Algae and Fish Farming – An EPS@ISEP 2022 Project

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Abstract. The European Project Semester (EPS) at Instituto Superior de Engenharia do Porto (ISEP) is a capstone engineering design program where students, organised in multidisciplinary and multicultural teams, create a solution for a proposed problem, bearing in mind ethical, sustainability and market concerns. The project proposals are usually aligned with the United Nations Sustainable Development Goals (SDG). New sustainable food production methods are essential to cope with the continuous population growth and aligned with SDG2 and SDG12. In this context, this paper describes the research and work done by a team of Erasmus students enrolled in EPS@ISEP during the spring of 2022. Since sustainable algae farming can be a suitable source of food, the team's goal was the design and develop a proof-of-concept prototype, named GREEN·flow, of a symbiotic aquaponic system to farm algae and fish. The smart GREEN·flow concept comprises a modular structure and an app for control and supervision. The proposed design was driven by state-of-the-art research, targeted to a specific market niche based on a market analysis, and considering sustainability and ethics concerns, all of which are described in this manuscript. A proof-of-concept prototype was built and tested to verify that it worked as intended.

Keywords: Engineering Education · European Project Semester · Fish and Algae Symbiosis · Smart Food Production · Sustainability

1 Introduction

This paper describes the work and research done by a group of Erasmus students enrolled in the European Project Semester (EPS) [2] at Instituto Superior de Engenharia do Porto (ISEP) in the spring of 2022.

EPS@ISEP is a capstone design project where students, organised in multidisciplinary and multicultural teams, are encouraged to create a solution for a real problem from scratch, following ethics, sustainability and market concerns [6]. The goal of this project-based learning process is to foster the kind of problem-solving, teamwork and interpersonal skills sought by employers.

The team consisted of five international students with various cultural and scientific backgrounds. Together, they combined their knowledge and skills to create a symbiotic solution for algae production that is modular, sustainable and valuable. This includes design, prototyping and testing for a budget of 100 €. The proof-of-concept prototype requires the use of sustainable materials and proper construction so that each organism in the process has a safe environment.

The relevance of this project lies in the challenge of finding new ways of producing food due for the growing population of the world. To properly create a symbiotic system between fish and algae, multiple factors have to be taken into account. Symbiosis encompasses various relationships between two or more individuals of different species [13]. The specific form of symbiosis used in this project is mutualism, where interaction occurs between two symbionts in which both organisms experience benefits or even have some need for this relationship [3]. In this context, the fish provide the algae with the nutrients they need to grow. In turn, the algae filter the water, allowing the re-circulation of the water back to the fish. The combination of algae and fish for farming purposes replenishes the food supply faster than nature.

After this brief introduction, the remainder of this document is organised into four additional sections: preliminary studies, proposed solution, prototype development and conclusion.

2 Preliminary Studies

To propose a concept and specify its requirements, the students analysed the state-of-the-art and market through the lenses of innovative, ethics and sustainability driven design.

2.1 Algae-Fish Mutualism

Algae, although not higher plants, perform oxygenic photosynthesis [16] and fish produce ammoniacal excretions. This means that fish excrete mainly nitrogen, in the form of ammonia, whereas algae only need water, light and nutrients (nitrate) to grow. Compared to plants, algae grow ten times faster, using a tenth of the space to produce the same amount of biomass. The integrated, often closed-loop, food production system that combines aquaculture (breeding fish or aquatic

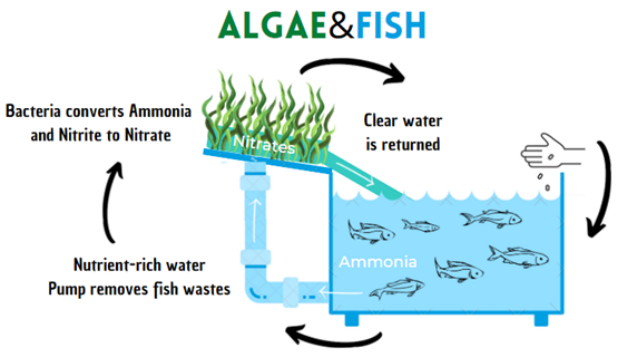


Fig. 1. Algae and fish symbiosis.

organisms) and hydroponics (growing plants on a nutrient-enriched water bed) in freshwater, shown in Figure 1, is an energy and cost efficient way to grow plants. These continuous systems allow algae to grow faster, require less water and land, and are free of artificial fertilisers. The principle of the process is that bacteria convert fish waste into food for the algae. The algae feed on it and purify the water. In summary, fish waste can be converted into plant food through the nitrogen cycle: the fish waste contains ammonia (which is toxic for fish) and the bacteria convert the ammonia into nitrate.

