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 the future on the job market. 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, out of an initial set of topics available, based on personal preferences and predispositions, found the most interest in trailing the topic of vertical farming, and in rendering their own approach to an indoor gardening solution, appropriate for space efficient incubation of plants. The paper portrays the research, analysis, and the thinking process behind the formulation of the idea, as well as details the design, development and testing of a minimum viable proof of concept prototype of the "Vereatable" solution.

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

1 Introduction

The European Project Semester (EPS) initiative is implemented – as of May 2018 – at 19 universities, scattered across Europe, located in 12 different countries [9]. 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. Participants have not been given the privilege of team-splitting since they did not know each other beforehand. Instead, 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, an uneven division was performed, forming three groups of five and a single group of six students. This paper focuses on the biggest of the teams, labelled with number 1.

Table 1 presents the composition of Team 1, including an appropriate mix of nationalities, with a slight bias toward electricity-oriented fields. The team assigned themselves the name of SAMARA – an acronym formed of the initials of all member's first names – and will be referred to accordingly further in the text.

Table 1: Team 1 (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

The team has been offered a wide selection of topics possible to be considered in the year 2018's EPS@ISEP edition. Out of them, once taking into consideration every member's preferences, motivation, skill set, and personal objectives, the issue of Vertical Farming has been uniformly selected. There are multiple phenomena and social tendencies contributing to the importance of this subject, as perceived by the SAMARA team. While our lives become steadily more industrialised and dense agglomerations are growing in size, one can observe people's will to reconnect with nature in a strong bond. The key aspect is an overall concern with the quality and purity of our food – with even key fast-food market players like McDonald's having introduced healthy alternatives to their core menu over the past decade or so. Many people are now actively avoiding ingredients and additions they believe to put their health at risk – and although the debate over some processes, e.g. genetically modified organisms (GMO), is still ongoing without a definite conclusion [15], 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 the traditional mean of 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 have to occupy even 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 [1,14]. 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 a growing need and will to stay in touch with nature. By bringing a user-friendly farming solution directly to a person's household, where herbs, minor fruits and vegetables like berries, lettuces, and tomatoes can be grown, not only everyday contact with nature is guaranteed, but the aforementioned concerns regarding quality and healthiness of one's food are reassured, when each step of the food's growth can be observed and controlled in person. Hence, the SAMARA team has decided to channel its efforts into proposing a viable end-user consumer product which would incorporate vertical farming solutions into the user's household. Such a device would offer a steady supply of fresh and healthy food directly in one's kitchen, supporting and encouraging good eating habits.

This paper presents the team's work and project outcomes following a separation of topics as given: an introduction, background analysis, complementary studies, prototype development, prototype testing, and further opportunities and conclusions. Each of these fields has a section assigned accordingly, totalling to six distinctive pieces, each further sub-sectioned according to the needs of manners discussed.

2 Background Analysis

Fresh food accessibility is an everyday problem, which is expected to be ever bigger issue every following year thanks to growing population and decreasing fossil fuels. It is vitally important to understand that humankind has to find solutions that are more sustainable and environmental friendly. By using vertical farms the amount of water used is decreased dramatically and also the land surface needed. In the sequel, analysis will be completed to show the path that lead the team to the final model and to make the product more attainable for everyday people thanks to thoughtful planning and research.

2.1 Existing Competitors

There are many types and technologies of vertical farms in the market, ranging from soil based basic solutions up to complicated multi-level hydro-aeroponics. Typically they provide users basic seed pods, when the product is acquired and after that, users can buy/order ones they prefer. Some products also provide app feedback to make growing easier. Examples of such products are:

Minigarden Vertical is a solution originating from Lisbon, Portugal [12]. Their concept is an affordable, straightforward system for creation of green walls, big or small, outdoors or indoors [11]. 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 [8]. Also the materials used are 100 % recyclable. However, plant watering cannot be said to be fully automated with 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 the people of Earth. They offer different options meant to be used indoor only [2]. This product is socket based, but allows to choose from many sizes. Starting from three slots automated system up to a 51 slot Wall Farm. Each capsule hosts a seed embedded in an advanced nanotechnology growing material, labelled as Smart Soil. Everything is grown without any use of GMO or pesticides, leading to all healthy naturally grown greens.

