New Strategies for Replanting *Posidonia Oceanica*

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Abstract — The seagrass *Posidonia oceanica* is essential for the Mediterranean marine ecosystems, but human activities have led to its decline. This project, conducted by engineering students in collaboration with SARTI Research Group at the Polytechnic University of Catalonia, aims to develop cost-effective methods for replanting *P. oceanica.* The team designed new chalk substrates for seedling growth, using virtual simulations and field tests near Vilanova I la Geltrú to evaluate their effectiveness. The final design of the chalk substrate features elliptical and cylindrical shapes, optimized for stability and ease of production. These substrates, connected by bamboo frames and secured with hemp fiber ropes, provide a sustainable and biodegradable solution for replanting. Virtual simulations using OrcaFlex helped refine the design by testing its behaviour under various environmental conditions. Initial results were promising, with substrates remaining stable and supporting seedling growth. The project emphasizes sustainable material use, with life cycle analyses confirming the environmental benefits of chalk and bamboo.

Keywords: Posidonia Oceanica, Seagrass decline, Sustainable restoration, Mediterranean ecosystem, Chalk substrate.

I. INTRODUCTION

Posidonia Oceanica is a seagrass categorized as an angiosperm. Its structure consists of roots, leaves, and rhizomes (underground stems) that grow vertically (orthotropic) and horizontally (plagiotropic) [1]. These rhizomes help resist sedimentation and spread the plant to new areas by keeping it anchored to the bottom. The leaves accumulate both inorganic and organic particulate matter [2]. Independent of the type of substratum, sand or rock, the combination of accumulated sediment and the two types of rhizome growth, forms a structure called *matte [3]*.

Seagrass meadows are crucial for marine biodiversity by providing nurseries for juvenile fish and shelter for a diverse range of organisms [4]. Furthermore, these habitats generate up to 14-20 liters of oxygen per square meter daily and they produce approximately from 5 to 20 tons of organic matter per hectare annually, enriching sediment composition [5]. Moreover, these ecosystems sequester carbon (“blue carbon") by capturing CO2 through photosynthesis process and their dense root system stabilize sediments to prevent coastal erosion.

However, coastal habitats are rapidly disappearing, making restoration efforts urgently needed. Human activity like trawling, pollution, and costal expansion affected these habitats, leading to significant reduction in their size and density (ranging from 13% to 50% of the P. oceanica seagrass meadows) in the Mediterranean region [6][7]. The slow growth and low recovery rates of P.

oceanica meadows make it difficult to fully restore them within human timescales, and the deteriorating state of the ecosystems contributes to the frequent failure of seagrass transplantation attempts [8].

In response to this, the 2024 European Project Semester (EPS) team, consisting of five international students, collaborated with the SARTI Research Group, based at the Technological Development Center in Vilanova I la Geltrú, to experiment with new methodologies for the transplantation of P. oceanica seedlings.

II. ANALYSIS

Firstly, to understand the topic and gain insights before the design phase the detailed research was conducted.

A. Environmental Factors

The growth of *P. oceanica* seedlings is dependent on optimal light, water clarity, and depth due to the photosynthetic process [2]. In addition, salinity and water temperature also have an impact on habitat restoration success. Effective seed germination and growth occurs at a salinity level of 37 PSU and a water temperature of 25ºC [9]. Currently, seedlings at the UPC Research Facility are cultivated in controlled tanks to ensure optimal growth.

Transplanted *P. oceanica* plants need to grow roots within the first year to survive [10]. Late winter is the ideal time to transplant the seagrass cuttings, while seedlings must germinate in a monitored aquarium for at least two months before being transplanted, and be planted in spring [2]. Damaged meadows can recover, but slowly, because plagiotropic rhizomes grow approximately 14 centimetres a year, whereas orthotropic ones grow from 2 to 7 centimetres [11]. *Posidonia Oceanica* meadows are typically distributed at depths of up to 40 meters, but shallow to medium depths (0-19 meters) are better to restoration. The optimal planting substrates for *P. oceanica* are hard substrates such as rocks and dead matte, with planting individual seedlings or plagiotropic rhizomes being most successful.

