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# Opensource Portable Coffee machine

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# SUMMARY

Coffee is one of the most popular drink in the world. However, there was not any proper coffee machine which can produce a lot of amount to the people within the outdoor situation.

This project was based on the Opensource to get benefit from other people's idea and publish the project process and result in order to share the benefit to other people. Reverse engineering approach was used to get a clear understating of the machine mechanism. Comparing to creating a new design without any basement, the reverse engineering made the project easier to start and progress. This project follows the Engineering Design Process for planning and progressing. It made the project plan organised by directing what to do next. Also, the process supports the project well by introducing the decision-making methods such as QFD method.

The potability, safety and cost were the important requirements for this project. Based on these requirements, the specifications, such as weight, total parts number, etc. were made to quantitatively approach the project. The design concepts were brainstormed and evaluated by the specifications. The prototype was manufactured and tested. Through reflecting on the feedback for the prototype the final design was planned.

The prototype function well as an espresso machine, but the potability can be further improved by reducing the weight of the machine. The COVID-19 situation limits the accessibility to the workplace, so all the practical works were could not be completed.

The project was uploaded on to the online blog and got more than 400 followers, but still it was hard to make meaningful feedback. The maximum budget limits the project a lot due to the expensive price of the coffee machine components.

Therefore, the coffee machine extracts the coffee well. Nevertheless, there was some still more parts that can change into opensource hardware and more part can be replaced by a lighter part to increase the portability.

# NOMENCLATURE

| | |
|---|---|
| A | Surface area $(m^2)$ |
| AM | Additive Manufacturing |
| C | Velocity of the flow $(m/s)$ |
| CAD | Computer Aid Design |
| FDM | Fused Deposition Modelling |
| PLA | Polylactic acid |
| Q | Volume flowrate $(m^3/s)$ |
| SLA | Stereo Lithography Apparatus |

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# 1 INTRODUCTION

This project was aimed to redesign a coffee machine. To accomplish this aim, three main points were set to consider: reverse engineering, opensource and engineering design process.

**Reverse Engineering**

Reverse engineering is a method to study an existing product by disassembling components and analysing the principle. Through this process, the function, operating principle, materials could be studied. Even one small product contains a lot of different parts and materials. Each decision for choosing the parts and materials is made with adequate reasons by a designer and engineer [1]. The supporting reasons for each decision can be identified and studied through reverse engineering approach.

For this project, the reverse engineering method was included in one of the design processes to analyse the working mechanism and materials of the coffee machine. The technical information was reversely linked with the function of the parts and feature of the materials. Based on what was learned from reverse engineering, the parts that needs to be redesigned were identified, and improved from the next procedures.

**Opensource**

This coffee machine project is going to be published in the blog to gain feedback and utilised by other people. Opensource is a concept that was first invented by software engineering. Now, the meaning and concept have been expanded into the hardware area. The opensource project must be opened to the public. It requires to allow by another user to freely use, modify and republish [2]. In contrast, close source design usually focuses on security and profit. The closed source design is generally registered in the patent to protect their value from other competitors [3]. However, this approach can limit the potential resource that can come from outside of the organisation.

Therefore, this project was set as an opensource to obtain a benefit from collective intelligent by sharing progression. While sharing ideas, the project was expected to get a high quality and quantity support from others through comments and messages. This expectation was made due to the variety of people's background. People who are interested in the project or experts on the related areas.

To make the project opensource, there were some aspects to consider. Firstly, the new design needs to be easy to access and build by nonprofessional people.

Secondly, the non-purchasable components were planned to be replaced with a new opensource components. These aspects were possible to accomplished through using Additive Manufacturing and laser cutting, which are relatively easy to access by the public compared to other manufacturing machines such as turning. Additionally, the file for operating these machines was planned to be uploaded on to the blog.

**Engineering Design process**

This project was planned to follow the same design process, which is commonly used in the industry. A book *Engineering Design Process* written by Yousef Haik was used [4]. Through applying the engineering design process to the project, the decisions for choosing the best design were all made with reasonable justifications.

The Yousef Haik's engineering design process contains nine different steps. However, this project was relatively small; therefore, nine steps were downsized into five stages. Firstly, the design requirement was established based on the aim of the project and the desire on the market. Secondly, the existing espresso machine was selected and reverse-engineered through disassembling the parts. Next, the design specification was made to analyse the ideas. Then, the design concepts were developed and selected. Lastly, the prototype was manufactured, and the final design was generated.

While making decisions for each step, the specific calculating method or decision matrix method, which was introduced in Yourself Haik's book, was used to decide the optimistic option. Therefore, the frame of the project plan was firmly constructed, and the high quality of the final design was expected.

# 2 LITERATURE REVIEW

Before applying the engineering design process, the general information related to coffee was researched. In this section, the coffee-related industry data, such as producing countries will be firstly introduced. Next, the coffee production process will be described. Finally, extracting methods will be demonstrated.

## 2.1 Coffee Industry

Coffee was firstly discovered in Ethiopia, Africa. Then spread out to Middle East Asia, and Europe and all over the world. Now, it became one of the most popular drink in the world with tea and a beer [5]. For instant, one of the most coffeeholic country is Finland. Finns consume the most amount of coffee in the world, which is 12kg of coffee every year on average [6]. Since coffee is consumed a lot over the world, many countries supply coffee to the market. For example, Brazil produces

32 per cent of the total supply, and Cambodia follows next [7]. The coffee industry has been continuously growing because of the increase in the consumption of coffee. To fulfil the customers' diverse desires, extracting and production methods have also been developed.

