Growing Mushrooms on Coffee Grounds – An EPS@ISEP 2024 Project

Noor Stapel[1], Roberto Lupu[1], Nils Kötting[1], Miro Heller[1], Vinyet Sorribas[1], Hugo Boulay[1], Abel J. Duarte[1,2,3], Benedita Malheiro[1,4], Cristina Ribeiro[1,5], Jorge Justo[1], Manuel F. Silva[1,4], Paulo Ferreira[1], and Pedro Guedes[1,4]

ISEP, Polytechnic of Porto, Porto, Portugal
[2] REQUIMTE/LAQV, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249-015 Porto, Portugal
[3] CIETI, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249-015 Porto, Portugal
[4] INESC TEC, Campus of Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
[5] INEB, Rua Alfredo Allen, 208, 4200-135 Porto, Portugal
epsatisep@gmail.com
https://www.eps2024-wiki1.dee.isep.ipp.pt/

Abstract. CoffeeMush is an innovative and sustainable project developed as part of the European Project Semester (EPS) at ISEP in 2024. This student project aims to tackle waste management environmental problems by turning coffee waste into mushrooms, a valuable food source. CoffeeMush consists of a smart device providing optimal conditions for mushroom cultivation, complemented by a user-friendly Android application for remote monitoring and control. The design was guided by ethical, sustainability, market and technical considerations. The paper describes the theoretical background of the project, the technical design, and the prototype development and testing. The results show the feasibility of CoffeeMush as a practical and environmentally friendly solution for urban mushroom cultivation, and its impact on sustainable food production and waste reduction.

Keywords: Engineering Education, European Project Semester, Coffee, Mushrooms, Composting, Sustainable Food Production

1 Introduction

The CoffeeMush project was developed in 2024 as part of the European Project Semester (EPS), an interdisciplinary programme catering not only to engineering students but also students from related fields of study. Offered by universities across Europe, EPS aims to equip students with the skills and knowledge necessary to tackle the contemporary challenges [3].

Nowadays, as society faces pressing environmental issues, the need to rethink daily waste management practices has become paramount. This project reuses coffee waste to create an innovative kitchen mushroom grower, addressing the imperative for sustainability and environmental responsibility.

TheOnlyOne EPS team embarked on a journey to design and develop CoffeeMush, a smart device to grow mushrooms in optimal conditions using coffee grounds. This solution includes a user-friendly Android application that empowers users to regulate and monitor the process remotely. All aspects of the project were guided by ethical, sustainable, and state-of-the-art technical principles.

This document reports the approach, research findings, and strategic insights, offering a comprehensive overview of the project journey. The technical, market, ethical and sustainability context are analysed in Section 2. Based on these studies, Section 3 introduces the concept and the design – structure, packaging, smart control and app – of the proposed solution. Section 4 presents the development and testing of the prototype. Finally, Section 5 draws the conclusions and proposes further developments.

2 Preliminary Studies

This section analyses related products together with associated market, ethics and sustainability concerns.

2.1 Related Products

The top eight composting techniques comprise open air composting, direct compost, tumbler composting, worm farm composting, effective micro-organisms composting, commercial composting, and mechanical composting [6]. Each has its unique advantages and applications, from small-scale household use to large-scale commercial operations. In the case of CoffeeMush, the cost, the compost time, and the final product, are the important aspects to consider. Table 1 compares the most representative products found according to these features.

Table 1: Product comparison

Name	**Cost (€)**	**Input**	**Output**	**Composting time**
Reencle [14]	585	Food leftovers	Grass compost	2.0 h
Mill [11]	939	Food leftovers	Chicken food	2.5 h
Lomi [12]	599	Food leftovers	Organic fertiliser	12.0 h
Foodcycler [9]	500	Food leftovers	Organic fertiliser	5.0 h
Bokashi Organko 2 [13]	90	Food leftovers	Organic fertiliser	2.0 w
Beyondgreen [1]	409	Food leftovers	Organic fertiliser	1.0 w
Mella [8]	447	Fruiting blocks	Mushrooms	2.0 w
Shrooly [5]	419	Fruiting blocks	Mushrooms	2.0 w

The Reencle composter [14] works silently and has a 3-layer filter system to prevent odours. Mill [11] and Lomi [12] composters offer modern designs at higher prices. The Foodcycler [9] composter has a shorter compost time, while

Bokashi Organko [13] and Beyondgreen [1] are more affordable but have longer composting times. Mella [8] and Shrooly [5] are mushroom fruiting chambers. Mella has three different boxes, which can have different types of mushrooms [15]. Shrooly is smaller and better for a single type of mushroom. Both solutions require user intervention and the purchase of the fruiting blocks.

