IE5557 Portfolio - Sustainable Development in Practice (A 2018/9)

**Aéropot – smart ultraponic system for indoor plant cultivation**

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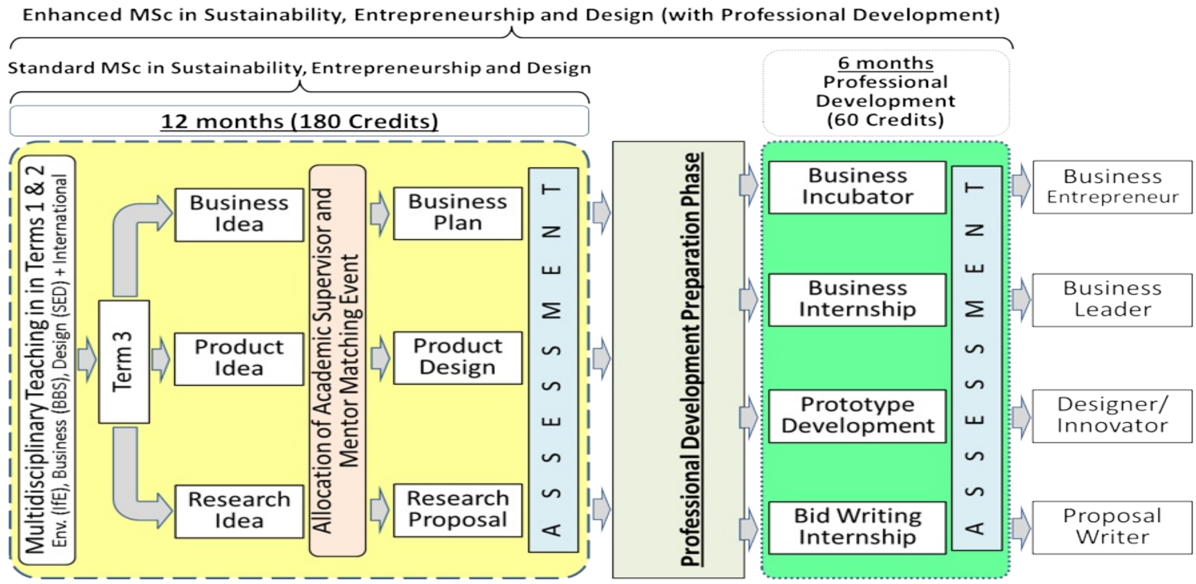
## Contents

**Abstract**

The world is facing an array of environmental and societal challenges such as overpopulation, growing urbanisation, changing climate, resource deficiency, pollution, etc. Novel solutions, that are valid, viable and sustainable, must be developed in order to deal with such issues if society, and the ecosystem as a whole, are to thrive in the future. Various new techniques of plant cultivation in a soilless environment emerged in the last few decades. Hydro/aero/ultra-ponic systems encompass many benefits from (i) substantial water conservation, (ii) all-year-round harvesting, (iii) low maintenance to (iv) cost reduction. A smart ultraponic system for indoor plant cultivation named Aéropot has been developed. It is a multifunctional ultraponic device solution to effectively and holistically tackle the 21$^{st}$-century challenges from the perspective of sustainability, design and business. It can cultivate plants with a small amount of water and without soil, which has the potential to address the issues of land and water scarcity within urbanized areas. This is a multidisciplinary project spanning across a variety of fields such as entrepreneurship, design, engineering, information technology and environmental sciences, with emphasis on practical outcomes. This paper is a reflective report and portfolio. It maps the post-study progression on the project and details personal development during the author's 'Professional Development' programme in years 2018/19.

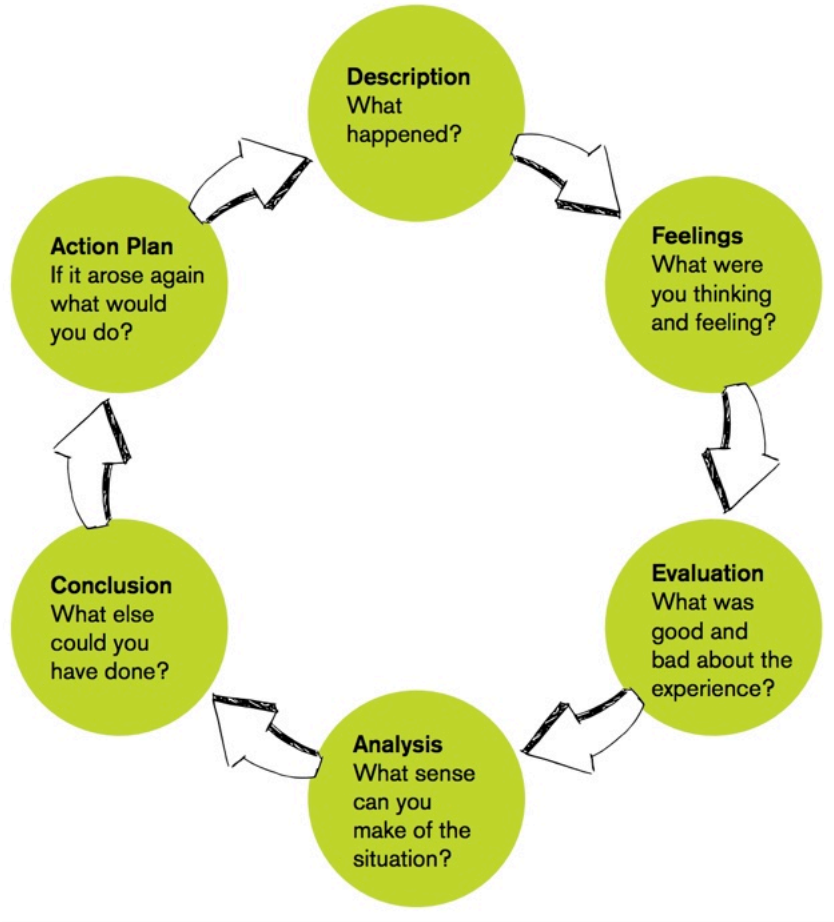
# 1. Introduction

During my 1-year *MSc in Sustainability, Entrepreneurship and Design* (180 Credits) course at the Brunel University I have registered for the *Enhanced MSc* (60 Credit) featuring 'Professional Development' programme. After the successful completion of the *1-year Standard MSc*, the 6-month 'Professional Development' period began in January of 2019.




*Picture 1 – Programme Structure of SusED MSc*

At the time of writing, the purpose of the 'Professional Development' period was to enable students to put theoretical knowledge and ideas into practice and support their effort's in the chosen career path (Brunel University, CHLS, 2017). My chosen path was the 'Prototype Development' for the programme extension. The primary aim was to develop a fully functioning prototype of an ultraponic device proposed in the final project in term 3 of the Year 1. The final project (i.e. dissertation) was produced in the form of a product design proposal and business plan. It thoroughly mapped the changing demography, gardening market and environmental trends that unquestionably formed the technical base for the product development. Alongside the written paper, I produced resources that were necessary for building the product prototype: the 3D print of the planter, the initial collection of all electronic components, first wiring schematic, application protocols documentation or lab test data to name a few. The gathered knowledge and material prerequisites were used in every stage of the development in the 'Professional Development' programme.




*Picture 2 – A reflective learning cycle by Graham Gibbs (1988)*

This paper is a conjunction of a reflective report and exhaustive portfolio of my 'Professional Development' experience. The purpose of reflective writing is to help critically and comprehensively recapitulate learnings from a particular practical experience (Gibbs, 1988). In this case, it is the prototype development of a smart ultraponic system, for indoor plant cultivation, named Aéropot. To correctly examine the experiences and learn from the process activities and development stages that went well or did not go well, the Gibbs' Reflective Cycle was followed throughout each section and subsection of this paper (Picture 2). The upcoming sections consist of the portfolio work merged with the reflective evaluation and consideration of the previous work and studies in Year 1. It helps to make connections between what was taught in theory and what was done in practice. Furthermore, there is an abundant provision of showcase material from the development stage throughout this paper.

## 2. Translating the theory to practice

Referring to the point in the introduction, this reflection report and portfolio builds upon the work of my dissertation (Jákl, 2018). It outlined the execution plan and technical blueprint for the eventual realization of the product in the 'Professional Development' programme extension. The initial idea for this project, however, stems from a completed assignment in one of the university's design module. It is where the fundamental knowledge base, in the areas of design, engineering, ecology/sustainability, was established. Both, the assignment and dissertation, laid down the basis for the development of the Aéropot product. The 'Professional Development' period provided me with a time and space to realize it. The forthcoming sections chronologically describe the work from the point in time where my dissertation efforts ended.

### 2.1. Making the chassis

Even though the chassis part of the Aéropot was originally made in the third term of the first year, the work continued even after completing the term. The description of the development process and following personal reflection take into consideration both phases, i.e. the making and subsequent alteration phase. Only by describing the entire development process, the learning can be appropriately understood.

*Picture 3 – 3D model of the planter*

To begin, the model of the chassis was designed in a CAD software package (Picture 3) and subsequently physically formed by a specialized 3D printer. This process was fairly straight-forward – except the laborious stage in which dimensions had to be set for each electronic part that was meant to be fit into a specifically dedicated area eventually. At this point, some electronic components were already selected for the final prototype, however, almost none of them was tested for its functionality, reliability and most importantly waterproof capacity. With this notion in mind, I made sure that there was enough space for each component even in the case where a component would be switched for a larger alternative. Alternatives were not known at this point yet, so there was still a certain level of risk involved – physical changes might have to be done in the future. Both parts i.e. the bottom planter and upper lid had sufficiently enough space to fit various types of electronic components as well as the pots to hold the plants. Nevertheless, I expected some iterations in the physical design to occur due to as-yet-unknown requirements for other electronic components. This was the first product prototype after all. Once the parts were printed, soaked and cleaned up from the support material, I smoothened up and painted the surfaces. I had help from university workshop technicians. And, it was the university workshops where I conducted most of my work at this stage (Picture 4).

