CAPÍTULO 1

AQUAPONICS FOR FOOD PRODUCTION – A SUSTAINABLE VERTICAL GARDEN AT SCHOOL OF ENGINEERING OF PORTO

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Cátia A. Sousa
ISEP/P.PORTO, School of Engineering, Polytechnic of Porto, Porto, Portugal
ALiCE - Associate Laboratory in Chemical Engineering, Faculty of Engineering, University of Porto, Porto, Portugal
LEPABE - Laboratory for Process Engineering, Environment, Biotechnology and Energy, Faculty of Engineering, University of Porto, Porto, Portugal
Department of Chemical Engineering, ISEP, Polytechnic Institute of Porto, Porto, Portugal.
ORCID ID: 0000-0003-3719-4454

Roque Brandão
ISEP/P.PORTO, School of Engineering, Polytechnic of Porto, Porto, Portugal
ORCID ID: 0000-0002-1121-4878

Abel J. Duarte
ISEP/P.PORTO, School of Engineering, Polytechnic of Porto, Porto, Portugal
CIETI, School of Engineering, Polytechnic of Porto, Porto, Portugal
REQUIMTE/LAQV, School of Engineering, Polytechnic of Porto, Porto, Portugal
Department of Chemical Engineering, ISEP, Polytechnic Institute of Porto, Porto, Portugal.
ORCID ID: 0000-0003-0218-1952

ABSTRACT; The greatest increase in the worldwide human population will rise concerns about the sustainability of cities and soils, climatic changes and food access or security. Furthermore, in the present day, many urban areas around the world are grappling with challenges related to their food supply infrastructure. Urban agriculture can play a crucial role for impoverished households by enhancing food security and generating income. Nevertheless, traditional agriculture contributes to soil erosion and soil and groundwater pollution. Additionally, climate change disrupts animal life cycles and leads to species extinction, significantly reducing the availability of food for humans and other organisms. For this reason, aquaponics holds promise as a method for integrating urban agriculture for plant cultivation and safe fish production. This project aims to develop and install an optimized aquaponics system at the School of Engineering, Polytechnic of Porto (ISEP). This vertical garden was created using two tanks with circa 2,000 liters of water for fish and spans three floors, featuring three flower boxes and over 120 positions for growing vegetables. Furthermore, in conjunction with this project, pedagogical activities were developed, involving students

from various ISEP courses, including Bioresources, Chemical Engineering, Biomedical Engineering, Electrical and Computer Engineering, Mechanical Engineering, and Informatics Engineering. This project highlights a successful implementation of a soil-less vertical garden in urban buildings, embraced by ISEP, enabling the complete integration of nature into urban environments and promoting greener and more sustainable cities.
KEYWORDS: Aquaponics, sustainability, food production, food safety, urban agriculture

AQUAPONIA PARA PRODUÇÃO ALIMENTAR – UM JARDIM VERTICAL SUSTENTÁVEL NO INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO

RESUMO: O maior aumento na população humana em todo o mundo levantará preocupações sobre a sustentabilidade das cidades e solos, mudanças climáticas e ao acesso ou segurança alimentar. Além disso, nos dias de hoje, muitas áreas urbanas ao redor do mundo estão a lidar com desafios relacionados à infraestrutura de abastecimento de alimentos. A agricultura urbana pode desempenhar um papel crucial para famílias empobrecidas, aumentando a segurança alimentar e gerando rendimento. No entanto, a agricultura tradicional contribui para a erosão dos solos e para a poluição dos mesmos e das águas subterrâneas. Além disso, as mudanças climáticas perturbam os ciclos de vida dos animais e levam à extinção de espécies, reduzindo significativamente a disponibilidade de alimentos para os humanos e outros organismos. Por esse motivo, a aquaponia surgiu como um método promissor para integrar a agricultura urbana no cultivo de plantas e na produção segura de peixes. Este trabalho visa desenvolver e instalar um sistema de aquaponia otimizado no Instituto Superior de Engenharia do Porto (ISEP). Este jardim vertical foi criado usando dois tanques com cerca de 2.000 litros de água para peixes e abrange três pisos, apresentando três canteiros de flores e mais de 120 posições para o cultivo de vegetais. Além disso, em conjunto com este projeto, foram desenvolvidas atividades pedagógicas envolvendo estudantes de diversos cursos do ISEP, incluindo Biorrecursos, Engenharia Química, Engenharia Biomédica, Engenharia Eletrotécnica e de Computação, Engenharia Mecânica e Engenharia Informática. Este projeto destaca uma implementação bem-sucedida de um jardim vertical sem solo em edifícios urbanos, abraçado pelo ISEP, possibilitando a completa integração da natureza em ambientes urbanos e promovendo cidades mais verdes e sustentáveis.
PALAVRAS-CHAVE: Aquaponia, sustentabilidade, produção de alimentos, segurança alimentar, agricultura urbana

