial reef structures made with Oceanite material **[22]**

rrreefs

rrreefs is a Swiss start-up that focuses on rebuilding and regenerating degraded coral reefs. The company develops a 3D-printed modular reef system made from clay, designed to support coral growth and provide habitat for marine life **[23]**.

The rrreefs system is based on interlocking clay modules that can be arranged in different shapes depending on the local reef conditions and restoration needs. These modules are designed to mimic natural reef structures, create habitat diversity, and provide sheltered spaces for coral larvae, juvenile fish, crustaceans, and other marine organisms. As shown in Figure 5, the modular units can form complex underwater structures.

rrreefs is relevant to MARIS HABITATS because both concepts use modular reef structures and aim to create underwater infrastructure that can interact with the surrounding marine environment. The company is also relevant as a business benchmark because it operates as an impact-driven reef restoration start-up and works with local partners to implement reef projects in different countries.

However, rrreefs differs from MARIS HABITATS in its main focus. rrreefs mainly focuses on coral reef regeneration through 3D-printed clay reef modules and local restoration partnerships. Based on the available product descriptions, there is no clear indication that a removable smart sensor box or long-term local environmental data logging is included as a core product feature. Therefore, rrreefs is a useful benchmark for modular reef design and reef restoration business models, while MARIS HABITATS aims to combine modular reef blocks with removable sensor-based monitoring for long-term environmental observation.

Figure 5: Underwater view of rrreefs modular clay reef structures used for coral reef regeneration **[24]**

2.5 Materials

For this project involving a marine habitat at a maximum depth of 50 m off the Portuguese coast, the materials must withstand a pressure of approximately 5 bar while fostering biological growth and protecting sensitive sensors. To ensure the highest level of efficiency and environmental compatibility, various materials used in international restoration efforts has been analyzed.

The selection of materials and the structural design of artificial habitats are fundamental to ensuring both environmental compatibility and long-term viability. For this project, concrete has been identified as the primary material due to its exceptional durability and its proven track record in underwater construction. Its capacity to provide structural integrity against significant environmental stressors—such as salinity, strong currents, and wave action—makes it the industry standard for creating resilient marine foundations. While the chemical properties of concrete, particularly its initial pH levels, have historically been a point of debate, recent research has shifted the focus toward a more nuanced understanding of its behavior in open marine environments **[25]**.

Studies indicate that the high alkalinity of newly submerged concrete (typically between 12–14) is rapidly diluted by seawater, resulting in no significant long-term detriment to coral growth or benthic colonization **[26]**. This suggests that ecological success depends less on extended curing periods or pH-neutral mixtures and more on the physical attributes of the habitat. Consequently, the following sections will detail how this project prioritizes structural complexity, substrate durability, and hydrodynamic stability **[27]**. By optimizing the weight-to-complexity ratio and ensuring low water absorption, it can be guaranteed that these structures remain stationary during extreme weather events while providing the necessary niches for biodiversity to thrive **[28]**.

Based on the research and articles reviewed, the following subsection evaluates different material options—ranging from traditional foundations to innovative biocompatible substrates—from which the selection for the most suitable components will be done for this specific implementation.

2.5.1. Structural Materials

A. Bacterial (Self-healing) High-Strength Concrete (HSC) This material incorporates bacterial spores, specifically *Bacillus sphaericus* (strain ATCC 14577), which remain dormant until a crack occurs. Water ingress activates the bacteria, which then precipitate calcium carbonate to seal the crack **[29]**.

- **Pros:** Achieves **96 % recovery in water tightness** within 56 days of seawater immersion **[30]**. It maintains structural integrity above **100 MPa**, which is more than sufficient for the pressure at 50 m. It significantly reduces rebar corrosion by sealing entry points for chloride ions **[31]**.
- **Cons:** Higher complexity in mixing and requires specific nutrients like calcium lactate and urea **[32]**.
- **Price:** Estimated at **180 €/m^3 – 260 €/m^3**.

B. Basalt Fiber-Reinforced Polymer (BFRP) Basalt fibers, derived from natural volcanic rock, are used to reinforce concrete or as standalone composite laminates **[33]**.

- **Pros: Naturally non-corrosive** and chemically stable in aggressive saline environments **[34]**. Vacuum infusion manufacturing can produce laminates with flexural strength up to **400 MPa** **[35]**. It provides a more resilient, damage-tolerant failure mode compared to the brittle collapse of traditional reinforced concrete **[36]**.
- **Cons:** Slightly lower peak flexural strength compared to glass fibers, although superior in long-term durability and environmental footprint **[37]**.
- **Price:** Estimated at **160 €/m^3 – 220 €/m^3** .

C. Geopolymer Gel Concrete A cement-free binder using materials like fly ash and metakaolin modified with nano-silica (SiO_2) **[38]**.

- **Pros:** Significantly **lower CO_2 footprint** than Portland cement **[39]**. It shows superior resistance to chloride and sulfate attack in “wet-thermal” marine environments **[40]**.
- **Cons:** Higher production costs currently limit wide adoption **[41]**.
- **Price:** Estimated at **150 €/m^3 – 200 €/m^3**.

D. ECOncrete® / Sulfoaluminate Cement (SAC) A proprietary concrete mix designed to reduce surface alkalinity to a neutral pH **[42]**.

- **Pros:** Surface **pH of 9–10** (closer to seawater's 8) promotes the settlement of “ecosystem engineers” like oysters, serpulid worms, and coralline algae. These organisms provide **bioprotection**, adding a calcified layer that strengthens the structure and limits oxygen/chloride penetration **[43]**.
- **Cons:** Requires specialized design to ensure the lower pH doesn't compromise the protection of internal steel if used.
- **Price:** Estimated at **140 €/m^3 – 180 €/m^3**.

E. Recycled Glass (Partial Aggregate Replacement) Crushed waste glass used to replace up to 30 % of fine aggregates in the concrete mix **[44]**.

- **Pros:** Improves **chemical resistance** and reduces water absorption **[45]**. It offers an eco-friendly way to utilize waste while maintaining sufficient compressive strength for marine applications **[46]**.

- **Cons:** Replacing more than 30 % of aggregate leads to a **significant reduction in compressive strength [47]**.
- **Price:** Estimated at **90 €/m³ – 140 €/m³**.

F. Biorock (Mineral Accretion) Uses low-voltage DC electricity to precipitate minerals (limestone) directly from seawater onto an iron frame.

- **Pros:** Accelerates biological growth by **400 %** and allows the structure to **self-repair** after impacts.
- **Cons:** Requires **constant power** from your buoy; if the power is interrupted, the iron frame corrodes rapidly.
- **Price:** Base infrastructure **120 €/m³ – 160 €/m³** (excluding electrical components).

2.5.1.1 Summary Table

The previous subsection regarding the materials evaluated for the project, is summarized in Table 3.

Table 3: Summary Table for materials evaluated

Material	Primary Requisite Met	Pros	Cons	Estimated Price / m³
Bacterial HSC	Longevity/Pressure	Autonomous repair; 96 % watertight	High complexity	180–260 €
Basalt Reinforcement	Corrosion Resistance	Non-corrosive; volcanic origin	Lower flexural peak	160–220 €
ECOncrete®	Sea-life Friendly	Neutral pH; bioprotection	Specific mix needs	140–180 €
Recycled Glass	Sustainability	Increased chemical resistance	Strength loss > 30 %	90–140 €
Biorock	Life Promotion	4:1 growth; self-repairing	Power dependent	120–160 €

2.5.1.2 Materials for Prototype vs. Final

For the prototype, a material must be selected that allows the model to be functional and suitable for the planned tests. The material should have characteristics that are as similar as possible to those of the final product, in order to make the prototype representative of the intended design. At the same time, it must be easy to obtain, process, and handle, since the prototype will be produced and tested by the team within the available resources.

TO BE CHECKED WHEN THE PROTOTYPE HAS TO BE DONE

- Option 1 :One possible option is to combine basalt fabric reinforcement with reused concrete or industrial waste. However, the pH level must be tested to ensure that the material is suitable for water exposure.
  - **pros** It is similar to the actual product and cuts down on costs.
  - **cons** It is impossible to modify the model design and there is no marketing advantage because it is not different from existing business.
- Option 2 : Polymer clay can be shaped into the desired model and then hardened by baking it in an oven.
  - **pros** It is possible to be mini version of the actual model in any shape and cuts down on

costs.
  - **cons** There are size limitations depending on the oven and it is different from the model of actual project so not sure if it will approve.

2.5.2 Sensor placements

Designing a successful marine habitat involves a delicate technical paradox. On one hand, the project's primary objective is to encourage biological colonization and the growth of marine life; on the other, the integrated sensors require direct, unobstructed contact with seawater to maintain accuracy. This necessity creates a significant challenge, as the very "bio-friendly" environment the team aims to foster can lead to marine biofouling on sensitive equipment, which critically compromises data reliability and sensor sensitivity **[48]**.

To resolve this conflict, the strategy focuses on three integrated design pillars. First, a careful selection of housing materials must be made to support structural durability while protecting the internal components. Second, evaluating specialized anti-fouling coatings that can prevent accumulation on sensor windows without leaching harmful chemicals into the surrounding habitat. Finally, the spatial distribution of the sensors must be strategically planned to allow for clear measurements while minimizing their exposure to rapid biological growth. This balanced approach ensures that the ecological goals do not come at the expense of long-term monitoring precision.

2.5.2.1 Materials for Housing

The housing material must protect the internal electronics from high pressure and corrosion while maintaining long-term durability in seawater environments.

Titanium alloy (TC4) or **316 L stainless steel** are recommended for pressure resistance and durability **[49]**. For more than 200 m depth, **Titanium** is preferred for long-term corrosion resistance **[50]**.

2.5.2.2 Antifouling Coatings

Even with durable housing materials, marine organisms may attach to exposed surfaces over time. For this reason, antifouling coatings are considered to reduce biological growth on sensors and maintain measurement accuracy.

- **PDMS (Polydimethylsiloxane):** A non-toxic, "fouling-release" coating that reduces the adhesion of algae and barnacles **[51]**.
- **CPT (Camptothecin)-based Paint:** A natural compound that has shown virtually no macrofouling after nine months of immersion **[52]**.
- **SLIPS (Slippery Liquid-Infused Porous Surfaces):** These provide exceptional resistance to organism attachment even in stagnant water **[53]**.

2.5.3 Biologic and geographical analysis

Fish structure

Fish populations are generally associated with habitats that exhibit high structural complexity and spatial heterogeneity **[54]**. Research suggests that complex environments provide essential ecological resources necessary for survival, including food availability, shelter from predators, and suitable areas for reproduction. Structural features such as crevices, cavities, and irregular surfaces may create microhabitats that support a greater diversity of marine organisms and increase the overall ecological value of reef systems.

Artificial and natural reefs typically contain irregularities and indentations that form small shelters or “nooks”, which can serve as refuge areas for fish and other marine organisms. These structural features are believed to reduce predation risk and provide protected spaces where fish can rest or reproduce.

Studies also indicate that fish communities tend to perform better in connected habitat mosaics rather than isolated structures **[55]**. Networks of habitats may facilitate movement, feeding opportunities, and ecological interactions between species, which can contribute to more stable and diverse marine ecosystems.

Location

The location of artificial reefs plays a key role in determining their effectiveness. The chosen site should encourage marine life to settle while avoiding interference with human activities such as shipping routes or commercial fishing areas. Water depth is another important consideration. Reefs placed too deep may not receive enough sunlight to support the growth of marine plants like algae, whereas reefs that are too shallow can be more vulnerable to damage from storms or human activity **[56]**.
Most of the artificial reef projects are placed at the depth of 10-20 meters, but it all depends on which species and what type of marine life are the reefs intended for.

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3. Project Management

3.1 Introduction

Managing a project that intersects marine ecology, hardware engineering, and software development requires a framework that balances rigid constraints with creative flexibility. This chapter details the management strategy employed by the group, organized across key knowledge areas including scope, risk, and procurement.

Due to the unpredictable nature of environmental hardware testing, an Agile methodology (SCRUM based) was adopted. This iterative approach was essential for managing the project. By prioritizing continuous feedback loops and adaptive planning, the team was able to pivot in response to technical challenges without compromising the project's primary milestones or budgetary limits.

3.2 Scope

The scope of this project is the design and development of a functional prototype of a smart marine habitat intended to support seafloor biodiversity and enable environmental monitoring in underwater conditions. The project focuses on creating a concept that combines an artificial habitat structure with a basic sensor system, while taking into account sustainability, durability, and ecological compatibility **[57]**.

From a product perspective, the project includes the development of a modular underwater habitat structure designed to provide shelter, attachment surfaces, and spatial complexity for marine organisms. In addition, the product includes an integrated monitoring concept based on selected sensors capable of collecting environmental data relevant to the surrounding habitat, such as temperature, pH, turbidity, or depth, depending on technical feasibility and component availability. The solution also includes a basic embedded electronics system for sensor integration, power management, and data handling, as well as a conceptual approach for transmitting or presenting the collected data. The overall product is intended to demonstrate how habitat restoration and environmental monitoring can be combined into a sustainable solution.

From a project perspective, the scope includes the research and analysis required to understand the environmental problem, existing artificial reef solutions, suitable structural materials, and underwater sensor technologies. It also includes the definition of requirements, concept development, design selection, structural modelling, component selection, and prototype integration. The project covers the testing and validation of the prototype under limited and controlled conditions, together with the assessment of market, sustainability, ethical, and project management aspects. The preparation of all academic deliverables, including the report, presentation, poster, flyer, and supporting documentation, is also part of the project scope.

The main outcome of the project is a functional prototype that demonstrates the technical feasibility and conceptual value of a smart artificial marine habitat. The prototype is intended to serve as a foundation for future development, testing, and scaling in real-world marine applications.

The Work Breakdown Structure (WBS) presented in the figures illustrates how the MARIS HABITATS system is divided into its main components and subsystems **[58]**. The diagram provides an overview of the product architecture, showing how the habitat structure, sensor system, energy and communication, deployment, and maintenance elements are organized.

Each main component is further broken down into smaller elements, representing the key functionalities required for the system to operate. This visual representation helps clarify the scope of the project by identifying all relevant parts of the system and their relationships.

Figure 6 presents the WBS for the product and Figure 7 the WBS of the project.

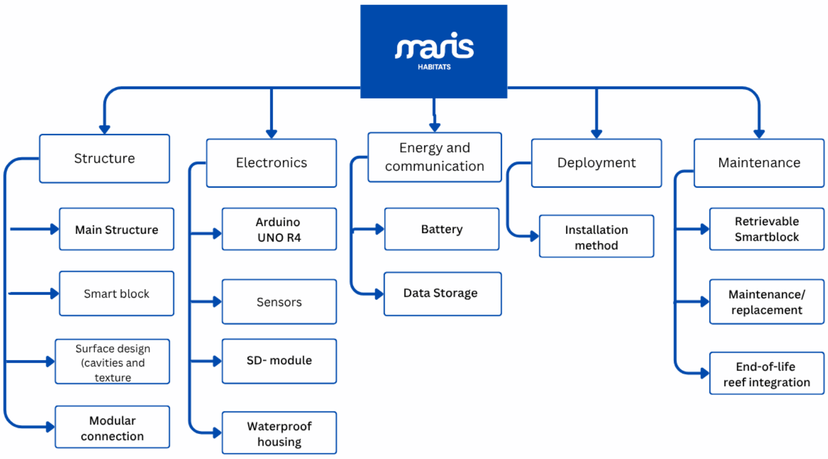


Figure 6: WBS of the product

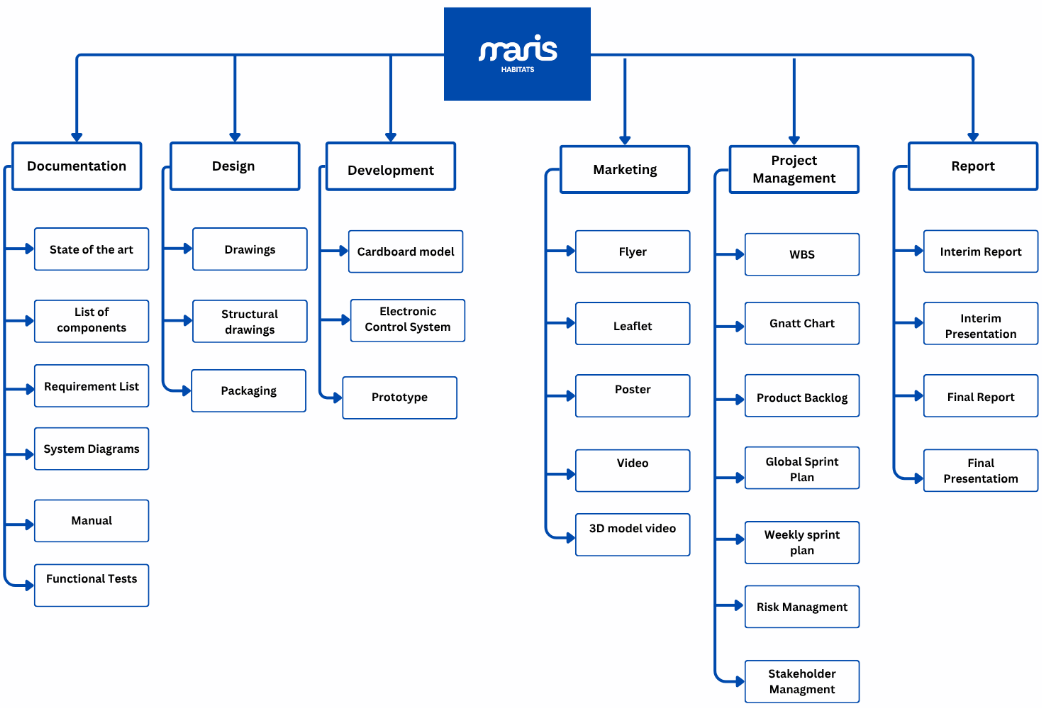


Figure 7: WBS of the project

3.3 Time

To ensure effective time management and the timely completion of the project, tasks were scheduled to be completed during school hours and before weekends. This approach helped maintain steady progress and allowed time for review and adjustments when needed **[59]**.

The team followed the milestone schedule defined by the project supervisors. These milestones provided a structured framework to monitor progress and ensure alignment with the overall project timeline. Table 4 presents the defined milestones.

Table 4: Milestones for the project

Date	Description
2026-02-28	Choose and share your top-3 preferred project proposals via email to epsatisep@gmail.com
2026-03-11	Upload the "black box" **System Diagrams** & **Structural Drafts** to the wiki (Deliverables)
2026-03-18	Upload the **List of Components and Materials (what & quantity)** to the wiki (Deliverables)
2026-03-21	Define the **Project Backlog** (what must be done and key deliverables - every member should preferably participate in every task), **Global Sprint Plan**, **Initial Sprint Plan** (which tasks should be included, who does what) and **Release Gantt Chart** of the project and insert them on the wiki (Report)
2026-03-25	Upload the detailed **System Schematics & Structural Drawings** to the wiki (Deliverables) and do the **cardboard scale model** of the structure
2026-04-12	Upload the **Interim Report and Presentation** to the wiki (Deliverables)
2026-04-16	Interim Presentation, Discussion and Peer, Teacher and Supervisor feedbacks
2026-04-22	Upload **3D model video** to Deliverables
2026-04-29	Upload the final **List of Materials (local providers & price, including VAT and transportation)** to Deliverables
2026-05-02	Upload refined Interim Report (based on Teacher & Supervisor Feedback)
2026-05-13	Upload **packaging solution** to Deliverables and Report
2026-05-27	Upload the results of the **Functional Tests** to the Report
2026-06-13	Upload the **Final Report, Presentation, Video, Paper, Poster and Manual** to Deliverables
2026-06-18	Final Presentation, Individual Discussion and Assessment (reserve the whole day)
2026-06-23	Update the wiki, report, paper with all suggested corrections
	Place in the Shared section of the MS Teams channel of your team a **folder with the refined deliverables (source + PDF) together with all code and drawings produced**
	Hand in to the EPS coordinator a **printed copy of the poster, brochure and leaflet**
2026-06-25	Demonstration of the **operation of the prototype**
	Hand in the **prototype and user manual** to the client
	Receive the **EPS@ISEP certificate**
	Bring **typical food** from your country

3.4 Cost

When estimating the total cost of the project, two main factors must be considered employee salaries and the cost of materials and components.

The average salary for a junior engineer in Portugal is approximately €1,500 per month, and the project duration is five months. With a team of six employees, the total salary cost is calculated as:

6 employees × 1,500 € × 5 months = 45,000 €

The material costs are divided into two categories: components and sensors. The total cost of the electronics and components 2552.90 €

A detailed overview of the individual component and sensor costs is provided in Table 5

In addition to the component costs, transportation and shipping costs must also be taken into account. These are presented in Table 6. Including shipping, the total cost of materials increases to 2863.35 €.

The project includes the cost of structural materials used for the habitat modules. Each block/module is composed of approximately 30 kg of concrete (C) and 70–90 g of basalt fiber (BF). Look at Table 7 table

Based on current market prices, concrete costs 89 € per 1000 kg, while basalt fiber costs 34.16 € per 1.36 kg. This results in an estimated material cost of 2.67 € for concrete and 1.76 € for basalt fiber per block.

Therefore, the total material cost per block is approximately 4.43 €.

It should be noted that this estimate is based on small-scale purchasing prices. For larger production volumes, the cost per unit is expected to decrease due to bulk pricing and supplier agreements.

It is important to note that this cost estimate represents the final product configuration, and not the prototype.

