Homegreens - Aquaponics System as an Educational Tool towards a Sustainable Future

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ABSTRACT: Aquaponics is an integrated production practice that emerges from the combination of two farming techniques: hydroponics and aquaculture. It consists in a simulation of a natural ecosystem that grows plants without soil substrate in the nutrient enriched waters recirculated from aquaculture systems. This type of production offers several advantages, namely economic and ecological ones.

Homegreens is a project that aims to create small saltwater and freshwater aquaponic systems, which can be installed in schools and serve as a didactic tool for introducing contents such as biology and sustainability to a juvenile audience. Implemented by a designers, biologists and agronomists' multidisciplinary team, the methodology was based on the development and quantitative validation of prototypes, and the installation and qualitative analyses of user's interaction.

These small scale aquaponic systems consists on a grow bed, an aquarium with a capacity for 45L, a protection barrier for the plant's roots, aeration, biofilters and a thermostat. Several simplified models were developed, presented and installed in two primary schools. Laboratory tests were conducted to validate the use of a cork grow bed and a 3D printed polyacid lactic (PLA) aeration and biofilter system.

Children's engagement and interaction with these simplified models, indicates that these systems will provide a biology and sustainability related group learning opportunity.

1 INTRODUÇÃO

Aquaponics (1) "is essentially the combination of aquaculture and hydroponics" (Blidariu & Grozea, 2011, p1.).

Hydroponics is a technique that allows cultivation without soil, and which uses a variety of inert cultivation beds as support. The plants are irrigated with a solution responsible for providing the amount of nutrients necessary for their growth. On the other hand, aquaculture consists of the production of fish, or other aquatic animals, in an isolated and controlled environment (Jensen, 1997; Blidariu & Grozea, 2011). Consequently, aquaponics is the combination of these two practices, providing the benefits of both, integrating a (2) "(…) polyculture consisting of fish tanks (aquaculture) and plants that are cultivated in the same water circle (hydroponic). The primary goal of aquaponics is to reuse the nutrients released by fishes to grow crop plants." (Graber, 2008, p.147-148). According to Blidariu (3) "both aquaculture and hydroponics have some negative aspects (…)" (Blidariu & Grozea, 2011, p2) and the combination of the two simulates a natural ecosystem with the ability to counteract the harmful consequences attributed to each of these activities when practiced separatly (Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014).

Aquaponics is seen as an alternative to traditional methods of food production, and is part of a set of practices associated with the development of a sustainable future. This practice promotes an increase of productivity, through available biological resources, allowing an organic production, free of pesticides, herbicides or fertilizers. Considering the absence of these chemicals we can estimate that farmers will also benefit by getting (4) “premium prices from soilless (hydroponic) or organic vegetables in a market quite sensitive to pesticide use in agriculture” (Pantanella, 2008, p.11).

In addition, other benefits are associated to aquaponics’ practice: it allows a highly efficient management of water resources, notably through permanent cycling, since its (5) “input is minimized, little water is discharged and this can itself be treated” (Blidariu & Grozea, 2011, p.3). Recirculation of water makes it possible to use this method of food production in areas with few water resources, where traditional agriculture would be impracticable.

Given the aquaponics potential as a sustainability related demonstration method, this paper presents the Homegreens project, which consists of the development of small-scale domestic aquaponics systems as pedagogical tools, through a multidisciplinary approach based on biology for species identification and product design for user-centered interface design. The proposal intends to provide an understanding of the various biological processes within an aquaponic system.

2 AQUAPONICS AS A SIMULATION OF AN ECOSYSTEM

We can consider aquaponics as a simulation of an ecosystem that we find mainly in rivers, and is based on a set of interactions between a particular biotic community, namely fish and plants species, which is housed in specific equipment designed to determine the adequate environment.

Golley theorizes the importance of the environment in the development of biotic communities and a key factor in achieving their balance, referring to Tansley, botanist and author of the ecosystem concept that first emerged in 1935: (6) “Tansley’s ecosystems concept was a physical concept that stressed that both physical-chemical environment and biotic organisms acted together to form an ecosystem, which was in turn formed part of a hierarchy of physical systems from the universe to the atom. The physical concept of equilibrium guided the organization and maintenance of ecosystems.” (Golley, 1993, p. 34).

Designing and operating a small-scale domestic aquaponic system requires the characterization of the biological, physical and chemical processes that allow the attainment of equilibrium and superior ecological performance associated with a food production. It also requires the design of the equipment and its components in order to provide an appropriate environment, and the understanding of the user / caretaker as a fundamental part of the ecosystem.