*Picture 4 – 3D print of the planter*

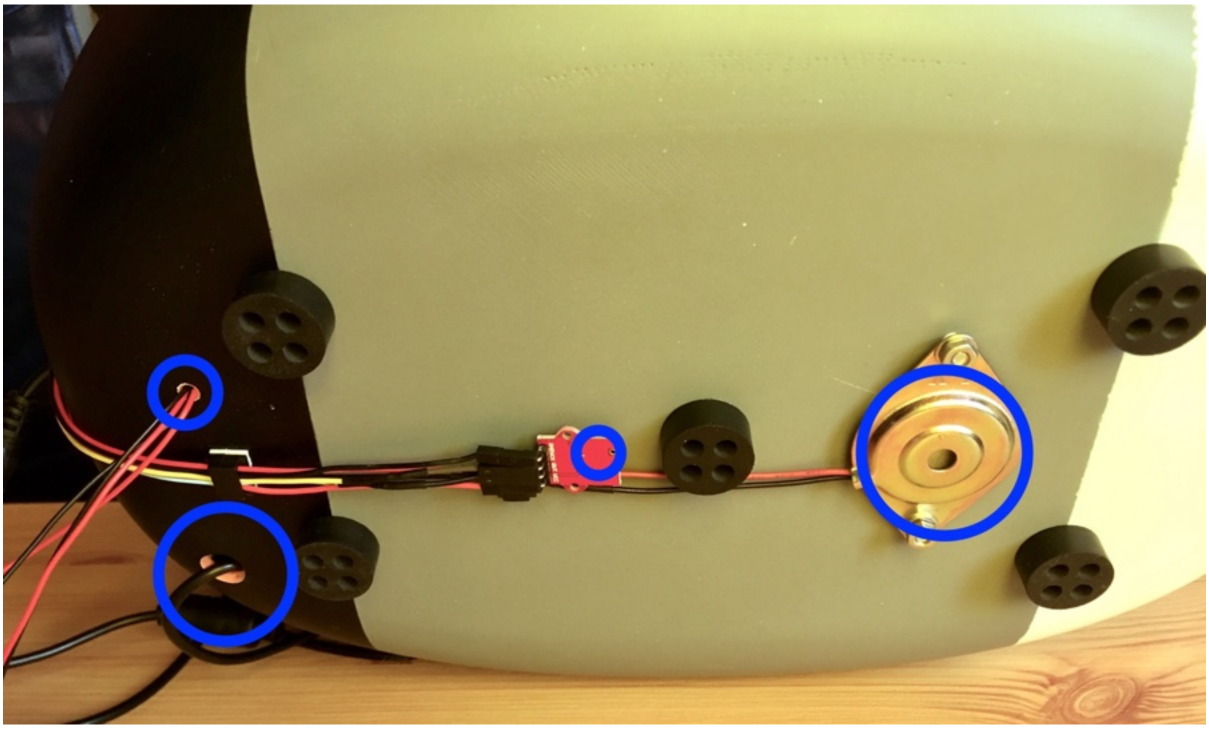
The selection of the right paint was crucial from the practical but also from the aesthetic point of view. The paint had to fill in the little pores, formed during the 3D printing process, and at the same time create a professionally looking object. Having spoken to the technicians, it was proposed to first use a transparent water-resistant coating that would fill in those pores – both from the inside and outside. The second or base paint layer was purely white. For future reference, I decided to use 3 matte shades of grey to cover the outer surface(s) – I wanted to see which one would be the most suitable for the eventual production and had the most interesting outlook from the design and marketing perspective. The inside 'tank' together with the bottom part of the lid part was painted black since the fertilizer liquid resided there. The reason for this was to limit the growth of algae or other bacteria by creating an environment with a deficient amount of light.

*Picture 5 – The process of painting the planter*

On the other hand, the upper part of the lid was painted glossy white in order to emit as much (LED) light as possible back to the outer space or, more desirably, to the plant leaves above (Picture 6). The upper top part was produced by an external company since it was essential to have a partly translucent surface with a white colouring in order to diffuse the light through it. It was in this phase, in particular, where I gained valuable hands-on skills. I learnt how to use different tools and machinery in the 3D printing, painting and sanding workshops.

*Picture 6 – The upper part or lid; it has two sub-parts*

Later, all the parts were assembled, and available electronics fitted. As it was mentioned before, there was a moderate chance that some components would have to be swapped or that there would be certain changes in the design. As the electronics were fitted inside, their functionality and more importantly reliability tested, it became obvious that it was necessary to find alternatives. Specifically, an ultrasonic distance sensor was damaged by the liquid's dispersed mist. This part was not water resistant and thus it was replaced by a pressure sensor. However, the sensor needed to be placed under the liquid to measure its full weight. The only way to achieve this was to drill a hole into the bottom wall of the tank (Picture 7). There were some structural concerns regarding the porous walls of the planter, nonetheless, the hole was drilled successfully. The sides around the hole were filled with silicon and two-component adhesive.



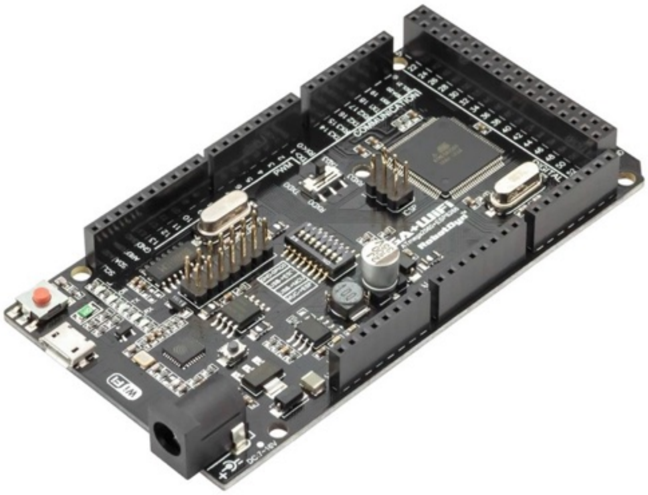
*Picture 7 – Planter design iterations*

Lastly, the atomizing component was comprised of an integrated circuit and piezoelectric disc. The disadvantage was in regard to its size; the atomizing disc was too raised above the liquid level. It meant that it had the inability to vaporize all the liquid within the tank. Hence, I decided to get a replacement part from a regular house humidifier. I drilled a hole into the bottom wall of the tank again, fit in the piezoelectric disc, isolated it properly and connected it to the circuit. The misting encapsulated all of the liquid's volume then. Both misters remained a part of the planter and would switch on or off in accordance with the liquid's height level.

### 2.2. Assembling the electronic components

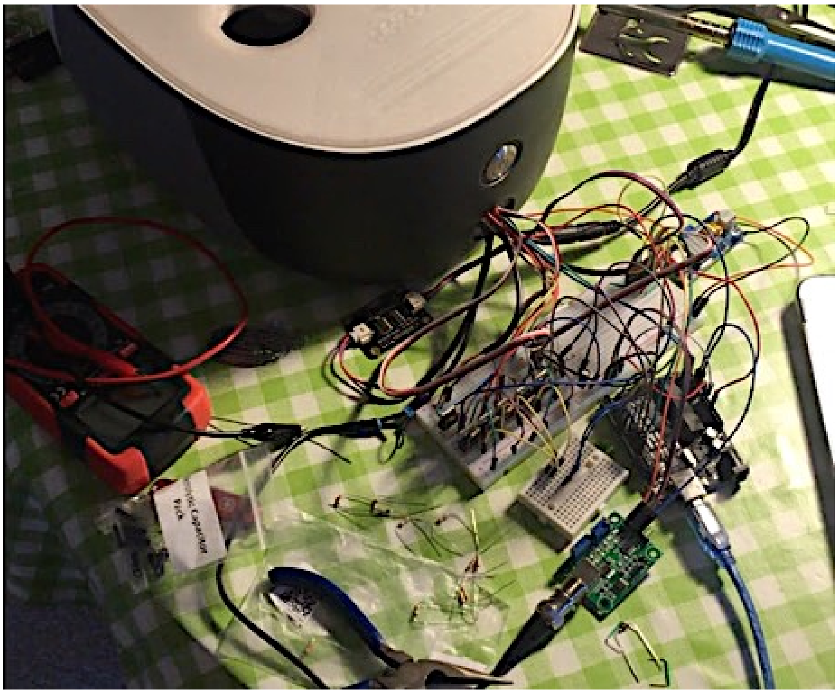
One of the main aims of the 'Professional Development' was to build a prototype with integrated electronic parts that were readily available on the market. Most electronics were sourced from a Chinese online marketplace called Aliexpress, as it offered an extensive array of low-priced products. Core components were the ultrasonic mister or atomizer, fan and lights – which are a bit less vital for the growth of the plant since the plant is normally exposed to the natural light. The mister was composed of the high-oscillation circuit board and a piezoelectric disc. There are two versions of the mister: an integrated one – which can easily be placed in the water without additional configuration. The other – a mister that is part of room humidifiers. It has the circuit board and disc separated, but it is not waterproof. Both models of these misters were placed at the bottom of the planter's tank. There, they created 'microscopic levitating droplets' from the liquid mix, that were consequently absorbed by the plants' roots. This was the most vital function of the device; essential for the optimal plant growth based on the ultraponic/fogponic principle.

If these peripherals were considered the heart of the Aéropot's system, then the Arduino microcontroller would be the brain. It is the control centre – a medium for communication between all external components. Arduino Mega R3 from RobotDyn (2019; Picture 8) was selected for the prototype production. First and foremost reason for the selection of Mega R3 was its high number of output and input pins which would allow for controlling and testing multiple sensors at once. The second reason was the integration of the wi-fi module named ESP8266. Hence, there was no need to have an external module in order to gain internet connectivity. The disadvantage of the aforementioned configuration was, however, its size. In the future, I would prefer to use smaller Arduino or probably even ESP32 with the help of multiplexers. It could switch between a limited number of inputs and outputs. Raspberry Pie might also be an alternative microcontroller for the future versions, though, it is rather a general-purpose computer. In order to satisfy the requirements of the Aéropot's system, Raspberry Pie microcontrollers had an unnecessarily number of capabilities and high operational performance that would go underutilised.



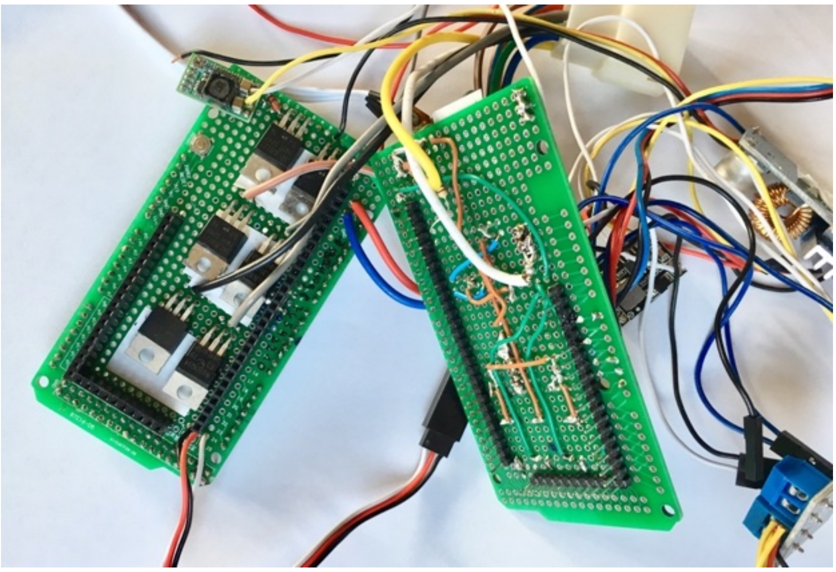
*Picture 8 – Arduino ATMega 2560 + ESP8266 by RobotDyn (2019)*

In order to select an appropriate microcontroller board, I studied various technologies, brands and types of microcontrollers that exist and were readily available on the market. Personally, this was a steep learning curve as I was not familiar with this field or market. Nonetheless, it led me to understand the technicalities behind the 'Internet of Things' phenomenon and introduced me into the world of smart device development.