Table 5: Table of all components and sensors with price

Item	Type	Price	Quantity	Supplier	Link
Adafruit 254	SD - module	6.45 €	1	Mouser	https://pt.mouser.com/ProductDetail/Adafruit/254?qs=GURawfaeGuAkwqCF4BmPzA%3D%3D
Arduino ABX00080	Microcontroller	16.69 €	1	Mouser	https://pt.mouser.com/ProductDetail/Arduino/ABX00080?qs=sGAEpiMZZMuqBwn8WqcFUipNgoezRlc4hyxN6ztJHTQeBAZUij8gNg%3D%3D
FDMM004GMC-XE00	MicroSD - card	21.88 €	1	Farnell	https://pt.farnell.com/en-PT/flexxon/fdmm004gmc-xe00/microsd-card-4gb-mlc-cmrcl-grd/dp/4378808
MC3090082	Silica gel (moisture absorber)	42.26 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mc3090082/silica-gel-25g-65-x-95mm-pk100/dp/2424372
LiFePO4 battery	LiFePO4 battery	76.24 €	1	Innpo	https://innpo.pt/baterias-recarregaveis-de-litio/bateria-lifepo4-12v-20ah-innpo-baterias-recarregaveis-de-litio.html
Watertight Box 5L	Underwater electrical box	805.66 €	1	Bluerobotics	https://bluerobotics.com/store/watertight-enclosures/watertight-boxes/watertight-box-component/?attribute_internal-size=134mm+x+100mm+x+74mm+%281+liter%29%2C+300m+depth
WetLink Penetrator Blank	Penetrator blank (M10)	70.50 €	15	Bluerobotics	https://bluerobotics.com/store/cables-connectors/wlp-blank/?attribute_size=M10+Thread
MCMF0W4BB2500A50	250 ohm resistance	0.55 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mcmf0w4bb2500a50/res-250r-0-10-250mw-axial/dp/2396012
Adafruit 2670	Perfboard / Breadboard	4.26 €	1	Mouser	https://pt.mouser.com/ProductDetail/Adafruit/2670?qs=XAKIUOoRPe7ATe8H6FaFPg%3D%3D
M316 SOA2CSS50-	M3 screws for perfboard	5.55 €	1	Farnell	https://pt.farnell.com/en-PT/tr-fastenings/m316-soa2css50/screw-socket-cap-s-s-a2-m3x16/dp/1419946
BarXT	Depth / Pressure / Temp	329.19 €	1	Bluerobotics	https://bluerobotics.com/store/sensors-cameras/sensors/barxt-extended-submersion-depth-pressure-sensors/
I2C Level Converter	Level converter board	25.65 €	1	Bluerobotics	https://bluerobotics.com/store/comm-control-power/tether-interface/level-converter-r1/
Surveyor Analog pH Sensor / Meter	pH surveyor	21.52 €	1	Atlas Scientific	https://atlas-scientific.com/embedded-solutions/surveyor-analog-ph-sensor-meter/
Industrial pH Probe – No Temp	pH test probe	531.45 €	1	Atlas Scientific	https://atlas-scientific.com/probes/industrial-gen3-ph-probe-nt/
Industrial Conductivity Kit K 1.0	Conductivity	595.05 €	1	Atlas Scientific	https://atlas-scientific.com/kits/industrial-conductivity-kit-k-1-0/
Total		**2552.90 €**			

Table 6: Table of the transportation

Supplier	Cost (inc VAT)	Shipping cost	Notes
Innpo	76.24 €	5.08 €	
Mouser	27.40 €	25.00 €	Free over 75 €
Farnell	70.24 €	11.99 €	Free over 75 €
Bluerobotics	1231.00 €	175.33 €	Prices in dollar
Atlas Scientific	1148.02 €	93.05 €	Prices in dollar
Total (products)	**2552.90 €**	**310.45 €**	
Grand Total	**2863.35 €**		

Table 7: Table of the price for the blocks

Material	Unit price	Quantity per block	Cost per block	Link	Backup
Concrete (C)	89 € / 1000 kg	30 kg	2.67 €	https://www.leroymerlin.es/productos/bigbag-hormigon-h-25-1000-kg-97867789.html	—
Basalt Fiber (BF)	34.16 € / 1.36 kg	70–90 g	1.76 €	https://www.amazon.com/-/es/Refuerzo-hormig%C3%B3n-basalto-picada-libras/dp/B07KPLPHHH	https://www.moertelshop.com/buy-basalt-fibres-for-concrete-cheaply_1

Material	Unit price	Quantity per block	Cost per block	Link	Backup
Total per block			4.43 €		

Prototype list

When selecting electronic components for the prototype, efforts were made to replicate the final product as closely as possible within the constraints of a €100 budget. In addition, components were sourced from as few suppliers as possible in order to minimize transportation and shipping costs.

The selected electronics used in the prototype are presented in Table 8.

The estimated total cost of the electronics is 102 €, including shipping, as summarized in Table 9.

For the remaining component selection, suppliers offering local pickup were prioritized in order to avoid additional transportation costs.

These materials are summarized in Table 10.

The different prototype cost scenarios are summarized in Table 11, showing how additional materials such as concrete and 3D printing filament affect the overall cost.

The impact of procurement strategy on shipping costs is shown in Table 12, where the difference between in-store pickup and online ordering is highlighted.

Although the estimated total cost exceeds the budget, some components and materials may already be available at the university, reducing the need for additional purchases. Furthermore, transportation costs may be avoided if other groups also are ordering from the same supplier and the total order exceeds the free shipping limit. Consequently, the actual cost is difficult to determine precisely but is expected to be lower than the estimated 136 €.

Table 8: Table of prototype electronics

Item	Type	Price	Quantity	Supplier	Link
DS18B20	Temperature sensor	6.22 €	1	RS	https://pt.rs-online.com/web/p/kits-de-desarrollo-de-sensores/2049893?gb=a
SEN0244	TDS sensor	10.18 €	1	Farnell	https://pt.farnell.com/en-PT/dfrobot/sen0244/analogue-tds-sensor-meter-kit/dp/3517934
SEN0257	Pressure sensor	15.09 €	1	Farnell	https://pt.farnell.com/en-PT/dfrobot/sen0257/analog-water-press-sensor-arduino/dp/4308257
Adafruit 254	SD - module	11.60 €	1	RS	https://pt.rs-online.com/web/p/accesorios-para-kits-de-desarrollo/2881813
Arduino ABX00080	Microcontroller	17.44 €	1	Farnell	https://pt.farnell.com/en-PT/arduino/abx00080/development-board-32bit-arm-cortex/dp/4208543
FDMM004GMC-XE00	MicroSD card	21.88 €	1	Farnell	https://pt.farnell.com/en-PT/flexxon/fdmm004gmc-xe00/microsd-card-4gb-mlc-cmrcl-grd/dp/4378808
4022211111	9V alkaline battery	5.47 €	1	Farnell	https://pt.farnell.com/en-PT/varta/4022211111/battery-alkaline-9v-pp3-1pk/dp/4584139
MP007080	Battery holder	3.41 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mp007080/battery-holder-snap-on-8-wire/dp/3652120
MOR01SJ0472A10	4,7 Kohm resistance	0.07 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mor01sj0472a10/res-4k7-5-1w-axial-metal-oxide/dp/1357891
FIT0096	Breadboard	2.50 €	1	Farnell	https://pt.farnell.com/en-PT/dfrobot/fit0096/solderless-breadboard-3-2-x2-4/dp/3879683
Total		**93.86 €**			

Table 9: Table of prototype shipping costs

Supplier	Cost (inc VAT)	Shipping cost	Notes
RS	17.82 €	8.00 €	Free over 95 €
Farnell	76.04 €	11.99 €	Free over 75 €
Total (products)	**93.86 €**	**8.00 €**	
Total with shipping	**101.86 €**		

Table 10: Table of low-cost prototype materials (Portugal)

Product	**Type**	**Price (incl. VAT)**	**Quantity**	**Supplier**	**Link**	**Comment**
Cement (CEM II 25kg)	Concrete material	5.39 €	1	Leroy Merlin	https://www.leroymerlin.pt/produtos/cimento-25kg-secil-13142325.html	Used for structural prototype blocks
Plastic lunchbox (single compartment)	Prototype enclosure	3 €	1	IKEA	https://www.ikea.com/pt/pt/p/ikea-365-recipiente-p-alim-c-tmp-retangular-plastico-s19269079/	Simple enclosure
Smaller plastic lunchbox	Backup enclosure	1.5 €	1	IKEA	https://www.ikea.com/pt/en/p/pruta-food-container-with-lid-blue-10597103/	Backup option
PLA filament 1kg	3D printing material	14.60 €	1	Filament 3D	https://fillment3d.pt/produto/pla-cinzento-winkle-1kg-1-75mm/	Backup option
Ceys Total Tech Universal Glue and Sealant 290 ml Transparent	Silicone sealant	8.99 €	1	Leroy Merlin	https://www.leroymerlin.pt/produtos/cola-e-veda-total-tech-universal-290-ml-transparente-ceys-13132966.html	
Continente cooking oil 1L	Oil for enclosure	1.69 €	1	Continente	https://www.continente.pt/produto/oleo-alimentar-continente-continente-5045342.html	Used only if needed
Total		**35.17 €**				

Table 11: Table of prototype cost scenarios

Scenario	**Total cost**
Prototype (with shipping)	101.86 €
+ Airtight container (IKEA)	104.86 €
+ Silicone sealant	113.85 €
+ Oil	115.54 €
+ Cement	121.19 €
+ PLA (no cement)	130.14 €
+ Cement + PLA	135.53 €

Table 12: Table of shipping cost comparison for prototype materials

Product	**Supplier**	**Shipping (store pickup)**	**Shipping (online)**	**Comment**
Cement (CEM II 25kg)	Leroy Merlin	0 €	TBC at checkout	Shipping depends on address and delivery option
Plastic lunchbox (single compartment)	IKEA	0 €	6 €	Standard small delivery, 4 € with IKEA Family
Smaller plastic lunchbox (backup)	IKEA	0 €	6 €	Standard small delivery, 4 € with IKEA Family
PLA filament 1kg	Filament 3D	0 €	TBC at checkout	Shipping must be confirmed before purchase
Silicone sealant	Leroy Merlin	0 €	TBC at checkout	Shipping depends on address and delivery option
Oil	Continente	0 €	-	-
Total		**0 €**	**TBC**	

3.5 Quality

Quality in this project is ensured by defining clear quality metrics for both the system and the documentation, together with acceptable thresholds and review procedures **[60]**.

For the product, key quality metrics include system functionality, structural stability, and sensor reliability. The system is considered acceptable when all core functions operate as intended, the structure remains stable under expected conditions, and the sensors provide consistent and reasonable data. These aspects are reviewed through testing in controlled environments and validation of system performance.

For the documentation, quality is measured in terms of clarity, structure, consistency, and completeness. The report must clearly explain the project, follow a logical structure, and include all required sections. The acceptable threshold is that the documentation is understandable, coherent, and meets the academic guidelines provided. This is reviewed through internal checks within the team and feedback from supervisors.

Regular reviews during sprint meetings are used to monitor progress and identify issues early. Corrections are made continuously to ensure that both the system and the documentation meet the expected quality standards.

3.6 People & Stakeholder Management

Human factors represent a significant source of uncertainty in project development, as team members may exhibit varying levels of engagement, performance, and responsibility. For this reason, it is essential to establish clear roles and responsibilities within the team, ensuring that each member understands their tasks and contributions to the overall project. This helps reduce the risk of unequal workload distribution and lack of participation.

To achieve effective task allocation and maximize project outcomes, responsibilities are assigned based on each team member's skills, field of study, and previous experience. This approach ensures that tasks are aligned with individual competencies, promoting efficiency, accountability, and overall team performance.

Academic supervisors from ISEP act as a key stakeholder by providing guidance, feedback and evaluation throughout the project. Their role is essential in ensuring that the project meets academic and technical standards **[61]**.
External stakeholders include research institutions, Non Governmental Organizations (NGOs) and governmental organizations governmental organizations interested in marine conservation and environmental monitoring. These stakeholders are potential future users or partners, as they can benefit from the data collected and the ecological impact of the solution.

Although marine life cannot be considered a traditional stakeholder, it is the primary beneficiary of the project. Therefore, its needs are considered throughout the design process to ensure that the solution is environmentally safe and supportive of biodiversity

3.7 Communications

Effective communication was essential to ensure coordination and steady progress throughout the project. Communication within the team was primarily facilitated through daily Scrum meetings, where members discussed completed tasks, ongoing work, and upcoming activities. These meetings helped maintain alignment, identify challenges early, and ensure continuous progress **[62]**.

In addition, regular communication with key stakeholders, particularly project supervisors, was maintained through weekly meetings held on Thursdays. These sessions provided valuable feedback

and guidance, supporting informed decision-making throughout the project. Furthermore, collaborative tools such as Microsoft Teams were used to support documentation, information sharing, and quick communication among team members.
Altogether, this structured communication approach contributed to efficient collaboration, transparency, and timely problem-solving.

3.8 Risk

The project involves several potential risks related to both technical and organizational aspects. One of the main risks is technical failure, particularly in the integration of sensors, electronics, and structural components in a marine-like environment. To reduce this risk, the system is tested in controlled conditions and components are selected based on reliability and compatibility.

Another significant risk is project delays due to time constraints and task dependencies. This is managed through sprint planning, regular meetings, and the use of buffer time to accommodate unforeseen issues.

There is also a risk related to limited resources, including budget constraints and access to specialized equipment or testing environments. This is addressed by prioritizing essential features and selecting cost-effective solutions **[63]**.

Team-related risks such as miscommunication or uneven workload distribution may affect progress. These risks are mitigated through regular Scrum meetings, clear task allocation, and continuous collaboration among team members (see Table 13).

Table 13: Table of different risks

Risk	**Description**	**Probability**	**Impact**	**Risk Level**	**Mitigation Strategy**
Technical failure (sensors/electronics)	Failure in integration of sensors, electronics, and structure in marine conditions	Medium	High	High	Test components and validate system
Power system failure (battery/solar)	Unstable or insufficient energy supply affecting system performance	Medium	High	High	Optimize energy use and include backup
Integration issues (hardware/software)	Difficulties combining system components effectively	Medium	High	High	Modular design and incremental testing
Project delays	Delays caused by time constraints and task dependencies	Medium	High	High	Sprint planning, regular meetings, and buffer time
Limited resources	Budget constraints and limited access to equipment or testing environments	Medium	Medium	Medium	Prioritize essential features and use cost-effective solutions
Team miscommunication	Lack of coordination or unclear communication within the team	Low	Medium	High	Regular Scrum meetings and clear communication

Risk	Description	Probability	Impact	Risk Level	Mitigation Strategy
Uneven workload distribution	Some team members contribute less, affecting progress	Low	Medium	Low	Clear task allocation and team collaboration
Corrosion of metallic components	Degradation due to exposure to saltwater	Medium	Medium	Medium	Use corrosion-resistant materials (BFRP, coatings)
Extreme weather (storms, currents)	Harsh conditions affecting stability and performance	Low	High	Medium	Stable structure and secure anchoring
Waterproofing failure (IP68 breach)	Water entering electronic components causing malfunction	Low	High	High	Seal testing and proper enclosure
Data transmission failure	Loss or interruption of data communication	Medium	Medium	Medium	Local data storage and redundancy

To further support the risk assessment, a risk matrix based on probability and impact was used. The matrix classifies risks into three categories: low, medium, and high, depending on their likelihood of occurrence and potential impact on the project.

Based on this matrix, risks such as technical failure, power system failure, integration issues, and project delays are classified as high risk, as they combine medium to high probability with high impact. These risks require priority attention and mitigation (see Figure 8).

Risks such as limited resources, corrosion, extreme weather conditions, and data transmission failure fall into the medium-risk category. These are monitored and addressed through preventive design measures and planning.

Lower-risk factors, including team miscommunication and uneven workload distribution, are classified as low risk, as they have limited impact and can be managed through regular communication and task organization.

The use of this risk matrix provides a clear and structured way to prioritize risks and supports more effective decision-making throughout the project **[64]**.

	1	2	3
1	Low	Low	Medium
2	Low	Medium	High
3	Medium	High	High

Figure 8: Risk matrix

3.9 Procurement

The procurement plan is presented in three tables. Table 14 provides an overview of the components required for the habitat, while Table 15 details the sensors used in the system. Table 16 presents the material composition and cost of the concrete blocks used in the habitat structure.

Each item includes both a primary supplier and a designated backup supplier, ensuring supply reliability and reducing the risk of delays due to stock shortages or delivery issues.

Table 14: Table of the different components

Product	**Type**	**Price**	**Quantity**	**Supplier**	**Link**	**Backup supplier**
Adafruit 254	SD - module	6.45 €	1	Mouser	https://pt.mouser.com/ProductDetail/Adafruit/254?qs=GURawfaeGuAkwqCF4BmPzA%3D%3D	Farnell
Arduino ABX00080	Microcontroller	16.69 €	1	Mouser	https://pt.mouser.com/ProductDetail/Arduino/ABX00080?qs=sGAEpiMZZMuqBwn8WqcFUipNgoezRlc4hyxN6ztJHTQeBAZUij8gNg%3D%3D	Digikey
FDMM004GMC-XE00	MicroSD - card	21.88 €	1	Farnell	https://pt.farnell.com/en-PT/flexxon/fdmm004gmc-xe00/microsd-card-4gb-mlc-cmrcl-grd/dp/4378808	Digikey
MC3090082	Silica gel (moisture absorber)	42.26 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mc3090082/silica-gel-25g-65-x-95mm-pk100/dp/2424372	element14
LiFePO4 battery	LiFePO4 battery	76.24 €	1	Innpo	https://innpo.pt/baterias-recarregaveis-de-litio/bateria-lifepo4-12v-20ah-innpo-baterias-recarregaveis-de-litio.html	Amazon
Watertight Box 5L	Underwater electrical box	805.66 €	1	Bluerobotics	https://bluerobotics.com/store/watertight-enclosures/watertight-boxes/watertight-box-component/?attribute_internal-size=134mm+x+100mm+x+74mm+%281+liter%29%2C+300m+depth	RobotShop
WetLink Penetrator Blank	Penetrator blank (M10)	70.50 €	15	Bluerobotics	https://bluerobotics.com/store/cables-connectors/wlp-blank/?attribute_size=M10+Thread	Robotshop
MCMF0W4BB2500A50	250 ohm resistance	0.55 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mcmf0w4bb2500a50/res-250r-0-10-250mw-axial/dp/2396012	Digikey
Adafruit 2670	Perfboard / Breadboard	4.26 €	1	Mouser	https://pt.mouser.com/ProductDetail/Adafruit/2670?qs=XAKIUOoRPe7ATe8H6FaFPg%3D%3D	Digikey
M316 SOA2CSS50-	M3 screws for perfboard	5.55 €	1	Farnell	https://pt.farnell.com/en-PT/tr-fastenings/m316-soa2css50/screw-socket-cap-s-s-a2-m3x16/dp/1419946	element14

Table 15: Table of the different sensors

Sensor	**Type**	**Price**	**Quantity**	**Supplier**	**Link**	**Backup supplier**
BarXT	Depth / Pressure / Temp	329.19 €	1	Bluerobotics	https://bluerobotics.com/store/sensors-cameras/sensors/barxt-extended-submersion-depth-pressure-sensors/	RobotShop
I2C Level Converter	Level converter board	25.65 €	1	Bluerobotics	https://bluerobotics.com/store/comm-control-power/tether-interface/level-converter-r1/	RobotShop
Surveyor Analog pH Sensor / Meter	pH surveyor	21.52 €	1	Atlas Scientific	https://atlas-scientific.com/embedded-solutions/surveyor-analog-ph-sensor-meter/	RobotShop
Industrial pH Probe – No Temp	pH test probe	531.45 €	1	Atlas Scientific	https://atlas-scientific.com/probes/industrial-gen3-ph-probe-nt/	RobotShop
Industrial Conductivity Kit K 1.0	Conductivity	595.05 €	1	Atlas Scientific	https://atlas-scientific.com/kits/industrial-conductivity-kit-k-1-0/	RobotShop

Table 16: Table of the concrete blocks

Material	**Unit price**	**Quantity per block**	**Cost per block**	**Supplier**	**Link**	**Backup**
Concrete (C)	89 € / 1000 kg	30 kg	2.67 €	Leroy Merlin	https://www.leroymerlin.es/productos/bigbag-hormigon-h-25-1000-kg-97867789.html	—
Basalt Fiber (BF)	34.16 € / 1.36 kg	70–90 g	1.76 €	Amazon	https://www.amazon.com/-/es/Refuerzo-hormig%C3%B3n-basalto-picada-libras/dp/B07KPLPHHH	https://www.moertelshop.com/buy-basalt-fibres-for-concrete-cheaply_1
Total per block			**4.43 €**			

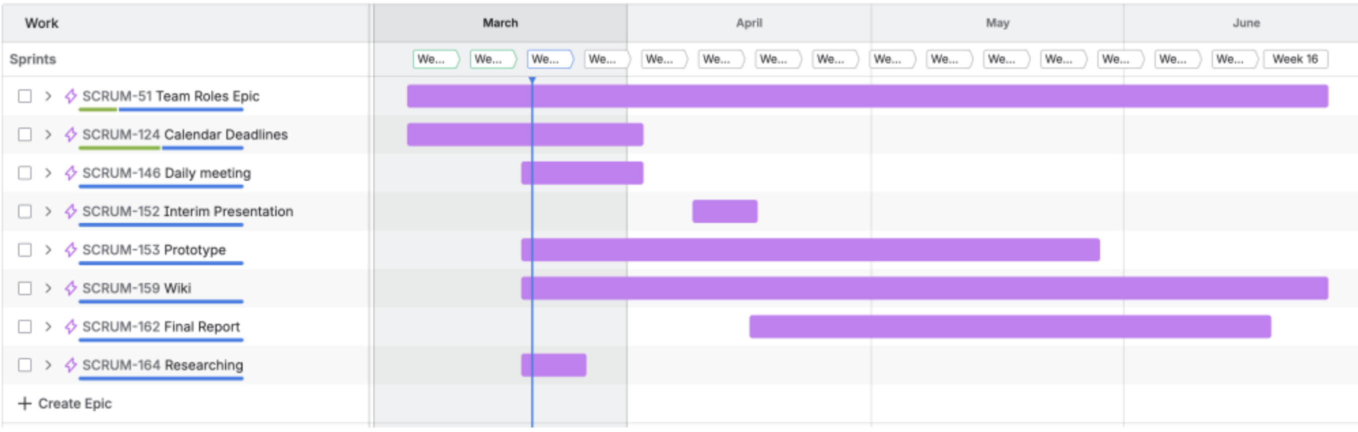
3.10 Project Plan

3.10.1 Gantt Chart

The project schedule was visualized using a Gantt chart to illustrate the timeline and key phases of the project.

As shown in Figure 9, the project timeline spans from March to June and includes overlapping phases such as research, prototype development, and documentation.

Figure 9: Gantt chart showing the project timeline from March to June.



3.10.2 Global Sprint

The global sprint plan provides an overview of the project timeline, including the duration of each sprint, start and end dates, and the number of available working days. Its main purpose is to ensure a realistic distribution of workload based on the team's availability throughout the project period. See Table 17 for the global sprint plan.

By defining how long each sprint lasts and how many working days are available, the team can better plan tasks and avoid overloading specific periods. Variations in working days reflect differences in availability, such as holidays or other commitments, which allows for more accurate and achievable planning.

Table 17: Table of Global Sprint Plan.

Sprint	Start	Finish	Working Days	Status
1	5 Mar	12 Mar	5 days	Done
2	12 Mar	19 Mar	5 days	Done
3	19 Mar	26 Mar	5 days	Done
4	26 Mar	2 Apr	5 days	Done
5	2 Apr	9 Apr	0 days	Done
6	9 Apr	16 Apr	3 days	Done
7	16 Apr	23 Apr	5 days	Started
8	23 Apr	30 Apr	5 days	To do
9	30 Apr	7 May	3 days	To do
10	7 May	14 May	3 days	To do
11	14 May	21 May	5 days	To do
12	21 May	28 May	5 days	To do
13	28 May	4 Jun	5 days	To do
14	4 Jun	11 Jun	5 days	To do
15	11 Jun	18 Jun	5 days	To do
16	18 Jun	25 Jun	5 days	To do

3.10.3 Backlog

The project backlog contains all identified tasks required to complete the project. Tasks are continuously updated and prioritized based on project needs, deadlines, and dependencies. Completed tasks are marked as "Done", while ongoing and future tasks are labeled accordingly. Table 18 lists the backlog.

Table 18: Table of Backlog.

PBI	Title	Status
A	Define project	Done
B	System diagrams and structural plans	In progress
C	Project backlog	Done
D	State of the Art	Done
E	Gantt chart	Done
F	System diagrams and drafts	To do
G	Global sprint plan	Done
H	List of components and materials	Done
I	Schematics and structural drawings	Done
J	Design development	In progress
K	Interim deliverables	Done
L	3D model and video	In progress
M	Interim report and presentation	Done
N	Functional testing	To do
O	Packaging solution	To do
P	Poster	In progress
Q	Folder and manual	To do
R	Brochure and leaflet	In progress
S	Prototype	To do
T	Video	To do
V	Final report	To do
W	Upload final deliverables	To do
X	Final presentation	To do
Y	Final review and submission	To do

3.10.4 Initial Sprint Plan

Sprint 1 (Week 3: 19 Mar – 26 Mar)

Sprint Goal: Establish the project foundation by defining roles, conducting initial research, and setting up key project documentation (see Table 19).

Table 19: Initial Sprint Plan.