2.2 Marketing

The marketing research involved identifying the strengths, weaknesses, opportunities and threats, marketing mix, marketing plan and marketing programme. The strengths include reusing waste, saving money, innovative design, respect for the environment, local food production, and accessibility for people on lower incomes. Weaknesses include the space required, the exclusive use of coffee waste, and the fact that mushrooms can be grown on coffee grounds without a smart device. The main opportunities are its good market potential and people's willingness to be environmentally friendly. The main threats include the large number of competitors and the price.

The marketing plan considered the product, price, place and promotion marketing mix: (*i*) CoffeeMush product embodies a sustainable solution designed to foster mushroom growth, addressing customer needs for eco-friendly waste management, and contributing to cost savings and environmental conservation; (*ii*) CoffeeMush pricing strategy aims to undercut existing kitchen composters, ensuring accessibility to a broader spectrum of consumers; (*iii*) CoffeeMush place is within the realm of kitchen composters, targeting home appliance distribution channels; and (*iv*) CoffeeMush promotion adopts a multifaceted promotional strategy encompassing both digital and physical media. The estimated cost of a device is 199 € and is made up of 121 € in material costs, around 20 € for production and assembly and 58 € for additional costs such as rent, electricity and promotion, as well as further development.

The brand name is CoffeeMush, fusing the words coffee and mushroom. The slogan "*Brew and renew, from coffee grounds to mushroom bliss!*" is simple, catchy and explains the purpose of the product. The logo depicts a mushroom with a coffee bean at its base, linking coffee and mushrooms (Figure 1a).

2.3 Ethics

Any project must consider all the ethical aspects involved in the manufacturing, design, and development of the product. Engineers have to follow the ethical code as they have a big impact on the world and people. However, the specific ethical standards and practices may differ from country to country.

Sales and marketing ethics are essential to a responsible business. It is crucial to respect the decisions and opinions of customers rather than imposing developer views. In the environmental field, it is mandatory to take measures to respect the environment, namely when making design choices or selecting materials, suppliers, producers, etc. Additionally, it is vital to consider the environmental impacts of the product, whether direct or indirect [4]. Last but not least, liability towards the environment, human rights, safety and data protection requires compliance with European Commission directives, following best design practices.

2.4 Sustainability

The sustainability of a product involves four main aspects: environmental, economic, social, and product life cycle analysis. For environmental sustainability, it is important to consider the use of natural resources, emissions during manufacturing, and waste processing to prevent further pollution. To ensure economic sustainability, coffee waste will be collected from local establishments like restaurants, schools, and hotels. In terms of social sustainability, the design of CoffeeMush ensures easy access for everyone, regardless of economic status. The product life cycle includes procurement, production, treatment, assembly, packaging, transport, use, and end, all aimed at making environmentally sustainable development decisions and avoiding potential environmental impacts of the product [10]. Above all, CoffeeMush contributes to Sustainable Development Goal 12 – "Sustainable Consumption and Production"[1] – of the United Nations.

3 Proposed Solution

This section presents the idealised concept and the design of the corresponding solution, involving a smart device, reusable packaging and a mobile application.

3.1 Concept

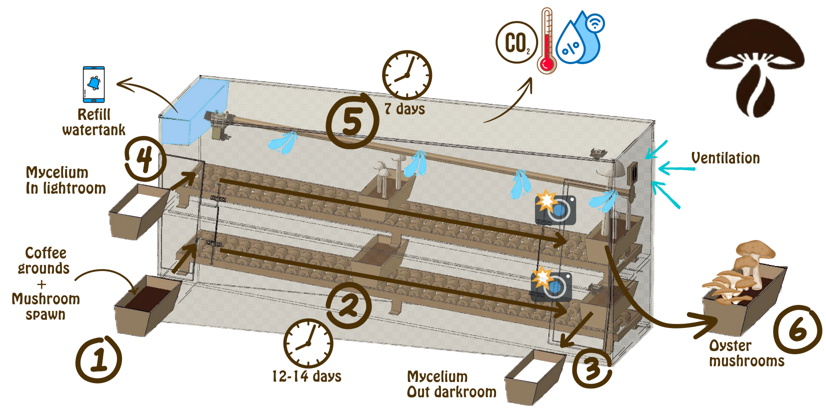
The concept behind CoffeeMush is to build an automated, sustainable, and low-energy device to grow edible oyster mushrooms from coffee grounds (Figure 1a). The product consists of two main chambers, a dark compartment for mycelium growth and a light-filled compartment for mushroom growth. Both chambers contain small growth boxes. The user fills the small boxes with coffee grounds and mushroom spawn, places them into the dark compartment, and switches on the device. After harvesting, the substrate can be reused for a second growth cycle. Finally, the decomposed remains can be used to fertilise the soil. The process can be repeated after washing and disinfecting the box.

