Vertical Farming – An EPS@ISEP 2018 Project

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Abstract. This paper summarises the joint efforts of a multinational group of six undergraduate students cooperating within the European Project Semester (EPS) conducted at the Instituto Superior de Engenharia do Porto (ISEP). The EPS@ISEP initiative, made available as a part of the Erasmus+ international students exchange programme, employs the principles of problem-based learning, facing students with – albeit downscaled – real-life scenarios and tasks they may encounter in their future professional practice. Participation in the project initiative outclasses most of the traditional courses through a wide spawn of its learning outcomes. Participants acquire not only hard skills necessary for an appropriate execution of the project, but also broaden their understanding of the approached problem through detailed scientific, management, marketing, sustainability, and ethics analysis – all in the atmosphere of multicultural and interdisciplinary collaboration. The team under consideration, based on personal preferences and predispositions, chose the topic of vertical farming and, in particular, to design a domestic indoor gardening solution, appropriate for space efficient incubation of plants. The paper portrays the process, from research, analysis, formulation of the idea to the design, development and testing of a minimum viable proof of concept prototype of the "Vereatable" solution.

Keywords: Collaborative learning, Project based learning, Technology, Education, European Project Semester, Vertical Farming, Aeroponics.

1 Introduction

The European Project Semester (EPS) initiative is currently implemented at 19 universities, scattered across 12 different European countries [6]. The programme is governed by the idea of facing the challenges of today's world economy and job market, where engineers will often double as entrepreneurs and work in small teams of many specialists of various professions. While being tailored for undergraduate engineering students at the 3rd or the 4th year of their degree, the project is open to any student capable of a meaningful contribution to the work. The spring semester of the academic year 2017/2018 at the Instituto Superior de Engenharia do Porto (ISEP), Portugal, had the participation of 21 students. The teams were assembled according to the team worker profile (Belbin test), the nationality and field of study of the participants, aiming at the most optimal mix of nationalities, fields of studies, and predisposed teamwork functions. Following the guidelines of the initiative regarding the optimal team size, there were three groups of five and a single group of six students. This paper focuses on the so-called SAMARA team (acronym formed by the initials of the member's first names). Table 1 presents the composition of SAMARA, showing an appropriate mix of nationalities, with a slight bias towards electrical-oriented fields.

Table 1: Team SAMARA of EPS@ISEP 2018

Name	**Country**	**Belbin Team Role**	**Field of Studies**
Anastasia Sevastiadou	Greece	Monitor Evaluator	Env. & Geotechnical Eng.
Andres Luts	Estonia	Resource Investigator	Electrical Eng.
Audrey Pretot	France	Complete Finisher	Packaging Eng.
Mile Trendafiloski	Macedonia	Complete Finisher	Comp. Science & Eng.
Rodrigo Basurto	Spain	Implementer	Mechanical Eng.
Szymon Błaszczyk	Poland	Implementer	Telec. & Comp. Science

In the first week of the programme, the teams were presented with a wide selection of possible topics to consider. Out of them, the SAMARA team, taking into consideration every member's preferences, motivation, skill set, and personal objectives, chose Vertical Farming. The SAMARA team recognised that there were multiple phenomena and social tendencies contributing to the importance of this subject. As societies become steadily more industrialised and people agglomerate in increasingly larger cities, there is a general will to reconnect with nature. The key aspect is an overall concern with the quality and purity of food – with even key fast-food market players introducing "healthy alternatives" to their core menu over the past decade. Many people are now actively avoiding ingredients and additions they believe unhealthy – and although the debate over some processes, *e.g.*, genetically modified organisms (GMO), is still ongoing without a definite conclusion [12], other practices, namely overuse of toxic pesticides in large field farming, is rightly perceived as alarming. Abuse of health standards is not the only problem faced by farming though. With the steady growth of human population, rises the demand for both food supply and the living space area. Conventional crop fields have however a tightly limited efficiency of the acreage use – and to provide more food, they require more space. Moreover, these fields are exposed to environmental threats, vermin and natural disasters alike. A single flood or drought can put at risk the well-being of a huge community. All above factors call for a transfer of our crops from – although considered beautiful by many – ineffective fields to a more controllable environment, where some risks can be eliminated and dedicated structures can be employed in order to utilise the third, vertical dimension, multiplying the spatial efficiency of farming. To top that, several sources claim that vertical indoor farms only use as little as 5 % to 10 % of water when compared with traditional means [2,11]. Yet still, simply moving the mass scale food production indoors and granting it one more dimension does not answer all concerns the SAMARA team has identified – nor it satisfies the team's set of goals for the EPS participation. Another aspect to be taken into consideration is the growing need and will to stay in touch with nature. By bringing a user-friendly farming solution directly to households, where herbs, minor fruits and vegetables like berries, lettuces, and tomatoes can be grown, not only daily contact with nature is guaranteed, but the aforementioned concerns regarding quality and healthiness of food are reassured, when each step of the food's growth can be observed and controlled in person. Hence, the SAMARA team decided to channel efforts into proposing a viable end-user consumer product, incorporating vertical farming solutions into households. Such a device would offer the user a steady supply of fresh and healthy food directly, supporting and encouraging good eating habits.