*Picture 9 – Early circuit tests*

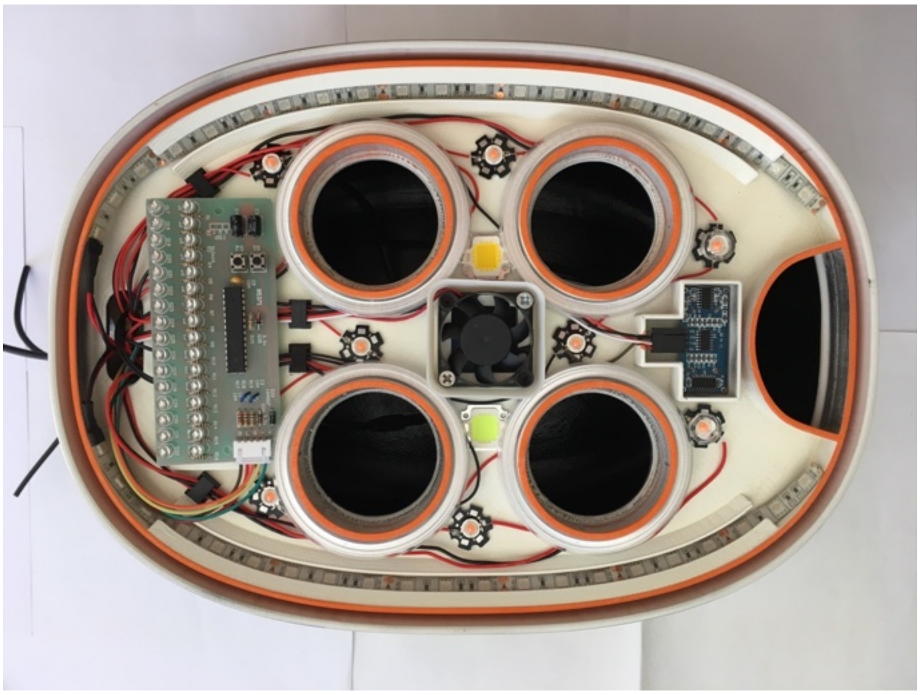
Once, all the ‘core’ components were gathered, I started assembling the circuit – first on a development board i.e. without permanent solder (Picture 9). The final (ideal) state of the circuit was intended to house all the ‘control’ electronics on two parallel shields that would simply slide into each other, together with the Arduino board. The control passive electronic components were transistors, MOS-FETS, relays and auxiliary components such as resistors, capacitors, inductors, etc. The challenging part here was to solder the components together and make sure all connections were correctly joined. If only one connection was fused with another, it might lead to a circuit shortage and possible permanent component damage. Therefore, I was conscientious and sketched the connecting lines on relevant boards beforehand to ensure they would all fit. Even though I was using two board shields for the Arduino Mega, I still needed to save some space. The idea was to fit the auxiliary components into the smallest area possible on one shield. So, the external cables and components themselves were better organized, easier to identify, and convenient to manage in the end. Besides the auxiliary components and cables, I also managed to mount DC step-down modules onto the board shields. This “motherboard” could then easily be connected with peripheral boards and components and later be inserted into the dedicated space within the planter’s chassis (Picture 10). For me, the most important learning arose in the moment when I had to figure out how to connect the components to relevant pins while having over 100 different single parts; ranging from medium to minuscule in size. I was proceeding step by step while having the final construction in mind. The circuit wiring schematic supported my efforts greatly as I almost never felt lost in my work. This skill will be useful to me within the field of product design and engineering in the future. However, even though I had a well laid-out plan, I was still making unnecessary, but not critical, mistakes where I lost a lot of time.



*Picture 10 – Arduino double-shield 'motherboard'*

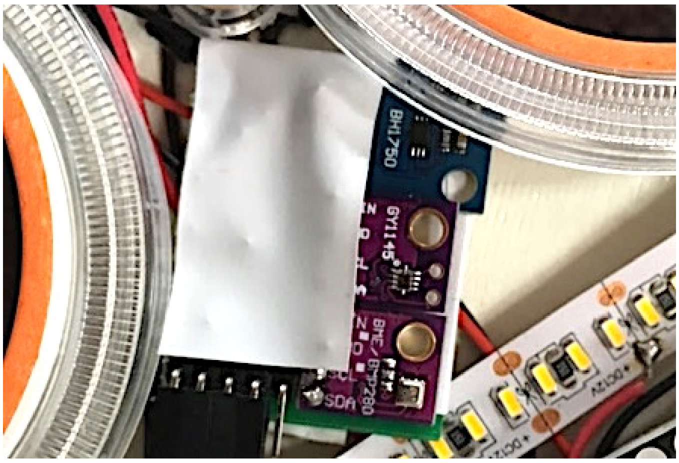
"Plants require a very specific set of environmental and functional properties to grow effectively" (Jakl, 2018). To reach the optimal environment for vigorous plant growth, an array of electronic sensors was incorporated. Those sensors were simply connected to input pins on the Arduino microcontroller. The incoming 'raw' data were then translated through relevant libraries in the source code. Vital data points included inner/outer temperature, light intensity, humidity, oxygen availability and nutrient intensity. Sensors of various parameters and manufacturers were chosen to measure the aforementioned properties of the environment. Later, the data, aggregated over a period of time, would determine the atomization time interval, fan speed as well as light intensity and wavelength composition (i.e. light colour). Specifically, a function evaluating the input data would launch an appropriate pre-defined protocol. This is further discussed in the next section.

At the time, I felt overwhelmed by the number of sensor options on the market. Considering the fact that each sensor had multiple different parameters, which quite frankly I was not confident about how to navigate through and understand it in the provided documentation(s). It took me some time to learn what parameters of each sensor were pertinent to my project. It was necessary to gain at least a basic understanding of the input data and write the code accordingly. Fortunately, there were many resources online including guidelines with an exemplary code to get the sensors swiftly up and running.



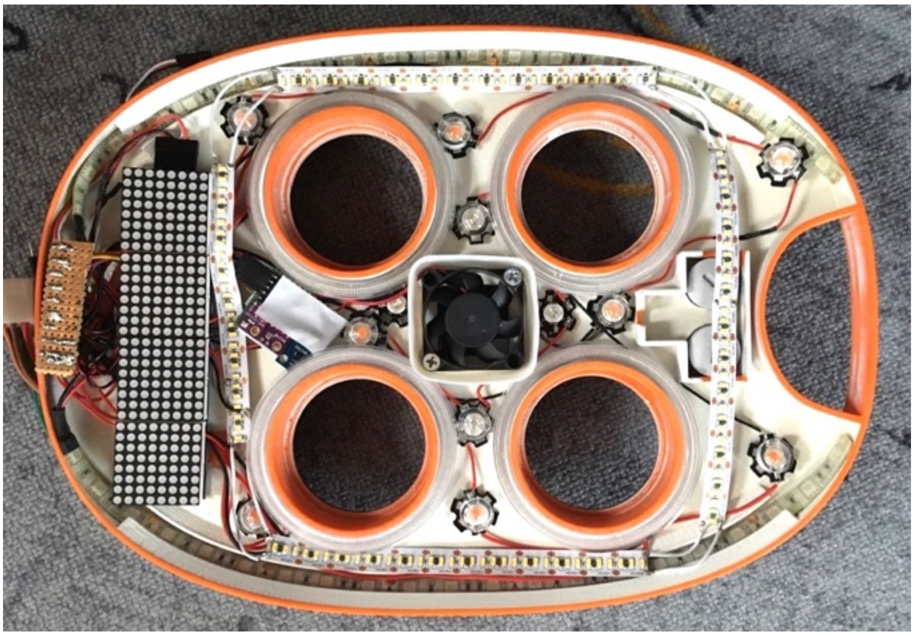
*Picture 11 – The testing stage – First set of components in the 'lid' part*

Once the sensors and auxiliary components were properly tested, it became implicit that some had to be swapped for others. Either the component or sensor failed in some way during the testing period or I found better alternatives available. For instance, the alternative performed better in terms of precision, range or another metric; or had additional capabilities e.g. it was water-resistant or water-proof. Conclusions about the performance were deduced from the official documentation of the part as well as independent online reviews and analyses. At first, the '16 LED Indicator (VU Meter) 8 - 12V' was swapped for the 'MAX7219 LED 8x8 Matrix Display' with a purpose of displaying liquid height level and fertilizer intensity (Picture 11). The original LED indicator was simply a VU meter with two sets of LED diodes that were typically used for music production purposes. Even after adjusting the circuit board, the lights did not work reliably: each line was reacting differently to the same amount of electric current and few diodes were regularly blinking, most likely due to electromagnetic interference from other electronic components. Besides, the size of the component was not too compact. Hence, four matrix display units were utilized instead. The units were exactly as long as necessary when connected in series and provided accurate control over each diode in the matrix. Next, an important component that was substituted was the ‘HC-SR04 Distance Sensor’. It was changed for the ‘MPS20N0040D-D Pressure Sensor 0-40kPa’; the sensor began outputting incorrect readings in the first stages of testing. This was quite likely due to the high level of moisture present in the tank. The receiver and transmitter units of the circuit were in direct contact with the mist. The water-resistant pressure sensor was mounted into the bottom wall of the tank. It worked reliably even after it was in direct contact with water. However, the readings were not as consistent. This sensor was overly sensitive to the changes in the atmospheric pressure. In order to have the correct and accurate information, the atmospheric pressure levels would have to be considered in the microcontroller’s code calculations. Eventually, a simple resistance metal contact/probe could be used. The resistance on the probe would change once the liquid was in contact with it and vice versa. Three critical states could be registered like so: *optimal* – above a certain height level, *low* – refill soon, *very low* – misting turned off. In the last case, the vitality of the plants is threatened. To reflect on this, I knew that using probes would be the most valid and easy way to determine the liquid level even before the chassis was developed. However, for the sake of testing and learning, I wanted to try other methods to learn about their use feasibility. Experimenting with different concepts and tweaking various electronic components, was an important part of the process in my opinion. The outcomes and practical learnings would be enormously useful in regard to the next version of the product.



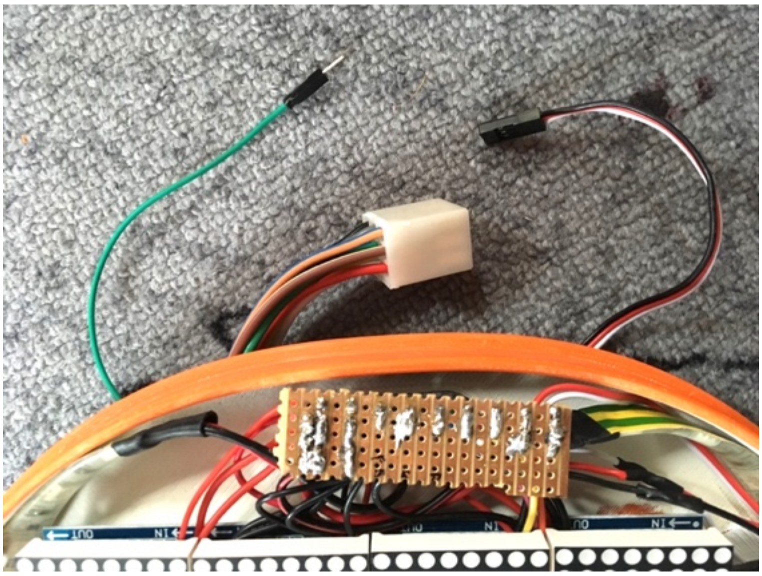

*Picture 12 – BH1750, GY1145 and BMP280 I2C sensors soldered on a single board*

Next, I swapped the 'DHT11 Temperature and Humidity Sensor' for the 'BME280 Humidity, Temperature and Barometric Pressure' for various reasons listed by the online community (i.e. electronic related websites and forums). Firstly, DHT11 had low resolution and accuracy and was sending data values that were differing with each sensor unit. Secondly, BME280 supported I2C communication whereas DHT11 did not. The end goal, for the sensors in the lid, was to have them soldered on one board and inserted under the transparent lid. There, they could monitor outdoor conditions (Picture 12). As I continued the research on sensors, the variety and quantity of sensors that I acquired greatly increased. My aim was to test as many as possible and incorporate them into the design of the planter. Later in the process, I could see what data streams would be useful for the decision-making process and provide the user with an objective overview of the plant's vitality. Continuing, the 'MQ Air Quality Sensor' was added alongside the 'GY1145 UV/IR/Visible Light Sensor' as an addition to the 'GY-302 BH1750 Light Intensity'. Besides a level of light buildup, plants also require specific composition or wavelengths of light as I detailed in my dissertation (Jakl, 2018). Therefore, the GY1145 sensor may be used to adjust the light configuration to the needs of the plant(s). This leads to the light setting within the lid part of the planter. Two high power LED diodes emitting green light were replaced with diodes of the same colour, nonetheless, the substituting type required less current and consumed less energy. Also, I added another LED strip with warm white light along the sides of the lid's inner space.



