Sustainable Food Production Through Vermicomposting
An EPS@ISEP 2021 Project

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Abstract

This paper reports the research and development of a smart and sustainable food production system through vermicomposting. The main goal of the project was to design, simulate, test and build a prototype following ethical and sustainable conduct. Wormify aims to solve the problem of feeding the growing global population, and to prevent food waste from going to landfills. These objectives were pursued by designing a modular system for urban rooftops or small balconies. Several modules can be connected to form a place where residents can meet and socialise. The system includes technical components that allow monitoring of the device through an app/website. The present paper goes through the state of the art, background research regarding sustainability, ethics and marketing, the concept and design, the development and final results.

Keywords— vermicomposting, food production, food waste, sustainability, IoT

1 Introduction

The European Project Semester (EPS) consists of a study program offered by different European universities, including Instituto Superior de Engenharia do Porto (ISEP). EPS involves students from different countries and majors working together to create an innovative sustainable and useful product, building a proof of concept [11]. In 2021, a team with members from Portugal, Roumania, Belgium, Poland, and North Macedonia studying Biomedical Engineering, Industrial Design, Product Development, Mechanical Engineering and Applied Computer Science, and Information and Communication Sciences for Business and Management joined forces to design and build a product that inspired and connected the people in the team.

From the list of open-ended project briefs offered to the EPS class in 2021, the team chose to smartify an everyday object. The research led to the problem of the population growth on Earth and the need to provide food to everyone. The demand for increased food production generates considerable stress on resources, such as land, water, and nutrients, making it urgent to find alternative, sustainable and reliable methods to produce the food [6]. In this context, solutions such as aquaponics and vermiponics can play a decisive role. Aquaponics takes advantage of the symbiotic relationship between plants and fish. With water re-circulation, bacteria convert fish waste into nutrients/food for plants, purifying the water [1]. Vermiponics is a novel way to grow plants that uses the nutrients from worm castings (specifically from worm-tea) to grow plants in a soil-less (or hydroponic) environment. The worms decompose organic matter and food scraps and produce an organic fertiliser, by a process called vermicomposting [13]. After researching and analysing existing products and the multiple involved aspects, the team decided to create a modular keyhole garden for urban buildings, which consists of a raised bed with plants, and a composting basket in the centre.

Additionally, vermicomposting transforms food waste into soil nutrients. Food waste is a global issue. In the European Union (EU) only around 88 million tonnes of food are wasted annually, representing costs of 143 billion €. Food waste is an ethical and economic issue, but it also depletes the environment of limited natural resources. It is estimated that food waste generates eight per cent of Global Greenhouse Gas Emissions. The food wasted should be distributed to the 33 million people in the European Union (EU) suffering from hunger and malnutrition [4]. Most of the food waste ends up in landfills, making up more than 50 per cent of global landfill waste [7]. This value can be reduced by transforming organic food waste into organic fertilisers through vermicomposting. The modular keyhole garden is a way of doing so.

The proposed system is able to monitor the most important parameters, ensuring optimal conditions both for the worms and the flora. The budget for the prototype was 100 €, and the default requirements included the selection of low cost solutions, open source and freeware software, adoption of the International System of Units, and compliance with EU Machine Directive (MD), Low Voltage Directive (LVD), and Restriction of Hazardous Substances (ROHS) in Electrical and Electronic Equipment Directive.

In this paper, the modular keyhole garden is introduced, starting with the background of the product (regarding related solutions, ethics, marketing and sustainability), then the description of the proposed solution, followed by a brief discussion. Finally, it closes with the conclusions and future work.

2 Background

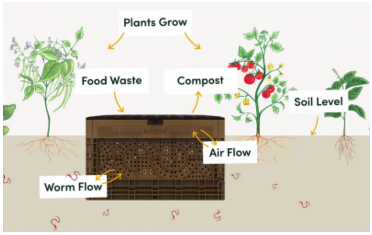
The background section covers existing solutions, ethics, marketing and sustainability studies regarding the product.

2.1 Related Work

The sustainable production of food in urban areas is still a developing market, mainly when it comes to imitate natural systems. Regarding vermicomposting, there are a few solutions available.