B. Substrate Material

In this project, chalk rocks were used as the base material for deployment units. Chalk, formed from calcite shells, is a natural material unlike cement, which can be harmful to the environment. One of the benefits of using chalk over cement is its softness, making it easy to shape for experiments. Moreover, its calcium carbonate content promotes plant growth when it decays in the sea [12] and the porous structure of chalk allows roots to grow. Additionally, chalk is not considered as an expensive material and is widely available, fitting the project's goal of cost-effective replanting. In agriculture, chalk is often added to the soil to increase the pH level, providing a suitable substrate for plants tolerant of high pH such as P. oceanica [13]. Cement was also considered but found unsuitable. While strong, cement is highly alkaline (pH 12-13.8) and its production emits significant greenhouse gases. Unlike naturally formed chalk, cement is not biodegradable, making it less environmentally friendly.

C. Relevant Case Studies

Although the search for an efficient method of replanting P. oceanica is recent, seagrass restoration studies date back to 1939, beginning with Posidonia seed germination. From analyzing various scientific articles, replanting methods for seagrass can be categorized into seven approaches [11]:

- Cement slabs with perforations
- Cement frames around a wire mesh retaining cuttings
- Flat deployment of metallic, plastic, or biodegradable wire mesh on the seabed, retaining cuttings

- Fixing the cuttings to the seabed using stakes or staples
- The digging of holes for the placement of matte blocks
- The planting of seedlings, germinated in the laboratory
- Planting seeds, collected from marine environment or beaches

Researching previous studies and experiments provided a foundation for new investigations. By examining these methods and results, the project group gained valuable insights and avoided repeating previous work. This helped the team understand how to conduct their analysis and experiments, and what factors to consider.

D. SARTI group Experiments

Currently, SARTI team tests method that consists of the cultivation of *P. oceanica* seeds in the chalk substrates inside monitored tanks and later deployment of grown plants to the sea from a boat. This strategy was to launch a large-scale and cost-effective restoration method in the Mediterranean Sea to benefit both the environment and society.

Therefore, the main goal of this project was to develop and evaluate new designs of the chalk substrates that were used to deploy the seedlings of *P. oceanica* that will be replanted.

III. METHODOLOGY AND DESIGN

In order to deliver a reliable design that can be used as a cost-effective replanting strategy of this seagrass, many ideas were tested to find the most appropriate one.

A. Deployment Site

Finding an optimal deployment site was crucial for increasing the success of replanting P. oceanica. The chosen site was off the coast of Vilanova I la Geltrú, in an existing P. oceanica meadow where also near the OBSEA observatory. On March 19, 2024, a trial using a new underwater ROV (Remotely Operated Vehicle) was conducted 50 meters from the observatory to find a dead matte, which is an ideal substrate for P. oceanica deployment. However, the place was too hidden in the tall seagrass for the ROV to track. Consequently, a second exploration with divers was deemed necessary to find better-suited drop sites.

B. Chalk Substrate Prototype

Chalk was collected from a quarry as boulders and then sliced into different shapes. In some cases, hard polishing was necessary to achieve the desired shape. The shape is crucial to ensure the substrate remains stable against currents and waves. Next, holes were drilled in the chalk slices for planting seagrass seeds. To increase the success rate, initial prototypes crafted by the project team were deployed from the boat onto the dead matte using green ribbons instead of *P. oceanica* seedlings to avoid wasting them. This approach allowed the team to refine the deployment process and ensure that the methods used would be effective for the actual seedlings.

Figure 1: Examples of chalk prototype

The prototypes were deployed in front of one of the OBSEA cameras, enabling live monitoring. This setup allows for continuous observation and analysis of the substrates' behaviour on the seafloor in real-time, providing valuable data for the study.