Growing algae instead of plants, not only reduces water and fertiliser use, but also avoids the wasteful fertiliser run-off and downstream eutrophication associated with modern agriculture [10]. Algae farming and related business are growing in popularity. There are several straightforward techniques to bring algae farming into individual homes. The most basic technique is to fill a container with water, add nutrients and a sample of algae, place the container in the sun and then monitor the algae [8]. In many Asian countries, microalgae are already used as a food additive and in other countries, such as the United States and the United Kingdom, their use is on the rise [17]. Algae can also be used to produce biofuel [4], animal feed [9], green plastic [19] and cosmetic products [18]. A very popular algae nowadays is spirulina. Due to its chemical composition, including proteins, carbohydrates, essential amino acids, minerals (especially iron), essential fatty acids, vitamins, and pigments, it is sold as a health product. Spirulina can increase energy levels, improve physical performance and reduce the carbon footprint of the user's diet [5]. As a result, the team decided to grow spirulina.

2.2 Marketing

Marketing is a market-oriented approach to business management aimed at satisfying the needs of potential customers, responsible for promoting products and services. In addition to operational activities designed to influence purchasing decisions, it encompasses all other areas of the business. In summary, marketing

ensures that more sales are made by identifying potential customers and the market, promoting the product and improving the image [12].

The basis of any marketing plan is a comprehensive market analysis. The result of the analysis will show the current position of the product in the market, as well as possible ways of distributing the product. Various influences on the company and therefore on the product have been considered, as well as the product's influence on the environment [22]. For example, in terms of political influences, the factor of a secure supply of components plays an important role. Political disputes that could lead to supply bottlenecks could jeopardise the production of the GREEN·flow. It is therefore important for the team to find out in advance about the political situation in the countries of origin. Another key factor with decisive results is the Strengths, Weaknesses, Opportunities and Threats analysis. In addition to the strengths of the product, such as the provision of spirulina as a superfood or decoration, and the green aspect associated with its production and use, GREEN·flow also presents various opportunities. These include the opportunity to teach about algae, to reduce food transport routes, to highlight problems in the food industry and raise awareness of sustainability. However, there are also possible weaknesses and threats such as cheaper supplements already on the market and a possible lack of consumer interest in algae. To avoid the latter risk, the team selected as the potential target audience those open-minded peopled who have already contact with green living. The branding, naming and logo of GREEN·flow present a consistent look. The green colour harmonises with the roundness and the circle. Together they represent the symbiotic cycle of the system. The team plans to market the product mainly through social media, corresponding to 37 % of the marketing budget. In addition, the GREEN·flow logo and information about the product will be published in local newspapers and using flyers. The effectiveness of the principles set out in the marketing plan will be continually reviewed, optimised and improved. Actions will be taken according to the plan, do, check and act cycle.

2.3 Ethics

Ethics is a broad scope philosophical discipline concerned with moral judgements. When applied to a professional context, it is referred to as deontology and defines the standards, limits and duties of any profession. The importance of deontology and ethics in everyday life is therefore not negligible. For companies and professionals, it supports the design of new human-centric products and consolidates an image of reliability and responsibility in the marketplace.

Deontological codes help professionals decide whether their actions are right or wrong. There are several deontological codes for engineers, namely the Code of Ethics and Deontology of the Portuguese Order of Engineers [15], which states that engineers must demonstrate the highest standards of honesty and integrity, and the North-American National Society of Professional Engineers [14], which postulates that engineers, in the exercise of their professional duties, must respect the fundamental canons, rules of practice and professional obligations. In short,

engineers use their multidisciplinary knowledge to create solutions to problems that respect and improve the quality of life on the planet.

Marketing ethics is at the heart of any business, as they drive the business forward. Indeed, markets are made to sell, and, consequently, there are several conflicting players. Sales ethics is a set of behaviours that ensure that every prospect and customer is treated with respect, fairness, honesty and integrity.