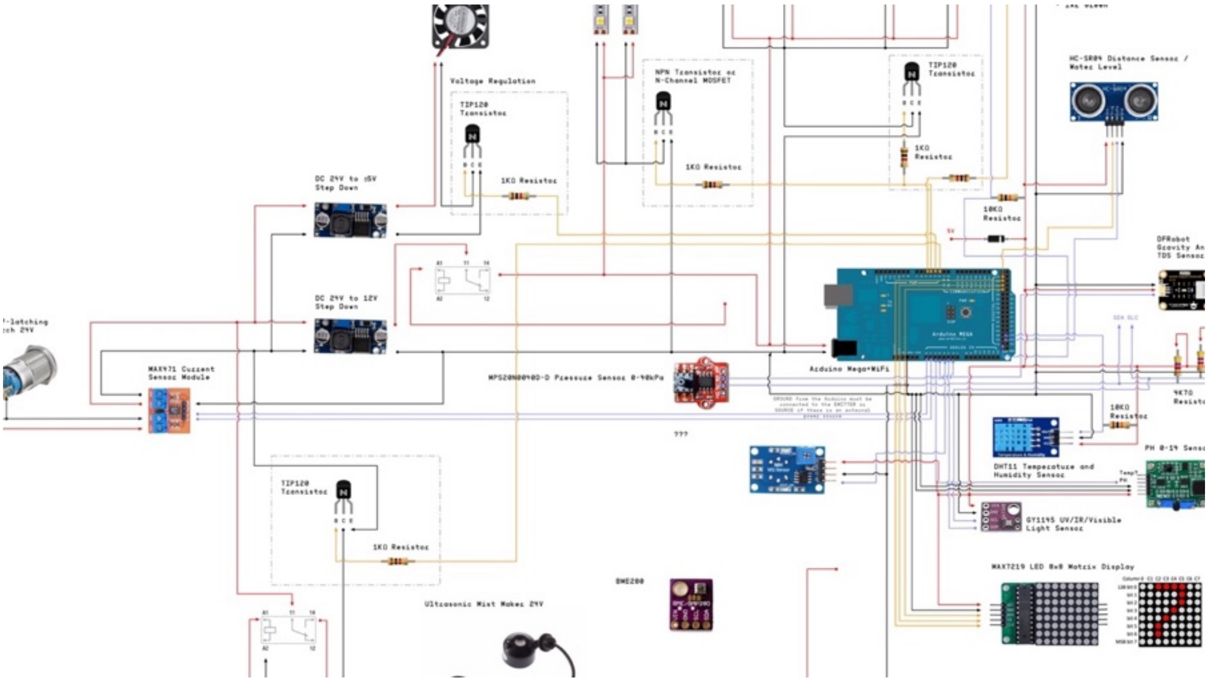
*Picture 13 – First set of components in the 'lid' part*

Once all components were placed in the lid, the cables were soldered in a systematic manner on a board with a plug-in terminal (Picture 13–14). The terminal was eventually connected to the 'motherboard' mentioned below.



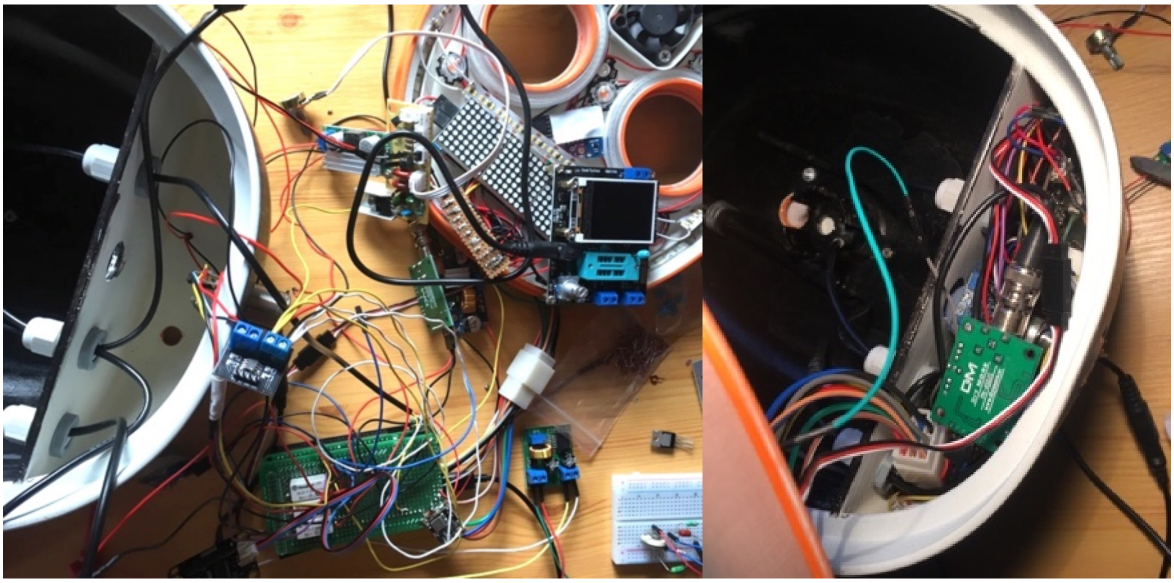
*Picture 14 – Board connecting lid's components to the plug-in terminal*

It is important to mention that there was an ongoing alteration of the circuit's design, eventually versioned as 1.2. It was due to the process of building and testing, in various areas of the product development, that organically led to such changes. Picture 15 depicts an excerpt from the final circuit that was followed during the assembling stage.



*Picture 15 – Aéropot wiring schematic version 1.2*

As the required components, peripherals, sensors and other electronics were acquired and independently tested for its reliability and validity, the circuit was progressively assembled and fit into the planter (Picture 16). Sensors and atomizer discs were fit into the dedicated areas of the tank and connected to the motherboard. It was hard to foresee if, and how all the electronics would fit inside the planter, as the circuit design was changing throughout time. I managed to carefully place it inside, making sure the circuit would not short itself. However, as soon as there was a need to physically modify it, it appeared to be a very laborious and time-consuming process. Specifically, to take the circuit out and put it back in. Because I did not know that this was an issue, I would have the electronics wired externally for the prototype build otherwise.



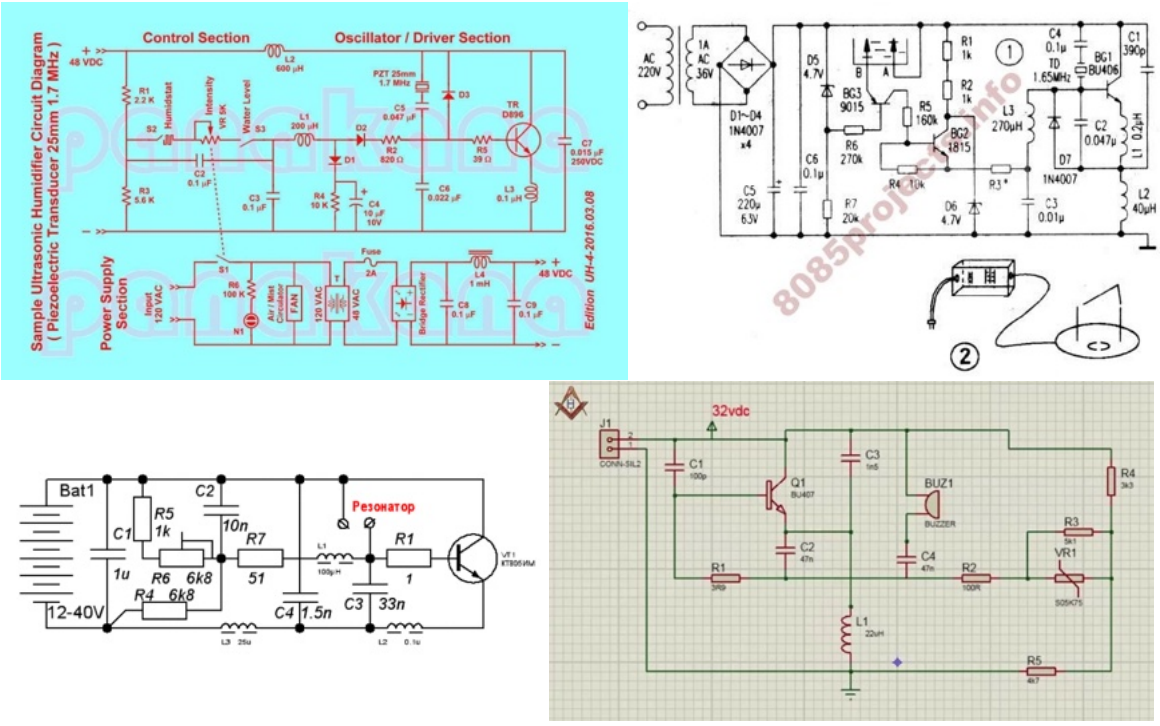
*Picture 16 – Final assembly and fitting*

Finally, with a basic code sketch, the device was connected to electric power and switched on (Picture 17). The basic functions such as lighting, misting and air ventilation worked well during the first launch. More details regarding the functionality of the prototype are provided in the upcoming sections of the report.

*Picture 17 – The first launch*

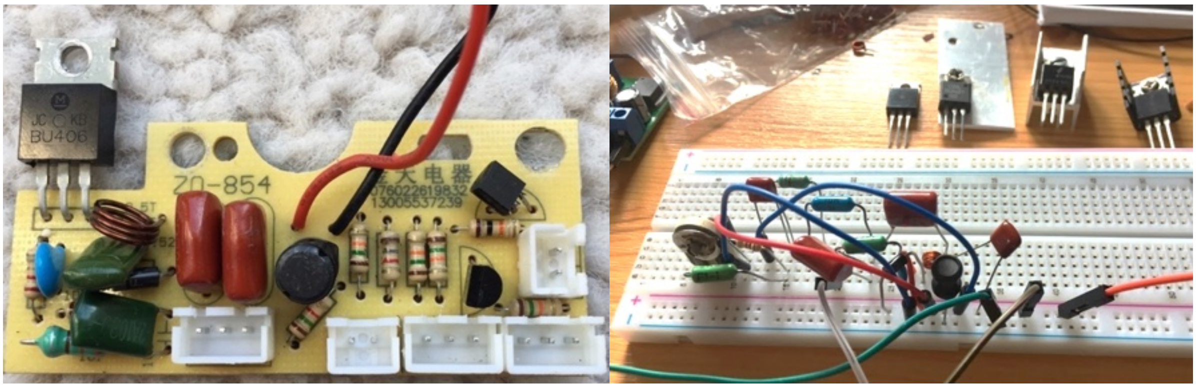
### 2.3. Building the humidifier circuit

An essential part of the Aéropot device is the ultrasonic mister or atomizer, consisting of the piezoelectric disc and driver. In theory, “the ceramic disk inside the mister oscillates at high frequencies and breaks the water into very small pieces that float in the air” (Jakl, 2018). The oscillation frequency is generated by the “driving” circuit. The driver supplies a pulsating voltage tuned specifically to the atomizer frequency of the piezoelectric disc. This frequency is around 1.7MHz in most cases. Since the piezoelectric disc was placed under the tank’s bottom wall, there was no other way than having the driver circuit externally connected to it. I decided to develop or rather re-create an existing atomizer circuit and eventually solder it on the ‘motherboard’. I managed to collect multiple versions of the atomizer circuit schematic online (Picture 18). I also had one physical replacement part for an indoor humidifier. I simply reconstructed some circuits, one after another, precisely according to the sketches. The circuits were then powered and connected to the piezoelectric disc. The results, however, were not satisfactory. Two issues arose: first, some drivers reached the optimal frequency, but did not produce the mist; second, some models of the circuit had no effect at all and did not come even close to producing the right frequency.