For outdoors, *Subpod* (Figure 1a) and *Urbalive* (Figure 1b) have two different approaches. The first and most natural solution is a composting basket that can be inserted on the ground [14], but it needs an outdoor space. The latter is a small planter with a self-watering system [15], which can be deployed on small spaces, such as a balcony.

Indoors solutions are, generally, less sustainable than outdoor ones because they require more maintenance and distance themselves more from nature processes. However, they are the most sustainable, interesting, and practical options for urban areas (e.g. apartments or restaurants) because they can be adapted to any home. *Urbalive* also provides products for indoors, such as those in Figures 2a and 2b. The first is a traditional vermicomposter, while the second is a planter with a self-watering system. Therefore, by acquiring the two, one could use the worm-tea produced in the composter to provide nutrients to the plants [15]. *Biovessel* compostes food waste (Figure 2c). It presents an appealing design and aims to bring nature to urban homes, using vermicomposting to create a more sustainable lifestyle [2]. This product does not allow food production, only vermicomposting.



(a) Subpod [14]

(b) Urbalive Outdoor Planter [15]

Figure 1: Outdoor Solutions

(a) Urbalive Worm Farm [15]

(b) Urbalive Indoor Planter [15]

(c) Biovessel [2]

Figure 2: Indoor Solutions

These solutions are interesting and useful, but there is a need to embrace further energy efficiency, ethics, and sustainability. The latter will be discussed on the next subsection.

2.2 Sustainability

Sustainability is a strong concept that has the value to keep us healthy as a society. Therefore, the team approaches sustainable development in its three pillars - environmental, economic, and social (illustrated in Figure 3) - to keep the environment unharmed. Wormify is a suitable and sustainable alternative for futuristic urban farming methods, answering the problem of feeding the growing global population.

Figure 3: Sustainability Pillars

Firstly, environmental sustainability leads to the main question about how humans should change the way they live in order to secure a sustainable life for themselves and future generations. With this product, the intention is to provide organic food to urban areas, and also to provide a solution for food waste by composting it in a worm environment.

Secondly, regarding the economic pillar, choosing sustainable materials for the product is a major step. Thus, the product will be designed with materials that can stand the test of time. The main components for building the system are bars in combination with connectors which are smartly designed to solve manufacturing, distribution, and packaging problems.

Finally, concerning social sustainability, the product has the ability to bring people together. This urban farming has benefits such as, reduce carbon emissions, increase local economic growth, increase public health, and improve food security. The neighbours can create an environment that is focused on health, wellness, and education for all of those who are interested in the quality of life and social respect.

Wormify will be a small step towards four important United Nations Sustainable Goals [8]:

- **Goal 2 - End hunger, achieve food security and improved nutrition and promote sustainable agriculture:** Wormify will help solve the problem of feeding the increasing global population with a sustainable approach regarding organic food production.
- **Goal 3 - Ensure healthy lives and promote well-being for all at all ages:** the team considers that this product promotes a healthy lifestyle and the organic foods produced are important for our health and well-being.
- **Goal 11 - Make cities and human settlements inclusive, safe, resilient and sustainable:** the target group of this product is residents from apartment buildings in urban areas. Wormify will provide more green to the city, which can fasten the air purification.
- **Goal 12 - Ensure sustainable consumption and production patterns:** Wormify uses organic fertiliser produced by the worms, thus there are no chemicals or waste. The materials are also recycled which prevents them from ending up in landfills.

2.3 Ethics

Ethical and deontological concerns play a major role in influencing today's society. According to a clear set of rules, the team can advise many actions that define them as an ethical company. Wormify was designed based on the four main ethical and deontological concerns related to the project, which are engineering, sales and marketing, environmental, and liability. The analysis of these topics is essential and each concern must be respected for the firm to succeed and have a positive impact on society.

Engineers must fulfil under a level of professional behaviour that requires the highest principles of ethical acts. Those actions are described by the terms honesty, impartiality, fairness, and equity, and must be committed to the safety of public health, and welfare. Engineers have the enormous responsibility of complying with a robust code of ethics and work on increasing the quality of life of not only their customers but of society as a whole.