Sprint	Period	Sprint Goal	Task
1	19 Mar – 26 Mar	Establish project foundation	Selection of materials
1	19 Mar – 26 Mar	Establish project foundation	Backlog, global & initial sprint plan, Gantt chart
1	19 Mar – 26 Mar	Establish project foundation	Detailed schematics
1	19 Mar – 26 Mar	Establish project foundation	Researching information
1	19 Mar – 26 Mar	Establish project foundation	Define project roles
1	19 Mar – 26 Mar	Establish project foundation	Flyer & logo presentation
1	19 Mar – 26 Mar	Establish project foundation	Cardboard model
1	19 Mar – 26 Mar	Establish project foundation	Wiki updates
1	19 Mar – 26 Mar	Establish project foundation	Daily scrum meetings
1	19 Mar – 26 Mar	Establish project foundation	Selection of components
1	19 Mar – 26 Mar	Establish project foundation	Structural drawing

The tasks in the sprint were divided into smaller activities, including research, documentation, design, and planning, in order to ensure efficient progress. Responsibilities were distributed among team members based on their respective roles, with a focus on areas such as research, documentation, and design. By the end of the sprint, key project elements such as clearly defined team roles, initial research, and planning documents had been completed, providing a solid foundation for the subsequent sprints.

3.11 Sprint Outcomes

The sprints officially started from 19 March to 26 March, as the previous weeks were mainly used to become familiar with Jira and project tools.

However, the initial work began earlier, and the first weeks were structured as follows:

An overview of the outcomes from the initial sprints is presented in Table 20 and Table 21.

Table 20: Week 1 outcome

Sprint	Period	Objective	Activities	Outcome
1	Week 1	Define project scope and direction	Brainstorming of project ideas, discussion of possible approaches, evaluation of feasibility	Selection of project concept and initial understanding of project scope

Table 21: Week 2 outcome

Sprint	Period	Objective	Activities	Outcome
2	12 Mar – 19 Mar	Develop system concept and research state of the art	Continued research on artificial reefs and sensors, worked on the state of the art chapter, explored materials and structural ideas, started defining system components, followed milestone plan	Clearer understanding of technical solutions and initial system concept defined

Sprint 3

The burndown chart for sprint 3 shows that additional tasks were identified and added at the beginning of the sprint, resulting in an increase in the total amount of work. This reflects a better understanding of the project requirements as the team moved from concept to design.

During the middle of the sprint, progress remained relatively stable, indicating that fewer tasks were completed in that period. Towards the end of the sprint, a significant decrease in remaining work can be observed, showing that most tasks were completed close to the deadline.

This pattern indicates that the team made substantial progress during sprint 3, particularly in the final phase, where key design elements and system components were defined. It also highlights the need for improved task distribution to ensure more consistent progress throughout the sprint (see Figure 10).

Figure 10: Week 3 burndown chart

Sprint 4

The burndown chart for Sprint 4 shows a noticeable increase in workload at the beginning of the sprint, indicating that additional tasks were identified as the project scope became clearer. This reflects an ongoing refinement of requirements and system definition. Shown in Figure 11.

Throughout most of the sprint, progress was relatively slow, with only minor reductions in remaining work. A more significant decrease occurs towards the end, suggesting that many tasks were completed close to the deadline.

This pattern indicates that work was concentrated in the final phase of the sprint. Although the planned objectives were achieved, this approach suggests a need for better time management and a more even distribution of tasks across the sprint.

Figure 11: Week 4 burndown chart

Sprint 5

The burndown chart for Sprint 5 shows no significant changes in the remaining workload throughout most of the sprint. This indicates that tasks were not actively tracked or completed within the sprint period. Week 5 is shown in Figure 12.

This sprint coincided with the Easter holiday, during which no substantial work was carried out. Additionally, the project management tool (Jira) was not updated during this period, resulting in a lack of visibility and progress tracking.

The sprint did not function as intended and cannot be considered effective from an Agile perspective. The absence of recorded progress highlights the importance of maintaining consistent engagement and updating project management tools, even during periods of reduced activity.

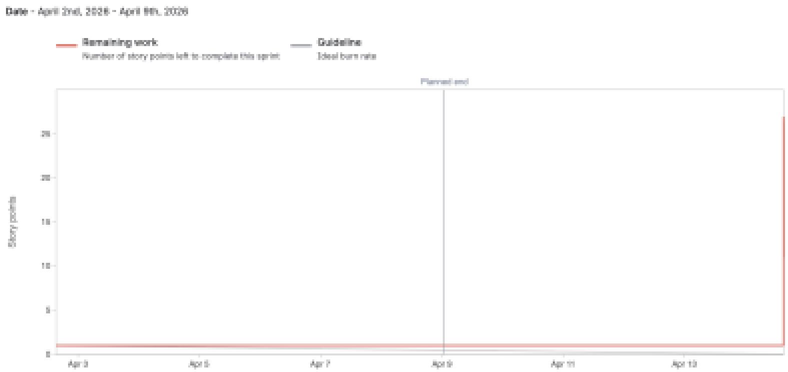


Figure 12: Week 5 burndown chart

Sprint 6

The burndown chart for Sprint 6, shown in Figure 13, indicates limited progress during the initial phase of the sprint, suggesting that relatively little work was carried out at the beginning of the period.

Subsequently, an increase in the remaining workload can be observed. This is explained because the incomplete tasks from Sprint 5 were carried over into Sprint 6. As a result, the workload appears to increase rather than decrease at that stage.

Towards the end of the sprint, a noticeable reduction in remaining work is observed, indicating that several tasks were completed before the sprint was concluded.

This pattern reflects an improvement in task completion compared to the previous sprint. However, it also highlights the importance of maintaining consistent progress and timely updates in order to ensure accurate tracking and effective sprint execution.

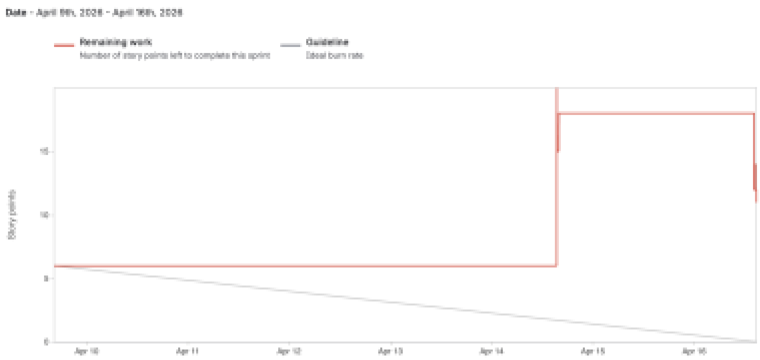


Figure 13: Week 6 burndown chart

Sprint 7

The burndown chart for Sprint 7, shown in Figure 14, indicates that the same issue persists, where tasks are not consistently updated or marked as completed during the sprint. As a result, the remaining work remains relatively constant for most of the period.

Towards the end of the sprint, a sharp decrease in remaining work can be observed, suggesting that tasks were completed or updated late. Consequently, the burndown does not follow a steady downward trend.

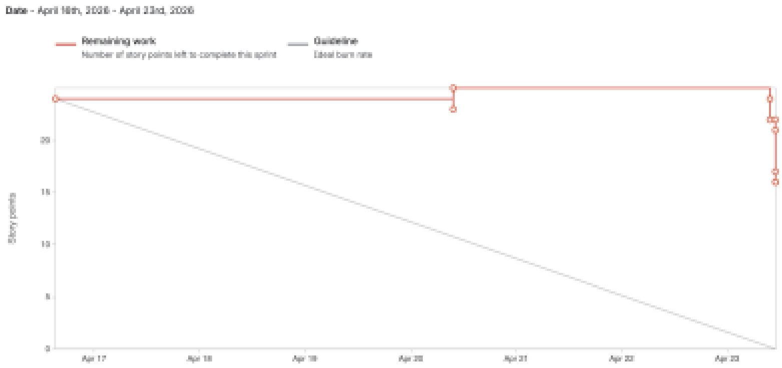


Figure 14: Week 7 burndown chart

Sprint 8

The burndown chart for Sprint 8, shown in Figure 15 indicates an increase in scope at the beginning of the sprint, suggesting that tasks were added after the sprint had started. Furthermore, the chart shows that task completion is concentrated toward the end of the sprint, with limited progress observed during the earlier phases. As a result, the burndown does not exhibit a consistent downward trend, but rather a delayed reduction in remaining work.

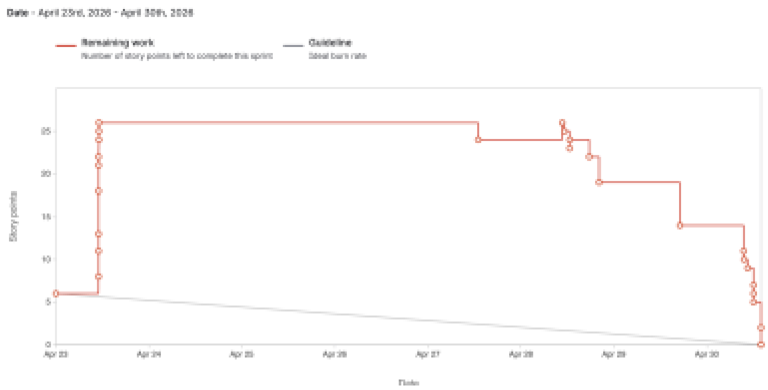


Figure 15: Week 8 burndown chart

3.12 Sprint Evaluations

Second week retrospective

Positive Aspects During this week, the team worked well together and showed good coordination in roles and responsibilities. The wiki and Jira were kept relatively updated, and the team made solid progress in research and design. There were also strong ideas developed for the project's features, structure, and overall concept, along with progress on the ethics work. Overall, the team showed improvement in both collaboration and organization.

Challenges During this week, the team faced several challenges. There was a lack of clear discussion about project expectations, which led to some uncertainty. Task division was not always effective, and deadlines were not used efficiently. The wiki and report structure were somewhat disorganized, with resources not properly organized or uploaded. Additionally, the team could have shown more initiative and been more critical of their work. Overall, better structure, clarity, and efficiency are needed moving forward.

Ideas for Improvement During this week, the team developed ideas to improve the project by focusing on one main "smartblock" with simpler supporting blocks. They also explored sustainable materials, clearer separation between prototype and final product, and ways to improve functionality, such as adding sensors and using 3D printing.

Actions for Next Week For the next week, the team should focus on finalizing the structure and deciding on the materials for the project. It is important to continue and complete the necessary research while also developing the product design. The team should create a few sketches and present them for feedback. Additionally, roles and tasks need to be clearly defined, and the wiki should be properly updated with sources and kept organized. Work on communication materials such as a flyer, key facts, and an elevator pitch should also be continued.

Third week retrospective

Positive Aspects During this week, the team made strong overall progress and showed improved organization. The wiki was well maintained, and Jira was used effectively to keep track of tasks. The product design became clearer, supported by good structural drawings and a successful cardboard model. There was also progress in marketing, and the team had good planning for the upcoming weeks. Overall, collaboration was strong, with everyone showing up on time and contributing to steady progress.

Challenges During this week, the team faced challenges due to missing components, which slowed progress and led to some waiting time. There were still uncertainties regarding materials, sensors, and electronics, and decisions about these were not finalized. Parts of the wiki were disorganized, and project management could have been more structured. Additionally, the team had not clearly defined a target customer and needed to improve consistency in updating and sharing progress.

Ideas for Improvement During this week, the team developed ideas to improve planning and analysis. This included visualizing the market analysis more clearly and creating a risk matrix to better understand potential challenges. The team also focused on preparing for the interim presentation in order to improve communication and confidence.

Actions for Next Week For the next week, the team should focus on deciding on materials and further developing the technical aspects, such as weight and water flow. Each member should take clear responsibility for specific parts of the project and break tasks into smaller subtasks if needed. The team should also create a plan for the upcoming period to stay organized and maintain steady progress.

Fourth Week Retrospective

Positive Aspects During this week, the team successfully delivered the scheduled presentations, and key project components were selected. This contributed to clarifying the technical direction of the project and ensured alignment among team members.

Challenges The communication presentation did not meet expectations. The content and delivery could have been better structured and more effectively communicated.

Ideas for Improvement No specific improvement ideas were identified during this period.

Actions for Next Week The team will focus on completing and submitting the interim report. Emphasis will be placed on ensuring that all required sections are finalized and meet the expected quality standards.

Fifth Week Retrospective

Positive Aspects The interim report was successfully completed and submitted, marking an important milestone in the project timeline.

Challenges The report was finalized later than planned, indicating inefficiencies in time management and task distribution. Ideally, the report should have been completed before the final deadline to allow time for review and refinement.

Ideas for Improvement No additional improvement ideas were identified during this week.

Actions for Next Week The team will begin preparing for the interim presentation, focusing on improving content clarity, structure, and delivery.

Sixth Week Retrospective

Positive Aspects The team made good progress in preparing for the interim presentation, demonstrating improved coordination and focus on communication aspects.

Challenges Some challenges were encountered during the week; however, they were not clearly identified or documented.

Ideas for Improvement Based on feedback from supervisors, the team identified the need to improve the visual identity of the project, particularly by incorporating marine elements such as fish into the flyer and branding materials.

Actions for Next Week The team will further develop the technical aspects of the smart system, with a particular focus on evaluating alternative battery options and improving the design of the smart module. In addition, work will continue on creating a 3D model video of the product to support visualization and presentation.

Seventh Week Retrospective

Positive Aspects The team identified a more suitable battery for the project, and the wiki was further improved. In addition, a meeting was held with Manuel, the project supervisor, to discuss the project and develop a more concrete plan moving forward.

Challenges The team was not able to create the 3D video as planned.

Ideas for Improvement No specific improvement ideas were identified during this sprint.

Actions for Next Week The team will finalize the selection of sensors, continue improving the wiki, and complete the 3D video.

Eight Week Retrospective

Positive Aspects The team conducted a meeting with a professor, which provided valuable clarification on how to approach the project. The list of components and materials was finalized, and the SmartBlock of the product was completed.

Challenges The team has not yet completed the 3D video and continues to face challenges in effectively distributing tasks among members.

Ideas for Improvement

Improved task allocation and clearer responsibility distribution should be implemented to ensure steady progress. In addition, intermediate deadlines may help avoid delays in deliverables such as the 3D video.

Actions for Next Week The team will prioritize completing the 3D video and establish a more structured task distribution plan to improve workflow efficiency.

3.13 Summary

The project has been managed using an iterative and structured approach, allowing the team to balance technical challenges with continuous development. Through defined scope, milestone planning, and Agile methods, the team has made steady progress in both design and implementation. While some challenges remain, particularly related to decision-making and organization, the project is moving forward with a clearer direction and improved collaboration.

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4. Marketing Plan

4.1 Introduction

The marketing plan for MARIS HABITATS focuses on positioning the project as a modular reef infrastructure and environmental data solution within the blue economy. Rather than claiming immediate biological recovery, the project focuses on what it can directly provide: scalable reef blocks, removable monitoring units, and long-term environmental data.

The reef blocks create a physical structure in the marine environment and can provide surfaces, cavities, and sheltered spaces that may support habitat formation over time. The removable smart sensor box collects environmental data from selected locations, helping customers understand site conditions and environmental changes around the reef.

This positioning is relevant for public institutions, coastal municipalities, research organizations, environmental NGOs, port authorities, aquaculture operators, and marine infrastructure companies. These customers may need reef infrastructure, environmental monitoring, or data-based support for restoration evaluation, sustainability reporting, research, or decision-making.

This chapter defines the market context, target customers, positioning, and marketing-mix strategy for MARIS HABITATS.

4.2 Business Idea Formulation

The business idea of MARIS HABITATS is based on the need for marine habitat restoration and long-term environmental monitoring. Coastal and offshore areas are increasingly affected by habitat degradation, pollution, overfishing, and climate-related pressures. At the same time, the blue economy is becoming more important, as it aims to use ocean resources for economic growth while preserving the health of marine ecosystems **[65]**.

Artificial reefs have already been used for habitat restoration, fishery enhancement, research, and coastal management. However, their effectiveness depends on suitable design, site selection, materials, and long-term monitoring **[66]**, **[67]**. This creates an opportunity for a solution that does not only provide a physical reef structure, but also supports environmental data collection.

MARIS HABITATS responds to this need by offering a modular reef block system with an optional smart sensor box. The reef blocks provide scalable underwater infrastructure, while the smart box collects environmental data from selected locations. The purpose of the data is to help customers understand site conditions and observe how the reef and surrounding marine environment change over time.

The paying customers are not individual consumers, but organizations that benefit from better monitored marine environments. These may include public agencies, coastal municipalities, environmental NGOs, research institutions, port authorities, aquaculture operators, and marine infrastructure companies. For these customers, MARIS Habitats can provide reef infrastructure and data-based support for restoration evaluation, sustainability reporting, research, and decision-making.

The business model can be developed in stages. First, small pilot projects can be used to test the structure, sensor system, and data collection method. Second, customers can purchase reef modules and optional smart boxes depending on the scale and purpose of the project. Third, annual monitoring services can be offered, including battery replacement, sensor inspection, data collection, and environmental reports.

This approach allows MARIS Habitats to move beyond a one-time product sale. The project can be positioned as a scalable marine restoration and monitoring service, where customers can start with a small installation and expand the system over time.

4.3 Business Model Canvas

In this section, the Business Model Canvas for MARIS HABITATS is presented. Figure 16 provides an overview of the main elements of the business model, including customer segments, value proposition, channels, customer relationships, revenue streams, key resources, key activities, key partners, and cost structure. Each section of the canvas is explained in more detail below.

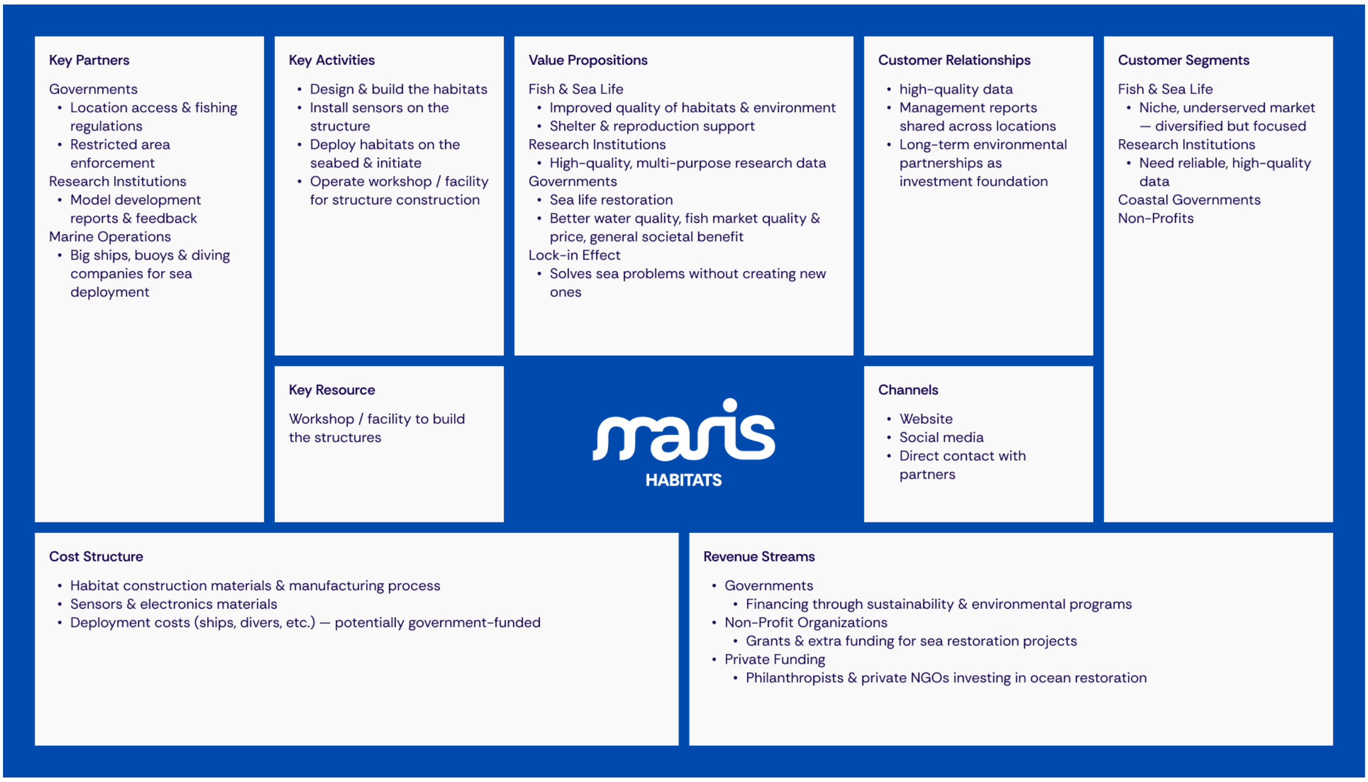

Figure 16: Business Model Canvas

1. Customer Segment The product is being created for the fish and the sea-life, they are a very niche market where few people are helping. It is very diversified but the team will try to narrow it down. Concerning who is the product being sold to, it is intended to be bought by governments and non profit organizations, who are the ones gaining the secondary advantage of the impact. A third part is involved, not the fish as the main beneficiary, or the society because the improvement in general of the seas, but also the science, since the team will be working with researching institutions to manage the data that will be collected data.

2. Value Proposition An improvement in life quality and marine environments is proposed to provide shelter and increase reproduction rates for sea life. For research institutions, the objective is the provision of high-quality data applicable to various research purposes. This project is of interest to governments as it facilitates the restoration of marine life, which aids in water quality for human use, improves the quality and market price of fish, and enhances the general quality of society.

3. Channels The primary focus is placed on reaching buyers through direct personal contact, while social awareness and transparency are established through a dedicated website and social media presence.

4. Customer Relationships Zero contact will be maintained with underwater life to ensure no disturbance occurs. Regarding research centers, real-time data is provided via automated services, while reports and management data are requested to be shared to foster cooperation across multiple locations. For governments, the focus is on developing long-term environmental partnerships that allow for a solid investment foundation.

5. Revenue Streams Funding is secured through various government programs for sustainable development and from non-profit organizations dedicated to marine restoration. Additionally, private funding is sought from philanthropists and private NGOs to support the project's goals.

6. Key Resources The main resource is the workspace, consisting of a facility with an initial area for research and computer-based tasks, and a second area fully dedicated to building models, ranging from material modeling to sensor implementation and testing. If mass production of the structures is required, a factory will be necessary to produce them sequentially and at a high rate of speed.

7. Key Activities The scope of activities includes the design and construction of habitats, as well as the installation of sensors. This is followed by the deployment of the habitats on the seabed and their subsequent initialization. The management of the resulting data is delegated to research centers and institutions.

8. Key Partners Governments are expected to act not only as clients but also as partners in determining site locations and establishing fishing regulations in those areas. The relationship with research institutions is mutually beneficial, as they are provided with data to analyze while offering feedback for the project. Furthermore, partnerships are sought with marine businesses, ship owners, and diving enterprises, to assist with transportation and sea deployment.

9. Cost Structure

The total budget is divided among the model construction (material and manufacturing costs), the sensors and necessary electronic materials, and the expenses associated with deployment, including ships, delivery, and divers. Additionally, worker salaries are included in the event of a transition to mass production.

4.4 Market Analysis

Marine ecosystem degradation is increasingly recognized as both an environmental and economic challenge. Coastal and offshore areas are affected by pressures such as climate change, pollution, overfishing, and habitat loss. These pressures can reduce habitat quality and create a need for restoration, monitoring, and better environmental decision-making **[68]**, **[69]**.

Artificial reefs have already been used in different parts of the world as tools for habitat support, fishery enhancement, research, and coastal management. However, their effectiveness depends on suitable site selection, structural design, material choice, and long-term observation **[70]**, **[71]**. Many existing reef solutions mainly function as physical structures and do not include environmental data collection as a core feature.