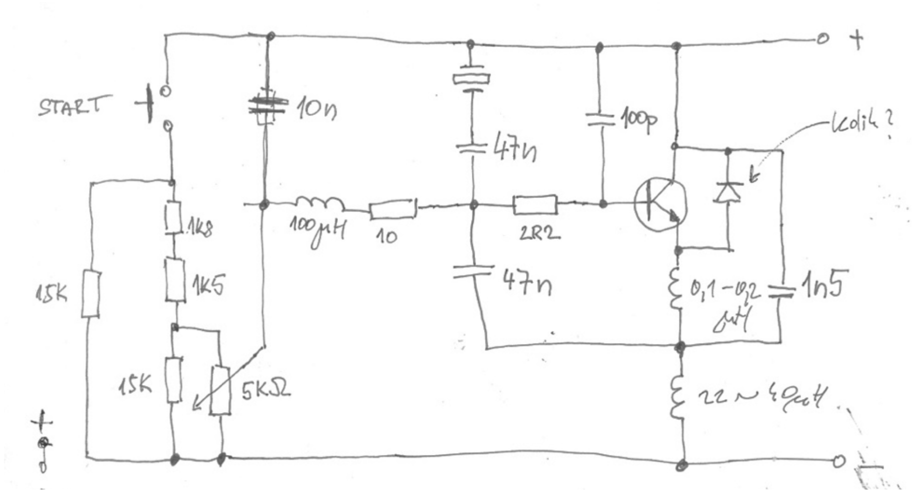

*Picture 18 – Collection of atomizer circuits*

Some circuit models worked better than others. Hence, the ones that were more successful, I attempted to tweak. As the functionality of many auxiliary components was unknown to me, I began with swapping values of individual resistors, capacitors and inductors. The aim was to see if and how, the resulting frequency would change. To support my efforts, I had an oscilloscope at hand – it displayed the exact frequency level and waveform characteristic. Nonetheless, the replicated circuits did not seem to work as anticipated. It was most likely due to the differing component characteristics. Parameters of particular parts were not provided alongside the circuit sketches. The reasoning here is that each component has certain parameters that can differ from model to model. Even if two same components have the same model number, some characteristics may not be the same. This theory applies particularly when it comes to transistors and their manufacturer. BU406 and BU407 are high-current NPN transistors that were part of all collected circuit sketches (except one) and they were in almost every replacement humidifier circuit available online. I bought a few of each model and from different manufacturers. The theory was confirmed when same transistor models, but each made by a different company, had a differing effect on the oscillation frequency – some had no effect at all.




*Picture 19 – On the left is the replacement driver circuit for a humidifier and on the right is one of the test circuits*

I did not know if the circuits recreated from the schematics would work at all; the only circuit that I knew was working consistently was the humidifier replacement part (Picture 19). Thus, I replicated the circuit from the replacement part. After some fine-tuning and optimization, the circuit was working fairly well. However, I had to make multiple compromises, so the circuit was quite different from the original one in the end. The most troublesome issue was with an inductor which appeared to be an irreplaceable part of the circuit. This inductor was a simple copper wire coil. This type of coil component was not a universal type or size. So, I made my own coil using a copper wire. Also, instead of using resistors with a fixed value, I replaced them with a variable resistor(s). As it turned out, this led to having a simple mechanism that allowed me to quickly find an optimal value of the resistance in the relevant part of the circuit. Eventually, this circuit performed the best out of all other (Picture 20), yet, not with the same effectivity as the original.




*Picture 20 – The most reliable version of the circuit*

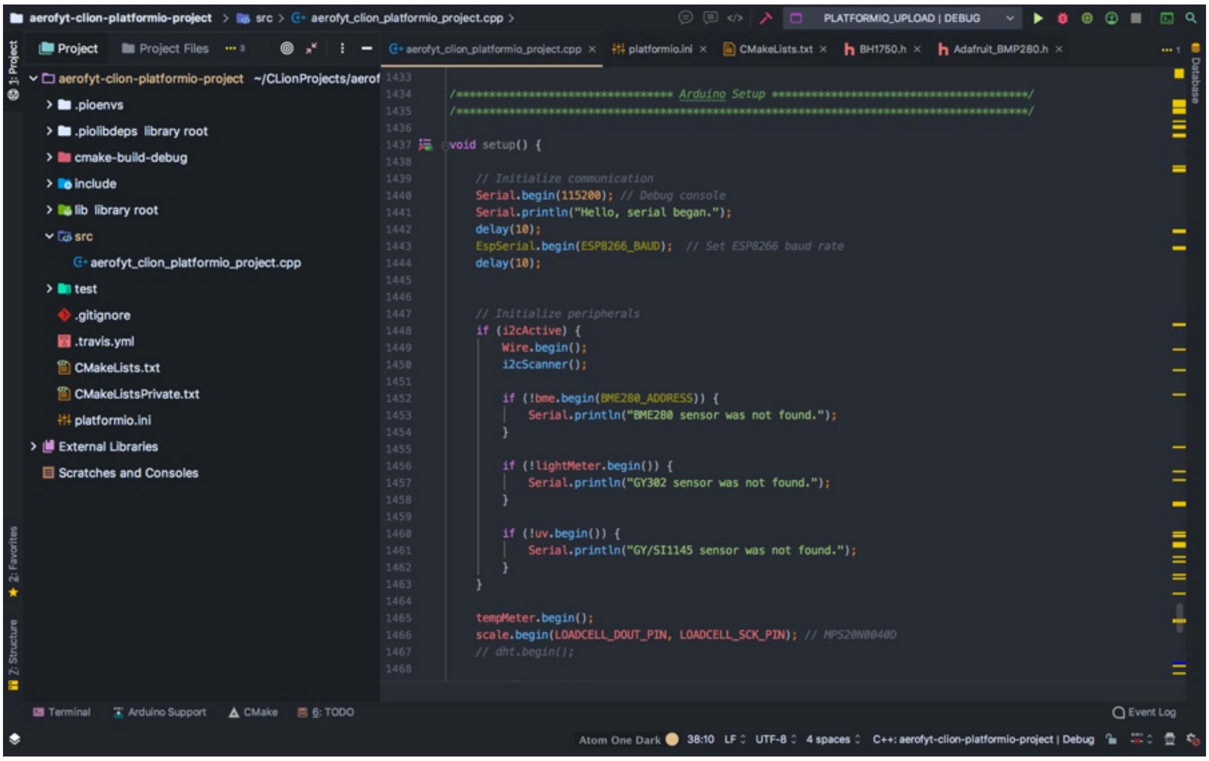
As with other circuits, I did not know the specific parameters of each component. At least, I attempted to buy similarly looking components with corresponding values. No change. The most valid reason for not achieving the desired outcome was the delicate nature of the circuit – any slight irregularity had an influence on the output frequency. I was using a solderless board and pin cables. It was possible that the board caused unwanted effects due to the fact that it had lengthier conductor paths and crammed components. Thus, it resulted in interfering electromagnetic fields. As soon as the circuit was permanently soldered, the performance would likely improve. Nevertheless, I did not get to that point during my 'Professional Development' period as I kept trying other transistor types; which I ordered from an array of different manufacturers.

This development stage was, without a doubt, the most laborious and time-consuming one and the practical outcome was minimal. I was not really successful at obtaining a fully working sketch of the driver circuit. Even by collecting exemplary sketches and testing different circuit alterations, the ideal version of the driver was not found. On the other hand, I tested various different alternatives of the circuit and learnt which component had what effect on the functionality of the driver, or more specifically, what effect it had on the output frequency. On a practical note, I gained an understanding of what role each resistor, capacitor, inductor and transistor played in the circuit. Even though the circuit seemed fairly simple at first, there were characteristics that had to be precisely tuned to gain the desired voltage frequency. I have studied the misting technology in great depth and personally have acquired a thorough understanding of the underlying technicalities. Besides that, I have gathered knowledge in engineering and circuit building in particular, which I know will be useful to me in my future endeavours. In any case, more learning within the field of frequency generators and piezoelectric technology will be essential for further project development.

### 2.4. Programming the microcontroller

"Classic Arduino Uno R3 microcontroller board is the central unit for communication between all the components; it is a plug-and-play tool for rapid system prototyping and experimentation. The Arduino is using a set of C/C++ functions that are then compiled directly into the board's internal memory" (Jakl, 2018). The writing of the code began with carefully analysing the already-developed wiring schematic and protocol graphs outlined in the dissertation. It was crucial to make sure all the electronics were in place and connected to the right input/output pin of the microcontroller. Of course, the coding was not done all at once, but throughout the development and testing process of each component. Yet, there were certain sequential steps that later progressed into a fully working program. As mentioned in the section about building the circuit, some sensors and peripheral components were individually tested so I had the "working code" at hand. Since the sensor output data were meant to be available in an online database and peripheral components such as the atomizer, fan or lights controlled remotely, additional libraries and code logic needed to be implemented. More about the app and data transfer in the next section.

Instead of using the Arduino's native IDE (integrated development environment) software I swapped for the CLion from JetBrains which was more suitable for complex projects. "CLion includes such features as a smart editor, code quality assurance, automated refactoring, project manager, integrated version control systems" (PlatformIO, 2015; Picture 21). I spent quite a bit of time learning about the CLion's user interface, understanding the workflow and fine-tuning its setting. Also, I had to integrate the 'PlatformIO Core' extension which was, so to speak, an overlay that could be added to the code editor. Above all the other features, it consisted of a command line, package manager, library manager, code compiler and debugger for a high variety of microcontroller boards, including Arduino. I knew that transitioning to another IDE package would require an additional learning curve in the whole process, yet, it was a highly beneficial skill to acquire. In the future, I would like to work with other microcontrollers and build applications for even more sophisticated smart devices, where utilizing IDE packages such as CLion and basics of C language (beyond Arduino syntax) were a must.




*Picture 21 – Main code file in the CLion IDE*

Rather than describing the development of the code chronologically (i.e. how the code was changing over time), going through each block of code individually offers a more comprehensive view of its functionality. Since the code file was changing organically (i.e.

whenever there was a need for modification), I would have to go into great depth to describe such changes, even if they were minor. On a pragmatic note, I do not remember how specifically the code was changing as changes and additions were made unsystematically in many cases. The file with the code had around 1,600 lines of code at the time of writing.

The first “block of code” was a definition of paths to Arduino libraries which contained re-usable functions and objects extending the programming environment. They could provide particular mathematical abilities or add hardware support for example. Most importantly, they could be quickly and easily implemented and save a considerable amount of development time. The Aéropot code file contained over 20 different libraries; mostly for the purpose of adding sensor and app communication support. Global variable definitions and library initialisations followed. The library is essentially a file that contains a class constructor (i.e. a block of variables and functions) that is used to create or initialize the instance of that class in the working file. To conclude, they simplify the workflow as the code functions can be quickly and effectively accessed and (re)used.