ZipGrow FarmWall is a Canadian company specializing in commercial scale wall-mounted, self-sustainable device. The product is designed to provide low maintenance, high yield hydroponic farming system, that is modular and automated. Their product is very user-friendly [16]. The wall is made of food-safe PVC that holds towers in place. The main base can contain five 152 cm towers. Plants are inserted into openings in the middle tower wide. There is no exact number of plants that can be put inside – the user can insert as many as there is room. The towers can be easily removed from the base, allowing to harvest and plant easily.

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

3 Complementary Studies

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

3.1 Marketing

The marketing part helped the team to point out its goals and target consumers. That is how we build our brand logo "Vereatable indoor garden" with the behind meanings of truly eatable, vertical garden, modularity between several modules and smartphone connectivity. As nature-lovers we wanted to share our convictions about the vertical garden way of life. Biological and healthy products are a trend from now but for the team it is a real healthier and greener manner to eat. Our product is respectable about the environment and energy consumption and helps people in their everyday life. The goal of our vertical garden is to bring consumers biological and healthy products home made and directly on hand. We have developed a vertical garden connected with the consumer smartphone and autonomous in water and light to make easier the culture of plants. 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 on the actual market our proposed product would be really competitive thanks to all our functionalities (water and light distribution system), the energy consumption and the shape for the price (from 75 €). Our price is studied only to cover the costs of production and suit to our expenses. The goal is to cheer our clients to share this better way of life and environmental conscious, which is really important for us more than any profits.

3.2 Eco-efficiency Measures for Sustainability

The main purpose of sustainable development is to provide solutions for the preservation of natural resources. Its aim is to save water and reduce the negative impact of people on the environment and guide them on a greener and healthier lifestyle. The team decided to use natural resources, such as wood, to create a system with low impact, choosing small impact and recyclable materials. 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. Our Vertical farm is distinguished for 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. We decided to support and work through the guidelines of The Vertical Farming Association, a two-year, non-profit organization focused 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 local produce.

3.3 Ethical and Deontological Concerns

Throughout the duration of this project there are five critical points that are in relation with both ethical and deontological concerns: Engineering, Marketing, Academics, Environmental and, finally, Liability ethics. The team adopted the National Society of Professional Engineers (NSPE) list of rules which is a good example of what an engineer should apply to his moral code. Our team decided to support and work within the guidelines of the ICC/ESOMAR International Code on Market and Social Research, which is based on 8 key fundamentals. The team has decided to behave ethically and shall do anything that might damage our market reputation. Our biggest priority is the consumers and, as a result, we shall not do anything which might damage our reputation such as misleading information about the general purpose and nature of the project. We will conform to all relevant national and international laws and we will ensure that the project is designed, carried out, reported and documented accurately, transparently and objectively. Our goal is to figure out the most effective way not only to have a smaller impact on the environment by the means of sustainability and efficiency but also healthier, insecticide-free products and the opportunity of a greener way of life for our consumers. Our first concern revolves around testing that the product works properly and making sure that all of the materials that were used are from certified suppliers. We need to make sure that the application is fully factual and the instructions on how to use it are concluded, before putting our product available on the market.

4 Project Development

The **Vereatable Indoor Garden** has been thought through 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 to spread necessary spendings in time.

4.1 Requirements

The project has been bounded by certain requirements as within the topic proposal. These were: "Propose a modular solution, make the design adaptable to different size areas", followed by an array of programme-wide prerequisites: to constrain the spendings to a 100 € budget frame, to prioritise the use of sustainable/reusable materials, to use and develop open source tools and software, to adopt the International System of Units[13], and to comply with the following European Union regulations: 2006/42/CE 2006-05-17 on Machinery[4], 2004/108/EC 2004-12-15 on Electromagnetic Compatibility[3], 2014/35/EU 2016-04-20 on Low Voltage[5], 2014/53/EU 2014-04-16 on Radio Equipment[6], and 2002/95/EC 2003-01-27 on Restriction of Hazardous Substances[7].

4.2 Functionalities

Working with living organisms – either animals or plans – is always complicated. These cannot be taken apart and separately tried out under different aspects and in different fields. For a plant to grow its environment has to support its development as a whole. Nevertheless, some basic principles of operation for maintaining this environment can be predicted, and so the developed device should: provide water and nutrition, in appropriate amounts and at appropriate intervals; provide lightning, of appropriate intensity and at the appropriate time of the day; offer space for the roots and the shoot of the plant to grow and develop.

Besides that, the product should offer certain functionalities to its users, therefore being able to: fall silent and turn off the lights at the night-time, preferably defined by the user to their taste, not to disturb the owner with its operation; offer reminders about any maintenance operations necessary to keep it operational. These could be realised through the means of wireless connection leading to a smartphone based application, involving the user's smartphone as a control terminal.