At the same time, public institutions, research organizations, environmental NGOs, port authorities, aquaculture operators, and marine infrastructure companies increasingly need measurable environmental information. This data can support restoration evaluation, sustainability reporting, research, and long-term site management.

This creates a market opportunity for a solution that combines modular reef infrastructure with practical environmental monitoring. MARIS HABITATS responds to this gap by offering reef blocks that can be installed alone or combined with optional removable smart sensor boxes. The sensor boxes collect data at scheduled intervals and store it locally for later retrieval, instead of relying on real-time underwater communication.

The primary target market consists of institutional and organizational customers rather than individual consumers. These include national and regional authorities, coastal municipalities, research institutions, environmental NGOs, port authorities, aquaculture operators, and companies involved in marine or coastal infrastructure.

The most realistic market entry strategy is gradual validation. Small pilot projects can first be used to test the reef structure, sensor box, maintenance process, and data retrieval method. After technical validation, the system could be expanded through public funding, research partnerships, environmental programmes, or project-based services.

In this context, MARIS HABITATS is positioned as a modular reef infrastructure and environmental data solution. Its market value comes from combining scalable reef blocks with optional monitoring services, allowing customers to start with a small installation and expand according to their budget, monitoring needs, and project goals.

4.4.1 PESTEL ANALYSIS

A PESTEL analysis is a tool used by many businesses to study the general environment in order to decide a business strategy. This general environment is divided into several segments from the industry and competitor environment. This analysis is conducted to identify changes in society to allow for the adaptation and integration of the business within it.

4.4.1.1 Political

Politically, the current situation is highly advantageous. The European Union (EU) has identified the same problem and has addressed it through the publication of The Nature Restoration Law (NRL), which mandates that member states take corrective action. Consequently, in the face of a sudden surge in demand, the market supply position is excellent, making the participation of government agencies in the project even more likely.

4.4.1.2 Legal

Following the framework of section 4.4.2.1, the United Nations (UN) has published The High Seas Treaty (BBNJ). This international law reaches more than 60 nations and provides a legal framework for establishing Marine Protected Areas (MPAs) in international waters, emphasizing area-based management tools and environmental impact assessments in the deep seas. These operations align with the business proposal and provide a structured framework to be followed.

4.4.1.3 Economic

Economically, 2026 has marked a leap from research to large-scale implementation, and the funds and budgets allocated to these efforts have grown accordingly. In line with the previously mentioned regulations, substantial amounts have been made available by various organizations:

- The EU, through the LIFE Program, is financing approximately 60 – 70 % of projects with grants ranging between € 1 M and € 5 M for those within the “Nature and Biodiversity” calls. Furthermore, under the specific mission “Restore our Ocean and Waters,” calls have been launched with a budget exceeding € 115 M for nature-based solutions and habitat mapping.
- The UN, following the BBNJ Treaty, has activated the Global Environment Facility (GEF) with a total fund of € 5.3 B, which supports environmental challenges through projects similar to this one. From this special fund, 50 % is being allocated to finance large protected areas in

international waters.
- Lastly, at the national level, both Spain and Portugal (both potential target locations) have initiatives such as the PLEAMAR and Empleaverde+ programs, or the NextGen funds (Spain), as well as the Blue Fund (Fundo Azul) and the 2026 State Budget (Portugal). All of these collectively aim toward fishing sustainability, marine restoration, and ecosystem recovery.

4.4.1.4 Social

On a social level, several arguments gain momentum year after year. The restoration and creation of habitats have their primary impact on the creation of "shelter zones." This allows for an increase in biomass, which socially stabilizes the economy of fishing areas and reduces conflicts arising from resource scarcity. Furthermore, these habitats indirectly boost diving tourism by diverting tourist pressure from overexploited natural reefs toward controlled, managed areas, promoting a sustainable blue economy.

In addition, the improvement of marine habitats enhances water quality and protects beaches from erosion. This increases the overall quality of life in coastal cities, particularly in high-tourism regions such as the target countries, Spain and Portugal.

4.4.1.5 Technological

Technologically, the project is currently at its least robust point. There is an ongoing boom where all activities must be monitored, recorded, and measured to demonstrate efficacy and numerically evaluate utility. Funding bodies, in particular, demand project reliability. Dependence is placed on a simple system that allows for these requirements to be met without overcomplicating the process.

Other projects involve 3D scanning of the implementation or restoration area for simulations, or high-resolution mapping using sonar. However, the project goals do not include these types of systems; due to the technological gap, a simpler monitoring system is preferred to provide the necessary security without resorting to excessive, highly invasive, and ultimately unnecessary testing.

4.4.1.6 Environmental

The implementation of marine habitats is subject to strict oversight by regulatory bodies under the EU Nature Restoration Law (NRL), which require studies proving that the intervention will not negatively alter pre-existing dynamics. To this end, baseline characterization studies are conducted for subsequent comparison after implementation.

Another study of great importance is ecological connectivity to assess interaction with the environment; this serves as the Gold Standard for creating ecological corridors that facilitate species migration and climate change adaptation. Finally, other impact assessment and ecosystem service studies support the project to ensure its success.

Despite these well-defined tests and studies, this area may prove challenging due to numerous regulatory requirements and limited professional experience in the field. Consequently, efforts will be intensified to satisfy both technical and social requirements.

4.4.2 SWOT Analysis

The main strengths, weaknesses, opportunities, and threats of MARIS HABITATS are summarized in Figure 17.

4.4.2.1 Strengths

One of the main strengths of MARIS HABITATS is the combination of modular reef blocks and a removable smart sensor box. The system is not only designed as a physical reef structure, but also as a tool for collecting environmental data around the reef over time.

Another strength is its modularity. Customers can start with a small number of reef blocks and later expand the system depending on the project size, budget, and monitoring needs. Since the smart sensor box is removable, maintenance, battery replacement, and data retrieval can be carried out without removing the whole reef structure from the seabed.

The system also has value for long-term environmental observation. Instead of relying on real-time underwater communication, the smart box stores data locally and allows the data to be retrieved during scheduled maintenance. This reduces technical complexity and power consumption while still supporting later analysis.

4.4.2.2 Weaknesses

A main weakness of MARIS HABITATS is the technical complexity of combining reef structures with sensors, batteries, waterproof housing, and data storage. Even though the system avoids real-time underwater transmission, the electronic components still need to operate reliably in harsh marine conditions.

Another weakness is the cost of marine-grade components. Pressure-resistant housings, underwater connectors, and durable sensors can be expensive, especially for the final product. The prototype uses lower-cost alternatives, but these are only suitable for controlled testing and cannot fully represent long-term marine deployment.

Maintenance is also a limitation. The system is designed for long-term local data logging, but the smart sensor box still needs to be retrieved periodically for battery replacement, sensor inspection, and data collection. This may require divers or technical partners, which can increase operational costs.

4.4.2.3 Opportunities

MARIS HABITATS can benefit from the growing demand for marine restoration, environmental monitoring, and data-based decision-making. Public institutions, coastal municipalities, research organizations, NGOs, port authorities, aquaculture operators, and offshore infrastructure companies may need solutions that combine reef infrastructure with environmental data collection.

There is also an opportunity to develop pilot projects with local authorities, universities, or marine infrastructure partners. These pilot projects could help test the modular reef blocks, the removable smart sensor box, and the annual data retrieval process before larger-scale deployment.

Another opportunity is the development of a service-based model. In addition to selling reef modules, MARIS HABITATS could offer annual monitoring services, including battery replacement, sensor inspection, data collection, and environmental reports. Basic datasets could also support research and education, while project-specific analysis could be offered as a paid service.

4.4.2.4 Threats

Several threats are related to the marine environment itself. Strong currents, storms, pressure, corrosion, and biofouling can affect the long-term performance of both the reef structure and the smart sensor box. These factors may increase maintenance needs or reduce data quality.

Regulatory approval can also be a threat. Since the system is installed underwater and interacts with marine environments, deployment may require permits, environmental assessment, and cooperation with local authorities. This can delay implementation.

Market adoption may also be slow because MARIS HABITATS is a hybrid system. It is not only an artificial reef and not only a monitoring device, so customers may need time to understand its value. Existing companies in marine infrastructure and reef restoration may also create competition, especially if they already have stronger market recognition or established partnerships.

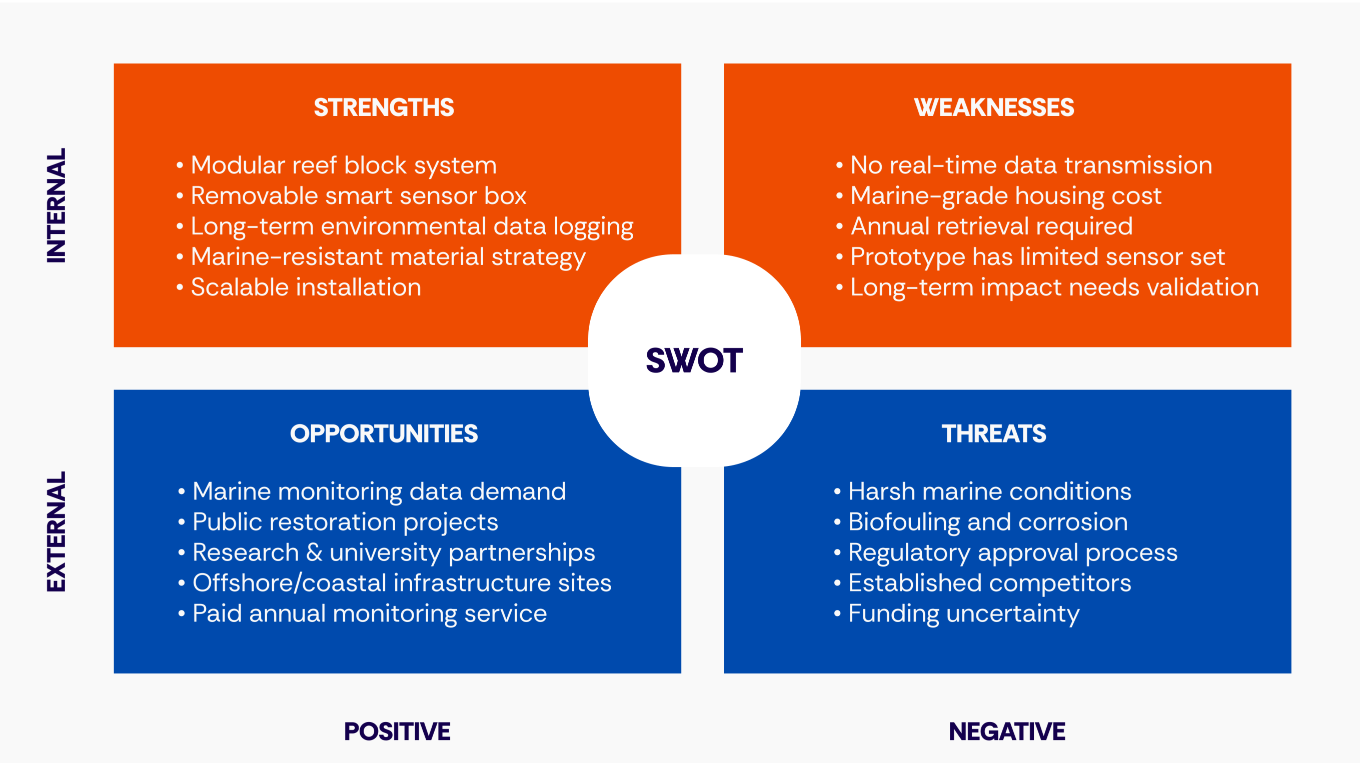

Figure 17: SWOT Analysis

4.5 Strategy

4.5.1 Strategic Objectives

To determine the team's objectives, a SMART framework was set, ensuring the goals are Specific, Measurable, Achievable, Relevant, and Time-bound. A 3 to 5-year horizon was defined to minimize ambiguity and ensure strategic alignment.

- Short-to-Medium Term: The primary objective is to demonstrate the system's feasibility through a functional prototype and establish strategic partnerships with research institutions, NGOs, and local authorities for pilot deployment.
- Long Term: Beyond the initial scope, the project aims to scale the solution into a modular and sustainable artificial reef system dedicated to marine ecosystem restoration and data-driven coastal management.

Monitoring, Metrics, and Baselines The implementation of specific and measurable Key Performance Indicators (KPIs) will serve as the project’s compass. A longitudinal monitoring approach will be utilized, comparing post-deployment data against a rigorous environmental baseline (the “Year 0” measurements). This comparative analysis is the only scientifically valid method to quantify biodiversity net gain, water quality improvement, and structural integrity over time.

Critical Relevance in a Global Context The urgency of these objectives cannot be overstated. As detailed previously, marine ecosystems are approaching a critical tipping point. The degradation of these habitats threatens keystone species responsible for essential ecosystem services, including global oxygen production—driven by phytoplankton and healthy reef systems—and the sustenance of human populations that rely on the sea for food security. This strategy is not merely a business goal; it is a response to a global ecological imperative.

Achievability and the “Experimental” Paradigm In alignment with the World Wide Fund for Nature (WWFs) classification, this project is categorized under the Experimental Frontier. Unlike mature projects with predictable outcomes, this project operates in a dynamic environment where it is necessary to push technical boundaries. Recognizing this “experimental” nature allows us to maintain operational flexibility. Marine variables—such as current shifts, temperature fluctuations, and pH levels—require an adaptive management style, allowing us to pivot team's tactics without compromising the core strategic objectives.

4.5.2 Segmentation and Targeting

Unlike traditional consumer products, this solution is not based on standard demographic or psychographic segmentation. Instead, it focuses on geographical and environmental conditions, especially coastal areas with similar marine characteristics.

At this stage, the main focus is on the Atlantic coast of Portugal and Northern Spain. These regions have similar ocean conditions and biodiversity, which makes it easier to apply the system without major design changes.

Although the European Union is the main institutional partner and initial market, the long-term goal is to expand to other regions with similar marine environments. Potential areas include the northeastern United States, southwestern Canada, western New Zealand, and central Chile.

In future developments, the system could also be adapted to different climates, including tropical and colder regions, allowing for wider global application.

From this perspective, the targeting strategy focuses on the main stakeholders within these regions.

After identifying where the system can be implemented, it is important to define who benefits from it.

The project aims to improve marine biodiversity, support fish population growth, and contribute to better water quality. In addition, it can help reduce coastal erosion and protect coastal infrastructure by absorbing wave energy.

Unlike traditional solutions, the system also includes an integrated monitoring component that provides continuous environmental data. This supports data-driven decision-making for coastal management and long-term planning.

For these reasons, the main target audience includes national governments, regional authorities, and coastal municipalities. These stakeholders are responsible for environmental management and have the capacity to invest in long-term infrastructure.

The partnership strategy is based on three main criteria:

- Environmental awareness: recognition of marine ecosystem degradation
- Financial capacity: ability to support long-term investment
- Strategic alignment: consistency with sustainability policies

In this context, the EU Biodiversity Strategy for 2030 provides a strong framework, as it aligns with the objectives of this project and supports funding opportunities.

4.5.3 Positioning

The positioning of MARIS HABITATS and selected existing companies is shown in Figure 18. The map is based on two main criteria: ecological reef design on the horizontal axis and environmental data capability on the vertical axis. These criteria were selected because MARIS HABITATS is not only intended as a physical reef structure, but also as a system for collecting environmental data around the reef over time.

ECOncrete, Reef Design Lab, IntelliReefs, and rrreefs are positioned on the right side of the map because they strongly focus on ecological reef design, habitat creation, or reef restoration. ECOncrete focuses on bio-enhancing concrete infrastructure, while Reef Design Lab and rrreefs use modular and 3D-printed reef structures. IntelliReefs focuses on Oceanite-based artificial reef structures for marine restoration.

However, these companies are positioned lower in terms of environmental data capability because their publicly available product descriptions do not clearly show a removable sensor box or long-term local data logging as a core product feature. Their main value is related to ecological design, material innovation, or reef restoration, rather than direct environmental data collection.

MARIS HABITATS is positioned in the upper-right area of the map. This is because the project combines modular reef blocks with a removable smart sensor box. The system is not designed for real-time underwater data transmission. Instead, it stores environmental data locally and retrieves it during scheduled maintenance, approximately once per year.

Overall, the positioning map shows that many existing companies focus strongly on reef design or ecological enhancement, while fewer solutions combine reef infrastructure with long-term environmental data collection. This highlights a potential market gap that MARIS HABITATS aims to address through its modular reef structure and removable monitoring unit.

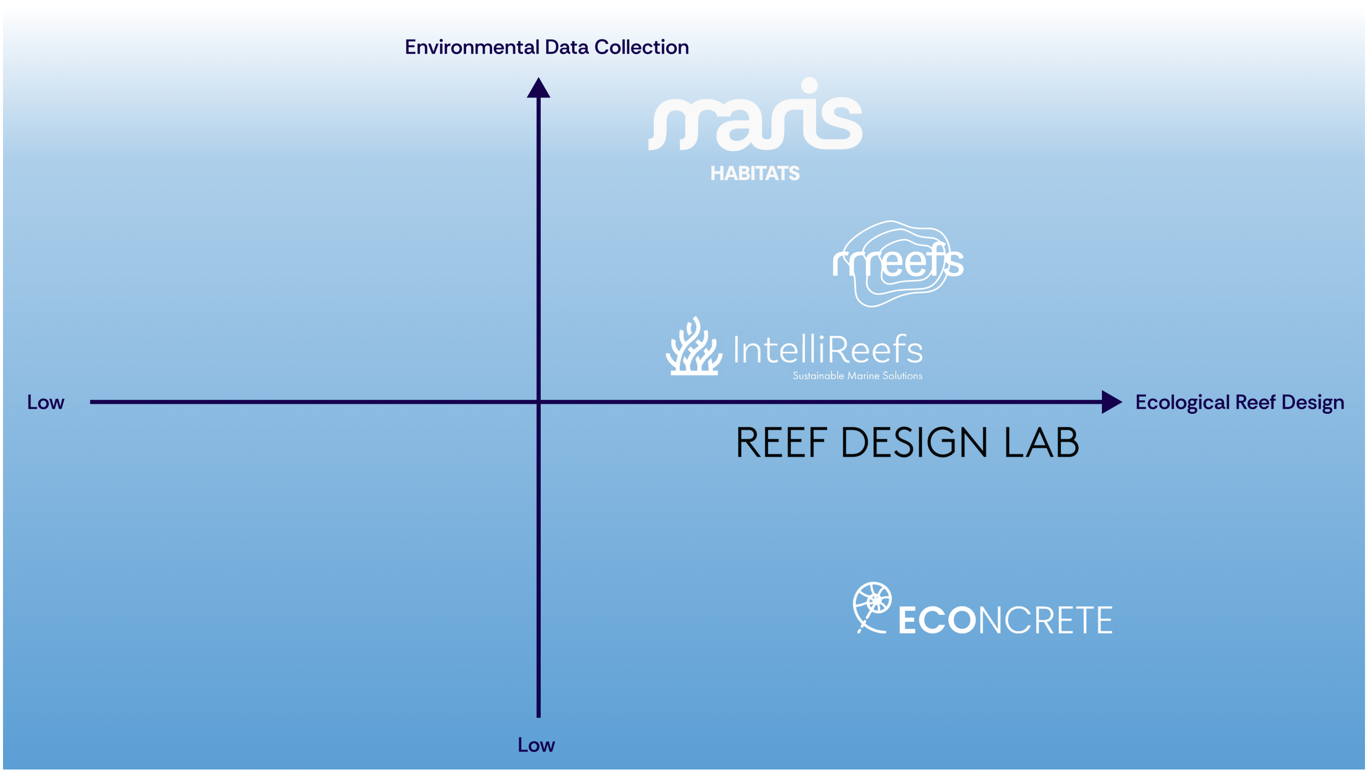

Figure 18: Positioning map of selected existing solutions and the proposed MARIS HABITATS system

4.5.4 Marketing-Mix

Product

MARIS HABITATS is a modular marine infrastructure and environmental monitoring system. The product consists of reef blocks, an optional removable smart sensor box, and a data-based monitoring service. The reef blocks provide cavities, rough surfaces, and sheltered spaces that may support habitat formation over time. The smart sensor box collects environmental data such as temperature, pressure/depth, and water quality indicators from selected locations around the reef.

The collected data is not intended to prove immediate ecological recovery. Instead, it helps users observe how the reef structure and surrounding marine conditions change over time. This makes MARIS HABITATS useful for marine restoration support, research, environmental monitoring, and long-term site observation.

A key part of the product strategy is modularity. Customers can first install the reef blocks alone and later add smart sensor boxes if monitoring is needed. This gives public institutions and companies more flexibility, because they do not need to invest in the full system from the beginning.

The smart sensor box is not included in every reef block. For larger installations, only selected modules may include monitoring units in order to collect representative environmental data while reducing total system cost. The removable design also allows battery replacement, sensor inspection, maintenance, and data retrieval without removing the whole reef structure from the seabed.

The final product could include different service levels. A basic version would include the reef blocks only. A standard version would include reef blocks and selected smart sensor boxes. A premium version could include yearly maintenance, data collection, sensor inspection, battery replacement, and environmental reports. In this way, MARIS HABITATS becomes more than a physical product; it becomes a modular platform for reef infrastructure, environmental monitoring, and data-based decision-making.

Price

The pricing strategy for MARIS HABITATS follows a modular and scalable model. Since the system is made of separate reef blocks and optional smart sensor boxes, the total price depends on the number of reef modules, the number of monitoring units, the selected sensor package, and the level of service required by the customer.

The reef structure can be priced per block. This allows customers to start with a small pilot installation and expand the system later by adding more modules. For larger restoration or monitoring areas, more reef blocks would be required, while smaller projects could begin with only a limited number of units. This makes the product more flexible for public institutions, research organizations, and companies with different budgets.

The smart sensor box would be offered as an optional add-on rather than being included in every reef block. For example, if a project installs 50 reef blocks, it may only need 5 smart boxes placed in selected locations. These boxes can collect representative environmental data from the site while reducing the total cost of the system. This is important because large installations do not need sensors in every single module.

Different sensor packages could also be offered. A basic package could include temperature and pressure/depth sensors. A standard package could include additional water quality indicators such as conductivity. More advanced options, such as pH or other specialized sensors, could be offered for projects with higher budgets or more specific research needs.

In addition to the physical product, MARIS HABITATS could offer an annual monitoring service. This service could include data retrieval, battery replacement, sensor cleaning, sensor inspection, and an environmental report. Through this model, customers would not only pay for the reef structure itself, but also for long-term monitoring and data-based insights. This creates a more stable business model and turns MARIS HABITATS into a scalable marine restoration support and monitoring service.

Place

Because MARIS HABITATS is not a consumer product, it would not be distributed through normal retail channels. The product is intended for institutional and project-based customers, such as public authorities, coastal municipalities, port authorities, research institutions, environmental NGOs, aquaculture operators, and marine infrastructure companies.

The distribution strategy should therefore be based on direct sales, partnerships, and pilot projects. Instead of selling the product through shops, the team would approach potential customers directly and offer project-specific solutions depending on the site, budget, monitoring needs, and environmental goals.

At the first stage, the main geographical focus would be the Atlantic coast of Portugal and Northern Spain. These regions are suitable as an initial market because they are close to the project location and have comparable marine conditions. Starting in nearby regions also makes communication, testing, transport, installation, and maintenance easier.

After validation through pilot projects, MARIS HABITATS could be expanded to other coastal regions with similar marine environments. Possible future markets include other European coastal areas and international regions where artificial reef structures or environmental monitoring systems are needed. However, expansion to different climates or ecosystems would require additional testing and local adaptation.