2.1 *Understanding an aquaponic system – Nitrogen cicle*

The nitrogen cycle is the main biological process responsible for triggering the actions that take place in these systems. It is through the process of nitrification that it is possible to transform the waste produced by the fish into food for the plants. (7) “Merging the two disciplines, wastewater treatment and crop production, requires moving the focus from optimizing the degradation, nitrification, denitrification and absorption rates to maximizing the recycling rates of phosphorus and nitrogen and to fulfilling the quality requirements of the resulting products such as plant biomass and effluent water.” (Graber, A. p 148).

The water is mechanically filtered to release separate the solid waste metabolized by the fish, then passes through a support structure of nitrifying bacteria, called biofilter, where the ammonia is transformed into nitrites, and these into nitrates, which are then absorbed by the plants. By going through these steps, the water is recirculated to the fish tank completely purified. Nitrogen is the main nutrient responsible for the development of plants. Although it is the most abundant element in the Earth's atmosphere, it presents itself as a non-absorbable stable molecule (N2). To make the absorption possible, the molecule has to be decomposed through a process called nitrogen-fixation, which is characterized by a chemical transformation, through the action of bacteria, responsible for incorporating elements such as hydrogen and oxygen, thus creating new chemical compounds such as ammonia (NH_3), nitrites (NO_2^-) and nitrates (NO_3^-) capable of being absorbed by plants. This process is common to the most diverse natural ecosystems, and is easily identifiable in the processes of organic matter decomposition (Somerville et all., 2014; Blidariu & Grozea 2011).

To achieve the equilibrium of the ecosystem it is essential to maintain a healthy bacteria colony, which can be monitored by daily measurements of the ammonia, nitrite and nitrate parameters. It is also necessary to ensure a correct ratio between the quantity of fish and the quantity of plants in order to ensure the balance of the ecosystem and the survival of the biota.

2.2 *Other Physical-Chemical Parameters*

Apart from the ones related to the nitrogen cycle, there are other important parameters for the maintenance of the ecosystem, such as dissolved oxygen, pH, temperature and luminosity. Oxygen is an essential element to the survival of all organisms and must be accessible to the biotic community that inhabits the ecosystem. The pH is the fundamental parameter to determine the water´s acidity level and an essential indicator for ecosystem monitoring: variations tend to cause a deficiency in the absorption of micro and macronutrients. The temperature of an aquaponic system should ideally be situated between 18-30° C, otherwise it will adversely affect the level of ammonia and the dispersion of oxygen. Luminosity is also plays an important role related mainly to plant growth; however, the fish tank should be restrained from light in order to avoid the development of algae responsible for the absorption of nutrients. Bacteria are also a photosensitive organism and should be protected from ultraviolet rays (Somerville et al., 2014).

3 DESIGN ALLIED TO BIOLOGY FOR NEW SUSTAINABLE SOLUTIONS

The growing debate about sustainability and circular economy is also the result of alarmingly evident ecosystem changes. The search for solutions that aim to meet global needs through alternative strategies has become imperative: (8) "we must design new approaches to managing environmental resources and sustain human development." (UN, 1987, p.40).

Recognizing the urgent need for action the United Nations General Assembly also declared 2011/2020 as the United Nations Decade on Biodiversity. (9) “Biological diversity underpins ecosystem functioning and the provision of ecosystem services essential for human well-being. It provides for food security, human health, the provision of clean air and water; it contributes to local livelihoods, and economic development, and is essential for the achievement of the Millennium Development Goals”. By 2020 people should be aware of the values of biodiversity and the steps they can take to conserve and use it, namely ensuring that agriculture, aquaculture and forestry are managed sustainably.

Designers are closely involved in this process; in fact, (10) “over the past hundred years, even when driven by the most positive intentions, designers have been active promoters of the ideas of wellbeing and ways of living that we have recently and dramatically discovered to be unsustainable” (Manzini, 2005).

They are co-responsible in determining the current system of material culture, whose logic, according to Vítor Papanek, is urgent to rethink: (11) "The environmental changes in our fragile planet are a consequence of what we do and the instruments we use. Now that the changes we are making are so great and so threatening, it is imperative that designers and architects make their contribution to help find solutions" (Papanek, 1995, p.10-11).

Over the last few years designers and scientists have looked to nature as a source of inspiration for formulating projects aimed at achieving a higher ecological yield.

This holistic vision proposes an integration in nature through the preservation and valorization of natural capital and biological phenomena. (12) "Like ecology before it, sustainability presents a holistic view of the function and value of natural systems, but human stabilities need to baseline metic to evaluate success” (Erlhoff, M. & Marshall, T., 2008, p.149). This new vision clearly

proposes a multidisciplinary approach as a way to generate and validate results, placing the designer as someone who establishes links between areas of knowledge.
Aware that one of the most relevant tasks is to educate future generations in this framework of values, the Homegreens project created the small-scale aquaponic systems as pedagogical tools that promote (13) "(...) alternative and better farming methods that rely on ecological relationships, cultural information, and a sophisticated knowledge of chemistry (...) "(Orr, 2002, p.138), and support the discussion sustainable development related issues.