1 | INTRODUCTION

Nowadays, more than half of the global population is living in urban areas. By 2050, an increase in the urban population is expected and estimated to reach 6.5 billion people, equal to two-thirds of humanity (ALVERIO *et al.*, 2023). The rapid growth of cities in the developing world is accompanied by increasing rural-urban migration and climatic changes, which lead to species extinction (SIMKIN *et al.*, 2022). Furthermore, an extreme poverty is currently concentrated in urban cities, leading to problems associated with the city governments struggle to accommodate the rising population in these areas. Ensuring the safety and sustainability of cities requires investment in creating green public spaces and improving urban management (SIMKIN *et al.*, 2022). To achieve a sustainable development demands significantly transforming the way we build and manage our urban spaces. Creating sustainable cities is one of the 17 global goals outlined in the 2030 Agenda for Sustainable Development, specifically Goal 11 ("Sustainable cities and communities") (UN, 2023). Furthermore, world overpopulation raises concerns about food scarcity and food safety for the entire population, aligning with Goal 2 ("End hunger, achieve food security and improved nutrition, and promote sustainable agriculture") of the 2030 Agenda for Sustainable Development (UN, 2023). For that reason, the production of food in urban areas is progressively recognized as a potential strategy to meet at least part of the shift in food demands from rural and urban areas, indorsing a sustainable agriculture (ALVES, & OLIVEIRA, 2022; RIAÑO-HERRERA *et al.*, 2023). Indeed, in developed countries, urban agriculture can be a crucial strategy for low-income households, contributing to food security and income generation (KUTIWA *et al.*, 2010). An integrated approach is crucial for progress across these multiple goals and concerns. Accordingly, the practice of producing vegetables on green roofs has been gaining attention in recent years as a method to facilitate agricultural and cities sustainability in urban areas (SHUKLA *et al.*, 2021; SONG *et al.*, 2022). Rooftop gardens are becoming an important part of the recent rejuvenation of urban agriculture, and offers alternative spaces to grow vegetable products for urban markets (SIMONE *et al.*, 2023). On the other hand, plant production occupies vast regions of the surface of the Earth and have a strong negative impact on the environment by inducing soil erosion or polluting the soil and groundwater by the use of pesticides, fertilizers (RADULOV, & BERBECEA, 2023). Additionally, climatic changes are interfering with the animal life cycle, causing species extinction and dramatically reducing the availability of food for humans and other species (SIMKIN *et al.*, 2022). To overcome the cultivation and food problems, in urban agriculture, aquaponics can be a promisor method for plants cultivation and fish production simultaneously (FAO, 2016). In fact, aquaponics is a growing commercial and scientific technology which uses aquaculture effluent to grow plants and fish, offering a solution to several sustainability issues, such as limited water availability, environmental pollution, increasing fertilizer cost and depletion of fertile soils (CALONE, & ORSINI, 2022). Some authors (DANNER *et al.*, 2019; KÖNIG *et al.*, 2018; KRASTANOVA *et al.*, 2022; MAO *et al.*, 2023) give a broad perspective on the aquaponics technology and conclude that these systems can be sustainably managed only with a thorough knowledge of plant components and types. Usually, leafy vegetables have been the preferred crop to grow in aquaponic systems, as they grow well in nitrogen concentrated water, have a short growing period, do not have high nutrient requirements and there is generally a high demand for them globally (DANNER *et al.*, 2019). This approach offers an eco-friendly location for food production, benefiting both residents and external markets. Globally, in 2022, the global aquaponics systems market reached $870 million (TAHA *et al.*, 2022). As a result, various countries are striving to implement these systems to efficiently produce food. In Portugal, a few companies with the help of universities are also implemented these systems. In Porto, School of Engineering, Polytechnic of Porto (ISEP) also supported the implementation of an aquaponics system in one of its buildings. As such, this work aims to develop an aquaponic system at pilot scale to produce leafy vegetables and fish, in ISEP. Moreover, this aquaponic system was used for educational purposes, through different pedagogical activities, involving students from various ISEP courses, such as Bioresources, Chemical Engineering, Biomedical Engineering, Electrical and Computer Engineering, Mechanical Engineering, and Informatics Engineering.