Companies generally enter the market intending to maximise sales, and, consequently, profit. To succeed in doing so, they take on tactics and campaigns to differentiate them from the competition and catch the attention of their target audience. The fight for a place in the market can sometimes lead to unprofessional behaviour and dishonest practices. However, Wormify planned and wants to implement and monitor a marketing strategy with ethics in mind to achieve success while keeping a solid reputation.

Environmental concerns have been around for many decades but with the huge impact of the media, these have been brought to the spotlight in recent years. Labels such as “sustainable”, “conscious” or “green” are many times used wrongfully and without proof. The team will ensure to not make false claims and to follow the sustainable steps presented further to make the product as environmentally friendly as possible.

Finally, to avoid product liability issues the team must comply with the EU Directives previously mentioned to protect the environment and public health.

Wormify is a product designed to respect all aspects mentioned, promising to follow a path of environmental consciousness that allows for sustainable food production everywhere.

2.4 Marketing

The team developed a marketing plan which helped establish the purpose, buyer personas, budget, methods, and deliverables for each campaign. Wormify’s strategy was defined with a focus on meeting clients’ needs and on developing long-term and profitable relationships with clients and suppliers. For this, the strategy control will be implanted through the Plan-Do-Check-Act cycle. The team will regularly track what works and what does not while measuring the effectiveness of the brand’s strategy. This way the brand will have the necessary tools to not only enter the market strong but to stay strong for a long time.

To come with a valuable strategy, the team defined the target group - people living in apartment buildings. They could use their roof to install the modular system or just use one module on their own personal balcony. This way the vermiponics system will not only allow them to produce herbs and vegetables sustainably but also will have the power to connect the residents to one and other, as it can function as a meeting spot to come together.

Wormify intends to establish its presence through social media and paid advertising to reach a bigger audience. Using social media, the team will share content and connect with the audience, being truthful and open about their intentions and sharing what, why and how we do things. A website was created to inform interested people and a meticulous logo was designed. The logo presented in Figure 4 is a clear reflection of the brand, as the predominantly green colour stands for organic foods, plants, and overall a sustainable/green environment. As for the elements, starting from the left, the Wi-Fi symbol symbolises the technical and smart quality of the product, the worm representing vermicomposting, and finally, the leaf shape illustrates the plant production.

Figure 4: Logo Wormify

The marketing study makes it possible to establish Wormify as a trusting company, breaking into the bio marketplace with a unique and cost-effective product.

2.5 Summary

This background research provided the team with a deep understanding of the current market. This product will fit into the market, and it will add value to it by providing organic food to city residents while bringing them together with a sustainable design and an ethical approach.

The following chapter goes into depth through the concept, design, and development of the product.

3 Proposed Solution

3.1 Concept

The Wormify team developed a smart and modular vermiponics system, specially targeted at residents of an apartment building. By aiming at this specific target group, the vermiponic system allows the residents to produce herbs and vegetables sustainably but it also has the ability to connect the neighbours, as it can function as a meeting spot to come together. On top of that, it has the opportunity to bring more green to the city environment.

The system is based on a modular easily movable Keyhole Garden, which takes advantage of vermicomposting to assist in fertilising the plants. Figure 5 shows the idealised design with multiple modules on a rooftop and also the single module.

Figure 5: Proposed Solution

Environmental ethics and sustainability had a strong impact on the design as well as on the packaging solution. The packaging is completely made out of corrugated cardboard. This can later on function as feeding for the worms.

One module of the vermiponic system is 1000 mm long, 400 mm wide, 500 mm high, and weighs about 80 kg. A humidity sensor, a temperature sensor, and two time-of-flight sensors per hole are integrated into each module to optimise the maintenance of the Wormify ecosystem for the user.

3.2 Design

3.2.1 Structure

For the design of the product, organic materials and a natural look were chosen. Moreover, the modularity of the product was determining for the final design. By making the product modular it is possible to use it in different sizes or set-ups. The parts of the vermiponics are designed with attention for assemble and disassemble possibilities very easily and without damaging the product.