This paper presents the team's work and project outcomes organised in six sections: introduction, background analysis, complementary studies, prototype development, prototype testing and conclusions.

2 Background Analysis

Accessibility to fresh food is already a problem, expected to worsen with the growing population. It is vital for humankind to find more sustainable and environmental friendly solutions. With vertical farms, the required volume of water and land surface decreases dramatically. The following analysis helped the team designing a solution for common people and build a proof of concept prototype.

There are many vertical farming types and technologies in the market, ranging from simple soil based solutions to complex multi-level hydro-aeroponics. Typically, they provide basic seed pods, which the buyer can keep or substitute. Some products also provide a mobile application to help the user to tender for the crops. Examples of such products are:

Minigarden Vertical is a solution originating from Lisbon, Portugal [9]. The concept is an affordable, straightforward system for creation of green walls, big or small, outdoors or indoors [8]. It is a modular solution, allowing it to fit into different areas. Modules are made out of high strength polypropylene copolymer and contain additives to provide high life expectancy, so that the product will not be damaged by extreme weather conditions, such as solar radiation and changing temperatures [5]. Also the materials used are 100 % recyclable. However, plant watering cannot be said to be fully automated due to the lack of an intelligent water distribution unit. It is up to the user to water the plants regularly or to create an automated system. The product is fully mechanical and contains no electrically powered elements.

Click&Grow is based in Tallinn, Estonia, and was founded in 2010. Their mission is to make healthy food available for all people. They offer different options meant for indoor only [3]. This product is socket based, but allows to choose from many sizes. Starting from three slots up to a 51 slot Wall Farm. Each capsule hosts a seed embedded in an advanced nanotechnology growing material, labelled Smart Soil. Everything is grown without any use of GMO or pesticides, leading to healthy naturally grown greens.

ZipGrow FarmWall is a Canadian company specialized in commercial scale wall-mounted, self-sustainable solutions. The product is designed to provide low maintenance, high yield hydroponic farming system, and is modular, automated and user-friendly [13]. The wall is made of food-safe polyvinyl chloride (PVC), holding the towers in place. The main base can contain five 152 cm towers. Plants are inserted into openings in the middle tower. There is no exact number of plants which can be put inside – the user can insert as many while there is room. The towers can be easily removed from the base, allowing to harvest and plant easily.

Although the most advanced vertical farming technologies found in the market are above the budget limits of this project (which was of 100 €), the Team, after analysing the competitor devices and their market strategies, was able to identify which features to include in their own product.

3 Complementary Studies

To develop the project with adequate depth, SAMARA team has conducted research and analyses in three complementary fields. These analyses help to understand the impact and aim of the team's work.

3.1 Marketing

The marketing analysis helped the team to define the goals, target consumers and brand of the proposed solution. The "Vereatable" brand logo associates the *veritas* (truth), edible and table concepts to vertical garden, modularity, sustainability, smart control and smartphone connectivity. As nature-lovers, the SAMARA team members want to share this vertical garden way of life, where the goal is to bring the production of biological and healthy products to the household. Besides biological and healthy products being a current trend, according to the team, they are greener. The proposed Vereatable solution respects the environment, has low energy consumption, controls autonomously the water and light conditions and interfaces with the consumer via smartphone. Vereatable is created for urban, busy and connected people who want to eat more natural and healthier and improve their nature environmental consciousness. The market analysis revealed that Vereatable is competitive in the actual market thanks to the smart functionalities (smartphone connectivity and autonomous water and light control), the energy consumption and price (from 75 €). This price covers the costs of production and remaining expenses. In terms of promotion, the ideal is to have the clients sharing this novel way of life and environmental consciousness.