2 I METHODOLOGY

2.1 Implementation of an aquaponic system

The aquaponic system was built in ISEP, in line with ISEP's sustainability policy, using two tanks with around 2,000 liters of water. The entire system was built at ISEP and consists of two tanks installed on the outside of the building, protected from direct sunlight. These tanks are connected to each other, and one of them houses the fish, where the water circulating in the system returns by gravity in a cascade, thereby promoting its oxygenation. The connection between the tanks allows the water to circulate to the 2nd tank, where the pump sends the water directly to the 5th floor. On the 3rd, 4th, and 5th floors, there are three flowerbed systems, each consisting of typical hydroponic tubes and, below them, a flowerbed running the full length of the window where it is installed (Figure 1). The flowerbeds are filled with expanded clay. Beneath the clay, decomposing microorganisms (or biofilm) are installed. When water reaches these setups, it enters the hydroponic tubes and cascades into the flowerbed. After passing along this flowerbed, it falls into the flowerbed assembly on the 4th floor. After making this journey on the 4th floor, it moves to the 3rd floor, and finally returns to the tank where the fish are located. The hydroponic tubes have more than 100 positions for growing vegetables, and various ornamental plants are planted on the expanded clay in the flowerbeds. This circulation system operates continuously to allow the flowerbeds to be flooded and drained.

Figure 1. Aquaponic system at ISEP on the 3rd, 4th, and 5th floors (photo by Jaime Neto).

2.2 Pedagogical activities with aquaponics

The first prototype of the aquaponics system appeared a few years earlier in a project from the European Project Semester - EPS course, but it was only in 2019 that a large-scale installation was carried out. The ISEP Student Association issued a challenge to its entire student community to form a group of volunteers to assist in the construction, startup, and maintenance of the system. Student involvement, therefore, began and continues on a voluntary basis. In the first year, 10 volunteer students from the Bioresources program and the Engineering programs in Chemical, Biomedical, Electrical, Computer, Mechanical, and Computer Science participated. In the following academic year, two students from the Master's program in Biomedical Engineering developed a sensor data acquisition system for physical and chemical characteristics as part of their dissertations. Additionally, a student from the Bachelor's program in Bioresources conducted their internship. The project also saw the participation of students from the Bachelor's programs in Bioresources and Electrical and Computer Engineering, as well as students from the Master's programs in

Mechanical Engineering and Computer Engineering, in maintaining the system throughout the academic year 2020/2021. Currently, there are 6 volunteer students from the fields of Chemical Engineering, Bioresources, and Biomedical Engineering who ensure its maintenance.

3 I VERTICAL GARDEN AT ISEP

The aquaponic system was seamlessly integrated into an ISEP building, without reducing the existing space or changing the building structure. It made the surroundings more pleasant with natural elements, becoming a constant point of interest for the ISEP community (Figure 2).