All the technical components are protected against humidity and integrated on the inside of the flowerpot. On the right side of the flowerpot, a closed compartment is integrated to protect the them. The keyhole garden is made of two concentric cylinders. The two cylinders will be connected through tubes. These tubes provide a passageway for the worms to go in and out of the composting centre. As previously mentioned, these tubes will have two integrated time-of-flight distance sensors to detect the movement of the worms. This way the user can track the worms and the direction of their movement.

Furthermore, there are two more sensors integrated into the flowerpot. The humidity sensor measures the humidity in the soil to inform the user when he has to water the plants. The other sensor in the flowerpot is a temperature sensor to measure the temperature inside the composting bin. Both sensors will be protected from humidity with a brass pipe. Figure 6 shows and specifies the different components of the flowerpot.

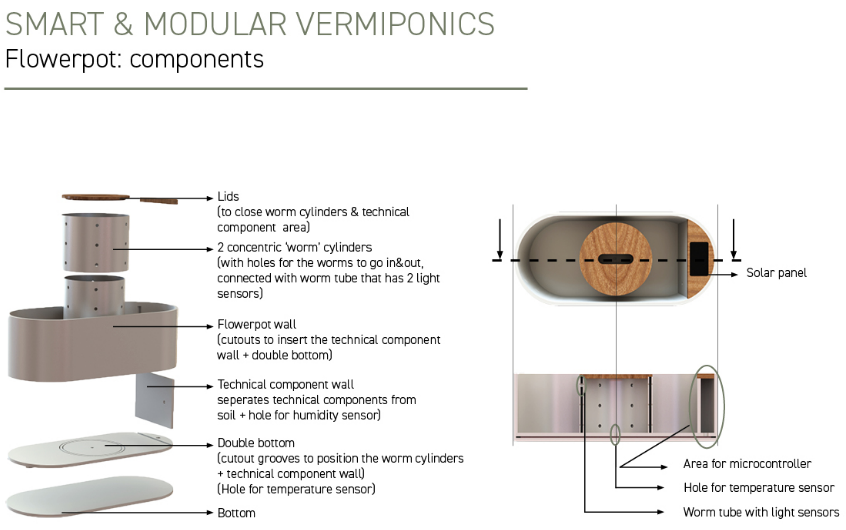


Figure 6: Flowerpot Components

3.2.2 Packaging

As the product is quite heavy and the packaging should sustain its weight, corrugated cardboard is the best option. This packaging offers transport safety, storage efficiency, less damage, retail presentation, and it is easy to assemble. Moreover, this decision was also based on the fact that this material can be composted [9], as long as it is uncoated with no heavy dyes, broken down, free from tape or labels [10]. Therefore, the cardboard can be reused, composted or recycled. Figures 7a and 7b illustrate the idealised packaging.

(a) Packaging solution (b) Packaging with worms and soil

Figure 7: Packaging

3.3 Development

3.3.1 Collecting the Worms

The team followed the traditional protocol to collect the worms from the land. Firstly, a bucket was inserted into the ground. Then, a layer of food waste was added, followed by a layer of dry leaves and shredded paper. Finally, the team inserted the lid on top to prevent other animals from entering the composting basket. After five days, we were able to remove the bucket from the ground and get the worms that were attracted to the food waste.

3.3.2 Prototype

The first step to build the prototype was to put the supporting structure together. With wood bars, rope and wood screws, we were able to build the structure. The flowerpot is reused, as well as the composting centre.

The composting basket was perforated with a soldering machine to allow the worms to travel through the different environments. Figure 8 shows the perforated basket in more detail.

Figure 8: Composting basket

When the structure was finalised, we put a layer of cardboard in the small centre basket and a layer of food waste. We started adding the worms, and then a layer of shredded cardboard and leaves. The soil was inserted around the basket in the centre.

The worms quickly adapted to the environment, travelling from the composting basket to the soil with ease. This stage is documented in Figure 9. It is clear that even without the layer of shredded cardboard and leaves, the worms are already almost unnoticeable.