3.1 *Designing pedagogic tools towards a sustainable future*

In 2005 the UN declared the Decade of Education for Sustainable Development, considering education a priority in dealing with environmental degradation, and promoting values, attitudes, capacities and behaviors to undertake that challenge and leave a more sustainable and safe planet as legacy to future generations.
Following these same guidelines, the aquaponics systems were implemented in two selected schools, whose pedagogical methodologies focus on Project Based Approach, (14) "(...) based upon the idea of children learning through hands on, meaningful experiences that center around their interests." (Claussen, 2017, p.2). The adoption of these strategies allows to keep the children motivated and receptive, and to relate content from several areas of knowledge. In this way, competences are acquired not only in the field of biology, but also, through the development of a design logic, in the field of mathematics, physics, social skills, among others. (Blumenfeld et al., 1991)
Since (15) "(...) the human being shapes society and its future through what is taught to young people" (Papanek, 1995, p.235), the dissemination of these contents in the context described was considered relevant because it contributes to the children's questioning, a fundamental step for the sedimentation of values on which to lay a worldview.

4 METHODOLOGY

Product development methodology was composed by the following phases, each with specific validation requirements:
- Define user needs and contexts;
- Select plants, fishes, fresh and brackish water;
- Select plants adapted to salinity conditions;
- Study control of light for optimal plant growth;
- Determine the components of the system;
- Characterize growth at aquaponics conditions;
- Develop concept designs;
- Prototype;
- Conduct user tests;
- Disseminate results;

The methodology was adapted according to the areas of knowledge and implemented by a multidisciplinary team composed of designers, biologists and agronomist engineers, in close collaboration

4.1 *Define user needs and contexts*

The development of the concept was carried out according to two moments: first, the study of references and consultation of sources, and second, the use of physical probes.
The first moment consisted in a technical and functional research on aquaponics, and its main focus was on the production scale systems and the state of the art. In the second moment, a set of Human Centered Design strategies were applied, using "probe" systems in basic schools. These systems provided relevant information collected in the form of reports and images. This strategy was based on (16) "(..) empathy, on the idea that people are designing for your roadmap to innovative solutions. All you have to do is empathize, understand them, and bring them along with the design process " (Ideo, 2015, p.22).

4.2 *Develop concept design*

Several experimental models were built using materials that allowed the validation of a system composition. In this stage, it was possible to define the interaction and technical performance of the system, according to the guiding concept.

4.3 *Prototype*

The selection of materials and conformation processes enabled the concept fulfillment and the compliance with sustainability criteria. Following the execution of technical drawings and selection of companies able to provide the required services, the components were fabricated and assembled into the first prototypes.

4.4 *Conduct user tests*

The prototypes of the aquaponic systems were installed in the designated schools, and the data collection that is taking place will allow a more accurate performance qualitative analysis.

5 RESULTS – THE AQUAPONIC SYSTEM

The result of the research carried out under the project Homegreens is an aquaponic system, designed as a pedagogical tool, that allows the cultivation of species in fresh water or salt water. It arose from the synergies with two basic schools, that provided inputs that guided the development focusing on the user.

The design (Figure 1) is composed of an aquarium (D), a grow bed (A), a root protector (B), a biofilter with integrated aerator (C), a valve for sediment extraction (E), and a support structure (figure 2).

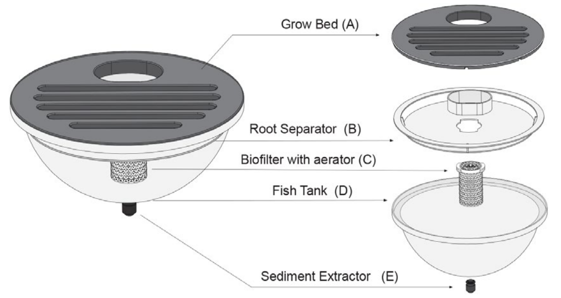

Figure 1. System componentes infographic.

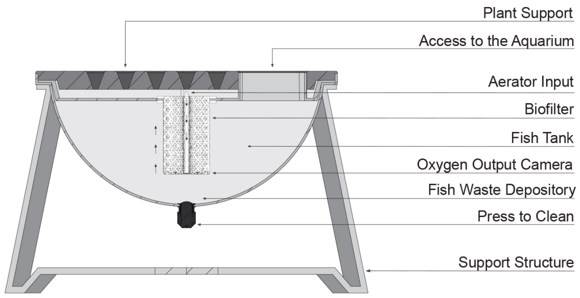

Figure 2. System performance infographic.

