Solar Dehydrator*

An EPS@ISEP 2019 Project

Dániel Szabó[1], Elisa Gillet[1], Ignacio Vallés[1], João Pereira[1], Marie Keppens[1], Pascal Krommendijk[1], Abel J. Duarte[1,4], Benedita Malheiro[1,3], Cristina Ribeiro[1,2], Jorge Justo[1], Manuel F. Silva[1,3], Paulo Ferreira[1] and Pedro Guedes[1]
[1]ISEP / PPorto – School of Engineering, Porto Polytechnic, Porto, Portugal
[2]INEB, Porto, Portugal
[3]INESC TEC, Porto, Portugal
[4]REQUIMTE / LAQV, ISEP, Porto, Portugal Portugal
epsatisep@gmail.com

ABSTRACT

This paper provides an overview of the development of a solar dehydrator, a project undertaken by a team of six Erasmus students from different countries during the European Project Semester at the Instituto Superior de Engenharia do Porto in the spring of 2019. The main objective of the European Project Semester is to develop teamwork, communication and problem-solving skills through team work and project-based learning. The purpose of the project was to design a sustainable solution to dehydrate and preserve food, build and test the corresponding proof-of-concept prototype, while respecting requirements such as the budget, the use of reusable materials and components or European Union directives. To achieve this goal, the team considered the technological, ethical and deontological, economic and environmental perspectives in the design of the Dryfoo prototype. This paper describes, after a short introduction, the performed research, the development and the testing of the proof-of-concept prototype, as well as the personal outcomes of this learning experience.

CCS CONCEPTS

• Social and professional topics → Professional topics → Computing industry → Sustainability • Applied computing → Education → Collaborative learning

KEYWORDS

Capstone projects; Designing sustainable projects; Education for sustainable development; European Project Semester; Collaborative learning; Project based learning.

ACM Reference format:

Dániel Szabó, Elisa Gillet, Ignacio Vallés, João Pereira, Marie Keppens, Pascal Krommendijk, Abel J. Duarte, Benedita Malheiro, Cristina Ribeiro, Jorge Justo, Manuel F. Silva, Paulo Ferreira and Pedro Guedes. 2019. Solar Dehydrator: An EPS@ISEP 2019 Project. In *Proceedings of the Seventh International Conference on Technological Ecosystems for Enhancing Multiculturality (TEEM'19). ACM, New York, NY, USA, 7 pages.* https://doi.org/10.1145/1234567890

1 Introduction

The European Project Semester (EPS) is an international capstone programme for students from engineering, product design and business backgrounds, offered by 19 universities located in 12 European countries. The aim of this one semester programme is to develop teamwork, project management, communication between different cultures, and linguistic capacities by making students work, in teams of three to six students, on a project based on a modern-day problematic [1].

The Instituto Superior de Engenharia do Porto (ISEP) has been an EPS provider since the academic year 2010-2011. The syllabus of EPS@ISEP comprises Project, Team building and Project Management, Marketing and Communication, Eco-efficiency and Sustainability, Ethics and Deontology, and Portuguese [2]. Apart from the central Project module, the remaining modules are short focussed support modules. The teachers involved are from different departments, who are available throughout the semester for coaching. The school also provides access to workshops and laboratories on a needs base [3].

EPS@ISEP implements project-based learning and teamwork methodologies, promoting the development of transversal skills and addressing sustainability and ethics in a multicultural and multidisciplinary set up [4], [5]. Furthermore, the programme complies with the 4C2S core professional competencies framework proposed by [6], which correspond to critical thinking and problem solving, effective communication, collaboration and team building, and creativity and innovation competencies – the four Cs identified by the American Management Association – as well as socio-professional ethics and sustainable development – the two Ss.

Sustainable development is one of the most important subjects today. With all the issues and problematic linked to this topic, more and more people are interested in making a change in the world by reusing, recycling, adopting renewable energy sources or preserving natural resources. This was the mind-set of a team of EPS@ISEP students, when, in the spring of 2019, they chose to design and build a solar powered dehydrator. The team comprised a French engineering student, a Portuguese electrical and computer engineering student, a Hungarian mechanical engineering student,

a Belgian Product Development student, a Dutch electrical engineering student and a Spanish mechanical engineering student. The Solar Dehydrator was intended to provide a sustainable inexpensive food preservation method, independent of the use of electricity.
This paper describes the steps taken by the team to achieve this goal: the analyses of the State of the Art, Marketing, Sustainability, Ethics and Deontology, the Design and Development of the proposed solution, the Tests and Results obtained and, finally, the Conclusions.