Environmental ethics aims to balance the social, economic and environmental aspects of a project or product. It studies the conceptual underpinnings of environmental values as well as the more concrete issues surrounding society's attitudes, actions and policies to protect and conserve biodiversity and ecological systems. The combination of algae and fish in aquaculture can replenish food supplies faster than nature. However, not all fish farms are sustainable. Many cause environmental damage by concentrating large numbers of fish in small areas and when the fish excrete waste or die, they pollute the surrounding waters. This is way environmental ethics is a pillar of project design.

Company liability comprises the compliance with the regulations and standards issued by the European Union as well as the obligation towards customers to ensure that all components used in the production process are of high quality and reliable. In accordance with legal, criminal and professional responsibilities, the living symbiotic system cannot be affected by malfunctions [21]. The aim is to avoid incidents with the product that cause harm to the user and living organisms, losing confidence in the company.

2.4 Sustainability

Companies are paying more attention to eco-efficiency. Sustainability driven design creates more value through technology and process changes, while minimising resource use and environmental impact throughout the life of the product or service. Eco-efficiency applies to all aspects of the business, from purchasing to production, marketing and distribution. The aim is to reduce the amount of resources, like water, energy or materials, and generate less pollution and waste during the creation, production, usage and the end-of-life recycling. Sustainability involves environmental protection, economic viability and social equity. Together they define the most sustainable outcome possible [20].

Environmental sustainability fosters a responsible way to co-operate with the planet, conserving natural resources and supporting global ecosystems to ensure the well-being of present and future generations. A kit to produce algae symbiotically at home is an example of sustainable food production [7].

The economic aspect is the part of sustainability that focuses on the use and protection of resources in order to create long-term sustainable value through optimal use, recovery and recycling. The concept is used to define and explain how valuable natural resources are today and how they can be in the future [11].

Social equity is the process of creating sustainable, successful solutions that promote well-being of all by understanding what people need where they live and work. This way, consumers are more engaged, informed and concerned about the

impact of the products they buy; and companies are partnering with social sustainability organisations to become more transparent, to make their operations or supply chains more ethical and to understand the human cost of business [1].

3 Proposed Solution

Based on the previous studies, the team idealised and designed a smart aquaponics solution to grow algae and fish.

3.1 Proposed Concept

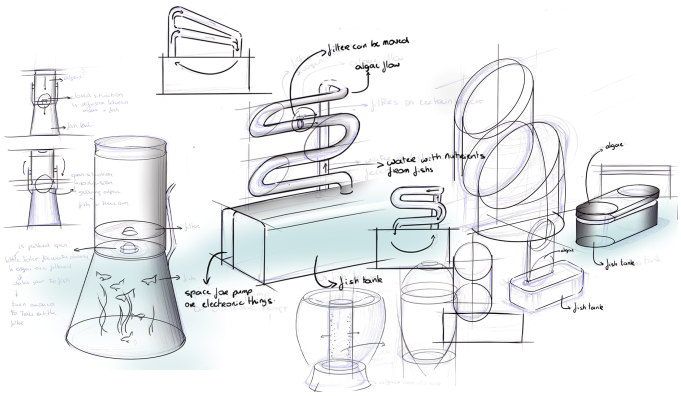


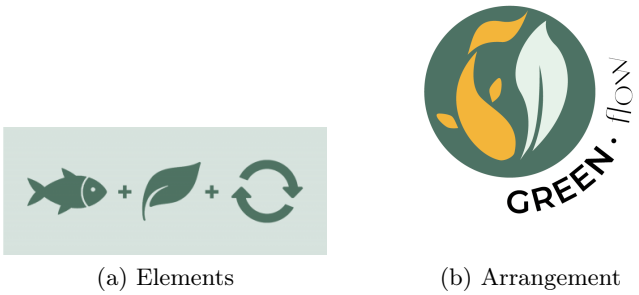
Fig. 2. GREEN·flow ideation sketches.

The GREEN·flow team designed a symbiotic modular ecosystem for the home environment. It focuses on the domestic users who have the space and time to immerse themselves in a slow-moving but long-term project. This target group wants to adopt a new way of life and contribute to a greener society.

The team started by sketching several possible approaches to the problem, as depicted in Figure 2. From these preliminary sketches, the product concept evolved into the solution shown in Figure 3, which consists of two main interconnected parts: a large fish tank and several small algae tanks. A pump makes the water flow between the tanks. The system also includes a leak sensor and a feeding system.