3.2 Eco-efficiency Measures for Sustainability

The main purpose of sustainable development is to provide solutions for the preservation of natural resources, reduce the negative impact of people on the environment and promote a greener and healthier lifestyle. The team decided to use natural resources, such as wood and recyclable materials, to create low impact. By using aeroponics, on one hand, it does not use herbicides due to the absence of fungi and, on the other hand, it recycles the nutrient solution, which is re-used in fertilization. Vereatable distinguishes itself by the minimal use of water, as it manages to use its irrigation system in a reasonable and fully controlled manner and drastically reduces the unnecessary use of water. The SAMARA team decided to support and work through the guidelines of The Vertical Farming Association, a two-year, non-profit organization focussed on promoting the industry. Vertical farming allows people to produce crops throughout the year because all environmental factors are controlled. It produces healthier and higher yields faster than traditional agriculture and is resistant to climate change. In addition, as the world's population becomes more urbanized, vertical farms can help meet the growing demand for fresh, locally produced products.

3.3 Ethical and Deontological Concerns

Throughout the duration of this project there were five critical points related with both ethical and deontological concerns: Engineering, Marketing, Academics, Environmental and Liability ethics. The team decided to follow the National Society of Professional Engineers (NSPE) list of rules [10], which are a set of moral rules engineers should adopt, as well to support and work within the guidelines of the ICC/ESOMAR International Code on Market and Social Research [4]. Since the biggest priority are the consumers, the team will not provide misleading information about the general purpose and nature of the solution, preserving its reputation. Moreover, it will conform with the relevant national and international laws and ensure the project is designed, developed, reported and documented accurately, transparently and objectively. The goal is to design the most sustainable and efficient solution to grow healthier, chemical-free products indoors, giving consumers the opportunity of a greener lifestyle. The first concern revolves around ensuring the product works properly and that all materials used are from certified suppliers. Additionally, it shall be advertised using a strictly factual description and include detailed user-friendly instructions.

4 Project Development

The **Vereatable** indoor garden has been designed as a cost-efficient solution for automated household-scale indoor farming. This does not imply being the cheapest product on the market, although the aim would be to achieve lowest sustainable selling point. The leading idea is to respect the customer's investment through high durability of the product, efficient use of resources, and expandable nature of the product, allowing possible further module acquisitions.

4.1 Requirements

The project requirements were the following: a modular solution adaptable to different areas, a 100 € budget to prioritise the use of sustainable/reusable materials, open source tools and software as well as the mandatory adoption of several international regulations [1].

4.2 Functionalities

Working with living organisms – either animals or plans – is always sensitive. For a plant to grow, its environment has to support its development as a whole. Nevertheless, since some basic principles of operation for maintaining this environment can be predicted, the developed device should: provide water and nutrition in appropriate amounts and at appropriate intervals; provide lighting of appropriate intensity and at the appropriate periods of the day; offer space for the roots and the shoot of the plant to grow and develop.

In addition, the product should offer certain functionalities to its users: fall silent and turn off the lights at night-time, preferably defined by the user to their taste, not to disturb the owner; and notify about any maintenance operations necessary to keep it operational. These can be realised through the establishment of wireless connection and the development of a mobile application.

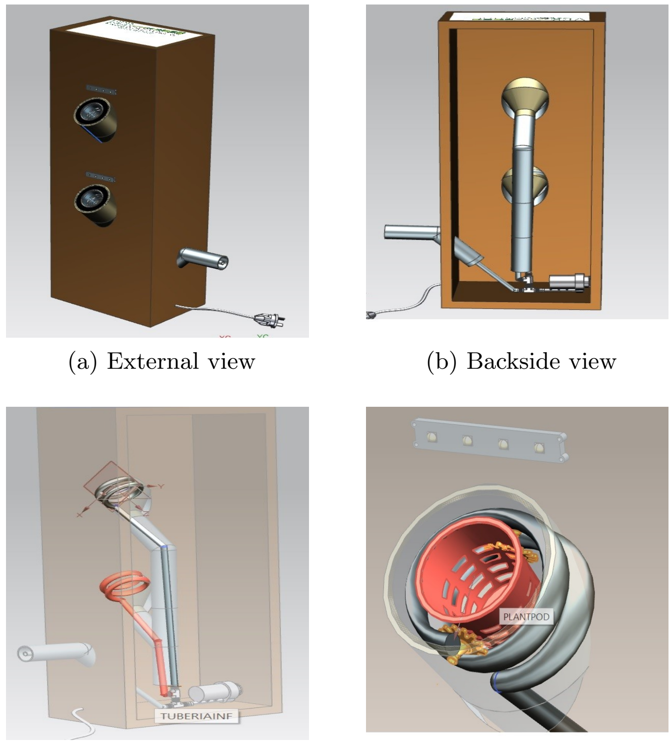
4.3 Structure

Figure 1 presents the computer-aided design (CAD) model of the prototype module. Figure 1a and Figure 1b show the module as a whole, and Figure 1c and Figure 1d focus on the piping and plant socket chalice details. The overall size of the module is 30 cm by 20 cm by 80 cm (width, depth, height). The casing is made of plywood and the water distribution inside uses PVC piping elements.