The installation and maintenance process would likely require cooperation with local partners. These may include diving teams, marine contractors, port operators, research institutions, or environmental agencies. This partnership-based distribution model is important because underwater installation, annual data retrieval, and sensor maintenance require site access and technical support.

Promotion

The promotion strategy should focus on clear, realistic, and evidence-based communication. Since MARIS HABITATS is presented as an environmental solution, promotion must avoid exaggerated claims or greenwashing. The system should not be promoted as a complete solution that can fully restore marine ecosystems by itself. Instead, communication should explain what the system can realistically provide: modular reef infrastructure, optional environmental monitoring, and long-term local data collection.

The main promotional message should emphasize the difference between MARIS HABITATS and existing artificial reef solutions. Many existing systems focus mainly on reef structure or ecological design. MARIS HABITATS adds value by combining modular reef blocks with a removable smart sensor box that stores environmental data locally for later analysis.

Promotion should be targeted at professional and institutional audiences rather than the general consumer market. Suitable channels include direct presentations to public authorities, research institutions, port authorities, environmental NGOs, and marine infrastructure companies. The team could also use project reports, technical brochures, academic presentations, environmental innovation events, and professional networking platforms.

Digital communication can also support promotion. A website or project page can explain the system, show the modular structure, describe the sensor box, and present pilot project results when available. Social media can be used for awareness, but the content should remain informative and technical rather than overly promotional.

For early-stage promotion, pilot projects are especially important. Demonstrating the system in a controlled or small-scale marine environment would help build credibility. Data collected from pilot deployments could later be used in reports, presentations, and case studies to show how the system works and what kind of environmental information it can provide.

Overall, the promotion strategy should present MARIS HABITATS as a realistic and modular solution for marine infrastructure and environmental monitoring. The focus should be on transparency, technical feasibility, long-term observation, and collaboration with institutions that are already involved in marine restoration, research, or coastal management.

4.5.5 Brand

The name of the product is Maris Habitats.Maris is of Latin origin, meaning “of the sea”. This name was chosen to reflect the mission: to give back to the ocean and support the growth of new marine habitats.

Logo

The Maris logo (see Figure 19) is inspired by the movement of the ocean: fluid and continuous. It captures the essence of water through a single, uninterrupted line, symbolizing flow, connection, and natural rhythm.

Figure 19: Maris Habitats Logo

Color System

The Maris color palette (see Figure 20) is inspired by the depth and diversity of the ocean. It balances cool aquatic tones with a vibrant accent, reflecting both calmness and life beneath the surface.

- **Deep Sea Blue** — #14004D **Foundation color** Represents depth, mystery, and stability
- **Ocean Blue** — #004AAD **Core brand color** Clear, strong, and evoking open water
- **Fish Blue** — #5C9FD5 **Secondary tone** Adds lightness and movement
- **Sky Blue** — #DDEBF6 **Background color** Soft, breathable, and minimal
- **Coral Orange** — #EE4C01 **Accent color** Inspired by coral reefs, used for highlights, energy, and contrast
- **Orca White** — #F9F9F9 **Neutral base** Clean, modern, and versatile

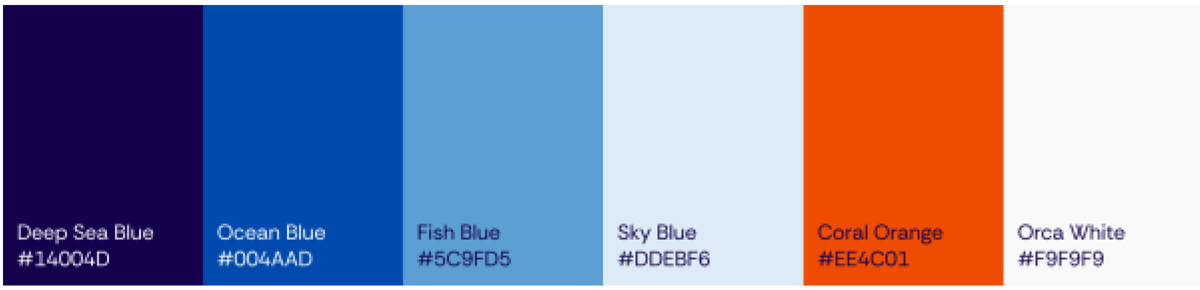

Figure 20: Maris Habitats Brand Colors

Graphic Elements

The graphic language (see Figure 21) of Maris is derived from marine ecosystems, translating organic underwater forms into bold, modern visuals. The organic shapes are inspired by coral, sea plants, and flowing water. Shapes are soft, rounded, and natural. The elements overlap to create depth, mimicking underwater environments and ecosystems.

Figure 21: Maris Habitats Graphic Elements

4.6 Marketing Programmes

4.6.1 Programmes

4.6.2 Budget

4.6.3 Control

Summary

Provide here the conclusions of this chapter and make the bridge to the next chapter.

Based on this market/economic analysis, the team decided to create <specify the type of product> intended for <specify the market niche> because <specify here the relevant market-related reasons>. Consequently, the team decided to design a solution with the following <specify here the features added for market reasons>.

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5. Eco-efficiency Measures for Sustainability

5.1 Introduction

This chapter examines the environmental, economic and social dimensions of the project, as well as the product’s life cycle, in order to assess its overall sustainability. The aim is to highlight the considerations taken to minimize negative environmental impacts when introducing artificial structures into marine ecosystems.

Particular attention is given to ensuring that the solution does not further disrupt or degrade existing ocean environments. This includes evaluating how the design, material selection, and long-term use of the product can prevent pollution and reduce ecological harm. By adopting a lifecycle perspective, the chapter also addresses how the product can be managed responsibly from production to end-of-life.

5.2 Environmental

This section considers the environmental impact of the project using principles inspired by the butterfly diagram, a model that represents circular material flows **[72]**. The model distinguishes between biological processes, where materials safely integrate into natural systems, and technical processes, where products are maintained, reused, and recycled to extend their lifespan (See Figure 22).

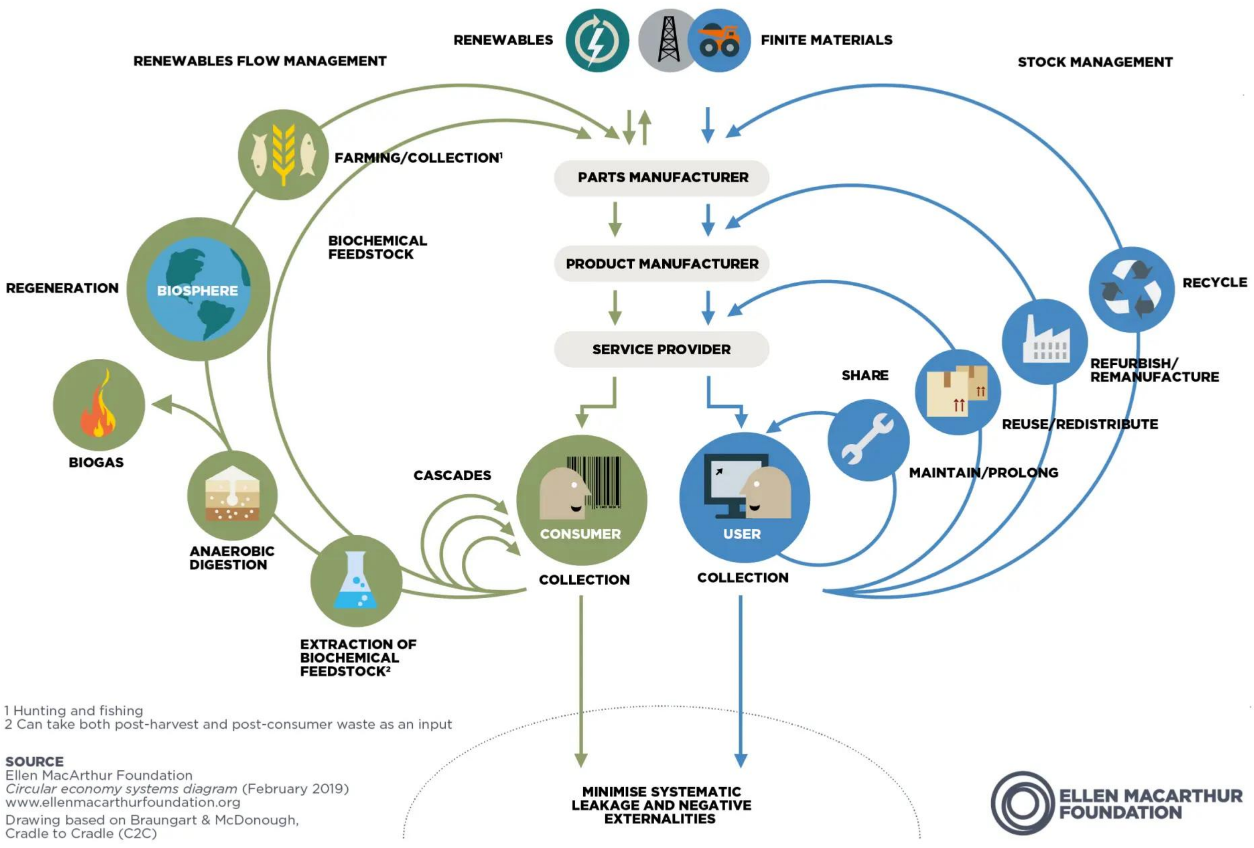

Figure 22: Butterfly diagram **[73]**

The MARIS HABITATS concept reflects these principles by combining long-term environmental integration with efficient use of technical components. From a biological perspective, the habitat is designed to support marine colonization over time. The use of non-toxic and durable materials allows algae, microorganisms, and small marine species to attach and grow on the structure, contributing to biodiversity enhancement **[74]** .

From a technical perspective, the system is designed with longevity and adaptability in mind. The modular concrete habitat structure is intended to remain underwater for long periods, while the electronic components are housed in a detachable waterproof enclosure attached to the habitat. This enclosure contains the battery, microcontroller, and data storage system. Sensor probes are mounted through the enclosure and remain exposed to seawater to measure environmental conditions such as pH, conductivity, pressure, and temperature. This modular design allows maintenance or replacement of electronic components without removing the entire habitat structure.

Maintenance requirements are reduced through the use of durable materials that can withstand harsh marine conditions. When maintenance is required, divers can retrieve stored data and replace batteries without disturbing the reef structure. This reduces unnecessary material replacement and extends the operational life of the system.

The project also considers the reuse of technical components. If monitoring is no longer required, electronic components such as sensors, batteries, and storage devices can be removed and reused in future installations.

For the prototype, conventional concrete or 3D printing may be used to reduce costs, while the final design uses basalt fiber-reinforced concrete to improve durability and corrosion resistance in marine environments. This approach reduces environmental impact while maintaining long-term functionality.

5.3 Economical

The economic aspect of MARIS HABITATS is mainly related to the long-term benefits created through ecosystem restoration and its integration with existing marine infrastructure. By improving marine biodiversity and supporting fish population growth, the system may help increase fishery productivity over time. This can create economic benefits for coastal communities that depend on fishing as a source of income and food.

Previous studies have shown that artificial reefs can increase fish biomass and support the development of fisheries, which can lead to economic improvements in coastal areas **[75]**. In this project, this idea is applied through habitat structures that provide shelter and breeding areas for marine species.

The system is also designed to be integrated with existing marine infrastructure, such as offshore wind farms or coastal protection systems. This approach reduces the need for completely new structures and allows existing installations to gain additional ecological functions, improving resource efficiency.

The integration of sensors adds another layer of economic value. The system collects environmental data that can be used for research, monitoring, and decision-making. In this project, this data supports more efficient marine resource management and may help reduce costs related to ineffective environmental monitoring.

Another important aspect is the modular and scalable design of the system. Habitat units can be deployed gradually and adapted to different marine environments, reducing the need for large initial investments. This allows pilot projects to be tested before full-scale deployment.

The modular monitoring system also helps reduce maintenance costs. Instead of replacing the entire structure in case of failure, only specific electronic components need to be repaired or replaced. This improves operational efficiency and reduces long-term costs.

In addition, the project can benefit from collaboration with public institutions, research organizations, and environmental programs. Marine restoration and biodiversity protection are increasingly supported by sustainability policies and funding initiatives **[76]**. This creates opportunities for financial support through grants and public-private partnerships.

Although the initial investment may be relatively high, the project can create long-term value through ecosystem restoration, fishery support, and improved coastal protection **[77]**. For this reason, MARIS HABITATS can be considered both environmentally sustainable and economically viable in the long term.

5.4 Social

The integration of environmental sensors also creates social value by generating data that can be used by research institutions and environmental organizations for marine monitoring and scientific research. This can improve understanding of marine ecosystems and support better environmental decision-making.

The project is also aligned with the market strategy by focusing on partnerships with offshore wind farms, coastal authorities, research institutions, and environmental organizations **[78]**. By integrating artificial habitats into existing marine infrastructure, the project promotes collaboration between technical and environmental stakeholders while reducing the need for additional construction.

In the long term, this approach can support sustainable fisheries, marine conservation efforts, and stronger cooperation between industries involved in ocean management.

5.5 Life Cycle Analysis

The life cycle of the project is considered from material selection to end-of-life, with the aim of reducing environmental impact while maintaining long-term functionality.

In this project, the material phase focuses on choosing durable and environmentally responsible materials. The final design uses basalt fiber-reinforced concrete. Basalt fibers are made from natural volcanic rock and are known for their resistance to corrosion and chemical stability in seawater, which makes them suitable for marine environments **[79]**. Electronic components, including the microcontroller, were also selected based on energy efficiency, reliability, and expected lifespan.

During the manufacturing phase, the reef structure is produced through concrete casting, while the monitoring system is assembled separately as a detachable smart block. This smart block contains the battery, microcontroller, SD card, and sensors. Keeping the electronic components separate helps avoid embedding electronics directly into the permanent structure and reduces unnecessary material waste.

The testing phase focuses on checking both the structural performance of the habitat and the operation of the monitoring system. Special attention is given to battery life, waterproof protection, sensor accuracy, and reliable data collection because these factors affect maintenance needs.

The structure is also designed for long-term use in marine environments. Its geometry includes cavities and irregular surfaces that help algae, microorganisms, and small marine species attach to the structure over time.

To reduce environmental risks, the smart block can be removed for maintenance, battery replacement, data collection, or repairs without disturbing the main reef structure. Separating the electronic components from the permanent habitat also helps reduce the risk of long-term marine pollution.

At the end of its life cycle, the structure is intended to remain in the marine environment and continue functioning as an artificial reef that supports biodiversity **[80]**. Electronic components can be removed and reused in future systems, which helps reduce waste.

5.6 Summary

This chapter has examined the environmental, economic, and social dimensions of the project, together with a lifecycle perspective, in order to evaluate its overall sustainability. The analysis highlights the importance of minimizing environmental impact while ensuring long-term functionality, economic viability, and social value.

Based on this sustainability analysis, the team selected a modular habitat design combined with a separate monitoring system and the use of basalt fiber-reinforced concrete as the primary structural material. This choice is supported by its durability, resistance to marine conditions, and suitability for long-term deployment without causing environmental harm. In addition, the separation of electronic components from the main structure contributes to reducing pollution risks and improving resource efficiency.

Consequently, the solution was designed with features that support sustainability throughout its lifecycle. These include a structure that can integrate into the marine ecosystem over time, a modular and retrievable sensor system that enables maintenance without disturbing the habitat, and a design that promotes marine colonization through varied shapes and surface characteristics. Together, these elements ensure that the system not only minimizes negative environmental impacts but also contributes positively to marine biodiversity and long-term ecosystem health.

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6. Ethical and Deontological Concerns

6.1 Introduction

This chapter outlines the ethical and deontological principles guiding the development of MARIS HABITATS, a smart artificial marine habitat designed to support marine life and collect environmental data. Since the project combines underwater structures, electronic components, and ecological restoration goals, ethical considerations must be included from the early design stage.

6.2 Engineering Ethics

Engineering ethics play an important role in the design and development of artificial marine habitats. According to professional engineering ethics, engineers should prioritize safety, public welfare, competence, and truthful communication **[81]**. In this project, these principles are applied not only to human users and installation personnel, but also to the marine environment affected by the system.

The structure must be designed with sufficient strength, durability, and reliability to withstand marine conditions such as saltwater exposure, currents, wave forces, and long-term material degradation. Concrete and reinforced concrete exposed to marine environments can be affected by chloride ions, sulphate ions, magnesium ions, wave action, and corrosion processes **[82]**. Therefore, material choice and structural stability are not only technical issues, but also ethical responsibilities.

Engineers also have a responsibility to ensure that the habitat structure and the monitoring system do not create unnecessary risks for marine organisms, installation personnel, or the surrounding environment. The habitat should not damage the seabed or disturb existing ecosystems more than necessary. Instead, it should be designed to provide shelter, attachment surfaces, and spatial complexity that can support local marine life.

Another ethical consideration is the separation between the prototype and the final product. The current prototype is not intended for long-term deployment in deep marine conditions. It is designed to test basic sensing, data logging, and housing concepts. Presenting the prototype as a fully marine-grade final product would be misleading. Therefore, the team must clearly explain the technical limits of the prototype and identify what would need to be improved for real deployment.

Transparency is also part of responsible engineering practice. Environmental data collected by the system should be accurate, calibrated when possible, and reported honestly. Even if the results do not show strong ecological improvement, the data should still be presented clearly because it can support future research and better decision-making in marine restoration.

6.3 Sales and Marketing Ethics

Sales and marketing ethics are important because MARIS HABITATS is presented as an environmental restoration and monitoring solution. The project should avoid greenwashing, which means making environmental claims that are exaggerated, misleading, or not supported by evidence **[83]**, **[84]**. The system should not be promoted as a complete solution that can fully restore marine ecosystems without long-term proof.

Instead, marketing communication should clearly explain what the system can realistically provide. MARIS HABITATS can support habitat creation, provide surfaces and cavities for marine organisms, and collect environmental data to observe how the reef and surrounding conditions change over time. These functions should be communicated honestly to public institutions, companies, research organizations, and environmental partners. Marketing communication should also avoid broad environmental claims and instead explain specific and realistic benefits of the system **[85]**.

If monitoring data is offered as part of a service or subscription model, customers should be informed about what data is collected, how often it is collected, how it is stored, and what limitations the data may have. This is important because environmental data may influence restoration decisions, sustainability reports, or public communication. The data should not be used to make stronger claims than the system can support.

The duty of information transparency also means that customers should understand the difference between the basic reef structure, the optional smart sensor box, and additional monitoring services. Since the system is modular, not every reef block needs to include sensors. This should be clearly explained so that customers can make informed decisions based on their budget, monitoring needs, and project goals.

6.4 Environmental Ethics

The project aims to support marine ecosystems while minimizing negative environmental impacts. Artificial habitats can help provide shelter and settlement surfaces for marine organisms, but they can also create risks if they are poorly designed, placed in unsuitable locations, or made from inappropriate materials. For this reason, site selection, material safety, structural stability, and long-term monitoring must be considered before deployment **[86]**, **[87]**.

Material selection is a key environmental concern. The habitat should be made from durable, non-toxic, and environmentally compatible materials that do not release harmful substances into the marine environment. Since the structure will remain underwater for a long period, the material must also resist degradation caused by seawater exposure and physical forces.

The surface texture and shape of the habitat should also be considered. Studies on ecologically enhanced marine concrete structures show that changes in surface complexity and material composition can influence species richness, live cover, and the balance between local and invasive species **[88]**. Therefore, the design should avoid overly smooth and simple surfaces. Instead, it should provide cavities, roughness, and sheltered areas that can support local marine organisms.

The project also considers the risk of biofouling on sensors. While marine growth on the habitat structure is desirable, growth directly on sensor surfaces may reduce data accuracy. For this reason, the sensor system should include protective design features, such as a separable housing, sensor guards, or maintenance access. Anti-fouling solutions should be chosen carefully to avoid harming marine life.

In addition, MARIS HABITATS can contribute to environmental awareness and education by collecting data related to the surrounding marine conditions. This data can help researchers, public institutions, and local communities better understand how artificial reefs interact with their environment over time. However, the data should be interpreted carefully and should not be used to claim ecological success without long-term observation.

6.5 Liability

Liability relates to the responsibility for possible consequences if the system does not perform as intended. Since MARIS HABITATS includes both a physical habitat and a monitoring system, liability covers structural, environmental, and data-related risks.

One possible risk is structural failure or movement. If the habitat or sensor box is not stable enough, it could be displaced by currents or storms and damage the surrounding seabed or nearby habitats. Artificial reef guidelines emphasize that reef materials should be stable and should remain at the intended deployment site **[89]**. For this reason, the final product must include proper weight, anchoring, and mechanical locking solutions.

Another risk is failure of the smart sensor box. If the box leaks, breaks, or records inaccurate data, the result may not only be a technical failure but also a problem for environmental interpretation. Incorrect temperature, pressure, pH, or water quality data could lead to wrong conclusions about reef performance or local marine conditions. Therefore, regular inspection, calibration when possible, and data validation should be included before the data is used for reports or decision-making.

The modular design helps reduce liability risks. Since the smart sensor box is separable from the habitat structure, electronic components can be removed, inspected, cleaned, repaired, or replaced without removing the whole reef from the seabed. This reduces disturbance to marine life and lowers the risk of leaving failed electronic components in the sea.

Responsibility also includes long-term degradation. Although the structure is designed to remain in the marine environment for a long period, the team must consider what happens if materials wear down, break, or lose performance over time. The system should therefore be designed and documented so that maintenance needs, operational limits, and responsibilities are clear.

Clear documentation and transparent data management are also important parts of liability. The team should define how the system is installed, how often it needs to be inspected, who is responsible for maintenance, and how collected data should be stored and interpreted. For ocean data projects, data management planning is recommended to ensure that collected data is properly stored, preserved, and documented **[90]**.

6.6 Summary

This chapter has examined the ethical and deontological considerations associated with the development of MARIS HABITATS. The main concerns include environmental protection, structural safety, data integrity, transparent communication, and responsibility for long-term maintenance.

Based on this ethical and deontological analysis, the team chose a modular habitat design with a separable smart sensor box. This design allows the habitat structure to remain underwater while the electronic components can be removed for inspection, maintenance, or replacement. This reduces disturbance to the marine environment and lowers the risk of leaving failed electronic parts in the sea.

The team also decided to distinguish clearly between the prototype and the final product. The prototype is intended to validate basic sensing and data logging functions in a controlled environment. The final product would require marine-grade sensors, pressure-resistant housing, anti-fouling measures, and long-term field testing. This distinction is important to avoid misleading claims about the current technical readiness of the system.

From an environmental perspective, the solution prioritizes durable and compatible materials, structural stability, and surface features that support marine organisms. From a data ethics perspective, the system should collect and report environmental data honestly, including its limitations. These decisions help ensure that MARIS Habitats is developed as a responsible marine restoration and monitoring solution rather than only as a physical product.

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7. Project Development

7.1 Introduction

Transitioning from a theoretical model to a functional underwater prototype involves a rigorous process of synthesis and troubleshooting. This chapter documents the technical execution of the project, detailing the mechanical assembly, electronic integration, and software architecture of the MARIS HABITATS system.

It serves as a technical log of the development lifecycle, highlighting how the theoretical foundations established in Chapter 2 were translated into physical components. From the challenges of ensuring watertight integrity for the sensor housing to the optimization of low-power data transmission, this section provides a comprehensive look at the engineering hurdles overcome during the fabrication and programming phases.

7.2 Ideation

The goal of this project is to design artificial marine habitats that can help endangered fish species and corals thrive again. Climate change and the warming of the oceans are disturbing marine ecosystems and damaging the natural balance of life underwater. Because of this, many species are losing safe places to live, hide, feed, and grow. The design is therefore focused on supporting nature itself, especially fish, corals, and other marine organisms.