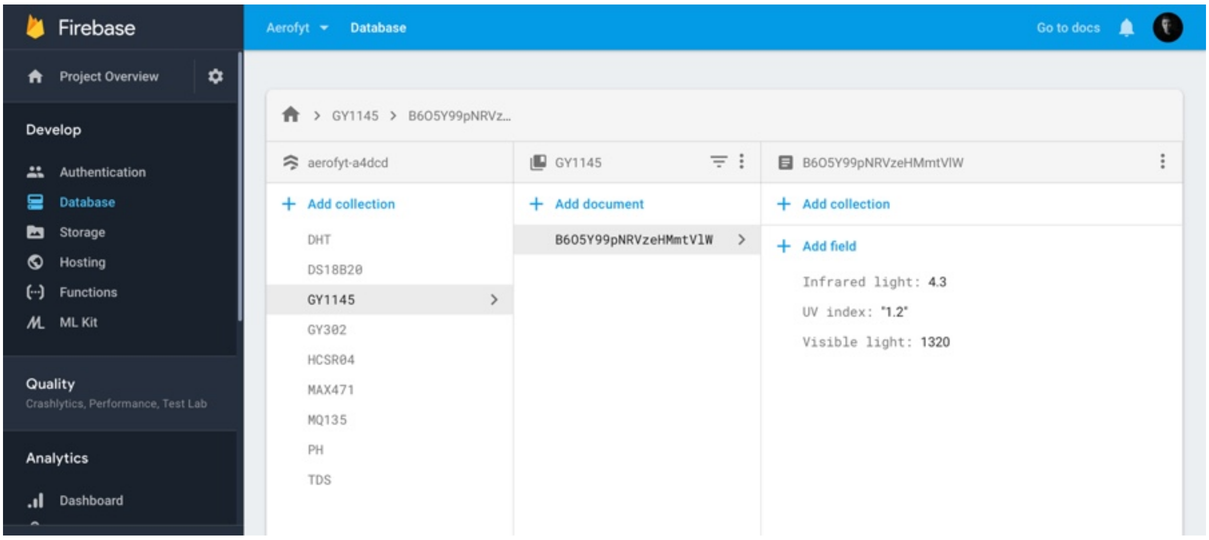
Aéropot is meant to be an ‘IoT’ or ‘smart’ device. It means it is remotely controlled and monitored via the Internet, with the use of a web or smartphone app. The internet connection is supplied by the ESP8266 Wi-fi module which is integrated with the Robotdyn Arduino Mega R3 board. Both modules, Arduino and ESP8266, communicate (serially) with each other through a set of so-called ‘AT commands’ or a library that simplifies groups of commands into functions and classes. There was an attempt to utilize serial communication with Arduino entirely through AT commands without a supporting library. I managed to send data from the Arduino to ESP8266 and subsequently to a server, and in the reverse order – sending data from the ESP8266 back to the Arduino. However, the issue was that once multiple different data streams were created, the complexity of the code became too high. The data streams needed to be specifically “translated” on each module, through a set of code logic which was not regarded as a favourable programming practice. Moreover, the reliability of this technique was questionable as there were not many examples or sketches that would be recommended by the online (Arduino/Blynk) community either. The only valid reason for following such a path was to have complete control over the output/input data which would eventually be sent through an HTTP request to the database. Since it would take a lengthy duration to essentially create my own communication library. Not to mention learning and applying the relevant theories as well as develop an own user interface for monitoring and control, I decided to use Blynk. Blynk is an IoT platform that connects to microcontroller boards and allows to build user interfaces in order to control and monitor peripheral hardware; it works with both iOS and Android devices. The app has a wide array of components such as buttons, sliders, graphs and other widgets, that can collectively be used to build an interactive and user-friendly interface. The coding was much simpler (at least at the beginning) in comparison to the first method: I included the relevant library and set the correct wi-fi authentication details, obtained a unique key and created an interface inside the app. It worked almost instantly, with the exception of a few cases where specific coding techniques had to be implemented.

Continuing with the code file structure: after the variable definitions, class initialisations and Blynk authentication information, the next block of code consisted of functions that would be utilized in loop timers. I do not go in-depth regarding the specific functionality of each function as that is outside the scope of this paper. Principally, there were two types of functions. First, functions reading the sensor data that were looped by a timer every 30 seconds. Besides including code responsible for connecting to the Blynk server, the functions also included Serial printing for debugging purposes. Most importantly, there was a code logic that transformed the data into a JSON format. The JSON data were then forwarded to the Webhook widget via an API command, which would eventually display the data in the app. The second sort of functions was supporting the ‘core’ functionality of the device. There was a function in particular, also within a timer, that would launch every 5 minutes to turn on the atomizer and fan. It was injecting “life” to the plants through misting the fertilizer mix and propelling fresh air (or oxygen) to their roots. Besides, there were other secondary functions for calculating the mean value of analogue sensors, scanning for I2C devices or recurring timestamps for the database logging to name a few. Most of them were of my own development.

The protocols that were proposed in my dissertation were not implemented yet as the device needed to be tested for basic functionality and determine right practices for use. For the requirements of the testing period, most variable values were static and did not change in accordance with the inner or outer environment. An exception was the LED light diodes which would turn on during night time to provide extra light. At this point, I still wanted to have full control over the “behaviour” of the code so I put “virtual switches” that would let me override the timer cycles. This was a simple logical condition within the code that would change once a button in the app was pressed.

### 2.5. Transferring the data

The primary aim of this project was to create a functional product prototype, including the underlying communication system. Even though the Blynk platform provided a quick and effective solution, I wanted to lay down foundations for the future communication system where I would have full control over the data output and permissions. The foundation, in this case, was a database where raw data could be stored, in order to be utilized for monitoring and statistical purposes. I opted to use a ‘Backend-as-a-Service’ (BaaS) called Firebase from Google (Firebase, 2019; Picture 22). In a nutshell, it is a hosting, authentication system, ready-made API and datastore in one. More than that, Firebase offers a plethora of tools and services for developing high-quality applications, both for mobile and web platforms. It can be quickly configured and scaled – an ideal choice for this project.




*Picture 22 – Real-time database of the Aéropot's data on the Google Firebase platform*

The way the data were actually sent to the Firebase database, however, was still through the Blynk's server. The microcontroller communicated with the Wi-fi module utilizing Blynk's core library, and subsequently, connecting to the Internet. Every time the Arduino reached a loop with a sensor reading, it would send an HTTP/S request with the sensor's information in a JSON data format. The conversion to the JSON format was mediated via a function reference from another library. Next, a widget named 'Webhook', that was added to the Blynk app's user interface, allowed HTTP/S requests to be sent to any third-party server or device. The request, if successful, would save the attached (sensor) data into the database. This process worked reliably and laid down a basis for future developments.

This section closely relates to the previous one. The result of the coding efforts led to the development of a data transfer or 'back-end' infrastructure, and eventually to a fully functional smartphone app. Through the Blynk platform, I successfully linked the Arduino microcontroller to the smartphone app for control, monitoring and testing purposes. Besides arranging the user interface in the app, I also had to include various supporting widgets such as the aforementioned ‘Webhook’, real-time clock (for timestamp recording), in-app terminal, etc.


*Picture 23 – Blynk smartphone app/UI*

I have had knowledge of and practical experience with SQL databases, however, NoSQL cloud-based databases (i.e. JSON structure or a combination of key/value pairs) has been a fairly new technology. Hence, I had to educate myself in that area and familiarize with the underlying concepts. Firebase was definitely a good choice since it had a solid base for scalability, and it was backed up by the Google company. Already, at the time of drafting this paper, the platform’s service offerings have been expanded and performance improved. Nonetheless, creating a reliable and functioning IoT device and/or service is not an easy task, as it requires knowledge of many different coding languages and models. There is no one-size-fits-all solution or service. Practically, it requires connecting services and products together and imagination and determination to achieve the given goal. My coding skills has improved in various areas; from defining own C/C++ functions and classes to formatting information in

JSON for the HTTP/S requests. My biggest struggle was getting the correct syntax form of the code. I spent plenty of time refining the code in order to make it fully operational.

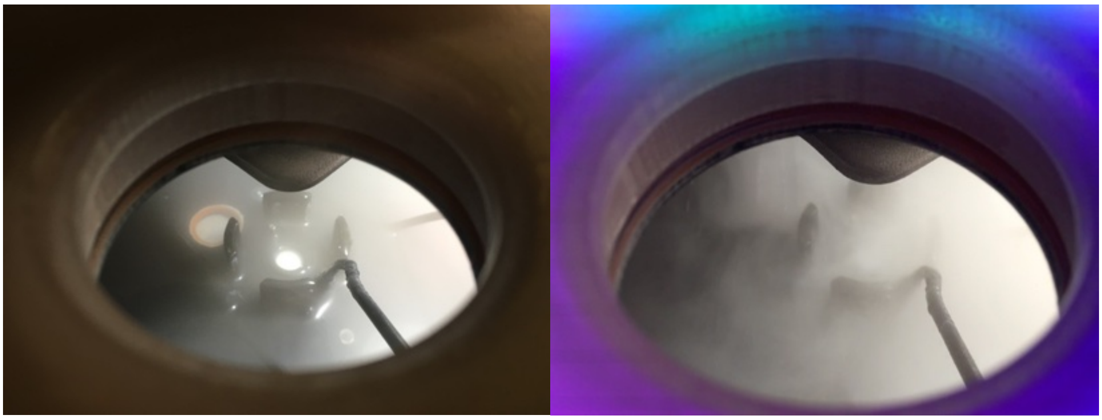
### 2.6. Growing the plants

Once everything was in place – electronics, microcontroller program, app UI and synchronisation mechanisms between all of them – it was time to test the Aéropot prototype and grow some plants. The process was fairly straightforward: choose plants, put them into the growing medium, keep the planter running and gather data from the sensors. As with most plants, the growing process takes time; it spans over a time period of weeks to months. Hydro/aero/ultra-ponically grown plants (should) grow faster and healthier than traditionally grown plants (i.e. soil method), because a balanced mixture of nutrients is delivered directly to the root system (Jakl, 2018). Therefore, the choice of plants for testing purposes was intentionally narrowed down to the plants which have a shorter growing/life cycle and were well attested in regards to -ponic methods.  Furthermore, Aéropot planter is meant to cultivate plants with a purpose of (i) flower caring/ornamental value, (ii) culinary provision (e.g. vegetables, fruits, and herbs), (iii) air purification, and (iv) medicinal use. Out of leafy greens, I chose lettuce, which had a fairly short life cycle and was typically grown with -ponic systems. Pea seeds were planted as well. I also had a set of kitchen herbs available such as basil, coriander and mint. From the ornamental flowers, I picked petunia. Plants with air purification and medicinal function were not tested during the 'Professional Development' period. Unfortunately, due to a lack of time and not having a permanent place during this period, the test was never fully completed. The planter and all the electronics were not easily mobile due to their size, fragility and stage of development. For proper testing, they would need to be stationary for a longer period of time. Therefore, in the following paragraphs, it is shown and explained how the initial stage of testing advanced, what learning was gained, which data were gathered and what conclusions were drawn from it in the end.