## 2.2 How Coffee Beans are Produced

### Coffee tree

Coffee is made from coffee beans, and these are grown on a coffee tree. A coffee tree can live for about a century and grow up to 9 meters. The fruit of coffee tree is called as a coffee cherry. Surprisingly, a coffee bean is not a fruit of coffee tree. It is a seed inside a coffee cherry [8]. According to the researchers, there are more than 25 species of the coffee trees in the world, and only two species are commonly used in the market to make coffee [9].

### Coffee Species


**Figure 2.1, Arabica and Robusta [10]**

The two most popular coffee species are Arabica and Robusta. Arabica coffee was first found in Ethiopia, and it has been occupying 70 per cent of the coffee market. The Arabica has lower caffeine and flatter shape than Robusta coffee. Arabica coffee is more expensive than the other coffee because it is hard to cultivated. On the other hand, Robusta takes the rest 30 percent of the market. It has smaller and rounder shape than Arabica coffee. Instant coffee is usually made with Robusta coffee due to the low price and a higher caffeine content [8, 10].

### Harvesting and Processing

There are two main ways to harvest and process the coffee from the tree: wet process and dry process. In the wet process, the coffee cherries are harvested by shaking the tree with machine. Collected cherries go into a squeezing machine to take out the seeds. Although the machine takes out the seeds, there are some remaining pulps attached to seeds [11]. These remaining pulps are removed by water. As this method requires much more water, it is called wet process. Also, this method produces a high quantity of coffee beans due to the operating method that runs by machine [5].

On the other hand, in the dry process, the coffee cherries are selectively harvested by human labour. Afterwards, the harvested cherries are dried under sunlight. Pulps are taken out merely with the small amount of water or no water [5]. Due to the little amount of water used in this process, this is known as dry process. The dry process produces more high-quality coffee beans than the wet process. After coffee beans passed these processes, they are sorted based on the size and quality [11]. Then, they are packed into a bag. These coffee beans are called green coffee.

**Blending**

The harvested coffee bean now needs to be blended. Most of the coffee available in the coffee market is blended coffee. The blending process mixes various green beans which comes from different farms and lands. The mixing process provides two main benefits and two sub-advantages. Firstly, it allows for creating a balanced and constant taste from the coffee. It is difficult to sustain the flavour with one sort of bean as the taste of the coffee is affected by many various factors. Secondly, Blending reduces the risk of getting the coffee from one supplier by diversifying the coffee bean suppliers. Thus, the coffee can be kept produced when there is a draught or problem in the one farm [12].

In addition, coffee usually made with only one species of coffee only Arabica or Robusta. However, sometimes the Arabica and Robusta coffees are mixed to combine the Arabica's taste and Robusta's strong kick of caffeine [12]. Moreover, it is rare but possible to get an un-blended coffee bean which is called single-origin coffee. They have a unique flavour and a higher price than blended coffee [13].

**Roasting**

The blended green beans need to be roasted by heat to maximise the flavour. To extract coffee from the beans, the green coffee requires to be cooked, and this process is called roasting. The bean is roasted between 180 to 250 degrees Celsius for about 50 minutes, this could be varied according to the barista's decision. The results come out in different colours. Those colours vary on the temperature and roasting time. The results can be roughly categorised into three different colours: light, medium and dark, and each outcome has different flavours [14].

**Grinding**

Before extracting a cup of coffee from the beans, they need to be ground. While grinding, the force is applied to beans, and they become cracked into smaller particles. This process increases the surface area of the coffee beans and allows to extract more flavours. There is various way to grind the coffee beans, but most popular methods are using an electric grinder or hand-cranked mill [12].

Grinding size depends on what kind of extracting method is used for the coffee. For example, the espresso method requires the finest coffee powder. Filleting method requires less fine than espresso while AeroPress requires much coarser powder. Therefore, the variation of the grinding size is proportional to the extracting time [15].

When the coffee bean is ground, it loses its flavour quickly, hence they are usually packed in the vacuum bags or cans. To get more fresh coffee, export asks to grind the coffee right before brewing it [16].

## 2.3 Coffee Extraction Methods

When the coffee is ground, it is ready to extract into a cup of coffee. There are various method to extract this coffee. In this Section, the most popular methods will be introduced.

**Figure 2.2, Drip coffee [17], French Press [18], Espresso machine [19], Percolator [20]**

**Drip coffee**

Drip coffee or also called as filter coffee uses a paper filter. The paper filter is put on a filter holder, which is usually made with plastic, ceramic, or metal. The user scoops the ground coffee on the filter and then pours hot water on to the coffee. When all the water drains down to the cup, it is ready to drink [17].

**French Press**

French pressing method uses a press pot, which is shown in second image of the Figure 2.2, Drip coffee , French Press, Espresso machine , Percolator . Press pot has a metal filter in the middle of the pot which can be moved by the stick button on the top of the pot. The coffee powder is prepared under the filter. Then, the hot water is poured into the pot and wait for about four minutes to brew the coffee [18].

**Instant coffee**

Instant coffee is usually made with Robusta coffee. To make an instant coffee powder, the Robusta coffee is firstly brewed on the water, and then the water is removed from the brew coffee by drying. When this process is finished, the instant coffee powder comes out. The powder is stored into the packages and sold into the market. The user can drink this instant coffee by simply adding hot water into it [21].