The structure had to meet several important requirements. It had to be modular, so that different units could be combined and adapted depending on the location and the needs of the ecosystem. It also had to be made from a material that would not harm the marine environment. Since corals need to grow on the structure, the material had to be suitable for marine life and preferably porous. At the same time, the habitat could not be excessively large or heavy, since this would complicate transport and installation. The design therefore had to balance practical deployment with sufficient weight and stability to remain in place and withstand sea currents.

To develop the concept, the team started with brainstorming sessions and research into similar existing projects. Different types of artificial reefs and marine restoration systems were researched, and also which materials could safely be used in the sea were studied. During this ideation phase, the creation of around six to seven different structural concepts was crucial. While the overall shapes of these concepts were quite similar, the main differences were in the materials and possible additional features such as sensors.

Several material options were explored, including basalt fabric-reinforced structures, polymer-clay, bacterial HSC, ECOncrete, recycled glass, and Biorock. Each material had its own advantages and disadvantages. Some were more expensive, while others were less suitable for coral growth or did not provide the level of porosity needed by marine organisms. Since fish and corals benefit from rough and porous surfaces, this became an important factor in the decision-making process.

After comparing the different options, basalt fabric-reinforced concrete was selected as the most suitable material for the project design. This material offered a strong balance between cost, weight, stability, and ecological suitability. It is not overly expensive, heavy enough to remain stable underwater, and easy to shape into modular forms. In addition, its porous surface makes it a good choice for encouraging coral growth and creating shelter for fish. The material can be formed by first making a mould in the desired shape and then placing the basalt fabric or mesh inside it. Depending on the required strength, the fabric can be arranged in one or several layers. Fine concrete or mortar is then poured, sprayed, or pressed around the reinforcement. After curing, the concrete becomes rigid while the basalt fabric remains embedded inside as reinforcement. For these reasons, basalt fabric-reinforced concrete was chosen as the best material for the final concept.

7.3 Concept

The final concept selected for MARIS HABITATS is a modular artificial marine habitat built from one repeated cone-shaped element, as shown in Figure 23. These modules can be connected side by side and stacked vertically, allowing the habitat to be expanded according to site conditions and ecological requirements. By using one repeated part, the system remains simple, scalable, and easy to reproduce, while still allowing a wide variety of structural arrangements.

The concept was selected because it provides a strong balance between ecological function and practical feasibility. Different configurations of the same module can create both smaller and larger shelter spaces, making the habitat suitable for a wide range of marine species. This adaptability is one of the main strengths of the concept, since different deployment sites may require different structural densities and sizes.

Another important aspect of the concept is the material choice. The habitat is intended to be made from basalt fabric-reinforced concrete, which combines structural weight and durability with a rough and porous surface suitable for marine colonisation. This surface can support the attachment and growth of algae, corals, and other marine organisms, while the weight of the material helps the structure remain stable under underwater currents.

Compared to other design directions explored during the project, this concept proved to be the most suitable. Earlier ideas such as spherical, hexagonal, and dome-based structures were less effective because they were either not modular enough or too difficult to manufacture and combine efficiently. For this reason, the cone-based modular concept was defined as the final structural direction of the project.

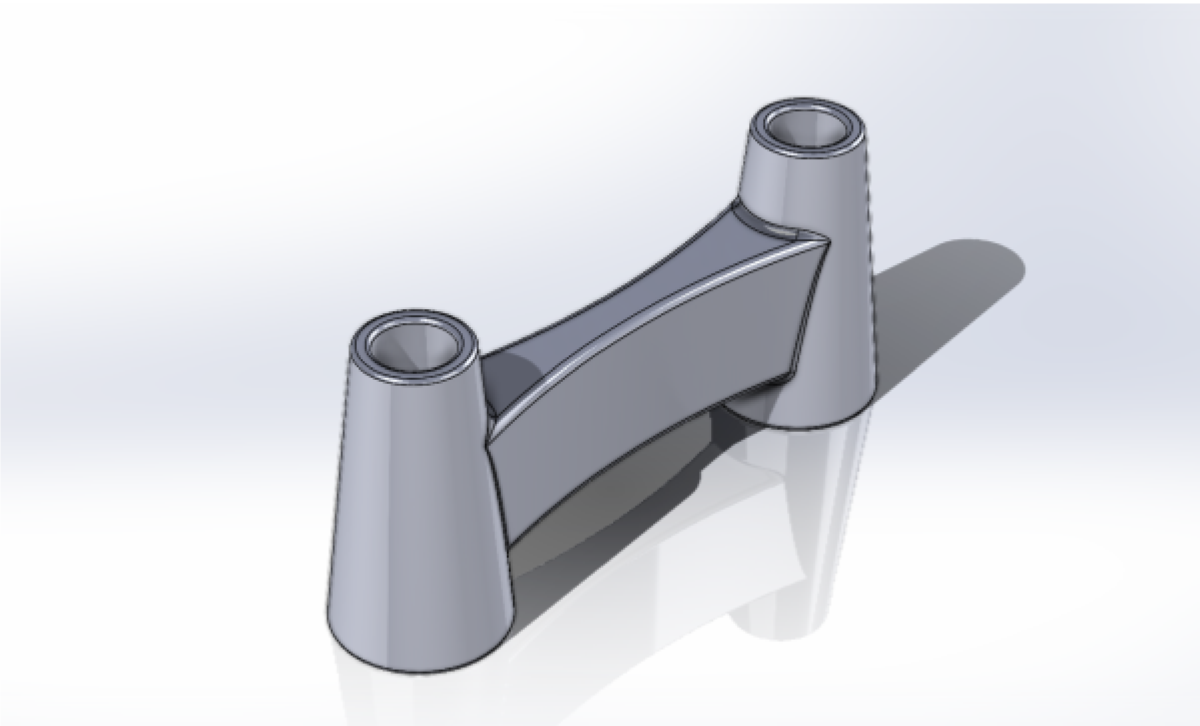


Figure 23: Selected modular unit forming the basis of the final habitat structure.

7.4 Design

7.4.1 Introduction

This section presents how the selected concept was developed into a feasible structural solution for underwater deployment. The design process focused on translating the general concept into a habitat that is modular, manufacturable, stable, and ecologically suitable for marine colonisation. The following subsections explain the main design decisions and the structural directions explored during the development process.

7.4.2 Design

The design phase focused on transforming the selected concept into a structure that could function in an underwater environment while remaining feasible to produce and deploy. From the beginning, the most important design requirement was modularity. The habitat had to be based on one repeatable element that could be combined in multiple ways without becoming too complex to manufacture or assemble. This requirement guided the entire design process and strongly influenced the selection of the final form.

Several structural directions were explored during this phase, including spherical, hexagonal, and dome-like concepts. Although these ideas offered interesting spatial qualities, they were gradually rejected because they did not satisfy the design goals strongly enough. Some concepts were too difficult to produce in a simple and repeatable way, while others did not provide the level of modularity needed to expand the habitat efficiently. In contrast, the cone-based element provided a clearer and more practical solution. Because the same unit can be repeated throughout the structure, the habitat can grow both horizontally and vertically while maintaining a simple and consistent construction logic.

The chosen design also supports ecological performance. By connecting and stacking the modules in different arrangements, the habitat can generate openings and sheltered spaces of different sizes. This is important because smaller and larger marine organisms require different types of refuge. The repeated units also create a more complex three-dimensional environment, which improves habitat quality and increases the suitability of the structure for fish, algae, corals, and other marine species.

Material selection was another important part of the design phase. The final design is based on basalt fabric-reinforced concrete, chosen for its combination of strength, weight, and ecological suitability. The material is heavy enough to improve stability under underwater currents, while its rough and porous surface can encourage biological growth over time. In this way, the design responds not only to structural and manufacturing requirements, but also to the biological purpose of the habitat.

Overall, the design phase transformed the initial concept into a clear and buildable solution. Instead of developing a complex habitat composed of many different parts, the design process focused on a single repeated module capable of generating a wide range of spatial configurations. This decision improved the scalability, manufacturability, and ecological potential of the habitat, and formed the basis for the structural development presented in the following subsection.

7.4.3 Structure

The structural development of the habitat began with a series of exploratory concepts. These early ideas were useful for identifying the design characteristics that were most important for the project, such as modularity, ease of production, structural repetition, and the creation of different shelter sizes. The figures below illustrate the main structural directions considered during this process. Figure 24 shows an initial idea.

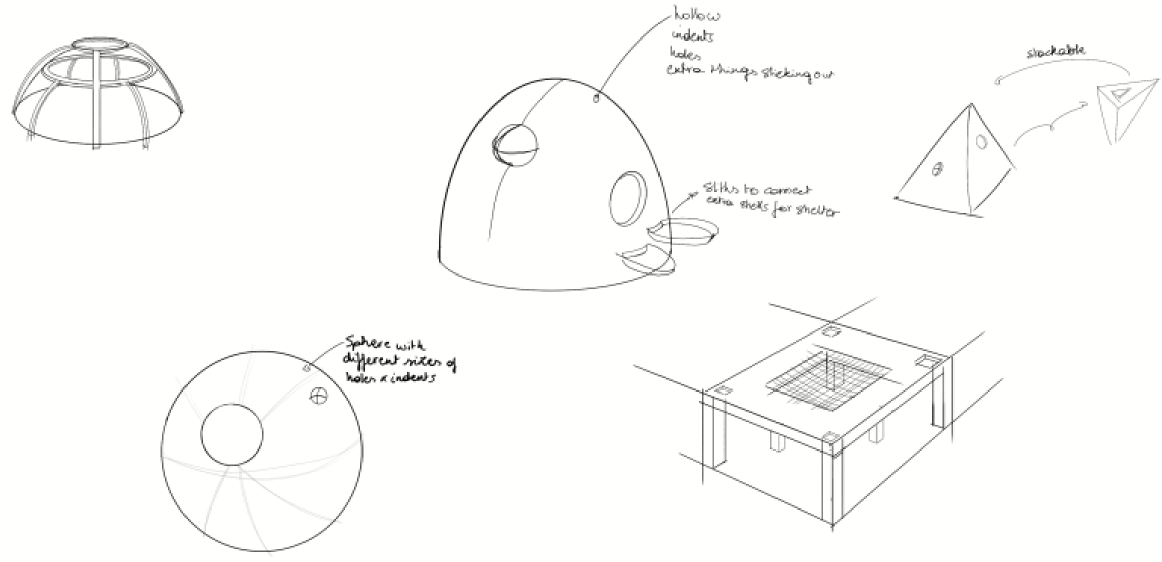


Figure 24: Early structural concept exploring enclosed shelter geometry.

One of the first directions explored was a more enclosed structure, shown in the early sketch above. This concept helped define the importance of shelter, internal space, and protection for marine species. However, although it offered enclosed refuge areas, it was not considered the most suitable direction because it did not provide the same level of modular flexibility as later concepts. As the design process continued, greater importance was given to repeatability and scalability.

Figure 25 illustrates the proposed habitat modular design.

Figure 25: Hexagonal modular concept explored during the structural development (AI generated render).

A second concept was based on a hexagonal module supported by pillars. This idea introduced a stronger modular logic and allowed several units to be connected into a larger structure. The concept was relevant because it explored how repeated modules could create a more adaptable habitat system. It also supported the study of elevated structures and the possibility of generating openings of different sizes. However, this direction was not selected as the final solution because the cone-based concept provided a simpler repeated form and clearer scalability (see Figure 26).

Figure 26: Structural variation exploring different opening sizes and configurations.

Further structural exploration focused on varying the dimensions and arrangement of the elements in order to create openings suitable for different marine species. This stage was important because it highlighted the ecological value of structural diversity. By studying how repeated parts could generate different internal spaces, the development process produced a clearer understanding of how geometry could influence habitat quality. These studies confirmed that the final design should allow variation in shelter size while still remaining based on one simple repeated part (See Figure 23 and Figure 27).

Figure 27: Selected modular unit forming the basis of the final habitat structure (AI generated).

After comparing the different structural directions, a concept based on one repeated cone-shaped module was selected. This solution was considered the most appropriate because it combines modularity, manufacturability, and ecological functionality. The same unit can be repeated many times, allowing the structure to expand horizontally and vertically while maintaining a simple construction logic. As illustrated in Figure 28, the arrangement of these modules creates a more complex habitat geometry with multiple shelter opportunities for marine organisms.

Figure 28: Example of the habitat formed by combining multiple modular elements (right picture is AI generated).

When several modules are combined, the habitat can cover a larger area of the seabed and create a more complex three-dimensional structure. This makes the system adaptable to different sites and allows the scale of the habitat to be adjusted according to the intended application. For this reason, the final structure is not defined by a single fixed form, but by a repeatable modular logic that can be expanded according to ecological and practical needs.

After defining the final modular structure, a suitable method still had to be developed for inserting the smart box. The development process of this solution is explained below.

Design Process of Sensor Structure

This was the first version of the smart block, in which the smart box was attached to the bottom of the modular structure. However, this solution was not aesthetically pleasing, so a new approach was explored in which the smart box could be integrated into the modular structure itself. It was also important to avoid changing the structure too much, since that would require separate moulds for these specific blocks, even though they would be produced in much smaller quantities than the standard blocks.

The first design iteration is shown in Figure 29, with a detailed view provided in Figure 30.

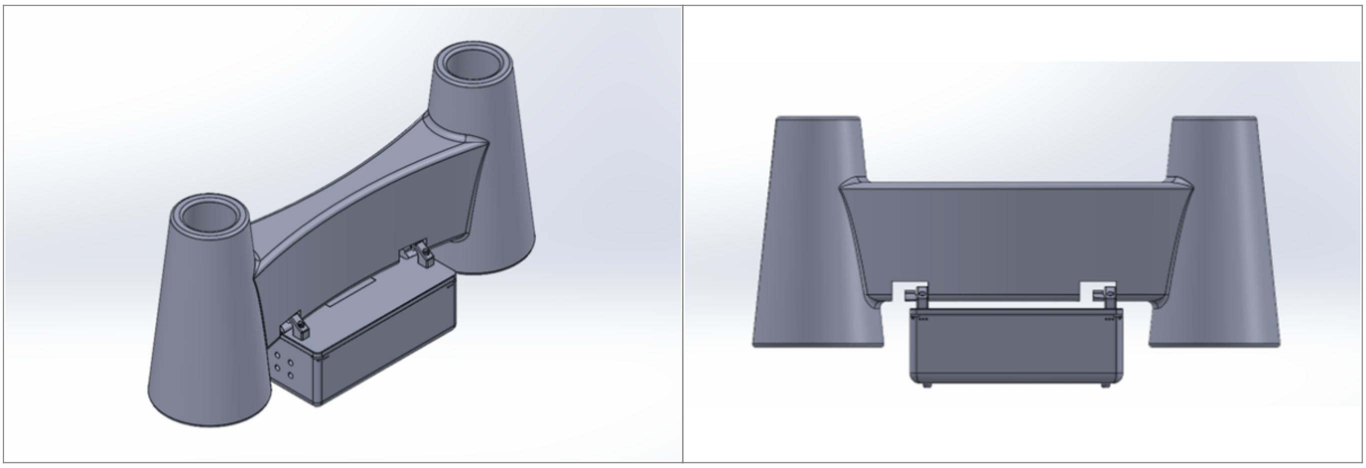


Figure 29: First variation of the smartblock

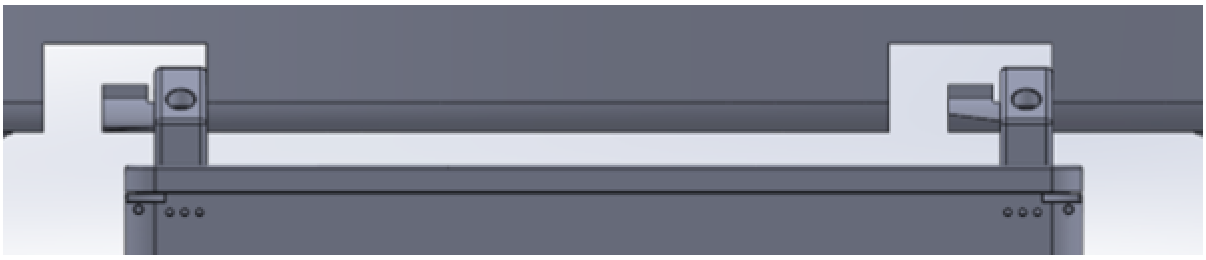


Figure 30: First variation of the smartblock (closeup)

In the second variation of the smart block, the smart box was much more integrated into the structure. However, this version required many modifications to the standard block. Additional openings also had to be added to ensure that the sensors had sufficient exposure to the surrounding water. This made the solution inefficient and impractical. As a result, another approach was explored, with a stronger focus on modularity so that a completely new mould would not be required.

Consequently, an alternative solution was explored, with a stronger emphasis on modularity to avoid the need for a completely new mould. The second variation of the design is illustrated in Figure 31, while a front view highlighting the structural modifications is shown in Figure 32.

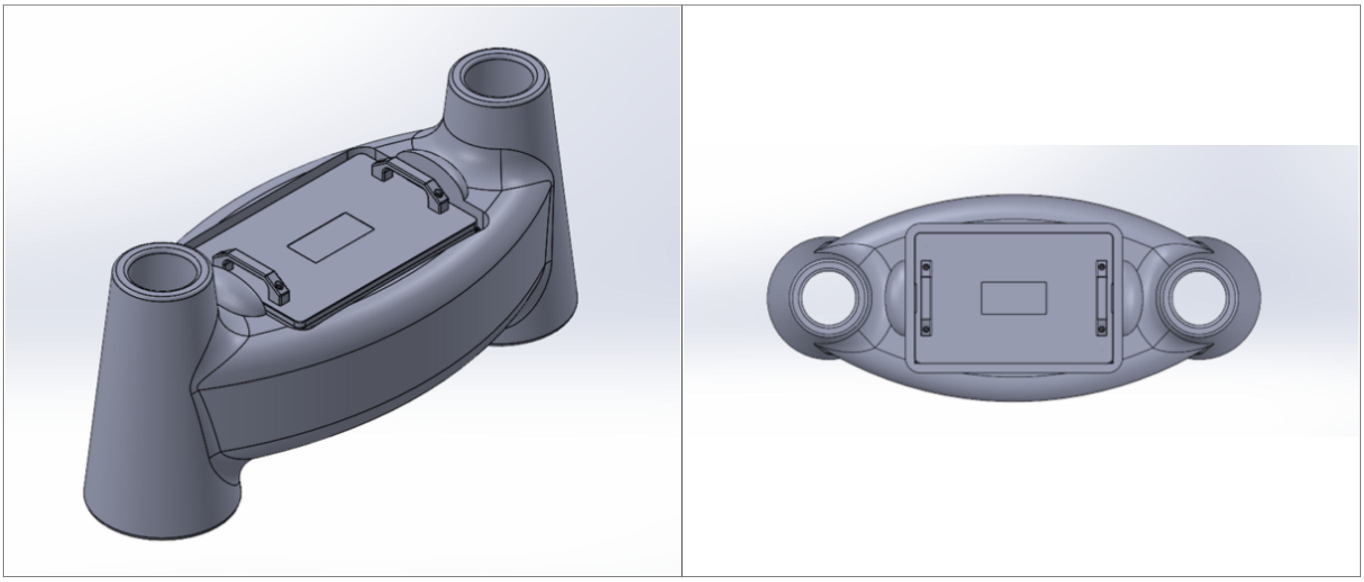


Figure 31: Second variation of the smartblock.

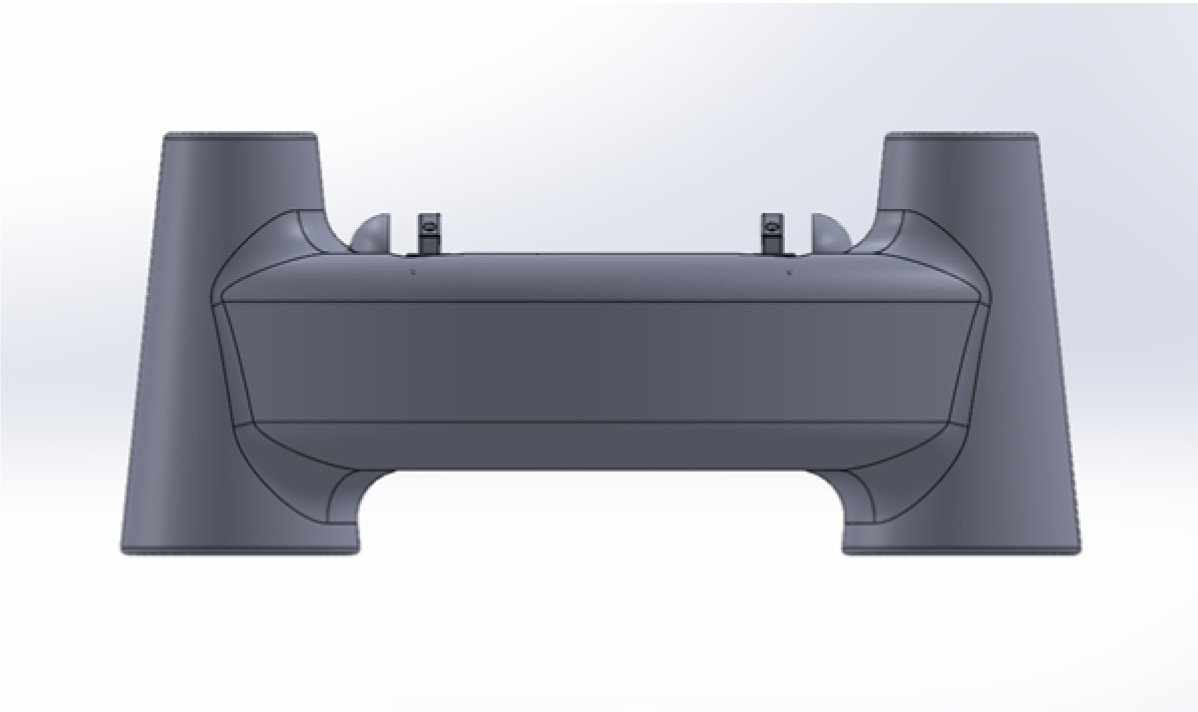


Figure 32: Second variation of the smartblock front.

This led to the development of a modular sensor solution. The supporting structure is constructed from titanium alloy TC 4 and can be installed in any reef block as required. Its design allows for easy placement and removal, thereby simplifying maintenance and component replacement. The sensor housing is positioned on two supporting tubes and secured with a chain attached to the host block, ensuring stability during operation. (see Figure 33 and Figure 34).

To facilitate maintenance, a distinct block design is used for the sensor unit. Over time, biological growth such as algae is expected to accumulate on the reef structures, reducing visibility and making it difficult to distinguish individual components. By incorporating a visually and structurally identifiable block, the sensor unit can be reliably located and accessed, even after prolonged submersion.