5.1 *Aquaponic system performance.*

In order to simplify its use all elements are housed in the main container, the fish tank. As shown in figure 2, this strategy allowed to take advantage of the upward oxygen circuit produced by the aerator, and to delineate a trajectory that allows the water to be cleaned. Thus, water with ammonia is elevated by the dispersion of oxygen through the biofilter, where the ammonia is converted into nitrites and then into nitrates. Then it rises to the plants' roots allowing nitrates to be absorbed, returning to the fish aquarium again, free of toxins. This configuration also allows a distribution of the amount of oxygen required to the entire biotic community within the aquaponic system.

Regarding the solid waste produced by fish, due to gravity it tends to settle on the bottom of the aquarium, and subsequently is ejected by the valve that serves as the border with the outside. In this way, an efficient cleaning of the system is guaranteed by the speed of the output of the water programmed according to the capacity of the container (45 liters).

5.1.1 *Fish Tank*

The aquarium is designed to be the center, characterized by its circular shape with a diameter of 60 cm. This allows the coexistence of several children around it, while promoting the understanding of the biological processes intrinsic to the ecosystem, through the observation of the biology at work. This is possible due to the selection of a safety compliance transparent acrylic glass, through witch all the actions that take place can be seen.

5.1.2 *Grow Bed*

The grow bed (figure 1 (A)) is used for the placement of plants and is also a cover for the aquarium. It has specific areas that allow the placement of several species simultaneously. The large hole serves as a access zone to the fish tank for daily feeding and also for interacting with the selected fish species (see section 5.1.7.). The selection of cork for this component was based mainly on two reasons: it possesses the mechanical characteristics necessary for permanent contact with water; and has a comfort to the touch quality important for interaction.

Since the grow bed will be in close contact with several living organisms, a quantitative laboratorial analysis was made, in order to understand the its impact in an aquaponic system.

The results of the tests were obtained and pointed to the use of darker cork, since it leached less pigment and also phenolic compounds into the water. Among these cork composites, the one with the best mechanical resistance was selected, thus ensuring a longer life for this component.

5.1.3 *Root Separator*

This component is an "invisible" barrier that allows reciprocal invasion control between fish and plants, while serving in parallel to support the biofilter. The use of transparent materials allows the user to follow all stages of the process. The piece is produced in transparent acrylic glass to ensure consistency between all elements of the design.

5.1.4 *Biofilter with aerator*

It is known that the larger the contact surface with water, the greater the proliferation of nitrifying bacteria and consequently the better the ecosystem performance. Thus, using digital prototyping in PLA (biopolymer), it was possible to evaluate several biofilter shapes. It was decided to use a triangular mesh for the realization of a cylinder, since this allowed the creation of a self-sustaining structure, dispensing with the use of additional material during the 3D printing additive fabrication process. One of the main features of the biofilter is the integration of an aeration diffuser at its base. A comparative analysis between several printed aerators was fundamental to obtain a uniform oxygen dispersion.

The biofilter is connected to the aeration pump, which routes the oxygen to its base, where there is a chamber with micro drills that allow its exit in a dispersed way (figure 2).

5.1.5 *Sediment extractor*

The sediment extractor creates allows a quick purge of the system. It operates by pressure, whenever the user exerts a vertical force. It has also been produced using a 3D printing additive fabrication in carbon fiber and nylon filament, obtaining the ideal resistance.

5.1.6 *Support structure*

This component is still under study. To this date, a preliminary structure has been used to collect data.

5.1.7 *Species selection*

The definition of the species of fish and plants to be introduced into the system is closely linked to interaction with children. The use of Garra-Rufa, selected for their interactive potential, was intended to explore a sensorial dimension through tact, establishing a proximity between the user and the fish. The same applies to the selection of plants: preference has been given to the use of perennial species, since they do not require seasonal harvesting. which could compromise the ecosystem's equilibrium. However, the system is capable of harboring other species.

6 CONCLUSION

The implementation of these systems in schools was welcomed with great enthusiasm by the entire school community. Children demonstrated great interest in actively exploring and participating in the system's assembly and care processes. The aquaponic system was considered by teachers an excellent tool to introduce practice of aquaponics in the classroom, and it was noticed that learning was directly re-

lated to the collective participation in the process.
Regarding the overall technical performance of the system, the results relate to the selection of materials and system characteristics, mainly focused on the user's interaction, rather than on technical and scientific criteria. The use of transparencies, leading to the development of algae and underdevelopment of the bacteria, is just one example. However, these scenarios can also be integrated in the learning experience, suggesting discussion subjects such as the resilience and adjustment capacity of ecosystems.

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Always use the official SI notations:

- kg / m / kJ / mm *instead of* kg. (Kg) / m. / kJ. (KJ) / mm.;
- 20°16′32′′SW *instead of* 20° 16′ 32′′ SW