4.3 Structure

Figure 1 presents the CAD model prepared of the prototype device. Figures (a) and (b) show the machine as a whole, and figures (c) and (d) focus on some important details, such as the structure of the plant socket chalice.

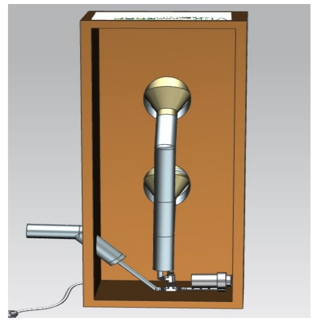
The overall size of the device is 30 cm by 20 cm by 80 cm (width, depth, height). The casing is currently being made of plywood and the water distribution inside uses PVC piping elements.

4.4 Control

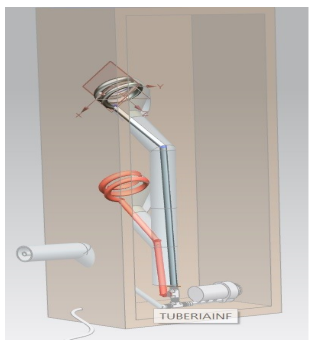
The core piece of the device's prototype control system is an ESP-12E chipset based LOLIN micro-controller by Wemos, operating under NodeMcu firmware. It has been chosen over the Arduino family of micro-controllers, one very well established for use in similar scale applications, due to comparatively higher computational power, embedded wireless connectivity, and lower average price [10].

This ESP type CPU unit is wired in with two different sensors: a digital TSL2561 I2C luminosity sensor and a simple analogue liquid level sensor unit. The connected outputs are a single RGB LED and three transistor-based relay circuits, appropriate for control over voltages higher than the operational voltage of the micro-controller. These are managing two 12 V LED bars and a single 9 V water pump. The circuit as a whole is powered by a 12 V DC unit, with a voltage step-down converter decreasing that to 9 V DC for the devices rated below the source's voltage. Appropriate limiting resistors and a flyback diode are applied where needed. Figure 2 depicts the electric schematic of the whole circuitry.

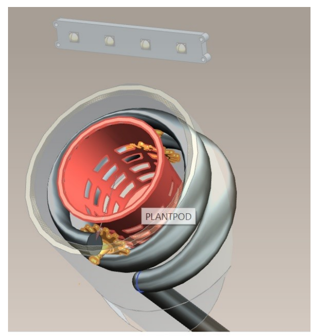
(a) View of the model from outside



(b) Backside view



(c) Internal piping view



(d) Detailed plant socket

Fig. 1: Design structure

The software in control is divided into three parts: a simple LUA program on the micro-controller, in direct charge of the components via the board's pinouts. A Microsoft .NET server installed on-line, providing endpoints to the prototype device and a smartphone. Finally, a natively-developed Java mobile app for the Android platform offering an easy to use interface for users' interaction. All three pieces are interconnected through the Internet.

The control flow of the core device is subdivided into two segments, one handling the start up procedures necessary to achieve full functionality (Figure 3) and the other supervising the continuous, ongoing work of the device once it has enabled (Figure 4). Taking into consideration limited capabilities of a simple 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 toward the server, where every cycle of operation (default duration of which is assumed as one minute) a batch of sensor readouts is exchanged for a batch of control requests to be executed (Figure 5).