C. Initial Design Concept

The group initially focused on the substrate's shape to address a recurring issue: the units flipping upside-down underwater due to currents and waves. Figure 2 shows an initial sketch of a complex substrate design.

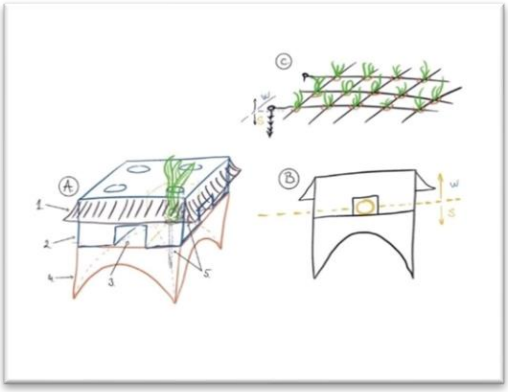

Figure 2: The sketch of the initial design (A) 3D view, (B) side view, (C) net design. The important parts of the shape are (1) anti-currents fixators, (2) main body, (3) net ropes canals, (4) sand fixators spots, (5) roots canals.

If preliminary tests were successful, the design would be 3D-printed in cement and attached at the knots of a net for in situ testing. The net would contain multiple substrate pieces, each holding four seeds, and the entire structure would be deployed simultaneously. Once on the seabed, a diver would anchor its edges, minimizing the chances of displacement by natural phenomena and improving time efficiency by deploying all plants at once. While this design offered several advantages, it had a major drawback: its complexity. The printer's limitations might hinder creating this specific shape, and using chalk had to be discarded. Even if the design were feasible, a large aquarium would be needed to accommodate all the substrates during the growth of P. oceanica seedlings before deployment. Additionally, the design required divers for deployment, which was costly and intended to be avoided.

D. Elliptic Design

Considering all the drawbacks from the first idea, our group adopted a simpler design to achieve similar hydrodynamic efficiency. The frame concept from the initial design was retained, connecting the rocks with a bamboo frame. This frame keeps the rocks together and better fixes them to the seabed, requiring greater force from currents and waves to move them.

The figure 3 and 4 displays a design composed of basic shapes. Its elliptical form is achieved by cutting a chalk slice without the need for complex techniques. Before this model is filled with seeds and either submerged in the sea or placed in an aquarium, it must undergo simulations using the OrcaFlex software tool (Figure 5). the model was adapted by overlapping multiple cylinders, with most having a thickness of 15mm and some, near the bases, having a thickness of 10mm to accommodate the required curvature.

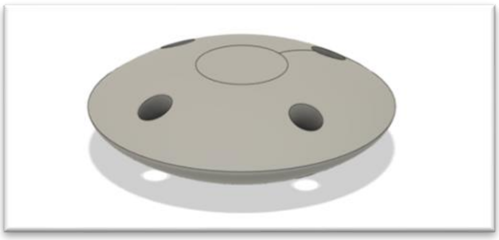

Figure 3: Elliptic body design

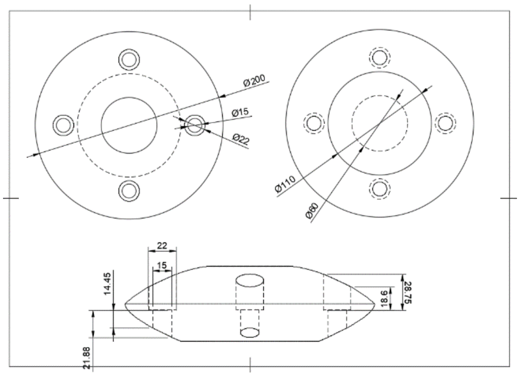

Figure 4: Technical drawing of the elliptic design from the figure 3.