As previously mentioned, the fish excrete nitrogen-rich faeces, which are filtered through a sand filter and absorbed by the algae. The algae require nutrients, light and an appropriate temperature to grow. As shown in Figure 3, the algae aquarium is easily attached and removed from the artificial wall for easy harvesting. The user can harvest the algae every week or two and consume them, as the algae are a great food supplement.

Fig. 3. Structural design proposal.



(a) Elements (b) Arrangement

Fig. 4. GREEN·flow logo.

3.2 Product Branding

The logo, illustrated in Figure 4, is an important part of product branding. It creates an image, attracts attention, differentiates from competitors, reflects a part of the image and forms the basis of the brand identity. The logo and the GREEN·flow name represent what the product stands for and means to the user. The GREEN·flow logo consists of three main elements that represent a symbiosis between two organisms that can lead to a circular system. The circle, made up of the fish and algae, represents the symbiosis and the small-scale circular ecosystem supported by the system.

The branding of the product comprises the logo and the name. GREEN·flow works by circulating water to the the benefit of both organisms. The "GREEN" part indicates the focus of the project, which is not only to produce algae as sustainably as possible, but to make the user embrace an ecological life style.

3.3 Product Design

The product design (Figure 3) combines a natural look with an industrial style, both modern and natural, which is also one of the aims of this product. Modularity played an important role in the final design. The product has three different sizes: small, medium, and large. The small version has a fish tank with two connected algae tanks, the medium version has four algae tanks, and the large version has six algae tanks connected to the fish tank.

The aquariums are attached to the front of the artificial wall, whereas the piping and the electrical systems to the back. This ensures that they are hidden from the user, so that the whole set can be nicely integrated into the home environment. The electrical system is protected from moisture and water in a closed cabinet. The leak sensor is installed inside the fish tank and connected to the app. The app alerts the user whenever the water level drops, indicating a possible leak or system failure, and allows the user to control the lights, i.e., the algae growth rate. Finally, the team plans to incorporate an automatic feeding system, also controlled through the app.

3.4 Packaging

GREEN·flow consists of three elements that need to be packed and shipped: the fish, the algae and the modular kit. The fish are transported in special plastic bags made of a safe material with rounded corners for the safety of the fish. As fish need oxygen, the bag must be filled up to 1/3 of water. To reduce stress on the organism, the bag should be kept vertically during transport and placed in a dark environment. As fish can only survive for a few hours in this situation, GREEN·flow excludes their transport over long distances. Unlike fish, spirulina can survive in its packaging for about a week. In this situation, transport is possible. However, it is important that the user transfers the spirulina to its tank as soon as possible after receipt. Finally, the whole kit needs to be packed. It contains the fish and algae tanks, the lamp for growing the algae, all the electronic equipment for running the symbiotic system and the instructions. The algae strains are also included in the kit.

The GREEN·flow packaging needs to adopt environmentally friendly materials, be reusable and provide a strong, functional package for the product. As Figure 5 shows, the primary box is made from strong and reusable recycled corrugated cardboard and the secondary box uses seaweed packaging to highlight the potential uses of seaweed. The wedging is made wheat and barley, a biodegradable and edible material, to feed the fish. Respecting the brand values, the designed packaging solution is functional, biodegradable and recyclable.

4 Prototype Development

After the design of the solution, the team built a proof-of-concept prototype to verify its proper operation.

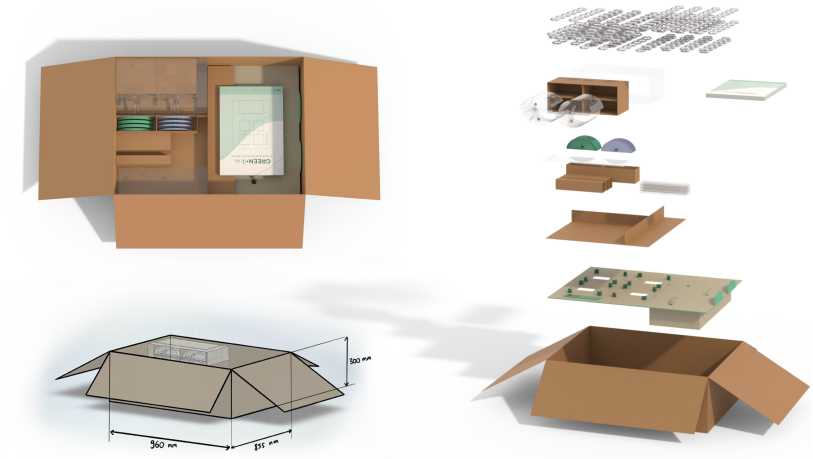


Fig. 5. Proposed packaging for the GREEN·flow kit.