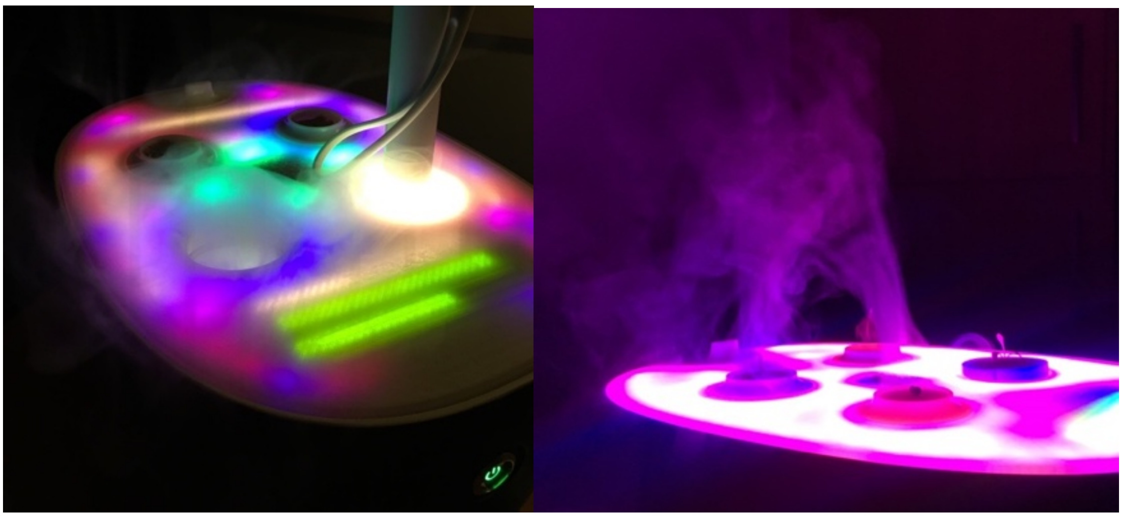
In order to begin, I needed to get a few things first: seeds, growing medium and fertilizer. Previously, it was mentioned what seeds would be used and why. There were many options for the growing medium, from plastic foam to clay pebbles, rock wool and others. Any type of pebbles would not really work as the pot was designed with an open bottom and the seed would most likely fall through. Eventually, I tested the plastic/polymer foam and rock wool. The plastic foam seemed like the right choice at first as it was a very sterile and reusable material. However, the foam did not have the desired water absorption capacity, which meant, it did not hold enough water moisture and it was not equally distributed at the same time. This ability was important, particularly in the initial stages of the plant's growth. Rockwool seemed to overcome such shortcomings, and so was the most suitable option for the Aéropot planter. It had only one possible drawback which was sterility. Pieces of the rock wool may fall into the liquid and potentially contribute to a pest contamination. Or, the pests could inhabit the rock wool medium in the pot and infect the roots from there. Lastly, the Formulex Universal Profile fertilizer mixed with water was used for testing purposes; 10ml per 1 litre of water was recommended for hydroponic use. The next step, after everything was set in place, was to observe how the Aéropot's planter and system operate.

There were essentially two tests – short-term (i.e. testing the immediate functionality of the device/system) and long-term (i.e. observing the reliability of individual parts and analysing output efficiency). Short-term tests included testing the functionality of external peripherals such as lights, fan and misters, reading and processing of sensor data, microcontroller's settings, etc. The long-term aim of testing would be primarily to observe the growth of the plants, and examine the effects of internal (e.g. fertilizer composition, misting frequency, pest production, etc.) and external influences (e.g. light intensity and composition, oxygen provision, etc.).

*Picture 24 – Light test*

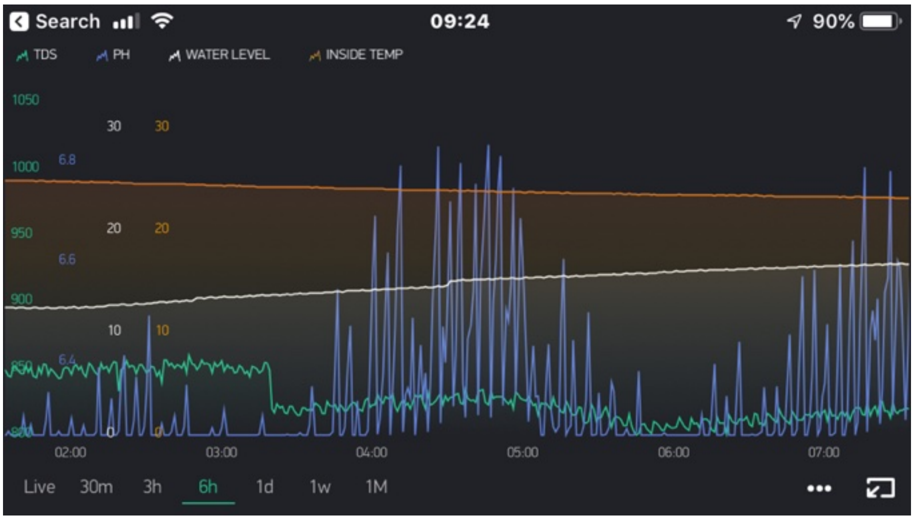


*Picture 25 – Atomizers (inside the planter's tank) test*



*Picture 26 – A mist coming out through the pots*

The light, atomizer and fan – the 'core' components – worked as expected (Picture 24-26). The mist was filling the tank's full volume. In addition, the connection to and the control from the app was well established and functional. The data were then sent to the Blynk's server, and consequently displayed in the app's 'Chart widget' (Picture 27). It visualized live and historical data and plotted them on a graph. There could be multiple 'data streams': TDS, PH and liquid levels together with the tank's inner temperature reading was fetched from the Arduino and saved in the database. This gave a well-organized and clear overview of the device's state. Therefore, the user could act in a case, when one or more of the monitored properties reached critical levels. Possibly, notifications would be sent if there was a deviation from the optimal range. In the long-term, the aggregated data could then be used to find correlations between the variables. More specifically, following the growth of the plant in parallel with the metrics, could help to determine each factor's effect. After a while, the aggregated data in the database might be utilized to find patterns in the plant's growth, and adjust the environmental/physical stimuli (e.g. light intensity, fertilizer concentration, PH level, etc.) to the optimal level at each growing stage.

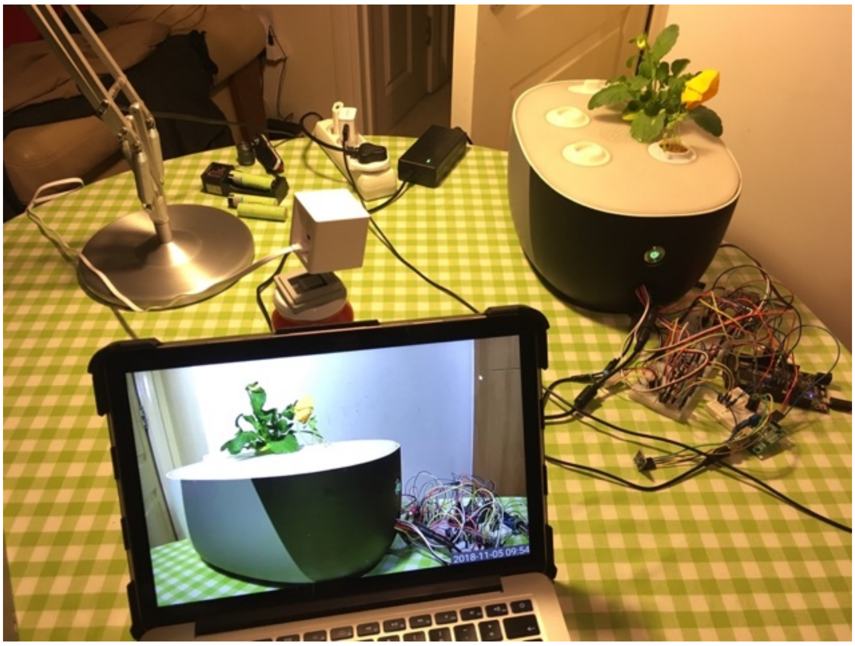



*Picture 27 – A chart widget displaying planter's sensor data over a period of time*

In regards to the short-term testing, most things seemed to work well, only with a few exceptions. The testing was not performed without any technical and other unexpected difficulties such as sensor failure or pests occurrence. For instance, I had to change the microcontroller code to incorporate certain functions during the testing period, and modify the code structure due to connectivity and reliability issues. Other issues that I dealt with, was a liquid leakage that come up through the bottom wall of the planter. This was because there were few holes drilled beforehand, that were not sealed completely. Once it was fixed, it appeared that the leakage was also coming over the wall, between the tank and space for the motherboard circuit. The liquid leakages were a problem with a fairly quick and easy fix. However, another issue that arose, was the pest contamination and consequent spread of crop diseases. On two occasions the pests, which were likely some type of algae, spread inside the tank (Picture 28).  The provision of air and fertilizer mixed in water were the most probable contributors and catalyzers of the phenomenon. This is an ongoing issue. For the time being, I have isolated the tank (the liquid in particular) from the outer environment as much as possible.

*Picture 28 – The growth of pests inside the planter*

Even so, I was able to see the state of the planter, through the app widgets that visualized the data (transferred from the physical sensors), I wanted to visually see the planter, to check if the plants were healthy and growing well. Hence, I used an online camera for remote monitoring (Picture 29). In the case of any electronic component's failure, the camera would be used to quickly inform the user. Especially if the core component – the atomizer – fails, then it can be observed that the leaves droop and fade. Furthermore, the same effect can be observed, if there is not enough water, or in contrast there is too much sunlight, or high concentrations of the fertilizer. Moreover, the online camera is a perfect method of presenting the prototype to an audience, without physically transporting it.

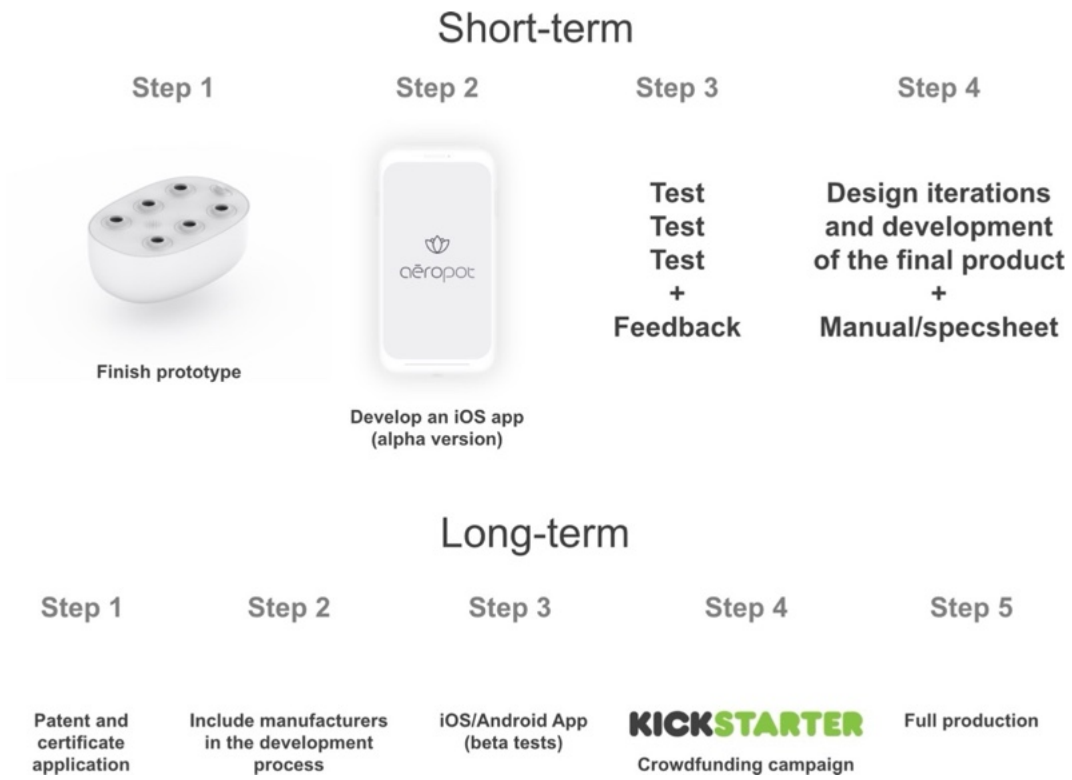


*Picture 29 – Remote camera control*

To conclude, this was the most rewarding part of the whole process; it was where everything came together. Seeing the planter and the underlying communication system work as one device – that was supporting the plant growth – was a major milestone achievement. Nevertheless, it is not yet possible to deduce valid conclusions with confidence as the process is ongoing. Even though I grew some plants, and transplanted a few, I cannot conclude that the Aéropot device cultivates plants better or worse than the conventional, hydroponic or aeroponic methods.