2 Background

2.1 Food Dehydration

Dehydrating food is an old practice used to preserve food economically, while keeping all its nutrients. There are two different types of dehydrators: electrical and solar. While electrical dehydrators all use the same method (heating element, a fan and air vents), solar dehydrators are divided in four types: direct, indirect, mixed and hybrid. The direct type, seen in Figure 1, is the simplest, where the sunlight dries the food directly through a glass. This method is cheap but the ultra violet radiation risks damaging the food [7].

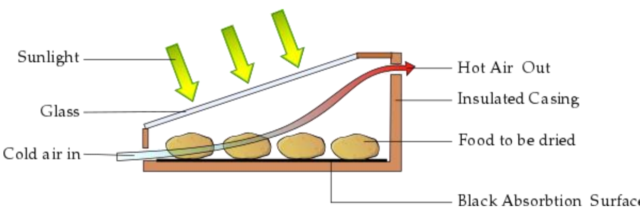

Figure 1 – Direct dehydrator [8]

The indirect type, in Figure 2, uses a solar collector to heat up the air. The warmer airflow will then enter the cabinet where the food is placed, eliminating the risk of food damaging due to the radiation. Usually, this type of device is bigger, more expensive and harder to make [9].

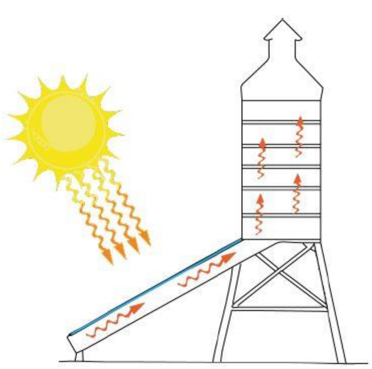

Figure 2 – Indirect dehydrator [10]

The mixed type, in Figure 3, combines direct solar radiation and a solar collector. It dries food faster than the indirect and direct types, but exposes the food to the danger of the solar radiation.

Figure 3 – Mixed dehydrator [11]

The hybrid type, in Figure 4, is a modern indirect dehydrator that uses other technologies to dry food faster. A common example is adding fans, which are powered by a solar panel. This combination provides the advantage of continuous drying even during nights or cloudy days. The cost, quality and efficiency are higher when compared with the previous types.

Figure 4 – Hybrid dehydrator [12]

Based on this state-of-the-art research, the team decided to design and build a hybrid dehydrator.

2.2 Marketing

The team started by analysing the market to identify the strengths, weaknesses, opportunities and threats (SWOT) of dehydrators, both at the macro and micro environment levels. While the internal diagnostic is focused on the strengths and weaknesses of the company/product itself, the external diagnostic considers the opportunities and threats of the outside environment. Table 1 displays the obtained SWOT matrix. It shows that the strengths arise from the usage of renewable energy and sensors and from the potential impact of the product in two markets. The weaknesses are linked with potential influence of the product in two markets since, when it comes to efficiency, it will be in disadvantage when compared with electrical dehydrators.
Next, the team mapped the product to the current market and performed a client segmentation and marketing mix. Based on this

marketing plan, the team decided to focus on customers who want to eat natural food and use environmentally friendly products. By focusing on this segment of customers, the product stands on an equal footing, even with the more efficient electrical dehydrators.

Table 1: SWOT matrix

Diagnostics	Strengths	Weaknesses
Internal	Focus on renewable energy. Potential influence on the restricted market of solar dehydrators and the broader market of electrical dehydrators. Use of advanced technology (sensors and mechanisms) usually absent in other solar dehydrators.	Despite influencing two markets, the product is in disadvantage when compared to electrical dehydrators.
	Opportunities	**Threats**
External	Growing demand for products using renewable energy and having low power consumption. Eco-design connects emotionally with people. Unaffected by laws and policies against polluting non-renewable energy sources.	Quite strong and growing competition. Existence of a more efficient drying technology.

The team named the food dehydrator product Dryfoo. Figure 5 shows the designed product logo.

Figure 5 – Product logo

For the brand, the team chose the name "BeSol". It is supposed to remind and encourage the possible clients to be more sustainable by taking advantage of the Sun.