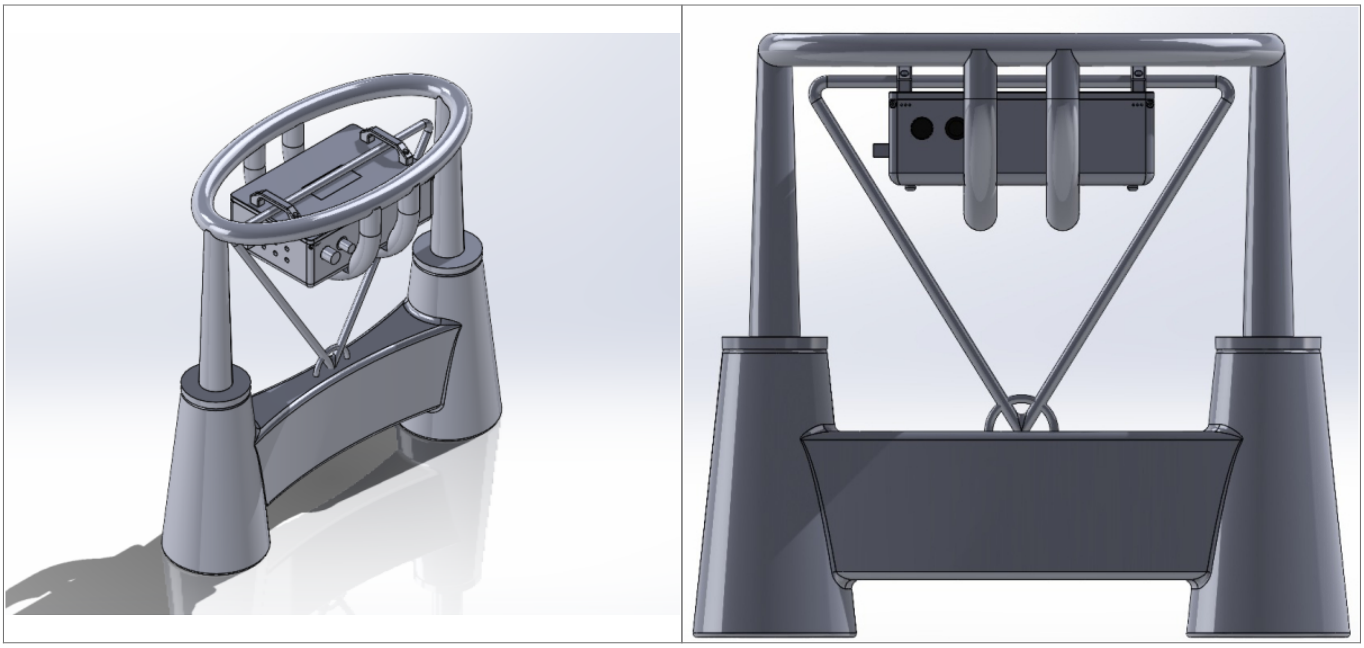


Figure 33: Final variation of the smartblock assembly.

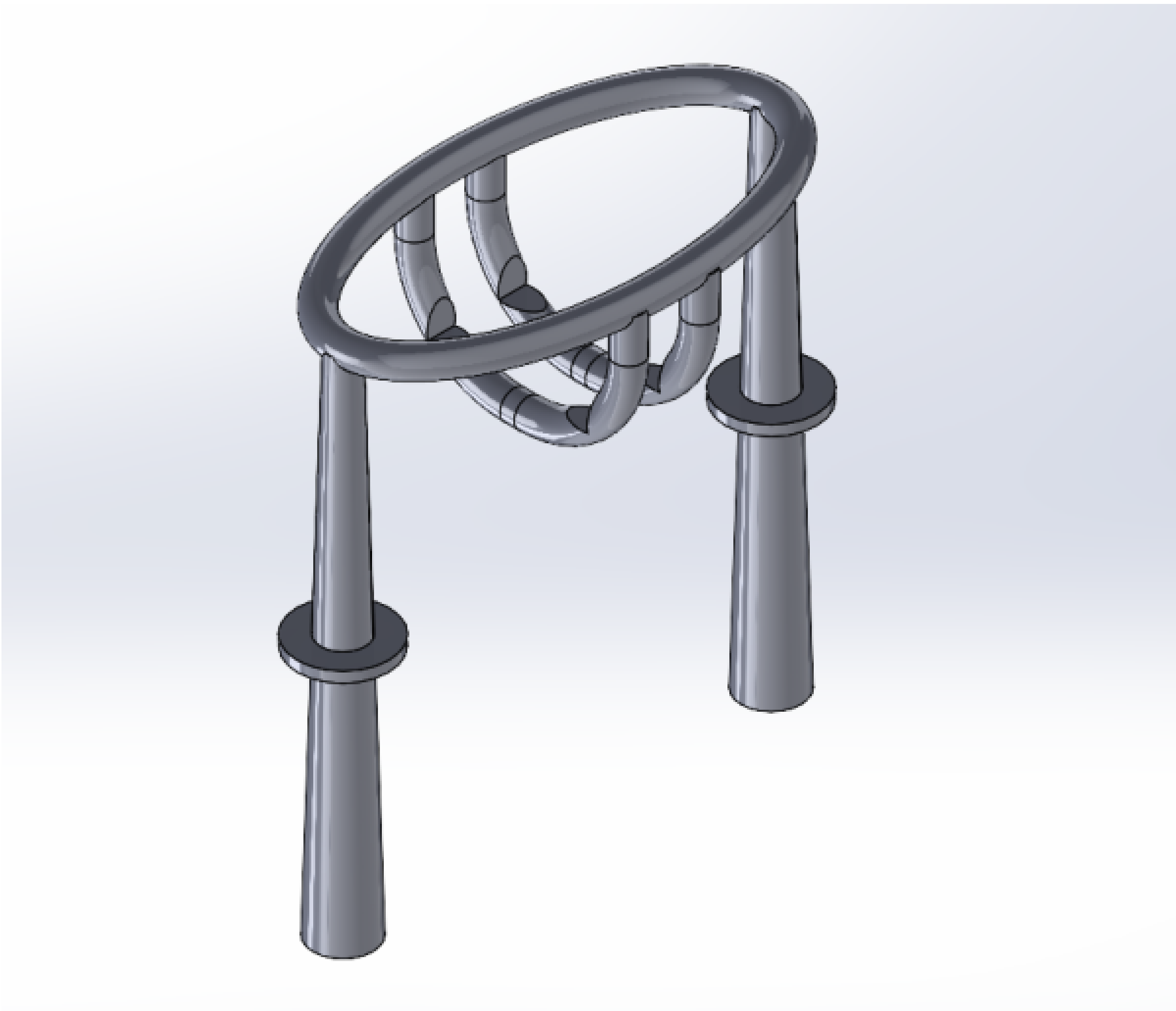


Figure 34: Final variation of the smartblock.

7.5 Smart System

7.5.1 Hardware

7.5.1.1 Black Box Diagram

Throughout this project, various approaches to data collection were explored. Initially, Version 1 was developed, while this version enabled continuous data communication, it proved to be highly complex and more prone to potential failures. Based on these findings, Version 2 was selected as the preferred because it prioritises robustness, reduced complexity, and ease of deployment, while accepting compromises regarding limited operational duration and the lack of continuous data communication.

Version 1 (V1) Buoy-Connected System

Figure 35 and 36 presents the smart system black box diagram. The system corresponds to a living laboratory where the:

- Sun (top left corner) is the source of energy. A buoy equipped with solar panels on top will store power in a battery and provide power to the system.
- Sea water (bottom left corner) is the growth medium. Four sensors will monitor the water environmental conditions (diamond).
- Fish and sea life (bottom right corner) are under observation. Fish and algae will be monitored (presence and size) to determine biodiversity and measure photosynthetic effects and chlorophyll on surfaces.

All this data will be reunited and sent to the On Board Computer (OBC) while also getting a timestamp by a Real Time Clock (RTC). All this will be powered by the battery through a Power Management System (PMS) that received the power from the buoy.

Both the buoy and the structure will have a positioning module, that will count with an Inertial Measuring Unit (IMU), a Doppler velocity Log (DVL) and a Global Navigation Satellite System (GNSS) receiver, to have everything registered about the position of both elements and make sure nothing goes wrong due to external factors such as storms, currents or human factors.

From the structure to the buoy, there will be a chain and a cable, for both structural support and data and power connection between the 2 elements. Finally, all the data collected will be sent to a data center, this will be done via the standard Iridium Satellite Network.

The main output will be a report with all the obtained data.

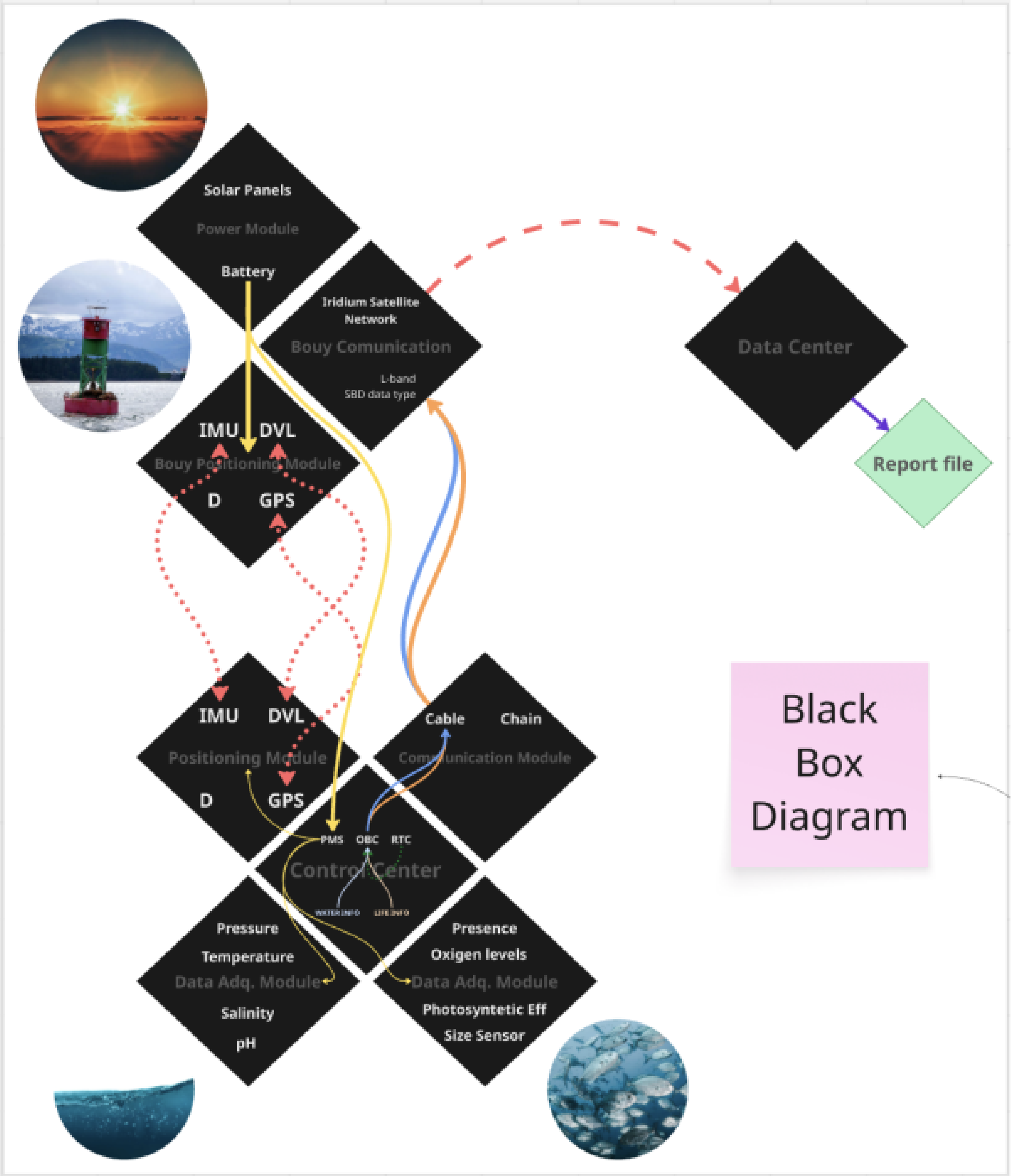


Figure 35: Black Box Diagram V1

Version 1.5 (V1.5) Buoy-Connected System 1.5

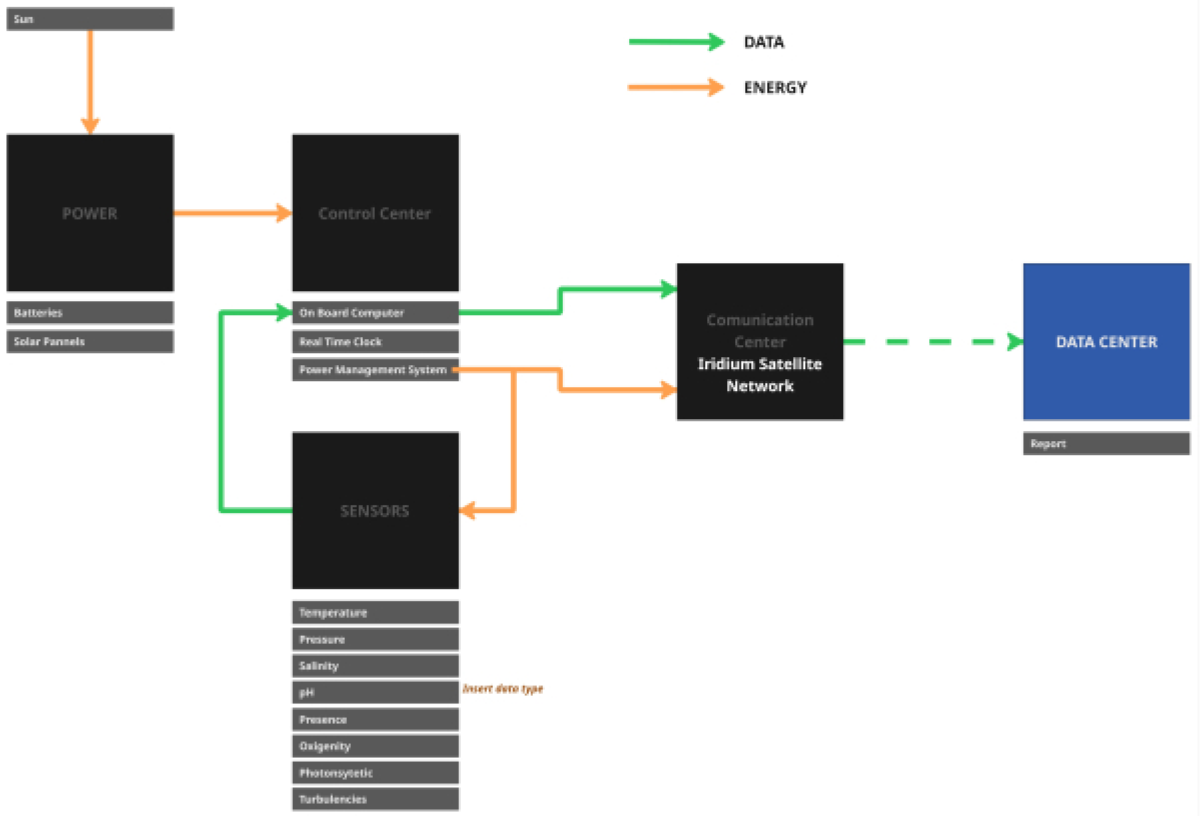


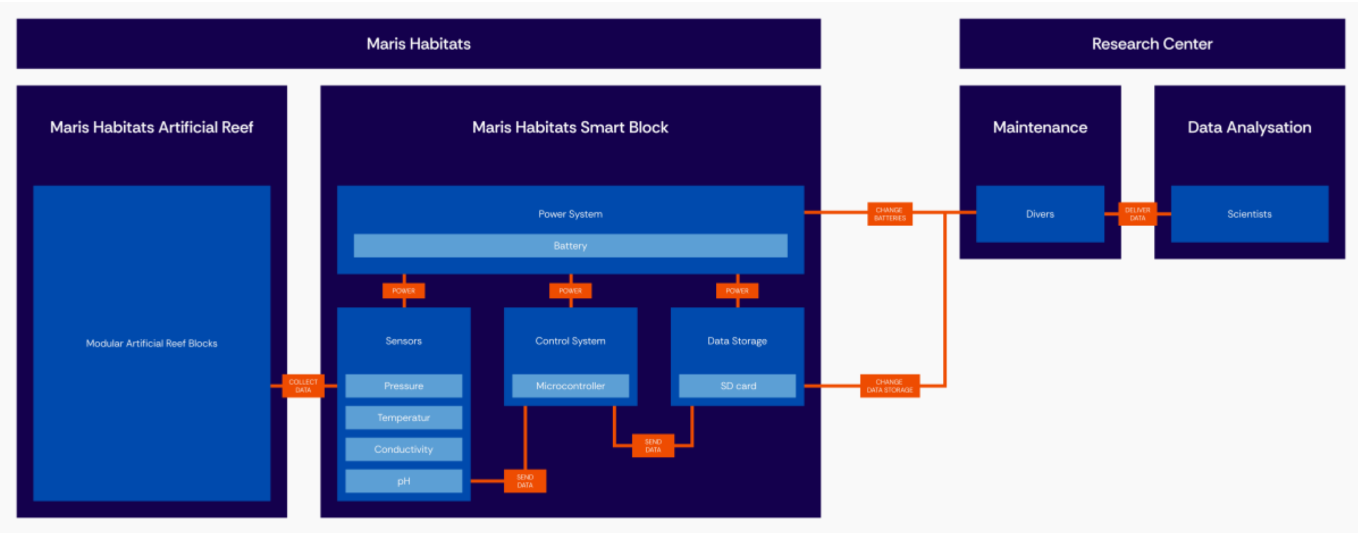
Figure 36: Black Box Diagram V1.5

Version 2 (V2) Smart Block System

Figure 37 illustrates a simplified, self-contained underwater monitoring system integrated into our modular artificial reef structure.

In this configuration, the system is based on a “Smart Block” that houses all electronic components, including the power supply, sensors, and data storage, eliminating the need for external infrastructure such as surface buoys, solar panels, or cable connections.

The entire system is powered by a lithium-ion battery. Environmental data is collected via sensors that measure pressure (depth), temperature, pH, and conductivity. All collected data is stored locally on a Secure Digital memory card (SD card); real-time transmission is not possible. Battery replacement and data retrieval are carried out through a scheduled maintenance procedure involving a diver. The estimated battery lifetime of the system is approximately 340 days, which limits the frequency of required maintenance operations to roughly once per 11 months. When battery replacement is necessary, a diver descends to the installation site and retrieves the Smartbox from the seabed. The enclosure must be brought to the surface in order to be opened safely. Battery replacement is performed aboard a boat, where the SD card is also replaced simultaneously to ensure secure and continuous data storage. After completion of the maintenance procedure, the Smartbox is redeployed and repositioned at its original location on the seabed. This integrated maintenance strategy allows both power supply and data storage components to be serviced during a single operation. After retrieval, the data is transferred to a research facility for analysis and evaluation, ultimately contributing to environmental monitoring and reporting.



Box Diagram V2

7.5.1.2 Electronics

Microcontroller & Battery

An Arduino Uno R4 Minima was selected as the microcontroller for the system. This version is simpler than the normal Arduino Uno R4 and does not include built-in Wi-Fi or Bluetooth however, wireless communication is unnecessary for this application, as radio-frequency signals are ineffective underwater.

The system is powered by a 12 V 20 Ah $LiFePO_4$ battery. To prevent excessive battery degradation and to extend its service life, the battery is not discharged fully. A minimum state of charge of 20 % is enforced, meaning that only 80 % of the nominal battery capacity is used. The battery's nominal voltage is 12,8 V. The total power consumption of the system during active operation is 1,505 W.

To minimize energy usage, measurements are performed once per hour. The system is designed to remain active for only 1 minute per hour, which is sufficient for sensor stabilization and for writing the collected data to the SD card.

Battery capacity: 12,8 V × 20 Ah × 0,8 = 204,8 Wh

Daily energy consumption (1 min/hour operation): 1,505 W/60 × 24 h = 0,602 Wh/day

Number of days: 204,8 Wh / 0,602 Wh/day = 340,199 days

Based on these calculations the system can operate for approximately 340 days on a single battery charge.

Sensors

Selecting sensors was quite challenging, as most sensors such as pH and conductivity probes are designed for temporary measurements and not for long term submersion. Additionally, the sensors must withstand the high pressure at the seabed, and many are not suitable for seawater. This resulted in expensive sensors, mainly sourced from suppliers in the United States.

The BarXT sensor **[91]** measures both pressure and temperature. From the pressure data, the depth can be calculated. An Inter-Integrated Circuit (I^2C) level converter is required to convert the 3,3 V logic signal to 5 V so it can be read by the Arduino.

The pH sensor **[92]** is sourced from Atlas Scientific. It is used together with a pH module **[93]**, which converts the signal into an analog signal that can be directly read by the Arduino's analog inputs.

For the conductivity sensor, no similar ready-made solution was available. It outputs a current signal of 4 mA–20 mA, which must be converted into a voltage of 0 V–5 V to be read by the Arduino. This is done using a 250 Ω resistor, according to Ohm's law (U=I×R).

$0.004\ \text{A} \times 250\ \Omega = 1\ \text{V}$

$0.020\ \text{A} \times 250\ \Omega = 5\ \text{V}$

Enclosure

The enclosure is one of the most critical and costly components of the system, as it must withstand high external pressure at the seabed. Suitable enclosures are therefore difficult to source.

Condensation is expected to form inside the enclosure as the air trapped inside is cooled by the surrounding seawater. This temperature difference can lead to moisture accumulation, increasing the risk of corrosion and electrical failures. To mitigate this risk, silica gel desiccant packets are placed inside the enclosure to absorb excess moisture.

The sensors from Atlas Scientific use ¾" NPT threads, while the enclosure is designed with M10 threads. This requires sealing the existing holes and machining new threaded openings in the enclosure.

However, the sensor from Blue Robotics is equipped with M10 threads, allowing direct installation into the enclosure without modification.

Table 22 presents a comprehensive overview of all sensors and components included in the system. The electrical schematics are shown in Figure 38.