Figure 2. Aquaponic system integration in ISEP building (photo by Jaime Neto).

It primarily produces lettuce (Figure 3), which is the least nutritionally demanding plant, and it has produced several hundred heads over the course of 3 years of operation.

Figure 3. Lettuce production at ISEP (photo by Jaime Neto).

Other plants were tested, such as zucchinis, chili peppers, passion fruit, bell peppers, tomatoes, and cabbages, but these plants exhibited excessive growth for the space in which the system is integrated (Figure 4A and B). In terms of ornamental plants, there are “peace lilies,” begonias, aspidistras, pothos, and prayer plants that provide a typical beauty of permanent decoration. Dealing with the fish has been more challenging (Figure C), but it has hosted a community of 5 wild carps that, as they grew, were donated for breeding.

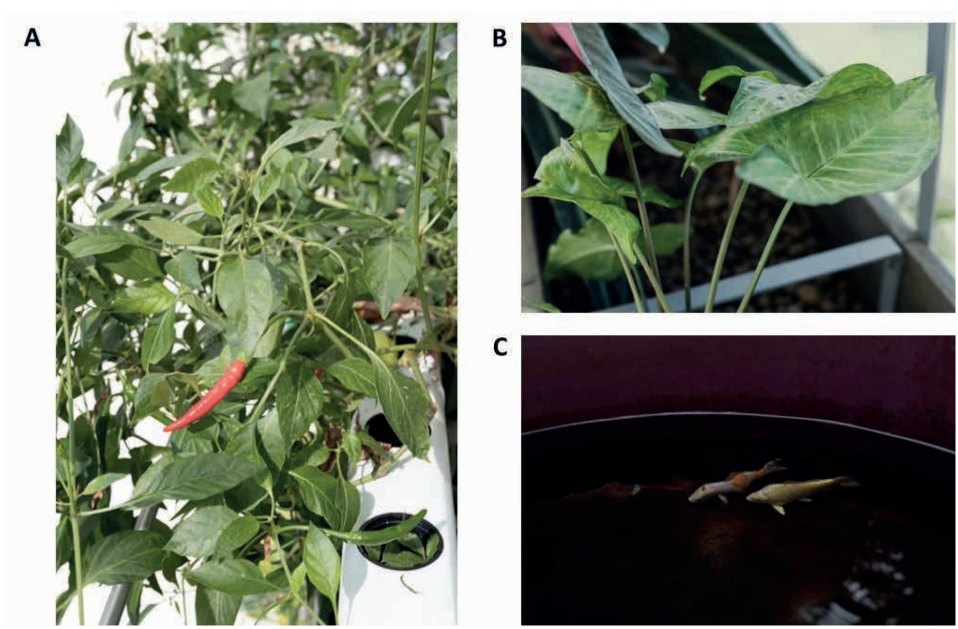

Figure 4. Other plants tested in aquaponic system. A - Chili peppers; B - Pothos (Syngonium angustatum); C – Tank for fish (photos by Jaime Neto).

The participation of students is important due to the high number of maintenance activities throughout the year, such as cleaning or inspecting the proper functioning of the water circuit. Students acquire skills in measuring physical-chemical properties and, gradually, they become involved in research activities related to the development of methods to automate the tests that are still being conducted. Students acquire skills in measuring physical-chemical properties, and over time, they become increasingly involved in research activities aimed at developing methods for automating the tests that are still ongoing. For instance, the volunteers monitor several physical and chemical properties, such as nitrates, phosphates, alkalinity, pH value, iron, and hardness, using traditional methods of analytical chemistry. Simultaneously, a system for collecting physical characteristics was constructed, including the temperature at various locations within the installation (Figure 5A), ambient humidity, luminosity (Figure 5B), circulation flow rates, the height of the fish tank levels, and a security system in the flowerbeds to prevent flooding. This system was developed by a Biomedical Engineering master's student and has been continuously acquiring data and storing information for over half a year.