4.4 Control

The core of the prototype control system is an ESP-12E micro-controller by Wemos, operating under NodeMCU firmware. It has been chosen over the Arduino family of micro-controllers, one very well established for use in similar scale applications, due to comparatively higher computational power, embedded wireless connectivity and lower average price [7].

A digital TSL2561 I2C luminosity sensor and a simple analogue liquid level sensor are connected to two ESP-12E inputs and a single red-green-blue (RGB) light-emitting diode (LED) and three transistor-based relay circuits, to control components with voltages higher than the operational voltage of the micro-controller, are connected to four ESP-12E outputs. The relays are managing two 12 V LED bars and a 9 V water pump. The circuit as a whole is powered by a 12 V direct current (DC) power supply unit, with a voltage step-down converter to 9 V DC. Appropriate limiting resistors and a fly-back diode are applied where needed.



(a) External view (b) Backside view

(c) Piping view (d) Plant socket

Fig. 1: Design structure

The control software includes: a LUA program installed in the micro-controller, which controls the components directly connected to the micro-controller. A Microsoft .NET server installed on-line, providing endpoints to the prototype and the smartphone. Finally, a natively-developed Java mobile application for Android platforms, offering a friendly user interface. All three pieces are interconnected through the Internet.

The control flow is subdivided in two segments, one handling the start up procedures necessary to achieve full functionality and the other supervising the continuous, ongoing work of the device once it is enabled. Taking into consideration the limited capabilities of the micro-controller processor as well as its limited access to certain elements of the system, *e.g.*, the database, part of the decision-making process is being outsourced to the server, where a batch of sensor readouts is exchanged for a batch of control requests every one minute.

5 Tests and Results

The SAMARA team conducted a series of tests covering the different subsystems:

Water Distribution System: The water pump has to produce a water flow with the right pressure for the sprinklers to create water drops over the plants. The output pressure is controlled through pulse width modulation (PWM). This watering process occurs periodically during the day. The time interval is customisable via the user-device interface. The initial test identified the need to adjust the piping. Once fixed, the plant chalices were successfully irrigated drop by drop. While the duration and frequency of the irrigation was successfully controlled using the developed mobile application, it was not possible to control the intensity of the pump – the motor did not react to any PWM settings beside the full duty cycle of 100 %, allowing only for a digital on/off control, rather than a gradual one.

Water Recollection System: The passive water collection system was designed collect any excess of water back to the water reservoir for the safe operation of the electrical components. The water recollection system conducted successfully any water excess back to the reservoir tank.

Reservoir Water Level Sensor System: The level sensor measures the water level inside the storage tank to inform the user, via the on-device feedback LED and the user-device interface, of the need to refill the tank. Once the proper relation between the sensor reading and the water level relation was found, the device worked as expected.

Lighting System: The LED bars, which are positioned above the plants, are intended to provide the luminosity required for growing plants. By default the bars are on, with the exception of user define curfew periods and when there is sufficient light. The LED bars offered full range of control via software, allowing for easy modulation of the light intensity. Due to the limited time available, the LED bars used in the prototype do not have adequate spectrum for growing plants, but they will be substituted in the final product.

Ambient Light Sensor System: The high-resolution luminosity sensor is expected to detect when the ambient lighting is sufficient to support the growth of plants. At such times, the lighting system is deactivated to increase the overall sustainability of the product. The digital sensor was placed on a range of different environments in order to check if its readings complied with the specification. The sensor worked as expected.

On-device Feedback LED: The RGB LED diode, located on the structure of module, provides a simple direct communication with the user. The diode in question is anticipated to react to the most important events, such as enabling wireless connection, depletion of resources or internal software errors. The diode should use different colours and uptime patterns for the various events-of-interest. While the diode was easy to connect and program, the quality of some colours was significantly poorer than others – while distinguishable shades of blue were easily achievable, yellows and oranges were mostly contaminated by their green component. Consequently, the choice of colours was adjusted. This motivates the need to find a different RGB LED.