(a) (b)

Figure 9: Initial stage

The assembled prototype is presented in Figure 10.

(a) (b)

Figure 10: Prototype

The plants used are basil. The choice for these plants was based on the fact that it grows quickly and it can be immediately used in cuisines. Although it grows better outdoors, it can also be grown indoors like most herbs. Moreover, basil has been studied regarding its health benefits relating to alleviating metabolic disorders, cognitive enhancement, strengthening the immune system, and oral and skin health [12].

3.3.3 Components

The following components were necessary to track the system.

ESP32 and battery: The selected micro-controller was the ESP32 (Figure 11a). It incorporates a Wi-Fi module and an integrated battery charger. The chosen battery was the Li-Ion Battery 18650 (Figure 11b), as recommended by the EPS32 data-sheet.

Solar panel: The solar panel is a free power source. It charges the battery through the ESP32 (Figure 11c). To choose this component with the correct specifications, the team calculated the worst case power consumption of the system. From research, the values obtained were [5]:

- Current: I = 0.190 A
- Voltage: U = 5 V
- Power: P = I x U = 0.95 W

(a) ESP32 (b) Li-Ion Battery 18650 (c) Solar panel

Figure 11: ESP32, battery and solar panel

Sensors: As previously stated, three different sensors were used to keep track of the system (Figure 12). The humidity or moisture sensor (Figure 12a) was placed in the soil to inform the user when he has to water the plants. The temperature sensor (Figure 12b) was placed inside the composting bin to regularly check if it is not overheating. There are also two time-of-flight sensors (Figure 12c) to detect the movement of the worms.

(a) Soil moisture sensor (b) Temperature sensor (c) Time-of-flight sensor

Figure 12: Sensors

Figure 13 presents the signal schematics, connecting the EPS32 and the sensors. Figure 14 displays the power supply circuit, involving the solar panel, the DC-DC converter, the EPS32 and the battery.

3.4 Tests

3.4.1 Symbiotic System

The relationship between plants and worms unfolded as expected. Vermiponics supports the production of plants at home since worms feed from the organic leftovers, fertilise the soil and the plants grow faster and healthier.