4.1 Assembly

The team was provided with all the necessary components and materials to assemble the prototype. The prototype (Figure 6) consists of two glass tanks connected by pipes, to create a well-functioning system. One of the tanks is used for algae and the other for fish. The fish tank is equipped with a pump (connected to the pipe leading to the algae tank) and water level and temperature sensors. The algae tank is lit by a light-emitting diode (LED) strip and has a filter to prevent unwanted material from getting through. From there, another pipe leads back to the fish tank, creating a water circulation. In addition, a dedicated control circuit[1] was implemented comprising both sensors, a relay, a water pump, a microcontroller, a colour LED driver, a colour LED strip and a power supply.

The electrical components were isolated from the water piping for leakage protection. The piping system incorporates filters to remove unwanted materials. The result was a working system, ready to accept living organisms. Overall, the prototype costed 42€.

4.2 Tests & Results

Once completed, the prototype underwent a series of tests to verify the correct and safe operation of the aquaponic system. First, the assembly tests successfully checked the whole water flow, involving piping, filters and tanks, and the operation of the individual components. Finally, the functional tests focused on the monitoring of the status (water level and temperature of the fish tank) and control (lighting of the algae tank and water pumping) of the aquaponic system

[1] https://www.eps2022-wiki4.dee.isep.ipp.pt/lib/exe/detail.php?id=report&media=final_circuit_schematic.png

Fig. 6. GREEN·flow prototype.

via the mobile application. The results showed that: (*i*) the app notifies the user whenever the water level in the fish tank is too low or high; (*ii*) the app displays the water temperature of the fish tank correctly; (*iii*) the app allows the user to control the lighting of the algae tank and pump successfully.

5 Conclusions and Future Developments

The aim of GREEN·flow was to design and develop a new environmentally friendly and marketable product. Specifically, the goal was to create a smart symbiotic algae and fish farming system that minimises the use of water and nutrients. The modular design, with an expected price of 300 €, promotes scalability.

The fish excrement is used to feed the algae and the algae purify the water for the fish, allowing the reuse and, thus, saving water. This symbiosis establishes a dependency and between both living beings. Moreover, it can be used to farm fish or to keep pet fish, while being able to harvest algae. This educational and fun kit therefore helps to raise consumer awareness of sustainable harvesting techniques.

Summing up all the background and development work, the team successfully achieved the project objectives and fulfilled their personal goals: to develop interpersonal, intercultural and teamwork skills, as well as critical thinking and design driven by ethics, sustainability and the state-of-the-art technology. The exception of the final test of the prototype with fish and algae, due to the lack of time after the reception of the living beings.

The difficulties encountered during the project were overcome with the dedication and the cooperation between team members, specially because they had no previous knowledge of electronics. The development of the prototype was the most time-consuming and labour-intensive stage, involving procurement of components, assembly, testing and refinement.

In the students words, "*we are proud of the results, we were able to make a prototype and elements around that make GREEN·flow even more realistic. EPS@ISEP provided an unforgettable experience both academically and culturally. During this project, the team learned to join forces to achieve the self-set goals. ISEP offered us the opportunity to carry out a very well structured project with a seamless follow-up while sharing the experience with a multicultural team. This has allowed team members to grow in terms of project management and technical skills in their respective fields of study.*"

As good as the results of this project have been, there are always ways to improve. In fact, to turn the prototype into a marketable product there is the need to work further. The GREEN·flow prototype was limited by time, budget, and insufficient knowledge in some technical areas. After reflecting on the less successful aspects, there are several possible future developments: (*i*) characterise the algae growing; (*ii*) design and develop an automatic fish feeding system; (*iii*) create an online purchase website; (*iv*) find a solution for transporting the fish, perhaps in partnership with pet shops; (*v*) create a wireless and waterproof connection between the electronic components for a more visual and practical appearance; (*vi*) add new electronic components, such as an LCD screen with battery, water temperature and algae culture data; (*vii*) refine the mobile application to offer more functionality for consumers; and (*viii*) check the quality of the materials used for the product and the packaging and select ethical suppliers.

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