**Espresso**

These days, using an espresso machine is the most common way to extract coffee in a cafe such as Starbucks. The coffee is extracted from the finest ground coffee with high pressure for a short period between 20 to 25 seconds. This extracted one mini cup of coffee is called one shot of espresso. If these shots are mixed with other ingredients, it can make different coffee-based drinks. For example, if it is mixed with water, then it is americano. If it is mixed with milk, then it is called latte [22].

**Percolator**

Percolator is also called a Moka pot. The structure of pot is divided into three parts: water boiler, ground coffee container and filter. The water is firstly boiled in the water boiler, and the steam goes through the ground coffee and passes the filter. The coffee extracted from high temperature and pressure. Then, stored on the top of the pot or directly goes to the espresso cup through the pipe [20].

**Bean-to-cup**

Bean-to-cup is one kind of espresso machine which has grinder integrated into the machine. As the name shows, the machine extracts coffee from the coffee beans after automatically grinding into coffee powder. Thus, it can provide a fresh flavour directly from the seeds. Additionally, it can extract a coffee by pressing one button, so it offers a convenient experience to users [23].

# 3 DESIGN REQUIREMENT

## 3.1 Market Research

**Portability**

The potential of the desire on portability of a coffee machine is expected to be increasing. According to the International Coffee Organisation, the coffee consumption rate has been continuously growing [24]. Also, the size of the outdoor industry, such as camping, has been rapidly increasing. This increase is even more rapid than the GDP in the US [25]. Thus, the desire for an outdoor coffee machine, which has high portability, is expected to be increased in the market. However, there are not many portable coffee machines in the existing market. There are some, but they are focused on small quantity extraction rather than mass production. However, people often go out camping with a lot of companies. Therefore, this project is going to focus on redesigning the portable coffee machine which can extract a lot of amount of coffee within a short time.

The mobile coffee machine will mean easy to convey from one place to another. It will also mean that the device must be easy to use in an outdoor situation. Thus, additional components such as strap should be added, and the weight should be cut down to allow user to easily carry.

**Case Study - Opensource Espresso Machine (by Zack Moss)**

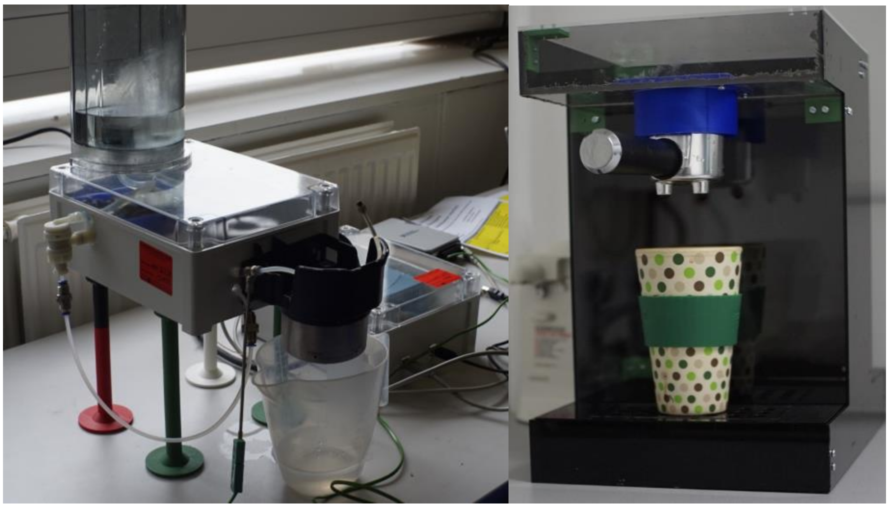


**Figure 3.1, Prototype and final version of Zack Moss Espresso machine [26]**

The opensource coffee machine project was also done in last year by Zack Moss and published in blog [26]. In his project, De'Longhi espresso machine was reverse-engineered, and then a new espresso machine was built through combining the parts from various sources. The components were originated from the disassembled De'Longhi machine, the online store or 3D printer. The electric controller was replaced by the Arduino board. The control system was isolated from the electrical parts to keep it safe. The pump holder, grouphead and machine legs were printed by FDM type 3D printer. He also designed the experiment to measure and analyse the water temperature, which comes out from the machine. After evaluating the water temperature stability of the De'Longhi espresso machine, he found a reasonable gain value for controlling the heater and pump, Then, the gain value was applied into the device setting.

University technicians, Chris Todd and Mike Herbert, who had supported the last year project also advised this project. They advised not to focus on the electrical control system. This advice was given due to the lack of compatibility on each component with Arduino. Changing the control board means rebuilding the whole machine, which is over-challenging to finish in one year. Also, supervisor, David Polson, emphasised that this project should focus on mechanical engineering rather than electrical or controlling engineering. Therefore, this project was aiming to focus on manufacturing and redesigning the housing and outer frame rather than the control board.

## 3.2 Need Statement

Based on the research, the need statement which clarifies the aim of the project was constructed. Rather than changing and replacing the need statement, the list was kept added when more considerable aspects came out.

This project will focus on building a portable coffee machine as an opensource design. This final design of the device must be easy to carry. The device must be safe. The progression of the project will be shared in the online blog. The comment and feedback will be considered and applied to the project. The following guidelines will further clarify the requirements:

- ✓ The machine must extract a coffee
- ✓ The extraction amount of coffee must be at least more than four portions, which are general number of a family member.
- ✓ The device must have light weight to carry by one hand.
- ✓ The device must protect the components from dust and dirt from outdoor.
- ✓ The electric components must be enclosed to prevent a hazard.
- ✓ The number of components must be few.
- ✓ Must be easy to get all the data related to this project, e.g. CAD file.
- ✓ Must be easy to purchase the components from an online store.
- ✓ It must be easy to build.
- ✓ The total cost of the device must not go over the budget (£300).
- + The machine must have a steaming function.
- + Coffee must be pre-ground before used in the device.
- + The coffee machine has flexible power sources.