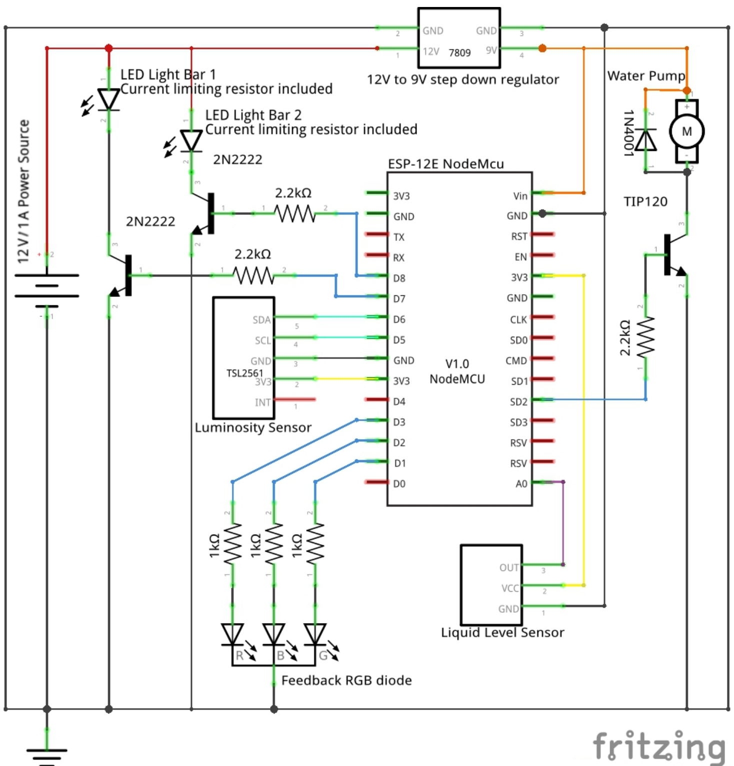


Fig. 2: Electric schematic of the control system

5 Tests and Expectations

As of the moment of writing this paper, the development of the prototype is being finalized, and no specific tests have yet been conducted. Nevertheless, with the components already being obtained, a whole series of scenarios can already be defined and scheduled for the examination. Element-by-element testing, also known as unit testing, can be conducted, incorporating both an appropriate operation of the hardware and intended behaviour of the software in control of it. Once each separate segment of the device is tested in isolation, integration tests shall begin, interconnecting the building blocks of the device and testing their cross-interactions up to the point at which full functionality is achieved.

5.1 Water Distribution System

The water pump is expected to provide enough pressure for the water from the reservoir to reach the plant-socket chalices and to pass through the sprinkler heads in there at a rate high enough for the creation of drops but not as overwhelming as to put the plants' roots at risk. The output pressure should

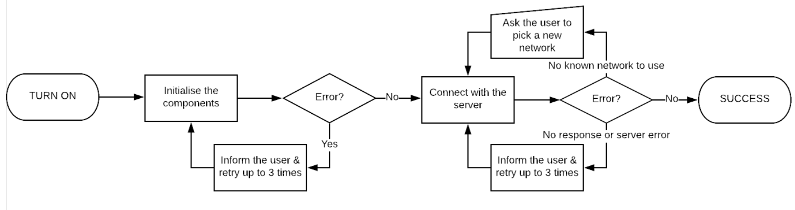


Fig. 3: Operation flow for the Device's initialisation

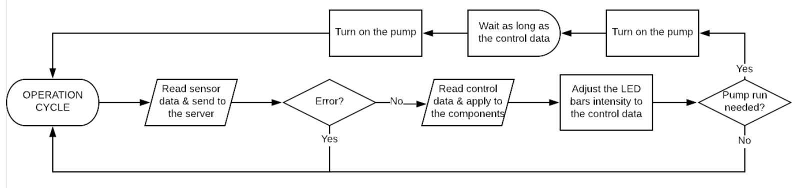


Fig. 4: Operation flow for the Device's continuous operation

be controllable through the means of software controlled pulse width modulation. The watering described above is not supposed to be a constantly ongoing process, but a temporary burst occurring in cycles throughout the day. Length of a single pumping run, as well as the time interval between individual busts, should be under control of the software, with a room for customisation via the user-device interface.

Test: The first test run left a lot to be desired in terms of the flow pressure. This however proved to be a case of not adequately secured connection within the tubing net. Once that has been discovered and fixed, the system proved to fulfil its basic objectives, delivering the water from the reservoir tank to the plant holding chalices. The duration and frequency of the watering sessions have been successfully controlled via the software means. It was not possible however 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 an analogue-like, gradual one.

5.2 Water Recollection System

The expectations toward the passive collection system are to recollect any water exceeding the plants' needs and direct it back to the water reservoir, in reasonably undisturbed and quiet manner. Humidity leakage should be kept as low as possible, for the sake of the safety of operation of the electrical components of the device.

Test: The water recollection system has shown no signs of leakage and successfully redirected any water excess back to the reservoir tank.

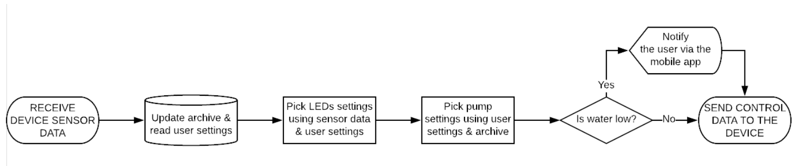


Fig. 5: Operation flow for the Server's handling of an incoming transmission

5.3 Reservoir Water Level Sensor System

The liquid level sensor oversees the reserves of water inside the water storage tank. Upon depleting the water below a level sufficient for continuous operation in foreseeable future, the user should be informed about a need of a refill through the means of on-device feedback LED and through the user-device interface.