Table 22: Sensor and Electronic Components

Item	Type	Power supply (V)	Operating current (A)	Output	Price	Quantity	Supplier	Link	Comment
BarXT	Depth / Pressure / Temp	2.5 - 5-5	0.0015		329.19 €	1	Bluerobotics	https://bluerobotics.com/store/sensors-cameras/sensors/barxt-extended-submersion-depth-pressure-sensors/	
I2C Level Converter	Level converter board	5			25.65 €	1	Bluerobotics	https://bluerobotics.com/store/comm-control-power/tether-interface/level-converter-r1/	
Surveyor™ Analog pH Sensor / Meter	Ph module	3.3 - 5.5	0.003		21.52 €	1	Atlas Scientific	https://atlas-scientific.com/embedded-solutions/surveryor-analog-ph-sensor-meter/	
Industrial pH Probe – No Temp	Ph test probe	3.3 - 5.5			531.45 €	1	Atlas Scientific	https://atlas-scientific.com/probes/industrial-gen3-ph-probe-nt/	
Industrial Conductivity Kit K 1.0	Conductivity	9.0 - 36.0	0.045		595.05 €	1	Atlas Scientific	https://atlas-scientific.com/kits/industrial-conductivity-kit-k-1-0/	includes calibration certificate
Adafruit 254	SD - module	3.3 - 6	0.1		6.45 €	1	Mouser	https://pt.mouser.com/ProductDetail/Adafruit/254?qs=GURawfaeGuAkwqCF4BmPzA%3D%3D	
Arduino ABX00080	Microcontroller	6 to 24	0.038	5V / 3.3V	16.69 €	1	Mouser	https://pt.mouser.com/ProductDetail/Arduino/ABX00080?qs=sGAEpiMZZMuqBwn8WqcFUipNgoezRlc4hyxN6ztJHTQeBAZUij8gNg%3D%3D	
FDMM004GMC-XE00	MicroSD - card				21.88 €	1	Farnell	https://pt.farnell.com/en-PT/flexxon/fdmm004gmc-xe00/microsd-card-4gb-mlc-cmrcl-grd/dp/4378808	
MC3090082	Silica gel (moisture absorber)				42.26 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mc3090082/silica-gel-25g-65-x-95mm-pk100/dp/2424372	Pack of 100
LiFePO4 battery	LiFePO4 battery			20Ah 12V	76.24 €	1	Innpo	https://innpo.pt/baterias-recarregaveis-de-litio/bateria-lifepo4-12v-20ah-innpo-baterias-recarregaveis-de-litio.html	
Watertight Box 5L	Underwater electrical box				805.66 €	1	Bluerobotics	https://bluerobotics.com/store/watertight-enclosures/watertight-boxes/watertight-box-component/?attribute_internal-size=134mm+x+100mm+x+74mm+%281+liter%29%2C+300m+depth	
WetLink Penetrator Blank	Penetrator blank (M10)				70.50 €	15	Bluerobotics	https://bluerobotics.com/store/cables-connectors/wlp-blank/?attribute_size=M10+Thread	4.70€ * 11
MCMF0W4BB2500A50	250 ohm resistance				0.55 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mcmf0w4bb2500a50/res-250r-0-10-250mw-axial/dp/2396012	
Adafruit 2670	Perfboard / Breadboard				4.26 €	1	Mouser	https://pt.mouser.com/ProductDetail/Adafruit/2670?qs=XAKIUOoRPe7ATe8H6FaFPg%3D%3D	Pack of 10
M316 SOA2CSS50-	M3 screws for perfboard				5.55 €	1	Farnell	https://pt.farnell.com/en-PT/tr-fastenings/m316-soa2css50/screw-socket-cap-s-s-a2-m3x16/dp/1419946	Pack of 50
Total			**0.1875 A**		**2552.90 €**				

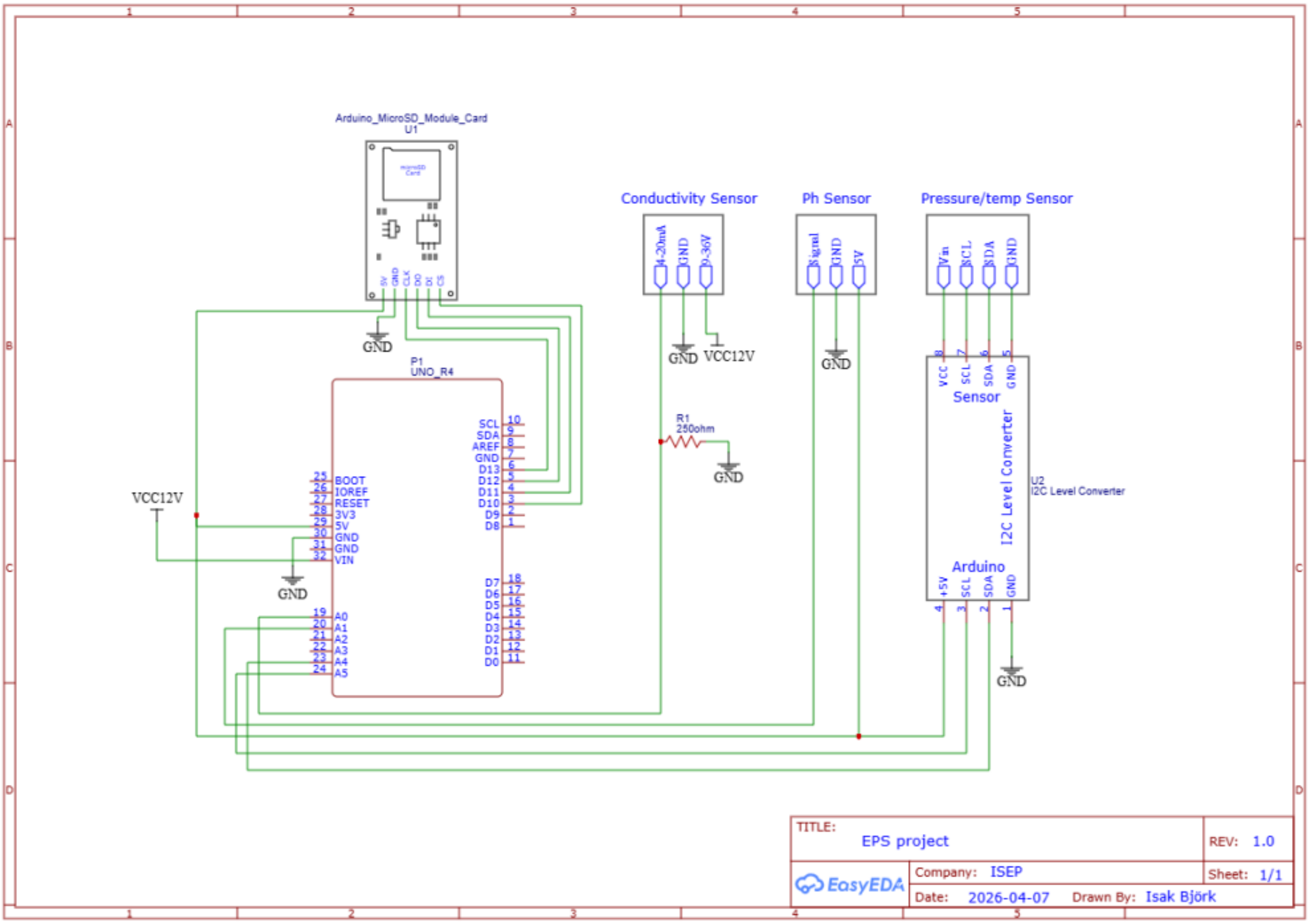


Figure 38: Electrical schematic overview

The use of an imaging system was initially considered to monitor fish growth. However, this approach has been deprioritized, as the primary focus of the project has shifted toward the analysis of quantitative sensor data.

Sensor-based measurements provide continuous, objective, and scalable insights into environmental conditions, which are more closely aligned with the project’s core objectives.

The inclusion of a camera system is therefore limited to supporting species identification, specifically to document the presence of fish within the reef environment. In addition, visual documentation of the reef structure will be conducted during annual maintenance operations, during which images of the installation will be captured once per year.

In Figure 39 you can see what the enclosure will look like with all the electronics inside. The picture on the left is with the sensors included. The picture on the right is without the sensors to show how much space the rest of the electronics will use.

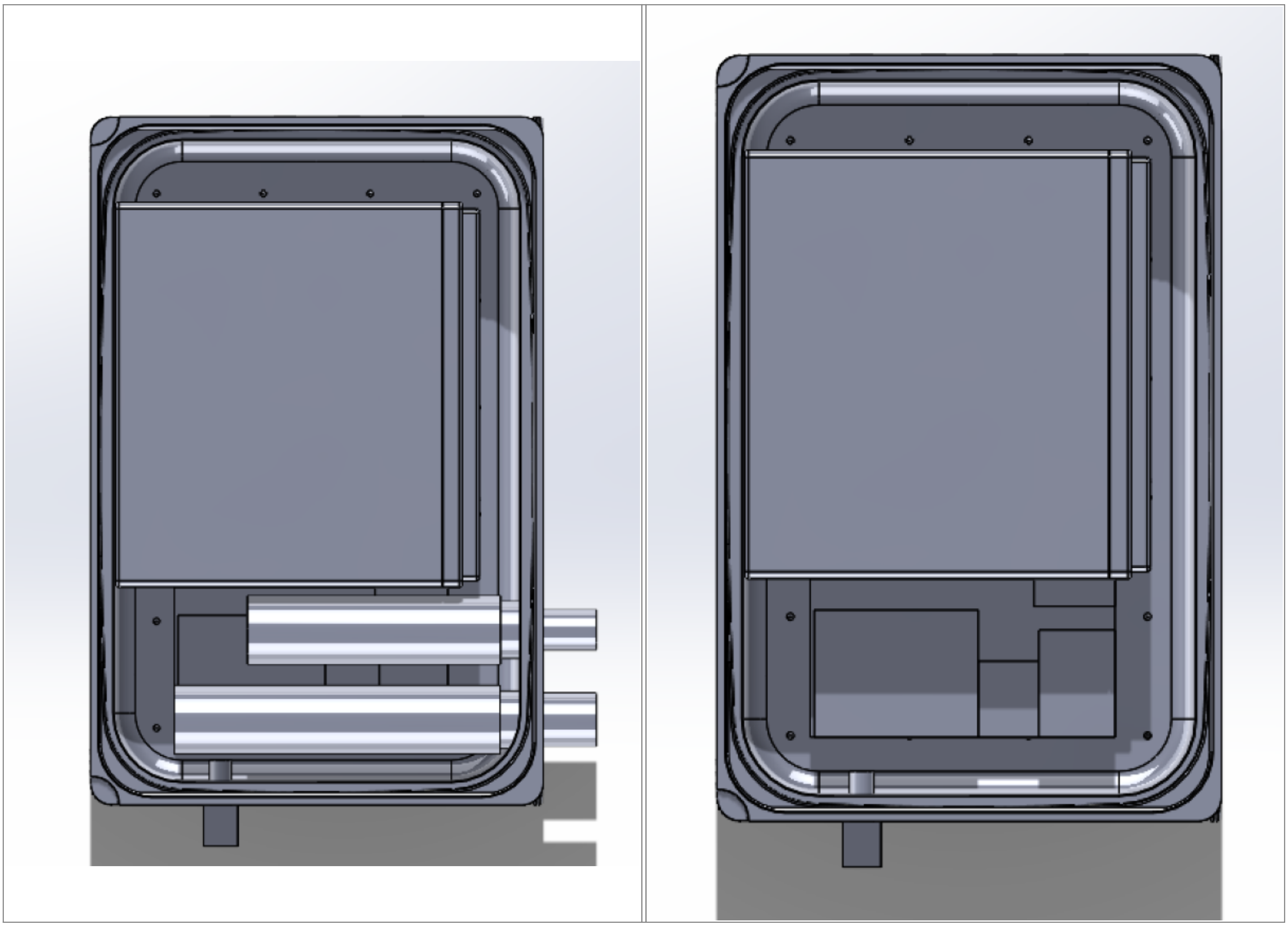


Figure 39: Inside of the enclosure with and without sensors.

7.5.2 Software

Describe in detail the: (*i*) use cases or user stories for the smart device and app; (*ii*) selection of development platforms and software components (use tables to compare the different options); (*iii*) component diagram.

7.5.3 Packaging

Present and explain the: (*i*) initial packaging drafts; (*i*i) detailed drawings; (*iii*) 3D model with load and stress analysis, if applicable.

7.6 Prototype

The prototype is designed to measure similar parameters to a CTD system, but instead of using a conductivity sensor to estimate salinity, it uses a TDS sensor. This is a significantly cheaper alternative and is sufficient for early-stage testing, where the main goal is to validate the system concept rather than achieve final measurement accuracy. The pH sensor is also excluded from the prototype in order to reduce cost, since it is not essential for testing the basic functionality of the system. Apart from the sensor selection and reduced measurement precision, the prototype follows the same general system design as the final product. For the enclosure, a simple airtight plastic container (e.g. from IKEA) is used as a temporary solution. This significantly reduces costs compared to waterproof enclosures and is sufficient for controlled testing environments. To ensure watertight cable penetrations in the prototype, a silicone-based sealant will be used. The same sealant may also be applied around the enclosure lid if leakage is detected during testing.

7.6.1 Structure

Compared to the final designed solution, several modifications are made for the prototype. The structural block is downscaled to 1:6, resulting in a model size of about 10 cm. This allows the structural concept to be tested in a smaller and more practical format. In addition, alternative materials are considered for the prototype structure. The block may either be produced using 3D printing or cast in standard concrete, rather than using the final material and full-scale production method.

The Smart Box is also simplified compared to the final design. Instead of using a dedicated underwater enclosure, a waterproof plastic box is used as the prototype housing. Holes are drilled in the enclosure for the water-measuring sensors, which are installed through the openings and sealed with adhesive to prevent leakage.

The enclosure will initially be tested without oil to determine whether it can withstand underwater pressure while protecting the internal electronic components. If the enclosure is not sufficiently pressure-resistant, it will be filled with oil as a pressure-compensation solution. This reduces the pressure difference between the inside and outside of the box while protecting the battery, sensors, and electronic components from direct contact with water.

These changes are made to simplify prototype construction and enable early testing of the system concept before developing the final full-scale solution.

7.6.2 Hardware

The prototype is designed to measure parameters similar to those measured by a CTD system, Conductivity, Temperature, and Depth. However, instead of using a conductivity sensor to calculate salinity, the prototype uses a TDS, Total Dissolved Solids, sensor.

Conductivity measures water’s ability to carry an electrical current. This ability is directly related to the concentration of dissolved ions, such as salts, minerals, and other inorganic materials. TDS, on the other hand, represents the total amount of dissolved substances in the water, including inorganic salts such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates, as well as small amounts of organic matter. TDS is typically measured in mg/L or ppm and is commonly used as an indicator of water quality.

Using a TDS sensor provides a significantly cheaper alternative to a conductivity sensor. For early-stage testing, this is sufficient because the main goal is to validate the overall system concept rather than achieve final measurement accuracy.

The selected sensors used in the prototype are presented in Table 23.

The pH sensor is also excluded from the prototype in order to reduce cost, since it is not essential for testing the basic functionality of the system. Apart from the sensor selection and reduced measurement precision, the prototype follows the same general system design as the final product.

The other electronic components used in the prototype are listed in Table 24.

For prototype testing, a low-cost solution is used both for the enclosure and structural elements. A simple plastic lunchbox can serve as a temporary enclosure, where holes can be drilled for sensor placement, making it suitable for controlled testing before investing in the final underwater housing. In addition, standard cement is used for structural testing, as it provides sufficient strength at a very low cost. These materials are summarized in Table 10.

PLA filament can be used either as an alternative material for the blocks. It can be used to create moulds for casting concrete blocks, or as the structure for the prototype instead of concrete. This allows for greater flexibility and repeatability during the design and testing phase. However, PLA is not suitable for long-term structural use in harsh environments, and is therefore primarily intended for prototyping and tooling purposes.

For the enclosure, a simple airtight plastic container (e.g. from IKEA) is used as a temporary solution. This significantly reduces costs compared to waterproof enclosures and is sufficient for controlled testing environments. To ensure watertight cable penetrations in the prototype, a silicone-based sealant will be used. The same sealant may also be applied around the enclosure lid if leakage is detected during testing.

If the external hydrostatic pressure exceeds the enclosure's mechanical limits at greater test depths, an oil-filled enclosure may be used as a pressure-compensation solution. Transformer oil would be the preferred choice due to its superior electrical insulation properties, however, it is difficult to obtain for small-scale prototyping. Therefore, cooking oil is considered as a low-cost and readily available alternative. Although it doesnt provide the same electrical insulation, it is expected to be sufficient for this low-voltage prototype and suitable for short-term experimental testing.

The electrical schematics for the prototype is presented in 40.

Table 23: Table of prototype sensors

Sensor	**Type**	**Power supply**	**Operating current (A)**	**Measurement**	**Price**	**Quantity**	**Supplier**	**Link**	**Comment**
DS18B20	Temperature	3V – 5.5V	0.0015	-55°C to +125°C	6.22 €	1	RS	https://pt.rs-online.com/web/p/kits-de-desarrollo-de-sensores/2049893?gb=a	Requires 4.7 kΩ resistor
SEN0244	TDS (Total dissolved solids)	3.3V – 5.5V	0.006	0–1000 ppm	10.18 €	1	Farnell	https://pt.farnell.com/en-PT/dfrobot/sen0244/analogue-tds-sensor-meter-kit/dp/3517934	
SEN0257	Pressure	5V	0.0028	0–16 bar	15.09 €	1	Farnell	https://pt.farnell.com/en-PT/dfrobot/sen0257/analog-water-press-sensor-arduino/dp/4308257	Not suitable for open seawater
Total			**0.0103**		**31.49 €**				

Table 24: Table of electrical components

Product	**Type**	**Power supply**	**Operating current (A)**	**Output**	**Price**	**Quantity**	**Supplier**	**Link**	**Comment**
Adafruit 254	SD - module	3.3–6 V	0.1		11.60 €	1	RS	https://pt.rs-online.com/web/p/accesorios-para-kits-de-desarrollo/2881813	
Arduino ABX00080	Microcontroller	6–24 V	0.038	5 V	17.44 €	1	Farnell	https://pt.farnell.com/en-PT/arduino/abx00080/development-board-32bit-arm-cortex/dp/4208543	
FDMM004GMC-XE00	MicroSD card				21.88 €	1	Farnell	https://pt.farnell.com/en-PT/flexxon/fdmm004gmc-xe00/microsd-card-4gb-mlc-cmrcl-grd/dp/4378808	
4022211111	9V alkaline battery			9 V 0.64 Ah	5.47 €	1	Farnell	https://pt.farnell.com/en-PT/varta/4022211111/battery-alkaline-9v-pp3-1pk/dp/4584139	
MP007080	Battery holder				3.41 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mp007080/battery-holder-snap-on-8-wire/dp/3652120	Pack of 5
MCKNP03UJ0251B00	250 ohm resistance				0.56 €	1	Farnell	https://pt.farnell.com/en-PT/multicomp-pro/mcknp03uj0251b00/res-250r-5-3w-axial-wirewound/dp/1903835	
FIT0096	Breadboard				2.50 €	1	Farnell	https://pt.farnell.com/en-PT/dfrobot/fit0096/solderless-breadboard-3-2-x2-4/dp/3879683	
Total			**0.138**		**62.86 €**				

Table 25: Table of low-cost prototype materials (Portugal)

Product	Type	Price (incl. VAT)	Quantity	Supplier	Link	Comment
Cement (CEM II 25kg)	Concrete material	5.39 €	1	Leroy Merlin	https://www.leroymerlin.pt/produtos/cimento-25kg-secil-13142325.html	Used for structural prototype blocks
Plastic lunchbox (single compartment)	Prototype enclosure	3 €	1	IKEA	https://www.ikea.com/pt/pt/p/ikea-365-recipiente-p-alim-c-tmp-retangular-plastico-s19269079/	Simple enclosure
Smaller plastic lunchbox	Backup enclosure	1.5 €	1	IKEA	https://www.ikea.com/pt/en/p/pruta-food-container-with-lid-blue-10597103/	Backup option
PLA filament 1kg	3D printing material	14.60 €	1	Filament 3D	https://fillment3d.pt/produto/pla-cinzento-winkle-1kg-1-75mm/	Backup option
Ceys Total Tech Universal Glue and Sealant 290 ml Transparent	Silicone sealant	8.99 €	1	Leroy Merlin	https://www.leroymerlin.pt/produtos/cola-e-veda-total-tech-universal-290-ml-transparente-ceys-13132966.html	
Continente cooking oil 1L	Oil for enclosure	1.69 €	1	Continente	https://www.continente.pt/produto/oleo-alimentar-continente-continente-5045342.html	Used only if needed
Total		**35.17 €**				

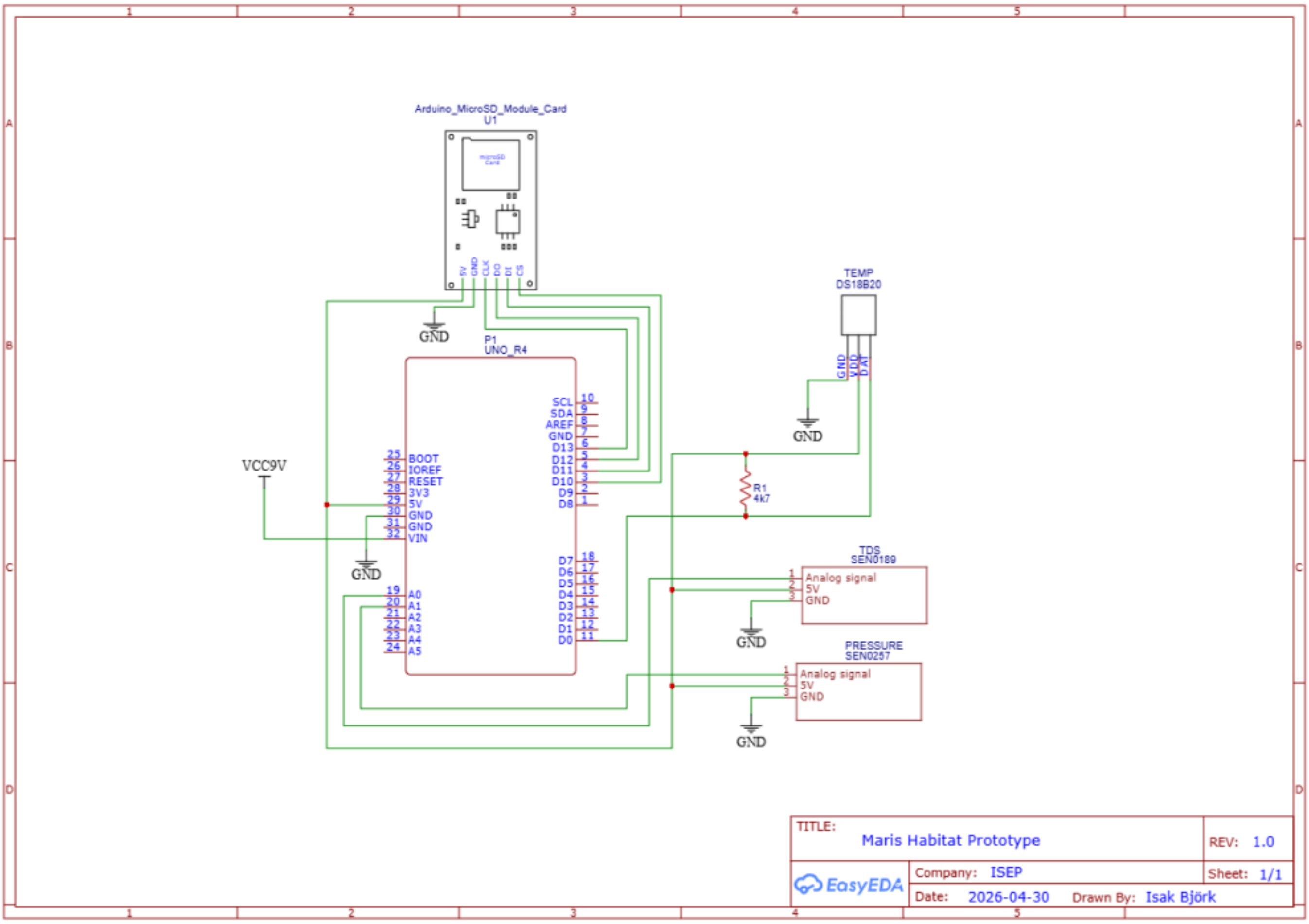


Figure 40: Prototype electrical schematics

7.6.3 Software

Detail and explain any changes made in relation to the designed solution, including different software components, tools, platforms, etc.

The code developed for the prototype (smart device and apps) is described here using code flowcharts.

7.6.4 Tests & Results

7.6.4.1 Hardware tests

Perform the hardware tests specified in Tests. These results are usually presented in the form of tables with two columns: Functionality and Test Result (Pass/Fail).

7.6.4.2 Software tests

Software tests comprise: (i) functional tests regarding the identified use cases / user stories; (ii) performance tests regarding exchanged data volume, load and runtime (these tests are usually repeated 10 times to determine the average and standard deviation results); (iii) usability tests according to the System Usability Scale.

7.7 Summary

Provide here the conclusions of this chapter and make the bridge to the next chapter.

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8. Conclusions

8.1 Achievements

Discuss here what was achieved (wrt the initial objectives) and what is missing (wrt the initial objectives) of the project.

8.2 Limitations

Identify here the limitations of the solution and prototype.

8.3 Future Development

Provide here your recommendations for future work.

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9. Acknowledgements

Last thing to do

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10. Bibliography

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