2.3 Sustainability

Sustainability is one of the main concerns of today's society and one of the most crucial aspects of this project. To ensure that every step of the production respects the environment, the team performed an analysis on the sustainability of the future product.

To prevent pollution and keep carbon emissions low, Dryfoo relies exclusively on renewable resources such as the wind and the sunlight. The radiation of the Sun is used to create heat inside the cabinet and to power up the electrical components, generating electricity through a solar panel. The wind helps the warmer air in the collector zone to move up to the drying chamber, where the food will be. In the absence of sunlight, a small battery will supply energy so that the dehydration process can continue.

Most of the elements used to make the proof-of-concept prototype were reused materials and components, which can also be recycled. Local suppliers were chosen to provide the remaining parts according with the performed life cycle analysis. More than two thirds of the prototype (70 %) are made of wood salvaged from leftovers. Wood is a natural and recyclable material, good insulator and easy to clean and machine. The remaining 30 % include the three bendable parts in polyvinyl chloride (bought) and the trays to hold the food (made from an old computer ventilation metal grid). Before cutting, each part was positioned in advance on the respective material in order to optimize the material used and avoid waste.

2.4 Ethics and Deontology

Ethics is a broad topic involving engineering, environment, marketing and liability dimensions. The environmental aspect has a significant role in the solution because of the adopted environmentally friendly design and the extensive reuse of materials in the prototype as detailed in the previous subsection.

In terms of the idealised business, Besol will consider liability, engineering and marketing ethics.

Liability aims to ensure safety of use and roughly translates to the compliance with the applicable guidelines, legislation and directives, which the team followed. Considering engineering ethics, BeSol will ensure fair conditions and a professional work environment for all collaborators. The marketing ethics addresses the fair, equal, and ethically neutral advertisement and distribution. As such, BeSol will guarantee that the marketing of Dryfoo will generate no controversy nor bad reputation. Last, but not least, based on consumer policies, BeSol will make every product distributed safe and fair to the end user. To keep this promise, BeSol will give free repairs within the two-year warranty period and, if the customer is done with or has bought a newer product version, BeSol will freely take back the product to either refurbish or recycle every material as sustainably as possible. This way the consumer will trust BeSol and believe it is an ethically aligned company.

3 Design and Development

3.1 Design

Based on the State-of-the-Art study, the team decided to build a hybrid dehydrator using a solar collector together and an electronic control system to make the drying process more efficient, while remaining environmentally friendly.

Figure 6 displays the designed structure. The air enters through the openings at the bottom and heats when passing through the black collector. This collector is made of black rubber to ensure a good radiation absorptivity. The warmer air flow rises, enters the food cabinet through small holes, passes through the four food trays, and exits through the chimney. The air circulation is facilitated by two fans placed above and below the food trays. Finally, the air vents are operated by a servo motor. All electronic components are powered by the solar panel located on top of the dehydrator, shown in Figure 7.

Figure 6 – Exterior and interior views of Dryfoo

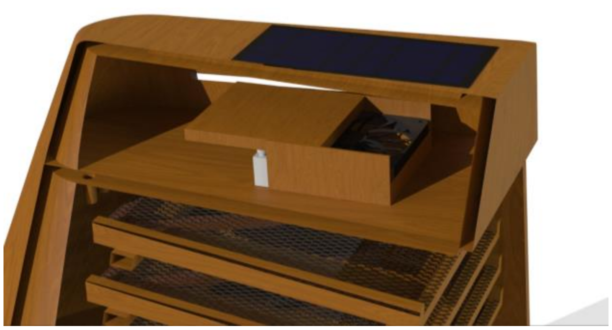

Figure 7 – View of the solar panel and fan

3.2 Cabinet Control

To maintain the desired temperature and relative humidity levels, Dryfoo is equipped with sensors, fans and a servo motor. When the temperature and/or humidity are out of the pre-set range, the fans are switched on/off and the air vents opened/closed, accordingly. The user can also interact directly with the cabinet by using the interface at the back of the dehydrator.

Electronics

Figure 8 displays the electronic control system diagram. It comprises two power supplies: the Sun (cabinet heater) and the solar-powered battery (electronics supplier). The battery is itself powered by a solar panel, making the Sun the only source of energy of the system. The user can control the product through the user interface, including select or define the drying period. Once the drying period is set, the device starts converting raw into dried food. The Arduino Uno, which is the main control unit of the device, is connected to the temperature/humidity sensors, the fans, the servomotor and the Liquid Crystal Display (LCD). The LCD and a set of four navigation display buttons are mounted on a pre-manufactured Printed Circuit Board (PCB) which sits as a shield on top of the Arduino. The buttons are connected to a single analogue pin and programmatically processed. Since the servo motor and fans consume a high amount of power, they are switched on and off by a dedicated transistor to save energy. All components are directly or indirectly powered by the battery.