User-device Interface: The smartphone mobile application is the main user-device interface. It is expected to offer the user insight into the operation of the device, allow the user to modify the user-dependent variables and notify the user about the status of the device. The mobile application and the micro-controller interact via a dedicated webserver, which offers endpoint methods for both client devices. The fine-tuning of these three software modules took the team more effort than anticipated. The remote webserver was deployed on an independent host, reachable by both the micro-controller and the mobile application through standard Hypertext Transfer Protocol (HTTP) messages. The webserver endpoint methods were successfully tested, first with artificial, mock-up requests from the Postman environment, and, then, through the counterpart code. In the end, a simple but stable communication system was established between the device and the smartphone.

6 Conclusions

The main objective of this project was to develop a modular and sustainable vertical farming solution for personal use. The project started with the analysis of the existing solutions, followed by complementary studies covering project management, marketing, sustainability and ethics. From this initial research, the SAMARA team set the requirements of the Vereatable indoor garden, a solution made for people who want fresh and healthy food, but without the time or the space required to grow it themselves. The proposed solution was designed to use recyclable materials and consume energy parsimoniously for sustainability reasons. Because of its specific features, Vereatable fosters sustainability and healthy eating in urban environments. The Team designed and assembled the prototype, including the control system, and, then, developed and debugged the different software modules. The research and development performed by team SAMARA provides a good base for new sustainable vertical farm products. The Team hopes to inspire new ideas to reduce the impact of today' s agriculture in the environment and provide a more greener and sustainable way of life.

Considering the EPS@ISEP process, the Team reports that, at the beginning of the semester, they were faced the problem of building a solid team with members from different cultures and using English as communication language. In the end, this experience was considered a preparation for future professional life, where similar situations are bound to occur. Regarding this collaborative learning experience, the team members reveal having learned to trust and help each other, to work in a multinational multidisciplinary team and to discover new things about themselves, as stated in the following opinions:

Anastasia Sevastiadou :"*I deeply believe that living abroad and participating in EPS was a crucial step in my life. Not only did it brought knowledge in various academic disciplines, but it also gave me the opportunity to work with people from different countries and different cultural backgrounds, to improve my English and learn some Portuguese. EPS taught me a lot about teamwork and how important communication skills are in a group project. The prospect of personal development is one more reason among the numerous others that made me participate in EPS, in that case, I conceder this experience very profitable.*"

Andres Luts: "*EPS was an amazing experience for me since I was working with people from different fields of study. This greatly improved my research abilities and I also improved my abilities in my field of work. Additionally, living in a new country in an international environment was something new for me and I learned a good deal of life skills.*"

Audrey Pretot: "*EPS was the most impactive experience of my short life. As French without a really good English, I felt my language skills improved along the semester. With some difficulties at the beginning of the semester, but, thank for goods team,mates, patience and motivation, I realized that I could overcome all difficulties. I learned a lot about project management, teamwork, marketing, communication and other fields which weren't mine. But I think that the most beautiful thing in EPS is learning about yourself, change your point of view about your own personality, become a little bit more mature and objective, improving yourself. Knowing your character even more in each difficult situation I needed to face at work with really different team mates from a different culture and in everyday life in a foreign country (a beautiful one) was really amazing. Even if sometimes this semester was frustrating thank you to my teachers, thank you to my classmates and especially thank you to my team mates.*"

Mile Trendafiloski: "*EPS was a wonderful experience for me, having to work with people of different nationalities and different backgrounds. I learned a lot about teamwork, consistency in work, product development and I greatly improved my current field of knowledge. To add more, I believe that EPS did not only help me with my academic and practical knowledge, but I acquired some assets that can be useful in my life and made new friends that hopefully will last throughout my lifetime.*"

Rodrigo Basurto: "*I have never worked like this before, I mean with engineers from different fields, making it possible to know and learn new things from them. Build a real project with its real issues that only appear in the real life made that project a real challenge to me. I really liked the semester and it has been profitable academically and also for growing as a person.*"

Szymon Błaszczyk:"*Through participation in the EPS programme, I have shone a new light on the set of my skills and assets. Having a bit of a control-freak attitude towards the projects I get involved with, and having jack-of-all-trades interests, I usually try to pitch into every single aspect of the work done, be it for better or for worse. Faced with the mere size of this EPS assignment, throughout the semester I have learned how important it is to simply put trust in my team mates' qualifications and the quality of their work. The multicultural environment itself wasn't something new to me, as I have been active in a Europe-wide student organization in the past years. As far as the technical side of the project considered, I got to work with some new technologies that never before got my interest, but in the end proved to be interesting and may get more of my focus in my future work.*"

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