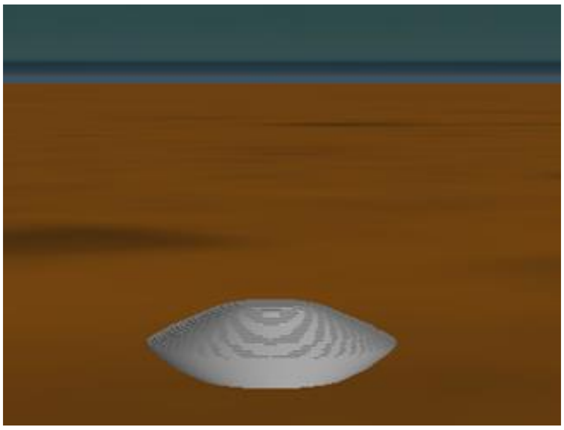

Figure 5: Elliptic design tested in OrcaFlex simulation tool

E. Cylindric Body

After considering results obtained from the simulations of the elliptic shape, the idea was to simplify our model and maintain desired properties. The similarities consist of the circular shape of both bodies, but the base diameter different. Experiments with a bigger shape were performed to see if the dimensions and the weight influence the behavior underwater. Below it is presented a cylindric body that has a diameter of 300mm and a height of 100mm (Figure 6, Figure 7).

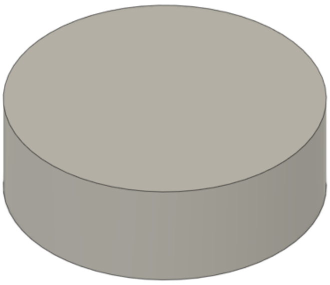

Figure 6: 3D model of the cylindric shape

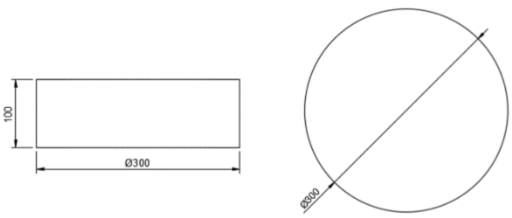

Figure 7: Technical drawing of the cylindric shape.

Having better properties than a cubic body and simpler construction then elliptic design, this shape was chose to use it as a part of a net/frame (presented in the section F).

F. Frame (Multiple Bodies)

At first, symmetrical frame was considered and the main idea was to find shapes with a good stability underwater and connect them with an organic material that will keep them together. This method came up as a response to the heavy currents that are moving and flipping the single stones.

Figures 8-9, illustrate an ideal 3x3 frame made of 9 stones: 4 large stones (300mm diameter, 100mm height) at the corners for stability and 5 smaller stones (200mm diameter, 100mm height) between them. This design ensures secure seabed fixation and reduces current impact, unlike single stones. Bamboo or wooden sticks connect the frame elements, with each stone fixed using thin rope or metal wire. Each stone is attached to the bamboo sticks at two points: the bottom and top. This setup enhances seabed stability and preserves the stones' integrity, minimizing the risk of breakage during manufacturing.