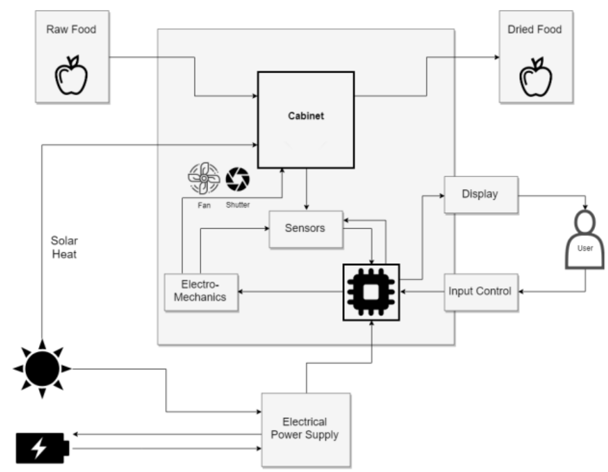

Figure 8 – Control system diagram

The two DHT22 temperature and humidity sensors monitor the conditions inside the cabinet. They are placed on the upper and lower part of the food cabinet. The team designed a dedicated PCB to hold the additional components such as capacitors, Light-Emitting Diodes (LED), resistors and transistors for easier maintenance. Standard sized headers were used to simplify assembly and disassembly. Figure 9 displays the 3D model of the dedicated PCB. The long header row on the left corresponds to the input and the smaller headers interface with the different components.

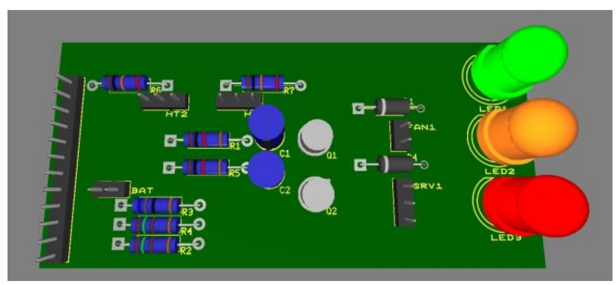

Figure 9 – 3D model of the designed PCB

Table 2 shows the power budget of the control system in the maximum consumption case. In this situation, the system requires a power of 1 W and a current of 205 mA. Based on this result, the team selected a 3.7 V battery capable of providing up to 19 W and a maximum current of 5200 mA.

Table 2: Power budget

Component	Voltage (V)	Current (mA)	Power (mW)	Qty	T. Power (W)
Arduino Uno	5.00	20.0	100	1	0.100
Battery Charger	5.00	0.15	0.75	1	0.001
Voltage Booster	5.00	0.60	3	1	0.003
Fan	5.00	74.00	370	1	0.370
Servo Motor	5.00	3.00 45.00	150 225	1	0.225
LCD Key Shield	5.00	30.00	150	1	0.150
DHT22 Sensor	5.00	1.10	5.5	2	0.011
LED	5.00	2.50	12.5	5	0.063
Diode	1.10	21.00	23.1	1	0.023
Maximum Power Consumption (W)					**0.946**

Functionalities

The drying process can be explained through the airflow diagram of Figure 10.