The application notifies the user when to: (*i*) move the boxes of grown mycelium from the dark compartment to the light-filled compartment; (*ii*) remove the boxes of grown mushrooms from the light-filled compartment for harvesting; and (*iii*) refill the water tank. The user can also check the water level in the tank and get an estimate of when the next boxes will be ready.

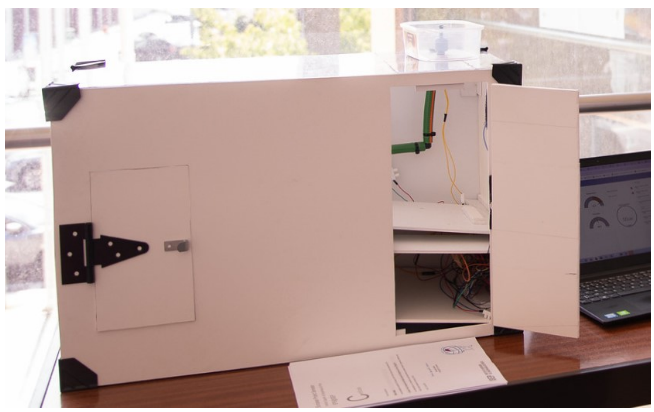
3.2 Design

Structure The design aims to provide optimum growing conditions for mushroom cultivation with low power consumption and minimum customer effort[2].

[1] https://sdgs.un.org/goals/goal12
[2] For drawings and schematics check at https://www.eps2024-wiki1.dee.isep.ipp.pt/.



(a) Concept



(b) Prototype

Fig. 1. CoffeeMush solution.

For ease of use, and considering Figure 1a, growth boxes should always be placed on the left and removed from the right side. Each side has a door that gives access to both compartments. The boxes are moved by means of an inclined roller conveyor, which uses gravity to move the boxes downwards and to the right. The device is divided into dark and light-filled compartments. Bearing in mind that mycelium and mushrooms need approximately 14 and 7 days to grow, each compartment contains 14 growth boxes to allow for the daily addition of new coffee grounds. A second growth of mushrooms is possible after the first harvest so that the box can be reinserted on the left side of the light-filled compartment for the second cycle. After a total of 4 weeks, the remaining substrate is composted and can be used as fertiliser in the garden or for indoor plants.

The two compartments are divided by staggered plates. These allow for the exchange of air and humidity inside the device without additional watering and ventilation and still keep the lower compartment dark. For optimum ventilation, there is a fan and an air outlet. Both the inlet and outlet are equipped with high-efficiency particulate air and activated carbon filters to prevent odours and spores from escaping and contaminants from entering [2][16].

The water tank is placed on the upper left side, using gravity rather than a pump. Water is dispensed through a solenoid valve into a perforated tube surrounded by a water-absorbing material, allowing it to evaporate and increase humidity. A recycled acrylic glass plate serves as the lid, allowing light into the upper compartment and providing a view over the mushrooms. A flap is provided for the easy refilling of water. The combined watering and ventilation system maintains a climate suitable for mushroom growth.

Furthermore, there are two cameras, each connected to a microcontroller. They take pictures of the most advanced mycelium or mushroom box and send the images via Wi-Fi to the API, which determines if the box is ready.

Packaging The packaging solution must be multipurpose so that it can be used afterwards. The selected packaging material is mycelium, which is intrinsically sustainable, water-resistant, flame-resistant and chemical-free [7]. Its biological nature means that it is a readily available and compostable resource. It can be transformed into a type of leather, fine paper, or foam. CoffeeMush's packaging consists of a mycelium foam box with two foldable central strips of mycelium leather. This solution protects the device during transportation and easily converts it into two bags for transporting coffee grounds and/or mushrooms.

Smart Control The control of the mushroom cultivation process monitors humidity, temperature, CO_2, light, water and growth via cameras, and acts via solenoid valves and ventilation. The microcontroller not only maintains the desired mushroom growth conditions, but is able to process images, backup data and publish all data to the Message Queuing Telemetry Transport (MQTT) broker. The maximum power consumption will be less than 10 W.

Mobile Application The Android application not only offers remote process monitoring, but also notifies the user when boxes are ready to be harvested or moved. It communicates with the Application Programming Interface (API) via HyperText Transfer Protocol Secure (HTTPS) which, in turn, subscribes the MQTT (Mosquitto) broker data topics.

4 Prototype Development

This section describes the assembly and testing of the proof-of-concept prototype consisting of the physical module (structure and control) and mobile application.