* + indicates post-added

## 3.3 Identifying and Prioritising Requirements

The requirements have been categorised into four parts: performance, safety, accessibility and cheap. Each requirement was listed on the table, and the importance was weighted with the number one to ten. The higher number indicates a more critical requirement for designing. The importance was weighted to further applied in the Quality Function Development method.

**Table 3.1, List of requirements**

| Requirements | D/W | Importance (1-10) |
|---|---|---|
| **Performance** | | |
| Extracting enough amount of coffee | W | 7 |
| Lightweight | W | 6 |
| Compact | W | 9 |
| Comfortable to carry | W | 7 |
| **Safety** | | |
| No sharp parts | W | 6 |
| Electrical components enclosed from water | D | 10 |
| Dust and dirty prevention | W | 8 |
| **Accessibility** | | |
| Ease to build/ Simple design | W | 6 |
| Access to components through shops | W | 8 |
| Components available by CAD files | W | 8 |
| Less use of components | W | 7 |
| **Inexpensive** | | |
| Low production cost | W | 7 |

D: desire/essential, W: want/not essential

# 4 REVERSE ENGINEERING

### Why an espresso machine?

The espresso machine was chosen for reverse engineering after comparing different types of coffee brewing devices. There are various types of tools for extracting coffee in the coffee market. For example, there are drip, French press, percolator, bean-to-cup, and espresso. Each different method uses different operating principles. Filtering, French pressing, percolator methods were not suitable for extracting a lot of amount in a short time. Bean-to-cup was convenient and suitable for extracting a lot of amount but the size of the machine was bulky. The commercial espresso, which is commonly used in café, has bigger and expensive than bean-to-cut due to the high-end quality. However, there are also compact style espresso machine for personal home usage. Therefore, the compact size espresso machine was chosen finally.

**Why De'Longhi EC685M**

**Figure 4.1, Nespresso Essenza mini [27], De'Longhi EC685M [28]**

After the compact espresso machine was selected for reverse engineering, the De'Longhi EC685M was chosen and purchased. Before purchasing the machine, two different devices were compared and discussed.

Nespresso Essenza mini was the first choice for reverse engineering. It is the first company that introduced the capsule coffee into the market. Due to the convenient and fast operation method, it becomes popular [27]. However, it requires a separate milk forming device to make a milk-based coffee, and it only accepts capsule coffee, thus it cannot use a ground coffee.

On the other hand, De'Longhi EC683M can extract coffee from the ground coffee. It is also compact espresso machine. Unlike Nespresso machines, it has a steamwand to make steamed milk for latte and cappuccino [28]. The £180 price was reasonable based on the £300 budget limit. Furthermore, most of the parts were possible to buy from the online store, and last year student used the same machine. Hence, it was easier to get access to the product data. Therefore, De'Longhi EC683M machine was reverse engineered.

**Why were the components on the De'Longhi machine reused?**

After the reverse engineering product was chosen, the remaining amount of budge was only £120. Thus, rather than creating a whole new design or purchasing a new main component from other resources, the project aim was targeting to change and modify the existing machine into an opensource and portable design.

Therefore, through reusing the main components from the disassembled machine, it was possible to progress the project without exceeding the budget limit.

**Disassembling De'Longhi EC685M**

Before disassembling the device, the related knowledge and data were all pre-collected from the online resources. Assembly drawing supported for disassembling the components without damaging the parts. Through using the Bill of Materials, the component's material and its purpose were analysed. Then, the main specs of the espresso machine were linked with each element based on the function. Finally, the main components' features and operating principles were further researched to understand the product more deeply.

