Sustainable Food Production Through Vermicomposting – An EPS@ISEP 2021 Project

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ABSTRACT

The European Project Semester (EPS) is a multicultural, multidisciplinary teamwork and project-based learning framework offered to engineering, business and product design undergraduates by a network of European Higher Education institutions, including the Instituto Superior de Engenharia do Porto (ISEP). In the spring of 2021, five EPS@ISEP students from distinct countries and fields of study joined efforts to address the smart and sustainable food production issue. This paper reports their research and development of Wormify, a solution based on vermicomposting. The main goal of the project was to design, simulate, test and build a prototype following ethical and sustainable practices. Wormify aims to minimize the problem of feeding the growing global population, and to prevent food waste from going to landfills. These objectives were pursued by designing a smart modular system for urban rooftops or small balconies. Several modules can be connected to form a place for residents to meet and socialize. The smart system allows monitoring through an app/website. This paper presents the background studies, the concept and design, the development and final results.

CCS CONCEPTS

• :; • **Applied computing**; • **Collaborative learning;**; • **Social and professional topics**; • **Computational science and engineering education.**;

KEYWORDS

Additional Key Words and Phrases: Vermicomposting, Food production, Food waste, Sustainability, IoT

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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 study areas working together to create an innovative sustainable and useful product, building a proof of concept [11]. In 2021, a team of students from Portugal, Romania, 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 a solution for a real problem that inspired and united the team: the smartification of 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 into organic fertilizer, by a process called vermicomposting [13]. This means vermicomposting can transform food waste into soil nutrients. In the European Union (EU) only around 88 million tons 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 8 % of Global Greenhouse Gas Emissions. The food wasted in the European Union (EU) would feed the 33 million Europeans suffering from hunger and malnutrition [4]. Most food waste ends in landfills, occupying more than 50 % of global landfill waste [7].

After researching and analyzing existing products and the involved aspects, the team decided to create a modular keyhole garden for urban buildings, composed of a raised plant bed with a central composting basket. 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.

This paper introduces Wormify, the modular keyhole garden, starting with the background research followed by the description of the proposed solution, a brief discussion, and the conclusion.

2 BACKGROUND

This section reviews the related solutions, ethics, marketing and sustainability aspects of vermicomposting.

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 partially buried composting basket [14]. 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 since they are more distant from natural processes, requiring more maintenance. However, they are the most interesting practical options for urban spaces (e.g. apartments or restaurants). Urbalive also provides products for indoors, such as those in Figure 1c and Figure 1d. The first is a traditional vermicomposter, while the second is a planter with self-watering. Therefore, by acquiring the two, one could use the worm-tea produced in the composter to provide nutrients to the plants [15]. Biovessel only composts food waste (Figure 1e). It presents an appealing design and aims to bring nature to urban homes, using vermicomposting to create a more sustainable lifestyle [2].

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.

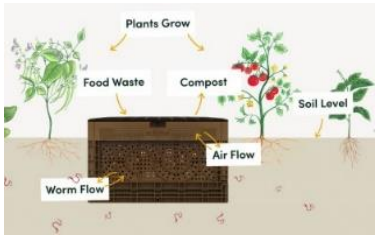
2.2 Sustainability

Sustainability is a strong concept that has the value to keep society healthy. Therefore, the team approaches sustainable development in its three pillars – environmental, economic, and social – to preserve the environment. Wormify is a suitable and sustainable alternative for futuristic urban farming methods, answering the problem of feeding the growing urban population and transforming food waste into organic fertilizer.

Firstly, environmental sustainability raises the question of how humans should change the way they live 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 building components are bars attached through 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, reducing carbon emissions, increasing local economic growth, increasing public health, and improving food security. The neighbors can create and share an environment focused on health, wellness, and education, promoting quality of life and social respect.

Wormify is 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 contributes with a sustainable organic food solution to feed the increasing global population.
- Goal 3 – Ensure healthy lives and promote well-being for all at all ages: this organic food production solution promotes well-being and a healthy lifestyle.



(a) Subpod [14]

(b) Urbalive Outdoor Planter [15]

(c) Urbalive Worm Farm [15]

(d) Urbalive Indoor Planter [15]

(e) Biovessel [2]

Figure 1: Related Solutions

- Goal 11 – Make cities and human settlements inclusive, safe, resilient and sustainable: Wormify makes urban areas greener, contributing to purify the air.
- Goal 12 – Ensure sustainable consumption and production patterns: Wormify uses organic fertilizer produced by the worms, free of chemicals. The used materials are recycled to prevent them from pilling up in landfills.

2.3 Ethics

Ethical and deontological concerns have a growing influence in today's society. 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.

Engineering professionals must embrace honesty, impartiality, fairness, and equity, and be committed to the safety of public health, and welfare. Engineers have the enormous responsibility of complying with a robust code of ethics and increasing the quality of life of not only their customers but of the society as a whole.

Companies enter the market to maximize sales, and, consequently, profit. To succeed in doing so, they take on tactics and campaigns to differentiate from the competition and catch the attention of their target audience. To ensure that this fight does not lead to unethical practices, the team planned to implement and monitor an ethics driven marketing strategy to achieve success while building a solid reputation.