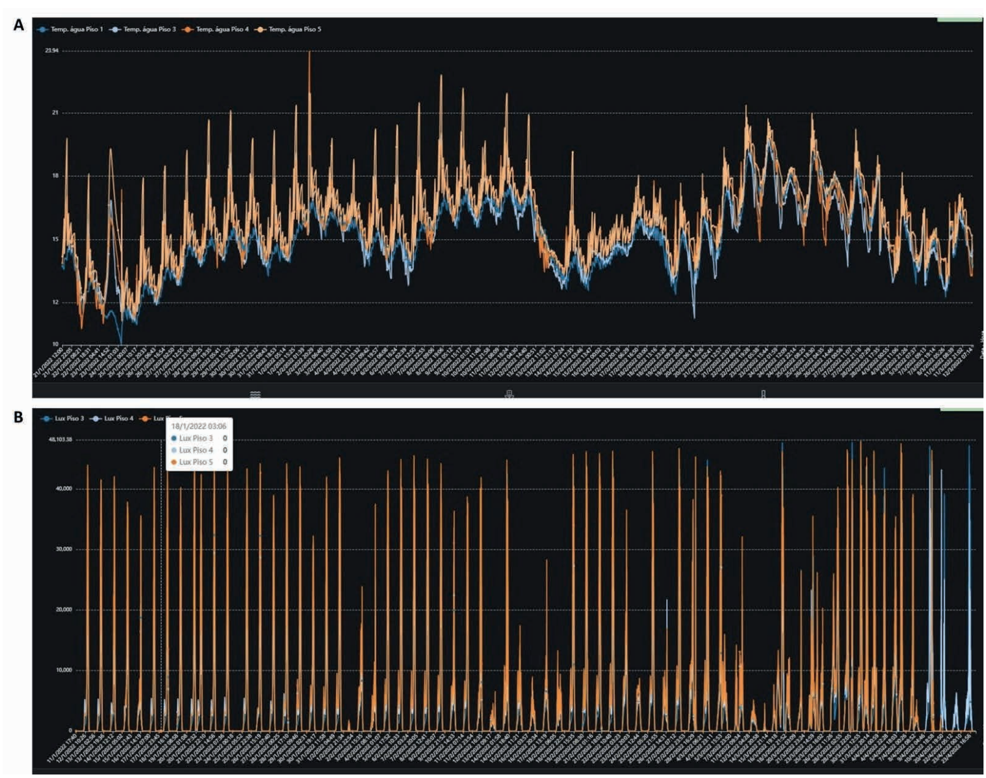

Figure 5. Aquaponic system monitorization over timer. A - Temperature; B - Luminosity.

4 I DISCUSSION

Aquaponics is a sustainable practice that combines fish farming, known as aquaculture, with soilless plant production, or hydroponics (MAO *et al.*, 2023). It operates on a closed-loop recirculation system, with the only water consumption being that lost through evapotranspiration. Nutrients circulate within the system in a cyclic manner, starting from their input in the form of fish feed and ending with their output as waste. The fish waste is initially decomposed by a biofilm reactor, typically in sand beds, and eventually absorbed by the plants. External inputs to the system's operation include the electricity needed to power the water circulation circuit (the current electric pump consumes less than €300 worth of electricity per year) and to operate the monitoring system, which has negligible power consumption compared to the submersible pump. Assuming there are no power failures, the system operates with minimal supervision. If hydroponic tube planting is maximized, with a one-month occupancy per plant site, it can produce approximately 12,000 lettuces per year. The lettuce produced through aquaponics exhibits equal or superior quality compared to lettuce produced through organic methods or even syntropic agriculture.

5 I CONCLUSIONS

The aquaponics system is easily replicable by individuals interested in having a garden but lacking land. It's a low-cost system that enables the cultivation of various types of vegetables for personal consumption. The aquaponics system implemented at ISEP is demonstrative. In fact, the system utilizes affordable materials and DIY solutions tailored to the installation locations. This approach enables us to accomplish the following: i) establish a productive installation – ensuring safe, high-quality production, close proximity to consumption, and eliminating the need for product distribution channels; ii) enhance people's well-being through their interaction with nature; and iii) engage in a mental exercise in harmony with nature, providing relaxation, stress relief, and moments of introspection.