Type of espresso machine: compact espresso machine

Manufacturer: De'Longhi

Model number: EC685M

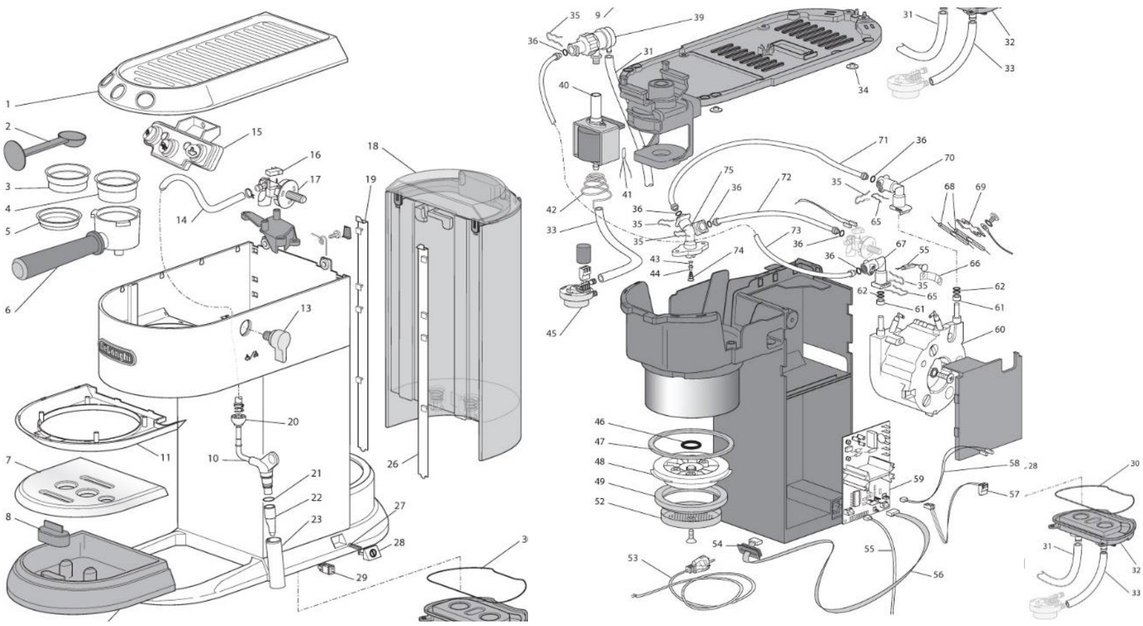


**Figure 4.2, Assembly drawing of the EC685M [29]**

1. The detachable parts such as water tank, grouphead and cup cover parts were all spaced out from the device.
2. The screws which can be approached from the outside were unscrewed. Two of them were located top backside of the main housing, the other one was placed on the grouphead, and the rest of them were put on the bottom part of the device.

3. The top metal cover and the bottom part cover were detached from the housing. While removing the metal cover, the wire was unplugged from the switchboard.
4. The power switch and the related wire, which were located bottom part of the device, was removed
5. The water tubes, which related to steamwand and water tank, were disconnected.
6. The inner plastic housing was held up from the metal housing
7. All the wire was disconnected from the control board and pump and ground.
8. All water tubes were disconnected by removing the connecting pins
9. The screws holding the thermoblock and control board were unscrewed
10. Thermoblock, pump, steamwand valve and control board were detached.
11. The grouphead parts were detached.

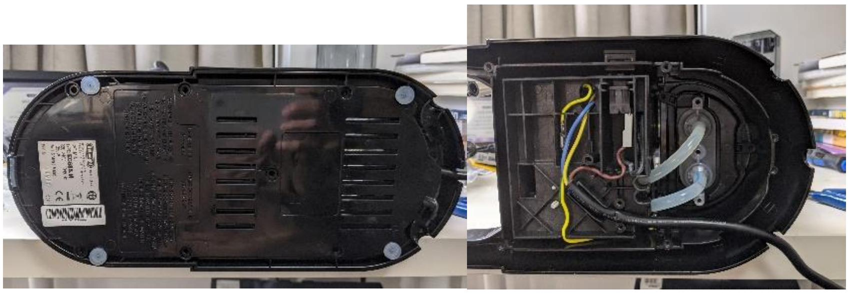


**Figure 4.3, The Bottom View Disassembled Machine**

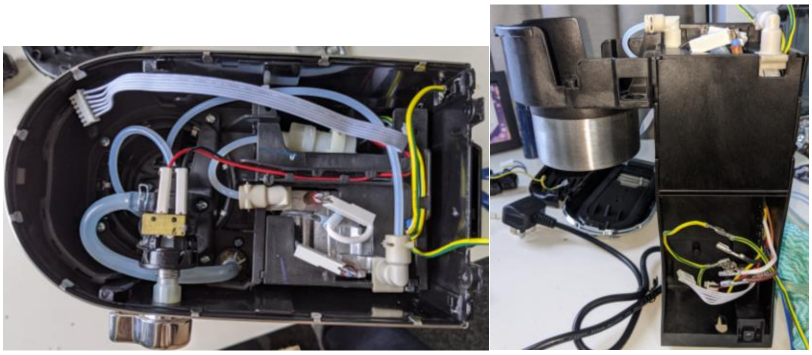


**Figure 4.4, Top and Side View of the Disassembled Machine**

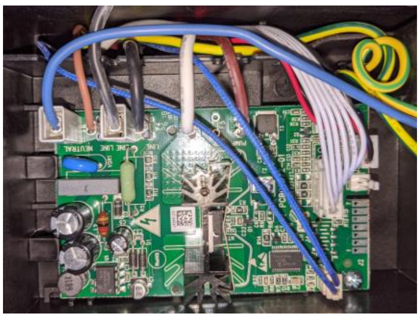


**Figure 4.5, Control Board Wiring**

After the disassembling process was finished, the bill of materials was made to analyse the materials used in the product. The material column on Table 4.1,Error! Reference source not found. was added into the table through observing. Then, the reason for each material's usage was analysed. For instance, most of the frame structures were made with ABS and stainless steel. ABS was chosen because of the properties, which are cheap, light and strong. Stainless steel is rustproof, and it has a high heat conductivity. Thus, it is ideal for the parts which are often contacting with the water. Also, the stainless steel was used on the top cover, which is designed for warming up the cups by released heat from the thermoblock.