Environmental concerns have been around for many decades. However, labels such as "sustainable", "conscious" or "green" are many times used wrongfully and without proof. The team decided to make only true claims and to develop a 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 logo was meticulously designed. The logo presented in Figure 2 is a clear reflection of the brand, as the predominantly green color stands for organic foods, plants, and overall a sustainable/green environment. As for the elements, starting from the left, the Wi-Fi symbol symbolizes the technical and smart quality of the product, the worm representing vermicomposting, and finally, the leaf shape illustrates the plant production.

Figure 2: Proposed Solution

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.

3 PROPOSED SOLUTION

3.1 Concept

The Wormify team developed a smart and modular vermiponics system, specially targeted at residents of apartment buildings. The vermiponic system will allow residents to produce herbs and vegetables sustainably and connect neighbors, as it can function as a social meeting spot. On top of that, it contributes to a greener city environment.

The system is based on a modular easily movable keyhole garden, which takes advantage of vermicomposting to fertilize the plants. Figure 2 shows the idealized design with a single and multiple modules on a rooftop. Environmental ethics and sustainability had a strong impact on the design as well as on the packaging solution. The packaging made out of corrugated cardboard can later function as feeding for the worms.

One module has a size of 1000 mm x 400 mm x 500 mm and a weight of about 80 kg when fully loaded. To optimize the maintenance of the Wormify ecosystem for the user, each module integrates a humidity sensor, a temperature sensor, and two time-of-flight sensors per central container hole.

3.2 Design

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 for easy (dis)assembly without damaging the product.

All technical components are protected against humidity and integrated inside a closed compartment on the right side of the flowerpot. The keyhole garden is made of two concentric cylinders which are connected through tubes. These tubes provide a passageway for the worms to go in and out of the composting center and are equipped with two integrated time-of-flight distance sensors to detect worm movement. This way the user can track the number of 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 to water the plants. The temperature sensor measures the temperature inside the composting bin. Both sensors are protected from humidity through a brass pipe. Figure 3a shows and specifies the different components of the flowerpot.

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. Figure 3b illustrates the idealized packaging.

3.3 Development

Worms. The team followed the traditional protocol to collect the worms. 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. Five days later, it was time to remove the bucket from the ground containing the worms attracted to the food waste.

Prototype. The first step to build the prototype was to put the supporting structure together. With wood bars, rope and wood screws, the team built the structure. The flowerpot was reused, as well as the composting center. The composting basket was perforated to allow the worms to travel through the different environments. Figure 4a shows the perforated basket in more detail. When the structure was finalized, the center basket was prepared with a layer of cardboard, a layer of food waste, the worms and a top layer of shredded cardboard and leaves. The flower pot around the central basket was filled with soil. The worms quickly adapted to

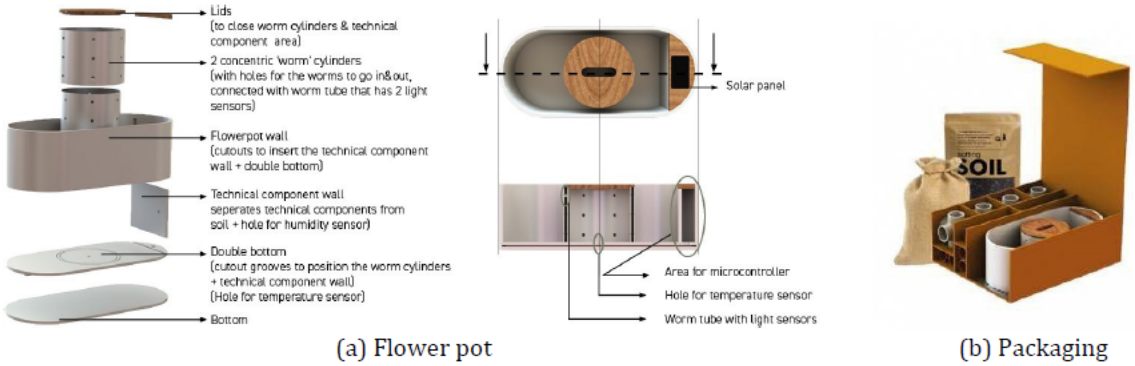


Figure 3: Design

(a) Empty basket **(b) Pot and basket** **(c) Module**

Figure 4: Prototype

the environment, travelling from the composting basket to the soil with ease. This stage is documented in Figure 4b. It is clear that even without the layer of shredded cardboard and leaves, the worms are almost unnoticeable. The assembled prototype, with basil and mint, is presented in Figure 4c. Like most aromatic herbs, they grow quickly, indoors or outdoors. They are known for their culinary and medicinal usage, namely to alleviate metabolic disorders, cognitive enhancement, strengthening the immune system, and oral and skin health [12].