On the other hand, although it supports fish and plants, the goal is to promote the technology of sustainable soilless fish farming and plant cultivation. The system finds its greatest utility in research, introducing innovation at the unit process level without disrupting the harmony of the symbiotic system, thus making the system much more productive. ISEP is committed to instilling values and principles in its students, acting as a catalyst for change and transformation in society. As an influencer of young minds in formation, ISEP plays a crucial role in spreading best practices in sustainability that can guide students in their future lives. Students' involvement in the design and implementation of this system was vital to its success, fostering student interaction with practical experience and research, promoting interdisciplinary teamwork, and enhancing academic achievement.

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COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

ALVERIO, G. N., SOWERS, J., & WEINTHA, E. **Displaced to cities: conflict, climate change and rural-to-urban migration**. United States Institute of Peace: Peaceworks, 2023. 978-1-60127-916-3.

ALVES, D. O., & OLIVEIRA, L. **Commercial urban agriculture: a review for sustainable development**. Sustain. Cities Soc., 87, p. 104185, 2022.

CALONE, R., & ORSINI, F. **Aquaponics: a promising tool for environmentally friendly farming**. Front. Young Minds, 10, p. 707801, 2022.

DANNER, R. I. *et al.* **Designing aquaponic production systems towards integration into greenhouse farming**. Water, 11, n. 10, p. 2123, 2019.

FAO. **Implementing aquaponics in the Gaza Strip**. FAO Aquaculture. 2016.

KÖNIG, B. *et al.* **Analysis of aquaponics as an emerging technological innovation system**. J. Cleaner Prod., 180, p. 232-243, 2018.

KRASTANOVA, M. *et al.* **Aquaponic systems: biological and technological parameters**. Biotechnol. Biotechnol. Equip., 36, n. 1, p. 305-316, 2022.

KUTIWA, S., BOON, E., & DEVUYST, D. **Urban agriculture in low income households of harare: an adaptive response to economic crisis**. J. Human Ecol., 32, n. 2, p. 85-96, 2010.

MAO, H. *et al.* **Influences of aquaponics aystem on growth performance, antioxidant parameters, stress parameters and gene expression of *Carassius auratus***. Fishes, 8, n. 7, p. 360, 2023.

RADULOV, I., & BERBECEA, A. Role of soil health in mitigating climate change. *In*: KUMAR, V. (Ed.). **Global warming - a concerning component of climate change**: Intechopen, 2023.

RIAÑO-HERRERA, D. A. *et al.* **Driving sustainable urban development: exploring the role of small-scale organic urban agriculture in Bogotá, Colombia: a case study**. Sustain. Cities Soc., 99, p. 104919, 2023.

SHUKLA, K., MISHRA, R., & SARKAR, P. **Understanding soilless engineered soil as a sustainable growing material for food production in a green roof**. Mater. Today: Proc., 43, n. 5, p. 3054-3060, 2021.

SIMKIN, R. D. *et al.* **Biodiversity impacts and conservation implications of urban land expansion projected to 2050**. Proc. Natl. Acad. Sci. USA, 119, n. 12, p. e2117297119, 2022.

SIMONE, M. D. *et al.* **A large share of Berlin's vegetable consumption can be produced within the city**. Sustain. Cities Soc., 91, p. 104362, 2023.

SONG, S. *et al.* **Home gardening in Singapore: a feasibility study on the utilization of the vertical space of retrofitted high-rise public housing apartment buildings to increase urban vegetable self-sufficiency**. Urban For. Urban Green., 78, p. 127755, 2022.

TAHA, M. F. *et al.* **Recent advances of smart systems and internet of things (IoT) for aquaponics automation: a comprehensive overview**. Chemosensors, 10, p. 303, 2022.

UN. **Sustainable development goals**. 2023. Acesso em: 18 September.