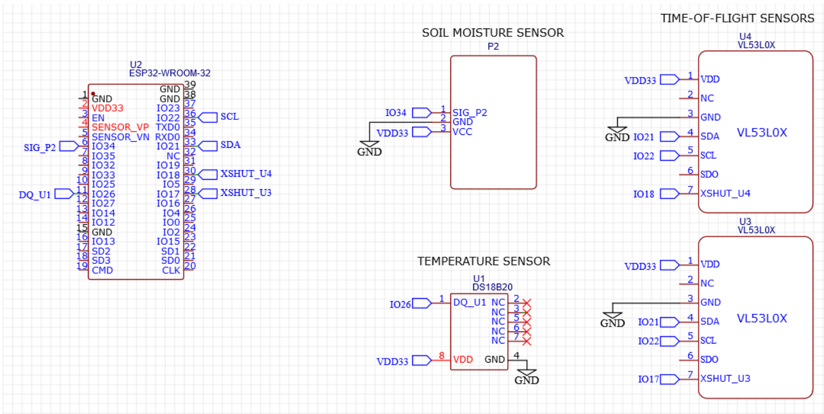


Figure 13: Signal circuit

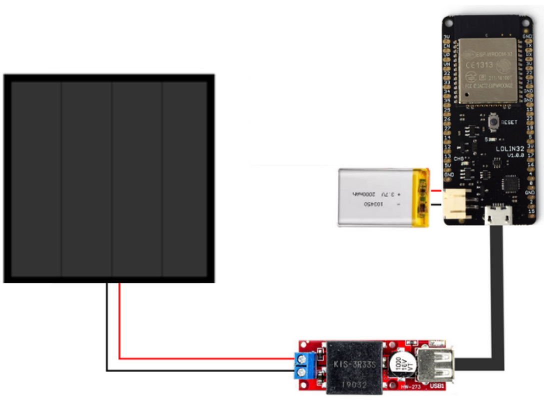


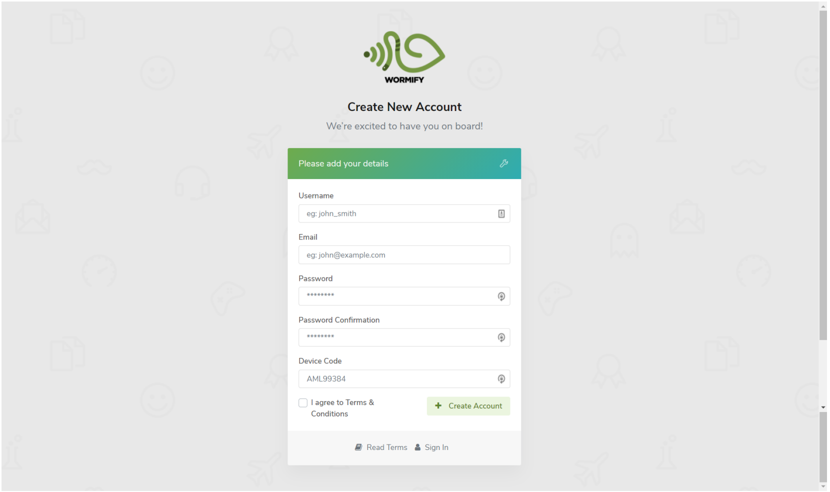
Figure 14: Power supply circuit

3.4.2 Website

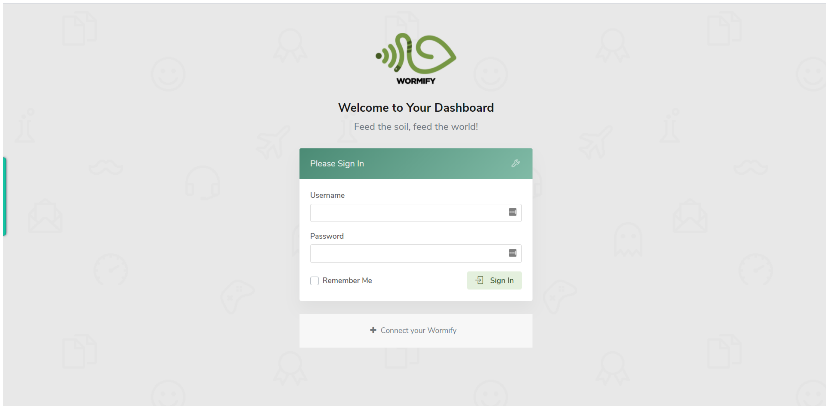
A website was created to show the data collected from the sensors. The information displayed on the website is shown in real-time and allows the user to monitor the system remotely. Figure 15 illustrates the website created. Figures 15a and 15b show, respectively, the pages to create a new account and to sign in to an already existing account. Figure 15c exhibits the layout and information displayed on Wormify's website.

4 Discussion

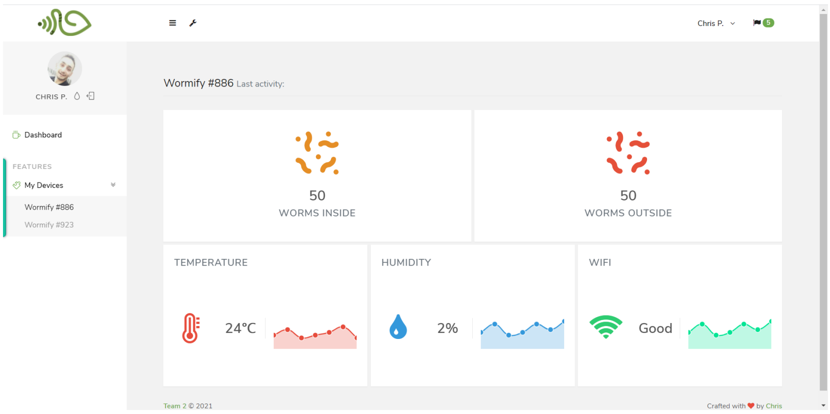
The team went through a deep analysis of components, parts, and materials which allowed for the creation of a product that not only answers the identified problem but that also has the potential to reduce food waste and to create an environment that unites residents from a city building. Once this target audience was defined, it was easier to view the whole concept on a more defined level. The analysis of the different materials was carefully done, with evaluations of each material to choose the most sustainable options. Aluminium and bamboo are the predominant materials in this product because of their lifespan and easy recyclability. Calculations of strength,



(a) Create new account



(b) Sign in



(c) Data layout

Figure 15: Website

dimensions, weight capacity were carried to ensure the safety and performance of the product.