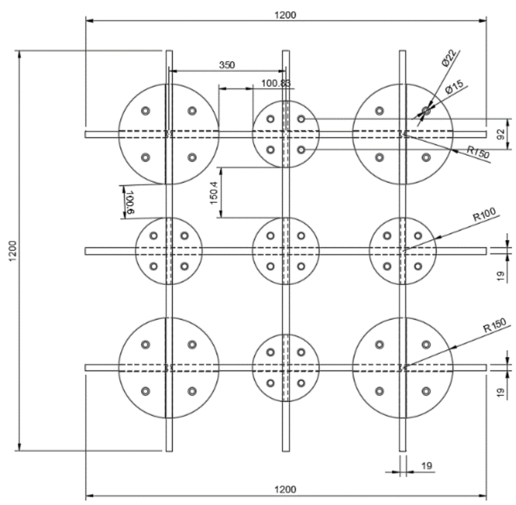

Figure 8: Technical drawing of the whole 3x3 frame, top view

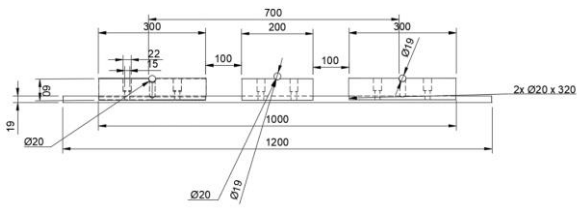

Figure 9: Technical drawing of the whole 3x3 frame, side view

Once it was concluded that the 3x3 frame behaves as desired, we tried removing some elements to verify if we can obtain a similar effect by using less material and time resources and so we removed one row and obtained an asymmetrical frame characterized by only 6 elements arranged as 2x3 and the stones have half of the size (150mm diameter and 50mm height) of the big stones from the previous structure (Figures 10-11).

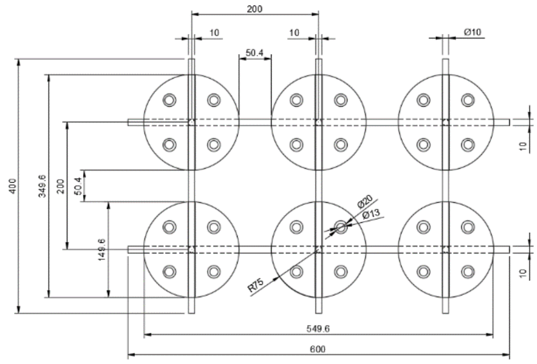

Figure 10: Technical drawing of the whole 2x3 frame, top view

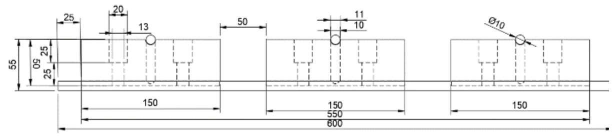

Figure 11: Technical drawing of the whole 2x3 frame, side view

IV. VALIDATION

This section describes the costs of all components involved in implementing the design and carrying it out in large scale operation.

A. Material and Production Costs

The project's focus is to find a cost-effective way of replanting P. Oceanica. To measure success, several parameters need to be considered such as material costs, production costs, and labor costs, in order to compare the design's costs with the conventional method of manual planting, which costs €100,000 per hectare.

The materials for this method include chalk, bamboo, and rope, bought in bulk to reduce costs. During the experimental phase, materials like chalk are provided for free by a local quarry. For large-scale production, the cost of chalk is estimated at €0.44 per module, based on the average price of limestone (€40 per tonne) and the requirement of 11 kg of chalk per module. Each module needs six 120 cm bamboo sticks. A set of 25 sticks costs €22.95 on Amazon, making the cost per module €5.74. The hemp rope, bought locally for €3.59 per roll (€0.02 per meter), costs €0.03 per module as each module requires 135 cm. Thus, the total material cost per module is €6.21.

A rock cutting machine slices chalk boulders, while a semi-round file shapes the slices and creates grooves for bamboo insertion. Handheld drilling machines are then used to drill holes for seed placement. SARTI already owns necessary tools, so original purchase costs are not factored in. Electricity costs, negligible due to low tool energy consumption, are €0.08 per hour for the rock cutter. Labor primarily involves building and deploying modules. It takes about two hours to cut slabs, drill holes, create grooves, and assemble the framework, with an additional half-hour for preparation. To estimate the cost per module, all expenses must be totaled. Transportation costs are excluded due to varying vessel prices. Materials cost €6.21 per module, with labor and transport costs added on top.

V. RESULTS

Simulations for the 2x3 frame (Figures 12 and 13) show the structure's behavior under 1.0 m/s and 2.0 m/s currents. Movement on the seabed is almost undetectable, but the asymmetry affects the burial level. One side of the structure tends to lift more, which could deepen some rocks. However, since most of the rocks remain above the seabed, this actually stabilizes the structure. Therefore, the 2x3 frame appears to be the better design for efficient replantation. It is comparable to the 3x3 frame in efficiency but is faster to produce and can be stored in an aquarium, unlike the larger 3x3 frame.