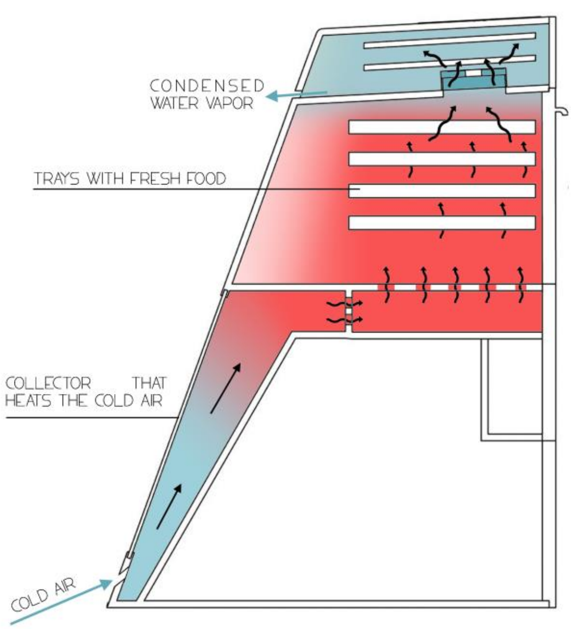

Figure 10 – Airflow diagram

The sliced fruit placed on the food tray is exposed to the heat of the warm airflow and, as a result, water molecules evaporate. The evaporated water molecules are carried by the upward airflow, speeding the drying process. This is only possible when the volume of air is not saturated with humidity. Therefore, to improve the efficiency of the process, Dryfoo was designed to increase the heat and decrease the humidity in the cabinet. This is achieved by heating the cool air coming in through the bottom openings and making it pass through the food trays, removing the water molecules. The fan on top of the food cabinet pulls out the warm humid air in a vortex flow. Dryfoo, when switched on, displays the Dryfoo and BeSol names and a loading progress bar on the screen, followed by the main user menu presented in Table 3. This list-based layout was chosen because of the 16x2 LCD used.

Table 3: Menu item list

Menu Item
Start Drying
Process Status
Conditions
Diagnostics
Standby
Stop Process
About

The basic interface controls include the Right button (→) to confirm an action, the Left button (←) to go back and, finally, the Up (↑) and Down (↓) buttons to scroll. In the main menu the Left button is redundant. The different menu items are explained below.

Start Drying

Fruits and vegetables are grouped in different categories, depending on the duration of the required drying period and the maximum recommended temperature. The device has a default maximum temperature because the maximum recommended drying temperature of the different fruit and vegetables is similar. Therefore, the user only needs to select or define the duration of the drying process. Table 4 shows an example of the duration set-up submenu.

Table 4: Start drying display

From	Submenu List	
Start Drying	↑ +1 h ↓ -1 h	Time: 24 h

After pressing the Right button, the drying process starts. During operation, it continuously monitors and ensures that the conditions in the food cabinet remain adequate. Once the selected drying period elapses, it stops.

Process Status

This submenu provides the status of the on-going process. Table 5 illustrates the displayed information.

Table 5: Process status display

From	Submenu List
Process Status	Chosen time: 24 h Time left: 2 h 35 min

Conditions

This submenu shows the temperature and relative humidity conditions at the top and bottom of the food cabinet, regardless of the device state (idle or in operation). The user presses the Up or Down button to select the corresponding sensor. The chosen option is indicated by an up or down arrow. Table 6 shows the result.

Table 6: Conditions display

From	Sub Menu List	After pressing the Right button
Conditions	Temperature: 35 °C Humidity: 67 %	When the up button is pressed, upper sensor is shown
	Temperature: 35 °C Humidity: 65 %	When the down button is pressed, lower sensor is shown

Diagnostics

When in idle state, the user can diagnose the different Dryfoo components through this submenu:

- Battery voltage;
- Servo motor (setAngle and getAngle functions);
- DHT22 sensors (read temperature and relative humidity);
- Fans (measure the power consumption to determine if they are stuck);
- LED (the light up sequence indicates the status).

These diagnostics are shown sequentially till the user presses the Right button.

Standby/Power Saving

This submenu is available only when the device is idle. Once selected, the display shows "Entering Standby…", indicating that Dryfoo will enter power saving mode in 2 s. This option turns the Arduino in low power consumption, stops the fans and servo motor, turns off the LCD backlight and makes the orange LED glow briefly. To cancel this mode, the user can press any button.

Stop Process

This submenu allows the user to stop an on-going process. The user will be informed that the process was cancelled and returns to the main menu.

About

This submenu presents information about the version installed: "Dryfoo: 1.0v Product by BeSol".

4 Tests and Results

The team tested the different electronic components and the operation of the assembled prototype.

4.1 Temperature and Humidity Sensors

The two DHT22 sensors consist of a humidity sensing component, a Negative Temperature Coefficient (NTC) thermistor and an Integrated Circuit (IC). To measure the humidity, two electrodes with moisture holding substrate are placed between a humidity sensing component. As the humidity changes, either the conductivity of the substrate changes or the resistance between these electrodes changes. This change in resistance is measured, processed and made available by the IC. The NTC thermistor measures the temperature. A thermistor is a variable resistor that changes its resistance with the change of the temperature. The values of the two DHT22 were successfully compared with reference sensors to determine the reliability of the provided readings.