**Table 4.1, Bill of materials of De'Longhi EC685M**

| Position. | Part description | Materials |
|---|---|---|
| | SLIDING BLOCK BLACK (PA66) | ABS |
| 0 | SCREW | STAINLESS STILL |
| 0 | HEATING ELEMENT SEAL | |
| 0 | INOX NUT M8 X 1 | STAINLESS STILL |
| 0 | INOX NUT M10 X 1.25 | STAINLESS STILL |
| 1 | COVER | STILL |
| 2 | MEASURING SPOON | ABS |
| 3 | Small one-cup filter | STAINLESS STILL |
| 4 | Large two-cup filter | STAINLESS STILL |
| 5 | Pod filter | STAINLESS STILL |
| 6 | SUMP | STAINLESS STILL, ABS |
| 7 | CUP PLATE | STAINLESS STILL |
| 8 | FLOAT | ABS |
| 9 | DIRT TRAY | ABS |
| 10 | FROTHER | STAINLESS STILL, ABS |
| 11 | COVER | ABS |
| 13 | KNOB | ABS |
| 14 | TUBE(SIL PLAT) DI=4 DE=8 | SILICONE |
| 15 | ASS. CONTROL BOARD | |
| 16 | MICROSWITCH | |
| 17 | TAP | PLASTIC |
| 18 | WATER TANK | TRANSPARENT PLASTIC |

| | | |
|---|---|---|
| 19 | PROFILE LEFT | ABS |
| 20 | JOINT | PLASTIC |
| 21 | O-RING | STAINLESS STILL |
| 22 | TUBE LOWER | PLASTIC |
| 23 | TUBE DISTRIBUTING | STAINLESS STILL, PLASTIC |
| 26 | PROFILE RIGHT | STAINLESS STILL |
| 27 | SPRING | STEEL |
| 28 | PUSH BUTTON ON/OFF | ABS |
| 29 | SWITCH | |
| 30 | GASKET | RUBBER |
| 31 | TUBE DI=4 | SILICONE |
| 32 | FILTERS ASSEMBLY | PLASTIC |
| 33 | TUBE DI=4 DE=8 | SILICONE |
| 34 | FOOT | RUBBER |
| 35 | CLIP | STEEL |
| 36 | O-RING D=3.85 | SILICON |
| 39 | VALVE | ABS |
| 40 | PUMP | |
| 41 | PROTECTOR | ABS |
| 42 | SPRING | STEEL |
| 43 | VALVE | ABS |
| 44 | RING | STAINLESS STEEL |
| 45 | FLOWMETER | |
| 46 | GASKET | ABS |
| 47 | GASKET | ABS |
| 48 | SUPPORT | ABS |
| 49 | GASKET | ABS |
| 52 | DOFFISER | STAINLESS STEEL |
| 53 | POWER SUPPLY CORD | |
| 54 | RUBBER PAD | RUBBER |
| 55 | SENSOR NTC | |
| 56 | WIRING | |

| | | |
|---|---|---|
| 57 | CONNECTOR | ABS |
| 58 | WIRING | |
| 59 | POWER BOARD | |
| 60 | GENERATOR | STEEL, CUPPER |
| 61 | SPACER 5XD5.2XD7.9 NATURAL | STAINLESS STEEL |
| 62 | GASKET | ABS |
| 65 | CLIP | STEEL |
| 66 | BRACKET | ABS |
| 67 | CONNECTION | ABS |
| 68 | TCO 192” | |
| 69 | TCP BRACKET | |
| 70 | CONNECTION | ABS |
| 71 | TUBE PTFE DI=2 DE=4 | SILICON |
| 72 | TUBE PTFE DI=2 DE=4 | SILICON |
| 73 | TUBE PTFE DI=2 DE=4 | SILICON |
| 74 | SPRING | STEEL |
| 75 | CONNECTOR | ABS |

All the parts are available to buy from the De’Longhi official website.
Total number of parts: 75

## Further research on the main components

The main components, such as thermoblock, thermocouple, pump, water tank, volume flow meter and relay, were further researched. In addition, the principle of the operation and other parts’ types used in other espresso machines were investigated.

## Heater

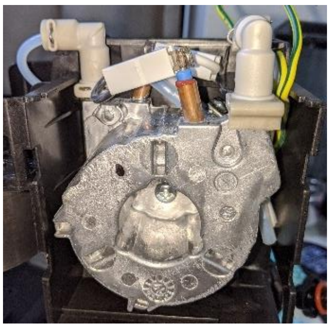


**Figure 4.6, thermoblock from the EC685M**

De'Longhi EC685M uses a thermoblock to heat the water. However, in the market, other machines use a single boiler or dual boiler. The advantages and disadvantages of them are compared in Table 4.2.

As Table 4.2 shows, the thermoblock used in the De'Longhi EC685M was decided to be reused in the new design. Considering not only the budge but also other aspects such as performance, reusing thermoblock was reasonable. Based on the heating performance, the dual boiler was the best choice. The project was targeting to make a portable espresso machine. Hence, the considering the size of the heater was important. The single boiler was another choice, but the water in the boiler needs to be refilled manually. Thus, the single boiler was not suitable for extracting a lot of amount of coffee in a short time. Therefore, the thermoblock obtained from the espresso machine was planned to be reused in the new design [30].

**Table 4.2, Single boiler, Thermoblock, Dual boiler comparison [30]**

| | Single boiler | Thermoblock | Dual boiler |
|---|---|---|---|
| Temperature stability | Low | Middle | High |
| Brewing and steaming simultaneously | Unable | Able | Able |
| Boiler refill | Manual | Automatic | Automatic |
| Size | Small | Middle | large |
| Cost | Low | Middle | High |
| | Not good for making a lot of coffee. | Recommend for milk-based coffees | Good for large quantity<br>Recommend for milk-based coffees |

### Thermocouple and Amplifier

In the machine, a thermocouple was connected on the output port of the thermoblock. A thermocouple is an electrical device which creates a voltage depending on the temperature. The voltage produced due to the thermoelectric effect. As shown in Figure 4.7. This effect occurs when two different material wires are joined, and one side is heated. Due to the correlation between temperature and voltage, the temperature can be calculated by the measured voltage. There is various type of thermocouple due to the differences in their used materials. Each of those types has different properties such as usable temperature range and tolerance of the measured temperature. They are identified by type name like K, J, N, R, etc [31].