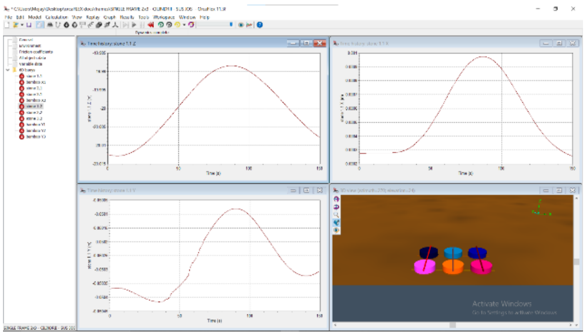

Figure 12: *OrcaFlex simulation of the 2x3 frame when exposed to a 1.0 m/s speed current*

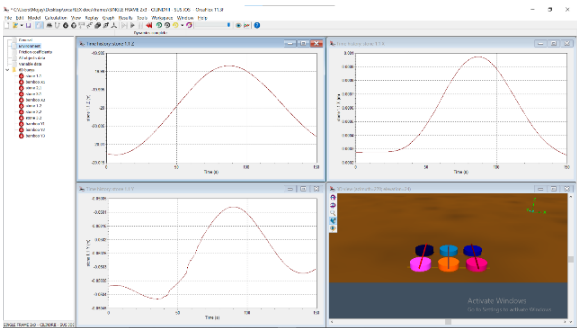

Figure 13: OrcaFlex simulation of the 2x3 frame when exposed to a 2.0 m/s speed current

Real-world tests were conducted using a structure made by the EPS team. The final deployed in the sea took place on 30.05.2024 (Figure 14) and is has been observed that the structure doesn't flip while getting to the bottom of the sea and it also maintains its position when it lands.

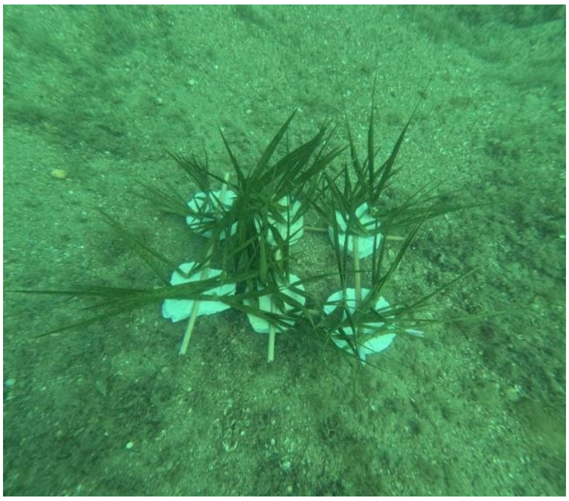

Figure 14: The 2x3 frame on the seabed

VI. CONCLUSIONS

In this project, an extensive analysis of various strategies for replanting *P. oceanica* were conducted, ultimately developing a novel and sustainable approach. Our designed method, using chalk and bamboo substrates, was shown to be both cost-effective and environmentally friendly. The use of virtual simulations through OrcaFlex allowed us to refine our designs and predict their behaviour under different marine conditions, enhancing the likelihood of successful seedling transplantation.

Real-world tests corroborated our simulations, the first deployment consisted in deploying single models demonstrating that the majority of our substrates remained stable and supported the growth of P. oceanica seedlings. Although one of the deployed rocks tipped over, this was attributed to an unforeseen collision rather than design flaws. As well as the second deployment where a 2x3 model was deployed, the plot also remained stable and supported the growth of P. oceanica seedlings. The overall positive outcomes suggest that our method holds significant promise for large-scale and cost-effective replanting efforts.

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