4.2 Charging System

The charging system uses the energy produced by the solar panel to power the electronic components. The solar panel is connected to the 3.7 V charging battery, using a protecting diode, and the battery is connected to the Arduino, through a voltage booster, to raise the voltage to 5 V. Figure 11 displays the charging system.

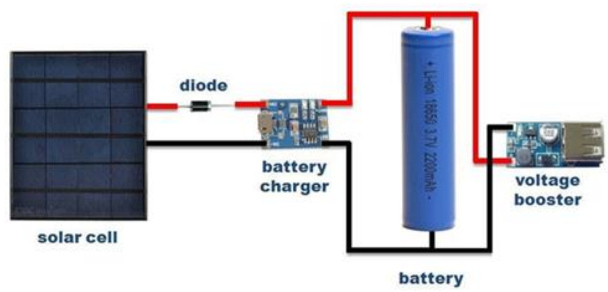

Figure 11 – Charging wiring diagram

Tests with and without sunlight were made to verify the effectiveness of this system. During daytime, the solar panel generated voltages around 4.5 V and the battery provided 3.7 V as wished. To simulate night-time, the solar panel was covered and battery was able to power up a LED for several hours without significant voltage drop.

4.3 Servo Motor

The servo motor test showed that the component worked as intended.

4.4 Fans

The fans should be 5 V fans. However, for sustainability and economical purposes, two small 12 V fans found in the storage department of ISEP were reused. These fans, when powered with the 5 V, were still able to rotate.

4.5 Dehydrator

The team tested the operation of the prototype by placing food on the food trays and starting the dehydration process. Figure 12 shows the initial state of the different sliced food used.

Figure 12 - Food before drying

Figure 13 shows their status after a seven-hour dehydration period. Besides the kiwi, the other food slices showed visible signs of dehydration. In the case of the cherries, mushrooms and bananas, these signs were clear. In the case of the apples, the drying process was half-way done. The kiwi slices showed no visible drying signs because kiwifruit is 83 % water.

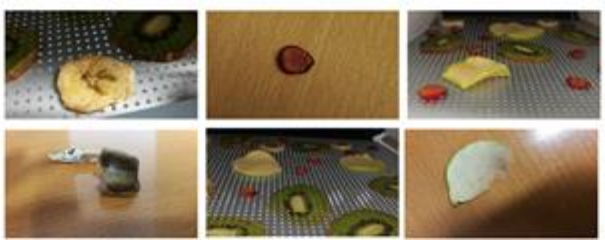

Figure 13 - Food after drying seven hours

Further details on the design, development and test of Dryfoo are available from the team's wiki [13].

5 Conclusions

This project was, for the whole team, a unique and enriching experience. It allowed every member to develop personal skills, such as teamwork, autonomy and communication, and foster the adoption of ethical and sustainable development practices. This was achieved through the design and development of an open-ended multidisciplinary project aligned with Sustainable Development Goal 2 (Zero Hunger) and Goal 11 (Make cities inclusive, safe, resilient and sustainable), set by the United Nations Educational, Scientific and Cultural Organization [14]. Short intensive support modules, covering marketing, project management, sustainability and ethics, were taught by teachers from different departments, who also accompanied the students along the semester, giving advice and feedback on their work.
According to the team, the semester went by smoothly and every deadline was respected thanks to the provided coaching. The design, assembly and test of the proof-of-concept prototype was successful. The requirements the team imposed on itself were all fulfilled. The prototype dries, in the shortest time possible for a solar dehydrator, any kind of food, thanks to the technology implemented. Depending on the temperature and/or humidity measured, the fans are turned on or off and the vents, located at the bottom of the product, are opened or closed. Finally, the user interface allows the user to choose the temperature and drying time matching the food to dry. The main difficulties were making the brand match the team's intended image and the cutting and assembly of the curved parts of the prototype.
In any case, this project allowed the participants to gain and deepen their knowledge on their field of expertise as well as on unrelated fields and the EPS@ISEP experience was, all in all, very rewarding.

ACKNOWLEDGMENTS

The team would like to thank the Instituto Superior de Engenharia do Porto for the unique experience provided.
This work was partially supported by the European Union (FEDER funds) through COMPETE and by National Funds through the Portuguese funding through the Portuguese funding agency, Fundação para a Ciência e a Tecnologia (FCT), under Project UID/QUI/50006/2019 and Project UID/EEA/50014/2019.

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