The prototype was implemented and is working as it should. Wormify depends on the user for watering the plants, providing the food waste, and occasionally one will also need to remove the excess liquid produced, which will be stored on the bottom of the product. Several tests were conducted to prove the functionality of the product. The worms were quick to adapt to the design of the structure, travelling from and to the composting centre without problems and composting the food waste at a regular pace.

The team considers the construction of this proof-of-concept was successful. Although some difficulties were met during the semester, the dedication of each member made it possible to build Wormify and to expand their knowledge. Wormify was created following sustainability measures and a rigid code of ethics. The marketing plan allowed the creation of the brand, which perfectly illustrates the essence of the product and the team.

5 Conclusion

5.1 Project Outcomes

The team set out to test the feasibility of creating a sustainable food production system for urban areas, for people living in apartment buildings. The team developed a marketing plan to promote Wormify. Th regarding the market, target audience, costs, and suppliers. Furthermore, the team analysed sustainability and ethical concerns, which allowed to create measures for eco-efficiency and to make sure the team respects a code of ethics.

The team made strength calculations to ensure each material could sustain the weight of the flowerpot, and reduced the weight of the flowerpot to a minimum but still maintaining enough space for efficient food production.

Wormify can reduce waste, enhance soil, and grow food without generating vermin, odours, or making a mess. Wormify accomplishes this by using worms and microbes in the surrounding soil, making it an effective and low-maintenance solution for any organic waste, including lawn and garden waste, paper, and other compostable materials.

5.1.1 Future Development

The system has a lot of potential that has not been yet explored. The rainwater collecting system can be connected through pipes to the flowerpots, making the system more autonomous because the user would not have to water it.

Additionally, the application can be further developed. A point system is to be implemented when the user waters or harvests the plants, and when one feeds the worms. It will allow for the creation of groups and collaborations to interact between the residents of the building.

Furthermore, more research needs to be conducted regarding the worm tracking system, as it is still rudimentary. Aspects like multiple worms passing at the same time need to be considered.

Finally, it would be interesting to implement microspheres of kefir water and alginate in the system, because worms like kefir and it can also act as a biofertilizer. Kefir is a mildly acidic fermented milk. It is naturally produced by the addition of lactic acid bacteria and yeasts to milk. In regard to mineral content, kefir is a good source of calcium and magnesium. Calcium is important because worms need a continuous supply of this element. Therefore, it would be interesting to produce microspheres containing kefir, using alginate, a natural polymer that cross-links in the presence of divalent cations such as calcium [3].

5.2 Personal Outcomes

The team members shared the following testimonies regarding this semester:

- “The EPS@ISEP programme was a great way to finish my bachelor’s degree. This programme allowed me to get more comfortable with the English language and to expand my knowledge to other fields. The people enrolled in EPS, from students to teachers, were always kind, available and hardworking. I was able to get out of my comfort zone and develop my ability to work with others. EPS is definitely an experience I recommend to every student.” – Ana
- “I participated for the first time in such a project. I had big emotions, because I was kind of afraid of what was going to happen in this programme. I liked the people I met in Porto. First of all, the members of the project teams, I have linked to many friends. And of course, the teachers were helpful and serious. We have learned many new things in this field and in particular, we have learned that teamwork requires collaboration, trust and honesty. It was a very pleasant experience that I will recommend with confidence especially in this incredible city.” – Victoria
- “I feel like this semester was a great experience on many levels. Working in a team with international students was challenging but a great opportunity. The EPS program, offered by ISEP, was very interesting and despite the circumstances of the Covid-19 pandemic, we were given many opportunities to still get as many presential classes as possible. This made the teamwork a lot easier. Porto is a great city. My Erasmus experience was everything I wanted it to be, so I could recommend every student to participate in an EPS program in Porto.” – Fien
- “Unfortunately I did not have the occasion to visit Porto. Due to the pandemic situation I was forced to stay at home. Nevertheless being part of the EPS programme was a unique experience. I met amazing people - my colleagues, coordinators and teachers. Participating in EPS gave me the ability of using theoretical knowledge in real life. What is more during Portuguese classes I learned a lot about Portugal: its language, culture and cuisine. EPS at ISEP was a great experience and I would recommend it to everyone.” – Jakub
- “This was my first Erasmus experience, and I can honestly say it exceeded my expectations. Initially, I conducted significant research on my possibilities and was unable to make a decision. I’ve heard that ISEP is excellent in the field of education. As a result, I opted to study here, learn English and Portuguese, and work on a real-life company-level project. Working as part of a team is essential in EPS, and because of the first team-building activities, we were able to work together in the most effective way possible. One aspect of the time spent completing the EPS that I will remember fondly was the opportunity to meet new people from all around the world and contribute my knowledge in a multi-skilled group.” – Kris

References

[1] Agriculture Academy’s. *What Is Aquaponics and How Does It Work?* Agriculture Academy, 2020. [Accessed in May 2021].

[2] Bionicraft. Biovessel - an ecosystem powered by food waste. https://www.kickstarter.com/projects/1576257573/biovessel-an-ecosystem-powered-by-food-waste, 2018. [Accessed in April 2021].

[3] Lina M. Blandón, German A. Islan, Guillermo R. Castro, Miguel D. Noseda, Vanete Thomaz-Soccol, and Carlos R. Soccol. Kefiran-alginate gel microspheres for oral delivery of ciprofloxacin. *Colloids and Surfaces B: Biointerfaces*, 175:706–715, 2016.

[4] European Commission. Food waste. https://ec.europa.eu/food/food/food-waste_en, 2018. [Accessed in May 2021].

[5] A. David. Guide to reduce the esp32 power consumption by 95 per cent. https://diyi0t.com/reduce-the-esp32-power-consumption/, 2020. [Accessed in May 2021].

[6] Simon Goddek, Alyssa Joyce, Benz Kotzen, and Gavin Burnell. *Aquaponics Food Production Systems: Combined Aquaculture and Hydroponic Production Technologies for the Future.* Springer Nature, 2019.

[7] J. Gustavsson and C. Cederberg. Global Food Losses and Food Waste. http://www.fao.org/3/i2697e/i2697e.pdf, 2011. [Accessed in April 2021].

[8] United Nations. The 17 goals. https://sdgs.un.org/goals, 2021. [Accessed in May 2021].

[9] Susan Patterson. Using cardboard in compost - how to compost cardboard boxes. https://www.gardeningknowhow.com/composting/ingredients/composting-cardboard.htm, 2020. [Accessed in May 2021].

[10] Kathleen Quinlen. Composting Cardboard: Do's and Don'ts. https://compostfairy.com/2019/11/07/composting-cardboard/, 2019. [Accessed in May 2021].

[11] European Project Semester. Concept — European Project Semester. http://www.europeanprojectsemester.eu/concept, 2021. [Accessed in April 2021].

[12] Keith Singletary. Basil: A brief summary of potential health benefits. https://www.researchgate.net/publication/324085682_Basil_A_Brief_Summary_of_Potential_Health_Benefits, 2018. [Accessed in June 2021].

[13] MasterClass staff. How to Make and Use Worm Tea to Fertilize Your Garden - MasterClass. https://www.masterclass.com/articles/how-to-make-and-use-worm-tea-to-fertilize-your-garden#how-to-use-worm-tea-to-fertilize-your-garden, 2020. [Accessed in June 2021].

[14] Subpod. Subpod® - Below-ground composting that actually works! – Subpod UK. https://subpod.co.uk/, 2021. [Accessed in May 2021].

[15] Urbalive. Urbalive — Flower Box. http://www.urbalive.com/flower-box, 2021. [Accessed in May 2021].