## 3. Business development

Most information regarding the Aéropot's business development was already stated in the dissertation paper (Jakl, 2018). The critical parts of the business plan were formed there; including the mission statement, target market, competitor analysis, and business model canvas. Naturally, it would be ideal to have the support of a business incubator or accelerator, to begin with. During the 'Professional Development' period, I was pitching my business idea on a few entrepreneurship competitions such as: NACUE Varsity Pitch, Central Research Lab Hardware Accelerator or Santander-sponsored competition at Brunel University – all based in the UK. They were 10-minute pitches in front of a judging panel followed by a Q&A session in most cases. Although not successful, the project showed its potential by reaching final rounds each time and receiving a positive as well as constructive feedback notes. In addition, I was able to network with the people in the industry and make a few valuable connections. In the future, rather than pitching the business on an endless number of competitions, I would rather come up with a clear plan, gather all the necessary materials for manufacturing, and then, begin a crowdfunding campaign online. Before this stage, a marketing campaign, most likely on social media, should be executed to reach the widest possible audience, to inform them about the release of the product. At that point, unless the circumstances change, Aéropot should be marketed primarily through online/Internet channels as that is the medium with such a far-reaching customer base worldwide. It can be marketed through a company website, social media (i.e. Twitter and Instagram), news and affiliated websites. No further details can be added regarding the campaign and its specific steps; the development of this stage is highly dependent on the situational circumstances and established connections within the industry. To support those efforts, it would be beneficial to register the company and consequently do a patent/design/copyright registration. The general plan is outlined in Picture 30.




*Picture 30 – Future plan with defined objectives*

Monetary funding is an essence of any start-up company, I'll continue seeking it in any way conceivable, specifically in the UK and EU countries. There are surely opportunities and investors that are not known to me (yet), hence more research, time and effort must be put into the search. Meanwhile, I want to keep working on the development of the Aéropot brand, smartphone application and user manual. Also, I would be finalizing the drawings and technical specifications of the planter, which can be later handed over to the selected manufacturer(s).

## 4. Programme experience

*"This MSc programme [Sustainability, Entrepreneurship and Design] has been designed by Environmental Sciences in collaboration with the College of Engineering Design and Physical Sciences (CEDPS) and the College of Business, Arts and Social Sciences (CBASS). This is a unique interdisciplinary MSc programme (with 'Professional Development') with the aim of fuelling an industrial economy that is by design, restorative, in which nothing is wasted (in effect a circular economy)"*

*— Brunel University, CHLS, 2017*

The first year was an intense study period where, in a variety of modules, I built the theoretical base and gained an understanding of the relevant concepts. I selected around 9 modules in the first two semesters, excluding an 'Integrated assessment' and 'Dissertation' modules. Some modules were compulsory, and some were optional. I aimed to choose modules that would be the most relevant to my personal and professional interests. At the same time, I asked myself why would I go to study something that I know much about? So naturally, there was a motivation to study something novel to broaden my knowledge base. Of course, it is reasonable and preferable to know one area in-depth, however, today's work environment is changing rapidly and requires a plethora of skills. In the end, I attended three modules in each course area of entrepreneurship, sustainability, and product design. They were all part of an overlying set of 'human activity' areas – namely, business, environmental sciences, and industrial engineering.

Most pressing issues in contemporary society are closely linked to those areas. Business and global capitalism go hand in hand with the industrial engineering field, as it is concerned with producing and selling products in more efficient and faster ways to as many people as possible. This, however, has obvious impacts on the natural environment and quality of (human) life in return. Thus, the MSc course taught me, among other things, how to incorporate the principles of sustainability; not only in terms of building a product but also in regard to my own critical thinking, skillset and every-day conduct. The teaching/learning style differed from a module to module, nevertheless, most of the lessons were led by professors with years of experience within their field. High emphasis was placed on increasing the independence of the students. Most written assessments and projects did not have a specified objective or structure. There was a general outline, but the topic was meant to be determined independently according to the student's interest and skill levels. Personally, this helped me to be more self-directed and focussed. I gained an understanding of the industry fields and their current state, which led me to narrow down my interests for the 'Integrated assessment' and 'Dissertation'. Throughout the first and second semester, I learnt about concepts such as the IoT devices or -ponic systems – fairly in-depth. In both of the papers, I laid a strong theoretical foundation which could then be realized during the 'Professional Development'. In the 'Integrated assessment' paper, initial research into -ponic market and technology was carried out as a part of a design competition called "Branching out" by Design Innovation in Plastics competition (2018). The final 3-page document included comprehensive insights into various topics regarding aspects such as: a problem definition, potential solution paths, competitor benchmarking, product design principles or conceptual proposal. It was logically split into three main categories: research, theory and product with the aforementioned subcategories. This was then followed by what was learned in the design studio lessons, including the practice of the 'Double Diamond' framework. In addition, the first 3D models of Aéropot's conceptual model proposal with a detailed description of each part were included. This was my first full design analysis and conceptual product proposal. The document's content and structure were a result of very thorough research, with a surplus of relevant references, and a laborious graphic design process. Retrospectively, taking time and being utterly punctual with this first assessment contributed greatly to the decision that had to be made regarding the dissertation's overriding topic, which followed soon after. Likewise, the process of making and structuring the document with relevant information from journal articles and websites helped to improve my understanding of each interest area, and further develop the necessary skillset at each design phase. Even though I had previous experience with CAD and graphic design, this was the first occasion where I utilized it for creating materials for a commercial product. When it came to the dissertation, I more or less expanded on the 'Integrated assessment' paper. The dissertation explored in-depth about each interest area, especially in the market research and technology chapters. The most crucial and extensive part was about the design and development process of the Aéropot device and system. At this point, it was about outlining the theoretical framework of the product's function, development process and business plan. A number of supplementary tools were utilized to identify internal as well as external strengths, weaknesses, opportunities and uncertainties (i.e. SWOT, competitor analysis, FSSD, cost analysis, etc.). The objective was to gather as much useful information that would be applicable during the 'Professional Development' stage.

I honestly enjoyed the diversity of modules that the course offered, both optional and compulsory. On the design part, the 'Sustainable Design' and 'Professional Design Studio' trained me how to navigate through a process of product development and introduced me to the sustainability principles and very specific mechanisms that can be implemented. Even though the 'Computer Aided Design and Manufacturing Techniques' module was not part of the course natively, it was offered to our course members to participate in the lessons. There, I managed to refresh my knowledge of and proficiency with the Solidworks and Keyshot software packages for 3D modelling and rendering purposes. Within the environmental sciences cohort were following modules: 'Biosphere', 'Clean Technology' and 'Introduction to Strategic Sustainable Development'. They were the most engaging and thought-provoking out of all for me. One of the foundations for my project stems from the sustainability aspect which was highly emphasized in these modules. I have learnt to deal systematically with complex issues by attaining theoretical and practically applicable methods, and hope to contribute to the growth of a circular economy and ultimately to move towards a more sustainable world. On a critical note, the business cohort of the modules was the least interesting for me personally as I did not attain an adequate amount of new information. It may be due to the fact that I studied business at my bachelor's degree. On the other hand, I attended a number of entrepreneurship workshops organized by the university and affiliated organisations (e.g. Innovation Hub). There, I developed my presentation skills as well as improved the business plan.

Throughout the course, I familiarized myself with the university's facilities and managed to be part of modules that gave me plenty of hands-on experience. I learnt how to use the workshops, which I later kept visiting in order to make the planter prototype. Besides wooden and metal workshops, there were also painting and 3D printing ones. Those were needed the most in regard to the planter production. The university technicians were very supportive and open-minded about the collaboration on the project. This was also the first time where the "theoretical creative process" bore its fruits in the form of the planter model. The rest of the work took place during the ''Professional Development'' period and was vastly about building and tweaking the planter, electronic parts and microcontroller software.

The primary reason to sign up for the 'Professional Development' pathway was to have space, time and motivation to continue working on the Aéropot project that commenced during the first year of my MSc course. I aimed not to leave the idea only on a paper, but rather realize it; even if it might not fulfil the desired expectations. I knew already from the beginning that there would be a lot of useful learning in the areas of design, engineering and programming. I did not wait until the ''Professional Development'' officially began in January 2019, but I started right after submitting my dissertation. Personally, there was a lot of motivation and excitement to start building the Aéropot device. Even though I had all of the theoretical ground laid down in my dissertation, building the product was a much more difficult task in reality.

First, I needed to gather the necessary materials. The largest and most noticeable part was the planter, which was already printed. It only required a few more modifications in regard to the fitting and surface. I also had to gather a lot of minor electronic parts though, without them, I was not able to start building. Meanwhile, I was experimenting with the parts I had; especially with the Arduino microcontroller. I took part in an electrical engineering society at the university, where I had a support group and facilities with the necessary tools during the studies. I had prior knowledge in weak-current engineering from my high school education, however, it had mostly been theoretical. I was not much of a hobbyist in that area, but that changed thanks to this project. I have been tweaking and experimenting with a variety of electronics since then. During the development period, if I found one component that was not appropriate for the Aéropot planter I ordered and tested another. This was one of the approaches to how I eventually managed to get a working prototype done.

## 5. Conclusion

In the duration of the 'Professional Development' programme, I was intensively working on the development of the ultraponic Aéropot device. Most of the set milestones from my final project were accomplished and I had a fully working product prototype at the end. Drawing upon various concepts (e.g. sustainability, -ponic systems, IoT, etc.), that I learnt during my course at Brunel University in Year 1, I managed to translate the newly gained knowledge to very practical use. There was an enormous number of different concepts that I had to understand or remind myself even after the programme commenced. The Aéropot is surely not yet perfect and it is not achieving its full potential; there are many ideas and iterations in the pipeline. But, in those few months, the device and control system really progressed forward. Furthermore, the practical work conducted during the 'Professional Development' period was a powerful method of learning for me. Writing this paper about the work process and reflecting upon the learnings, helped to personally understand my strengths and weaknesses, and above all to recognize what could be done differently and/or better in the future. It is not sufficient to gain experience in order to learn without reflecting on it, it may quickly be forgotten, and its learning potential lost.

I am still determined to keep honing and testing the product. Once I am confident enough that the product is reliable and useful to be commercialized, I will focus on looking for investments and manufacturing partners. Now that, I have gathered information about the building process of the prototype device and system, I can begin drawing plans and necessary material for the realization of the marketable product. I would like to take the time to thoroughly think about the next steps and determine what the product purpose should be about in the end. More specifically, I want to determine the direction for further development. For example, should the product be more industrial-like, thus concentrate on the effectiveness and yield rate, or carefully develop the informative system and user experience in order to utilize the product as an educational tool? This comes down to the market needs and opportunities, but more importantly to my personal vision. Answers to these questions will be crucial as they will shape Aéropot‘s every next step.

Word count: ±10,200 words

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