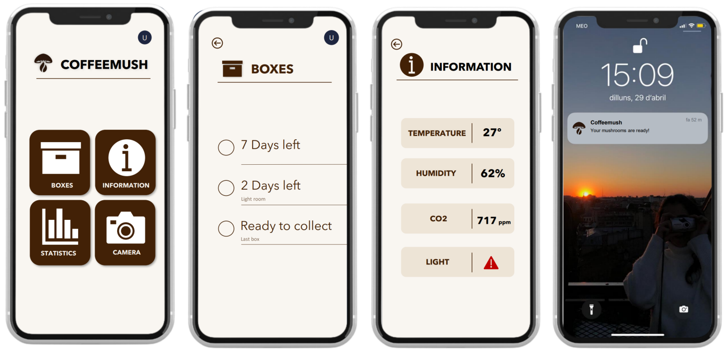


Fig. 2. CoffeeMush app

4.1 Assembly

Structure The prototype structure follows the original design with the exception that it has no roller conveyor and only contains one camera (Figure 1b).

Electric Design The control of the environmental conditions, monitored by humidity and temperature sensors, is made via the fan and the solenoid valve connected to the water tank. The application notifies the user when: (*i*) to refill the water tank based on the readings of the float switch; and (*ii*) the darkroom is too bright based on the readings of the light level sensor.

Mobile Application The front-end Android application, built in flutter/C++, communicates via HyperText Transfer Protocol (HTTP) with the back-end API. This API, built with Python Flask library, and the MongoDB database run in a docker. The database was administered using Mongo-express, a dedicated web-based administration interface. The back-end API implements the set of operations listed in Table 3. Figure 2 shows, from left to right, the main screen followed by box status info, real-time monitoring info and notification screens.

4.2 Tests & Results

Smart Control Table 2 displays the functional results of the smart control system.

Table 2: Device: functional results

Use Case	Result
Power Supply Verification	Pass
– LM7805 outputs 5 V	Pass

...continued

Use Case	**Result**
Light Sensor	Pass
– Output voltage changes with light intensity	Pass
Water Float Switch	Pass
– Float switch changes GPIO pin state (HIGH/LOW)	Pass
AHT20 Sensor	Pass
– Correct temperature readings	Pass
– Correct humidity readings	Pass
Solenoid Valve Control	Fail
– Solenoid valve opens/closes based on control signal	Pass
– Water flows through the solenoid valve	Fail
Fan Control	Pass
– Fan turns on/off based on control signal	Pass
Power Indicator	Pass
– LED lights up when power is on	Pass

The solenoide valve test partially failed due to a lack of water pressure. The water tank - made of an ice cream box – is placed immediately above the valve, not creating the necessary pressure.

Web/Mobile Software Application Table 3 holds the functional and performance (exchanged data size and latency) results of the implemented API. The latency tests were made by making ten consecutive calls to each operation and calculating the corresponding average (μ) and standard deviation (σ) values. Table 4 presents the load impact in the longest operation (worst case). The load tests consist of making 10, 100 and 1000 simultaneous requests to the operation with higher average latency in Table 3.

Table 3: API: functional and performance results

Operation	**Method**	**Result**	**Size** (B)	**Latency** (ms)	
				μ	σ
Check token	GET	OK	207	6	0
Connect	POST	OK	332	9	7
Disconnect	DELETE	OK	334	7	3
Get Data	GET	OK	331	6	3
Get User	GET	OK	290	8	2
Login	POST	OK	426	21	7
Logout	DELETE	OK	245	25	10
Register	PUT	OK	315	14	1

Table 4: API: load results

Requests/ Results	**Operation**	**Method**	**Size** (B)	**Latency** (ms) μ	σ
10/10	Logout	GET	245	36	11
100/100	Logout	GET	245	28	8
1000/1000	Logout	GET	245	763	331

These results show that the app provides a friendly user experience.

5 Conclusion

CoffeeMush is an environmental and innovative solution to grow mushrooms out of coffee waste. Unlike most kitchen composters, CoffeeMush outputs an edible end product. The reusable packaging solution made from mycelium, an environmentally friendly material, is an example of ethics and sustainability. CoffeeMush comes with an app which informs the user about the current internal environment and the state of mycelium/mushrooms as well as notifies when to take action based on other sensor data. The device can smartly operate the fan and the solenoid valve to control air quality and humidity.

In addition, TheOnlyOne team members report that EPS@ISEP has contributed to develop:

- Teamwork and collaboration skills namely intercultural teamwork, group dynamics, role distribution and communication.
- Project management and organisation skills like long-term project management, organisational strategies and time management.
- Technical and problem-solving skills such as design thinking, prototyping and interdisciplinary knowledge.
- Personal development particularly adaptability, verbal and written communication and leadership.

CoffeeMush can be improved in several ways. To regulate temperature and humidity more efficiently and solve the problem of the lack of water pressure, the current fan and perforated tube should be substituted by a new heating/-cooling system. Finally, to increase the process quality, it should be possible to monitor separately the humidity and temperature of each compartment: (*i*) the mycelium requires lower humidity and the mushrooms higher humidity; and (*ii*) the dark and light-filled compartments heat and cool differently. Both improvements would require design changes, such as using solid instead of staggered plates between compartments and a heating/cooling system per compartment.

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