Components. The control system encompasses the following components:

- ESP32 micro-controller, integrating a battery charger and Wi-Fi module, and an 18650 Li-Ion Battery recommended by the ESP32 manufacturer.
- Solar panel to charge the battery via the ESP32. The maximum power consumption $P_{\max} = 0.95\,W$ corresponds to a voltage $U = 5\,V$ and a maximum current $I_{\max} = 0.190\,A$, obtained from data-sheets and [5].
- Humidity sensor, placed in the soil, to measure and inform the user when to water the plants, a temperature sensor, positioned inside the composting bin, to regularly check there is no overheating, and two time-of-flight sensors to detect the movement of the worms.

3.4 Tests

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, fertilize the soil and the plants grow faster and healthier.

Website. A website was created to show the data collected from the sensors (Figure 5). The information displayed on the website is shown in real-time and allows the user to monitor the system remotely.

4 DISCUSSION

The team performed a deep analysis of components, parts, and materials to create a product that answers the identified problem, transforms food waste and unites urban building residents. Once this target audience was defined, it was easier to detail the whole concept. The analysis of the different materials was carefully done, with evaluations of each material to choose the most sustainable options. Aluminum and bamboo are the predominant materials in this product because of their lifespan and easy recyclability. Calculations of strength, dimensions, weight capacity were carried to ensure the safety and performance of the product.

The prototype was implemented and is working. Wormify depends on the user for watering, providing the food waste, and, occasionally, to remove the excess liquid produced, which will be stored on the bottom of the pot. 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 center and composting the food waste.

Although some difficulties were met during the semester, the dedication of each member made it possible to build Wormify and

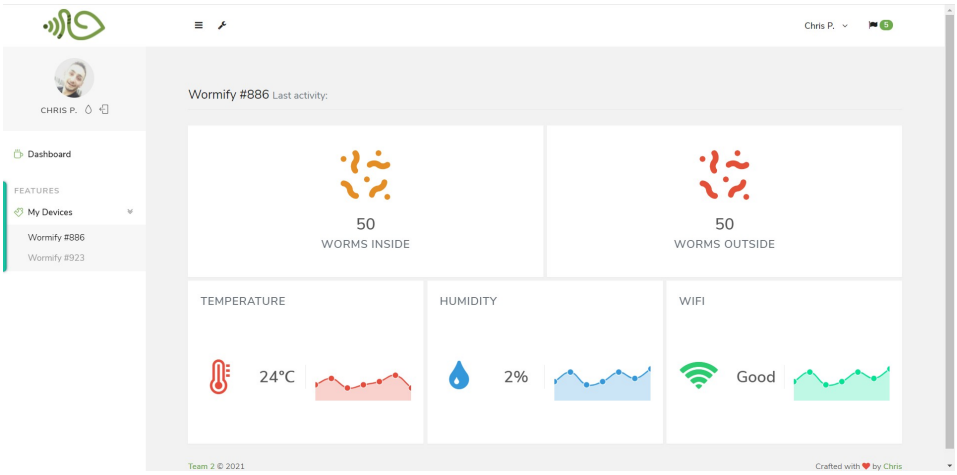


Figure 5: Website

to expand their knowledge. Wormify was created following sustainability measures and a rigid code of ethics. The marketing plan allowed the creation of a brand considering the essence of the product.

5 CONCLUSION

Motivated by the idea to create a sustainable urban food production system, the team designed Wormify, a vermiponics keyhole garden for apartment residents. Regarding the market, the target audience, costs, and suppliers were identified and a marketing plan defined. The design of the structure, driven by sustainability and ethical values, involved strength calculations to ensure each material could sustain the flowerpot, and the optimization of the flowerpot dimensions to reduce weight and provide enough area for efficient food production. Wormify relies on soil worms and microbes to reduce waste, enhance soil, and grow food without generating vermin or odors. It is an effective and low-maintenance solution for transforming organic and compostable waste.

The potential of the system can be further explored. The collected rainwater can be used to create a sustainable self-watering system. The application can accumulate reward points when the user feeds the worms, waters or harvests the plants to establish collaborations between building residents. The worm tracking system requires further research regarding aspects like multiple worms passing simultaneously. Finally, it would be interesting to explore with a bed composed of microspheres of kefir water and alginate, a natural polymer that cross-links in the presence of divalent cations such as calcium [3]. Kefir is a mildly acidic fermented milk naturally produced by the addition of lactic acid bacteria and yeasts to milk. In this context, it constitutes an important source of magnesium for the worms as well as a bio fertilizer.

In the end, the team members shared the following testimonies regarding their EPS@ISEP experience:

- "The EPS@ISEP program was a great way to finish my bachelor's degree. This program 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 work with others. EPS is definitely an experience I recommend." – 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 program. I liked the people I met in Porto: the team members and the teachers. We have learned many new things and, above all, that teamwork requires collaboration, trust and honesty. It was a very pleasant experience that I recommend in this incredible city." – Elena.
- "I feel like this semester was a great experience on many levels. Working in an international team was challenging but a great opportunity. The EPS program, offered by ISEP, was very interesting and despite the Covid-19 pandemic, we were given as many face-to-face opportunities as possible. This made the teamwork a lot easier. Porto is a great city. I can recommend every student to participate in EPS at 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 program 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. 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. I opted to study at ISEP, 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. I will remember fondly the opportunity to meet new people from all around the world and contribute with my knowledge in a multi-skilled group." – Kris.

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