Test: Although the sensor used caused minor inconvenience unexpectedly mapping the depth of submersion into numerical readings in an exponential way, once the proper relation has been found, the readouts allowed tracking changes in the water reserves and the device proved to react them as expected.

5.4 Lightning System

The LED bars above each of the plant habitats are expected to provide enough luminosity for an appropriate plants' growth. They are to work constantly throughout the day, with two exceptions. At a user-defined period, considered to be a curfew, the lights are to be shut down. The other exception comes from an interaction with the ambient light sensor system described below.

Test: The LED bars offered full range of control by the software means, allowing for easy modulation of the light intensity. That being said, at the maximum capacity of slightly above 2000 lux, the elements used for the prototype could be upgraded in the upcoming prototypes to improve to conditions offered to the plant cultivated.

5.5 Ambient Light Sensor System

The high-resolution luminosity sensor is expected to detect the situations in which the ambient lighting present in the room is on its own enough to support vegetation. At such time, based on the feedback from the sensor system, the lighting system should deactivate as to increase the overall sustainability of the product.

Test: The digital sensor has been placed on a range of different environments in order to check if its readings fall in accordance with the usual ranges documented in research. The sensor did not malfunction in any way and its feedback did not exceed nor fall behind the expected bounds.

5.6 On-device Basic Feedback LED

An RGB LED diode shall be placed within the chassis of the device, having in mind the need for a simple direct communication with the user. The diode in question is expected to react accordingly to the most crucial events handled by the device, such as enabling wireless connection, depleting the resources collection, or experiencing internal software error requiring a restart of the device. The diode should use different colour and uptime pattern for various events-of-interest from the user's point of view in order to maintain readability.

Test: The diode installed has been easy to connect and program, yet the quality of representation of some parts of the colour spectrum turned out to be significantly poorer then others - while distinguishable shades of blue were easily achievable, yellows and oranges were mostly contaminated by their green component. Because of that, the choice of colours utilises has been adjusted to the possibilities of the elements. No issues have been found turning the diode on and off, also at high frequency. Fading proved to by unnecessarily complex operation for the little benefit it offered.

5.7 User-device Interface Channel

Perhaps the highest tier of complexity is introduced through the user interface based on the use of a smartphone mobile app. As the micro-controller used for the device comes with a native Wi-Fi connectivity and well-documented web-based functionalities, it will be connected to a dedicated server.

The mobile app is expected to offer insight into the operation of the device (e.g. summarising the periodical use of water), to allow modifying the user-dependent variables in the software (e.g. the curfew hours), and to offer notifications and reminders about the device (e.g. about the need of water reservoir refill).

Test: Aligning and fine-tuning all the elements of the software system took the team more effort than expected at first, yet in the end software for all three platforms would have been ready. Functioning as a middle-man, the remote web-server has been enabled on an independent hosting, where both the micro-controller within the device and the mobile application could reach it through the standard http web protocols. Endpoint methods dedicated to communication with both of the client devices have been tested, first with artificial, mockup requests from the Postman environment, then through the counterpart code. Some tweaks had to be done on all ends considered to take into account limitations of each of the platforms. In the end, a simple but stable system has been created.

6 Conclusions

The main objective of this project was to develop a sustainable solution regarding vertical farming for personal use. Before starting to develop a product, a lot of research was required. For this research it was best to start with evaluating the different existing solutions to this problem. The second aspect that needed research and discussions were the different topics of project management, marketing, sustainability and ethics. Out of all this research the different requirements of The Vereatable, indoor garden were set. The Vereatable indoor garden is made for people who want fresh and healthy food but don't have the time or space to grow it themselves. Our goal was to make it as sustainable as possible by using recyclable materials and consuming very little energy. Because of its specific features and target it will fit right in a modern world, where sustainability and healthy eating are a big part of everyday lifestyle.The Team designed a prototype and a control system, built and assembled the electrical components, developed the software and eventually finished the prototype.

The research and development done by team 1, team SAMARA, of the EPS@ISEP provides a good base to work on new sustainable products regarding vertical farms. The team hopes to inspire new ideas to other people with our work because we believe that through our project on vertical farming we entered a field with great opportunities to change today' s agriculture impact on the environment and provide a more greener and sustainable way of life.

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