The thermocouple cannot be used independently due to the low amount of produced voltage, which has micro-scale. Thus, it is essential to use an amplifier to increase the scale of the voltage to a readable scale. In this espresso machine, the amplifier was integrated onto the control board, so it was difficult to disassemble and investigate it further [31].

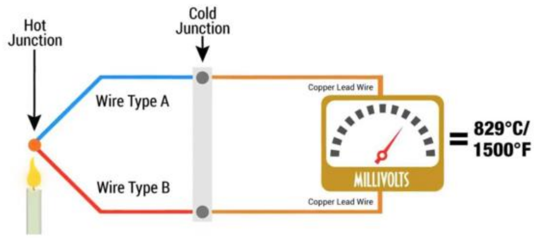



**Figure 4.7, Thermoelectric effect [31]**

### Pump

**Figure 4.8, Pump inside EC685M**

For espresso machine, there are two main pump types: vibratory and rotary. They both have advantages and disadvantages of using an espresso machine. Those features are tabulated in Table 4.3. For the EC685M, this machine was aiming to be a compact home espresso machine. Thus, the vibratory pump was chosen, which is relatively more compact than the rotary pump. The new design used the existing pump due to the portability, which was one of the requirements for the design.

**Table 4.3, Rotary Pump Vs Vibratory Pump [32]**

| | Rotary pump | Vibratory pump |
|---|---|---|
| Advantages | Long lifetime<br>Less noise | Inexpensive<br>Compact size |
| Disadvantages | Large size | Have more noise than a rotary pump<br>5 to 6 years of lifetime |

**Grouphead**


**Figure 4.9, E61 Grouphead [33], De'Longhi EC685M Grouphead**

Grouphead is a part that located in the front of the espresso machine. This part connects with the portafilter. Grouphead is one of the most important part in espresso machine because inside the grouphead the water and coffee powder meet**.** The main function of the grouphead is sustaining the water temperature comes from the heater, thus,  is usually made with metal [33, 34]. However, professional grouphead such as E61 grouphead cost minimum around £400. Therefore, this project is going to focus on using the existing grouphead which is made with plastic, rather than buying a new grouphead,

**Water tank**

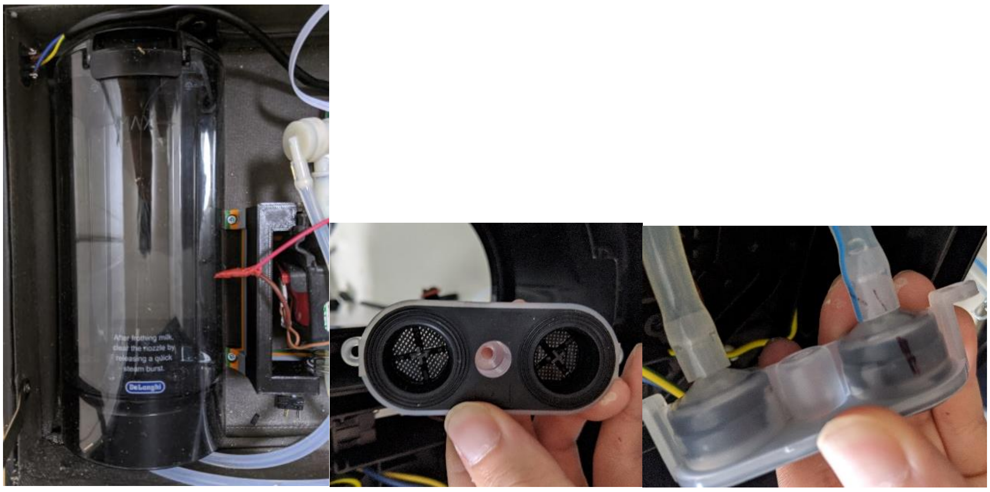


**Figure 4.10, Watertank Parts**

The water tank parts were composed with a reservoir and the connector. The connector has two connecting holes that one is linked with the volume flow meter and pumps input, and the other one is connected with the output of the pump which is also spreading out into the grouphead.

### Volume flow meter

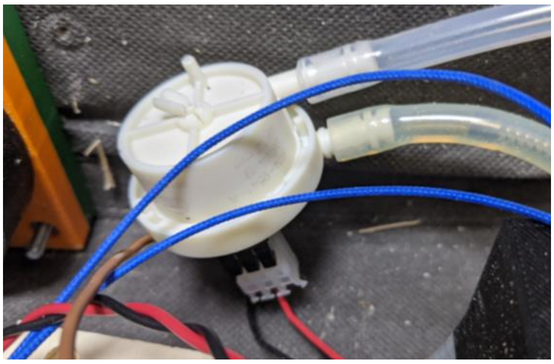


**Figure 4.11, Volume Flow Meter**

A flow sensor is a device which measures the volume flow rate of the liquid or gas. A flow rotates the turbine inside the sensor and generates a small amount of electricity. The flow rate is proportional to the voltage, so it is possible to calculate the flowrate by voltage. Through using Equation 4.1, the volume of the flow past the sensor can also be calculated. Q indicates volume flow rate. C is flow velocity and A is the surface area of the pipe. For this espresso machine, the flow sensor will be used to adjust the amount of water used for extracting the coffee by adjusting the pump operating time.

