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

Abstract. CoffeeMush is an innovative and sustainable project developed as part of the European Project Semester (EPS)@ISEP 2024. The 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 development focused on ethical and sustainability considerations, and the use of low power technologies. The paper describes the theoretical background of the project, the technical design, the prototype development and the results of the various tests carried out. 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 program catering not only to engineering students but also students from diverse fields of study. Offered by universities across Europe, EPS aims to equip students with the skills and knowledge necessary to tackle the contemporary challenges [4].

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 conclusion and proposes further developments.

2 Preliminary Studies

2.1 Related Work

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 [7]. 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

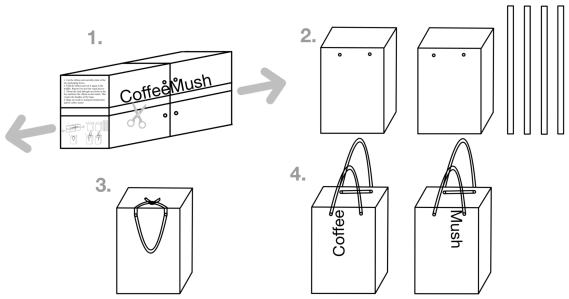
Name	**Cost (€)**	**Input**	**Output**	**Composting time**
Reencle [15]	585	Food leftovers	Grass compost	2.0 h
Mill [12]	939	Food leftovers	Chicken food	2.5 h
Lomi [13]	599	Food leftovers	Organic fertiliser	12.0 h
Foodcycler [10]	500	Food leftovers	Organic fertiliser	5.0 h
Bokashi Organko 2 [14]	90	Food leftovers	Organic fertiliser	2.0 w
Beyondgreen [2]	409	Food leftovers	Organic fertiliser	1.0 w
Mella [9]	447	Fruiting blocks	Mushrooms	2.0 w
Shrooly [6]	419	Fruiting blocks	Mushrooms	2.0 w

The Reencle composter [15] works silently and has a 3-layer filter system to prevent the odours. Mill [12] and Lomi [13] composters offer modern designs at higher prices. The Foodcycler [10] composter has a shorter compost time, while Bokashi Organko [14] and Beyondgreen [2] are more affordable but have longer composting times. Mella [9] and Shrooly [6] are mushroom fruiting chambers. Mella has three different boxes, which can have different types of mushrooms [16]. 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 (SWOT), marketing mix, marketing plan and marketing program. 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.

(a) Device with top and bottom growth boxes



(b) Packaging for device protection and coffee grounds transportation

Fig. 1. CoffeeMush solution design.

The marketing plan considered the Product, Price, Place and Promotion (4 P) marketing mix: (*i*) CoffeeMush product embodies a sustainable solution designed to our problem, fostering mushroom growth, addressing customer needs for eco-friendly waste management, and contributing to cost savings and environmental conservation. (*ii*) CoffeeMush price aims strategically to undercut existing kitchen composters in the market, ensuring accessibility to a broader spectrum of consumers. (*iii*) CoffeeMush place is within the realm of kitchen composters, targeting home appliance distribution channels. (*iv*) CoffeeMush promotion adopts a multifaceted promotional strategy encompassing both digital and physical mediums. The estimated price for 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

For any project, it is crucial to 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 consumers' decisions and opinions rather than imposing the necessity and purchase of the product. In the environmental field, it is essential to take measures to respect the environment in the product development. It must be taken into account in all aspects of the project, such as in the selection of materials, or in the choice of the factories where production takes place. Additionally, it is vital to consider the environmental impacts of the product, whether direct or indirect [5]. Last but not least, liability has been focused on environmental impact, human rights, safety compliance, consumer instructions, and data security. Following the European Commission's directives is mandatory for CoffeeMush.

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 of its useful life, all aimed at making environmentally sustainable development decisions and avoiding potential environmental impacts of the product [11]. Above all, CoffeeMush contributes to Sustainable Development Goal 12 – "Sustainable Consumption and Production"[1] – of the United Nations.

3 Proposed Solution

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. 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,

[1] https://sdgs.un.org/goals/goal12

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 main aim of the design is to provide optimum growing conditions for mushroom cultivation while ensuring low power consumption and minimum customer effort.

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 two compartments: one dark and one light. 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 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 odors and spores from escaping and contaminants from entering [3][1].

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 [8]. Its biological nature means that it is a readily available and compostable resource. It can be

transformed into a kind of leather, fine paper, or foam. CoffeeMush's packaging consists of a mycelium foam box with two foldable central strips of mycelium leather, as depicted on Figure 1b. This solution protects the device during transportation and easily converts it into two bags for transporting coffee grounds and/or mushrooms.

Smart Control It offers smart control over the mushroom-growing process. Humidity, temperature, CO_2, light, and water level sensors are used together with a camera to be informed about the conditions, while solenoid valves and ventilation help provide the desired conditions. The device also includes a microcontroller that is able to provide those conditions, but for more complex tasks, like image processing or data backing up, information is sent to the Message Queuing Telemetry Transport (MQTT) broker. The maximum power consumption will be less than 10 W.

Mobile Application The Android application serves as a monitoring system for the whole process and a reminder for the user's tasks. It is communicated with the Application Programming Interface (API) via HyperText Transfer Protocol Secure (HTTPS) which, at the same time, is subscribed to the MQTT (Mosquitto) broker topics related to the project.

4 Prototype Development

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.

Electric Design The environmental conditions are regulated by humidity and temperature sensors, which send signals to the fan and the solenoid valve connected to the water tank ensuring needed conditions. The water level in the tank is monitored by a water float switch, which will signal the application to refill the tank when necessary. Additionally, a light sensor checks the amount of light in the darkroom to ensure it is not too bright. If there is too much light, the user will receive a notification.

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.

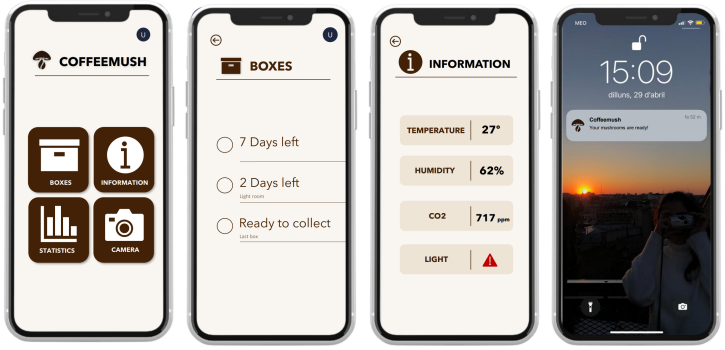


Fig. 2. CoffeeMush app

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
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 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 in 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/	**Operation**	**Method**	**Size** (B)	**Latency** (ms)	
Results				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

5.1 Project Outcomes

To conclude, CoffeeMush is an environmental and innovative solution to grow mushrooms out of coffee waste. Unlike existing kitchen composters, CoffeeMush outputs a useful end product. An example of ethics and sustainability has been taken is the packaging solution, which does not have to be thrown away as it can be reused. Furthermore, the package is made of mycelium, an environmentally friendly material. CoffeeMush comes with an app, which notifies the user about the state of the mycelium/mushrooms. It contains cameras and other sensors that inform the user when to take action. Nonetheless, the device can smartly operate the fan and the solenoid valve, which control air quality and humidity.

5.2 Personal Outcomes

In addition to the reported project results, team members reveal that EPS@ISEP also contributed to their personal development:

- "*I learned to work and effectively communicate with people from diverse backgrounds and cultures. Additionally, I gained experience in design thinking and constructing a prototype from scratch.*"
- "*EPS@ISEP gave me the opportunity to work on a long-term international project with a group of people from different cultures and fields of study. It improved my teamwork and scientific skills and showed me the importance of communication and management.*"
- "*I learned a lot about group work and that different cultures have different habits in working, in meetings and in the way they were trained to do a project in university. This taught me the importance of communicating clearly and regularly. Furthermore, I learned how to cooperate in a group with different fields of studies. This gave me insight into other fields of engineering.*"
- "*I learned the importance of clear communication and effective teamwork with people from diverse backgrounds. The experience expanded my knowledge in various engineering fields and emphasised the value of organisation. These lessons will be invaluable in my future projects.*"
- "*I learned how to approach a project of such dimensions and about other aspects of the engineering field that are not related to my specialisation. As far as teamwork is concerned, I realised the importance of roles inside a team as well as the necessity of people with different personal skills. Although the different backgrounds were a challenge for TheOnlyOne team, it became clear the importance of organisation and communication.*"
- "*This project helped me realise how to work as part of a team on a big project. What I learnt will be useful to me in the future. What's more, coming from different countries has made this experience unique and irreplaceable.*"

5.3 Future Development

CoffeeMush can be improved in several ways. Firstly, costs can be reduced by optimising the manufacturing process and buying materials in bulk. To increase the process quality, there should be a camera, a humidity sensor and a temperature sensor in the dark and light-filled compartments to separately monitor: (*i*) the state of growth of the mycelium and mushrooms; (*ii*) the ideal humidity for the growth of the mycelium (lower humidity) and mushrooms (higher humidity); and (*iii*) the temperature, since the dark and light-filled compartment can heat and cool differently. Finally, to regulate temperature and humidity more efficiently, there should be dedicated heating/cooling and vaporisation systems instead of the current fan and perforated tube.

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