$$Q = \mathrm{CA}$$

**Equation 4.1**

### Relay

High voltages such as 110v or 220v are used in pump and heater of the espresso machine. However, the control board cannot address this high voltage directly. Thus, it is possible to expect that the relay is integrated on to the control board. Relay is a switch which electrically operates. It can allow controlling the high voltage supply with the digital signal created from the control board. Figure 4.12 well describes the principle of the relay. The left side of Figure 4.12 shows an open condition of the circuit 2 which has high voltage, and the right side shows close condition. At the open condition, the circuit number 1 does not provide electricity to the electromagnet. Thus, the circuit 2 will not be closed. When the circuit 1 supplies the voltage to the electromagnet, the switch on the circuit 2 moves and close the circuit 2. Therefore, on the espresso machine, the control board will turn on and off the electricity supply to manage the pressure and temperature.

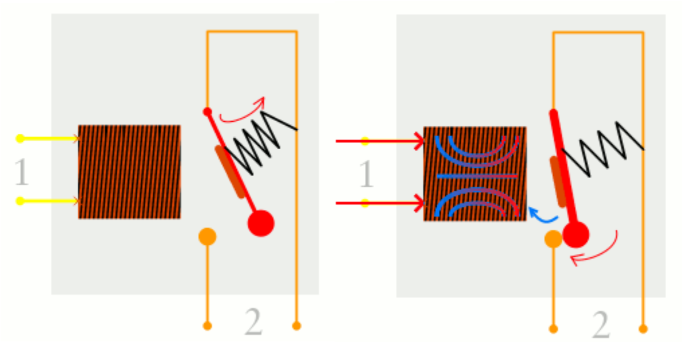



**Figure 4.12, Relay Operation Principle [35]**

### Specs and Components relationship

The specs listen on Table 4.4 was matched with the components in espresso machine while disassembling. For example, the 1.1L of water tank capacity is set by the water tank size, which has a part number 18. Also, the machine has three different colour selections because of the three different available colours on the outer frame parts. Through doing this process, the relationship between function and the components could be clearly identified.

**Table 4.4, Performance Specification of De'Longhi EC685M [28]**

| **Feature** | **Value** |
|---|---|
| Weight | 4,2kg |
| Rated voltage/Frequency | 220-240 V / 50-60Hz |
| Input power | 1300W |
| Pump pressure | 15bar |
| External dimensions | 149x330x303 (WxDxH) $(mm^3)$ |
| Water Tank Capacity | 1,1L |
| Number of filters | 3 |
| Maximum cup height | 12cm |
| Body material | Stainless Steel, ABS |
| Milk system | Manual |
| Heating system | Thermoblock |
| Cup warmer | Passive |
| Available colour | Black, Red, Metal |
| On/off switch: ✓ | |
| Auto shut-off: ✓ | |

| |
|---|
| 1&2 cups filters: ✓ |
| Removable drip tray: ✓ |
| Removable water tank: ✓ |
| Water level indicator: ✓ |
| ESE (Easy Serving Espresso) pods: ✓ |

# 5 DESIGN SPECIFICATION

In this section, the design requirement was quantified into specification. Then the specification was evaluated and ranked according to QFD. The design requirement and need statement were guidelines for the project. Since they could not be directly measured and calculated, those guidelines were difficult to directly apply into the decision process. Thus, the specification is needed to quantify the requirement to be used in decision making. The design requirement was restructured with using more engineering terms in order to measure and calculate. When the specification is all listed, the importance of each aspect was analysed by the performance specification method and QFD method. Firstly, the performance specification method was used for listing all the specifications. Then, based on correlation between requirement and specification, the ranking of the specification was evaluated. Furthermore, the ranked and weighted values of the specification were utilised during the selection of the design concepts.

### Performance Specification Method

Six different specifications, which can be adjusted through progression the project, were chosen. Then, it was listed on the table with the minimum targeting values.

**Table 5.1, Performance Specification Method**

| Metric | Value |
|---|---|
| Number of parts | < 75 (Less than original machine) |
| Size | < 500 x 350 x 120 $mm^3$ |
| Weight | < 4.2kg without water |
| Ratio of accessible parts | - |
| Production cost | < £300 |
| Electric parts enclosed | 100% |

### Quality Function Development method (QFD)

Through using the QFD method, the ranking and weighting value of each specification was calculated. This was done to identify which specification is more important and further used when making decision. To calculate and evaluate, the specification was listed on the top of the raw on QFD table, and the requirements were listed on the left side of the column. Then, the strength of the relationship was evaluated with number 1,3 and 9. The technical importance score was calculated by adding all the multiplied values between customer importance rating and the relationships value. By the resulting technical importance scores, the ranking of the specification can be determined, and this ranking can be used on making the right decision while designing the prototype and final design. In addition, the correlation is indicated by positive, negative and none on the top of the chart. This shows how the specification are relating to other specification. Thus, if it is positive then the relationship is proportion. If it is negative, then it is having a reverse proportion relationship [36].

Table 5.2 shows the ranking of the specification, but the score represent that the number of parts and size have almost the same technical importance. The QFD chart allows the designer to not only recognise the ranking of the specification but also help to evaluate the design concept by calculation through using the numbers. The QFD chart was further used on the next chapter when evaluating and selecting the design concepts.

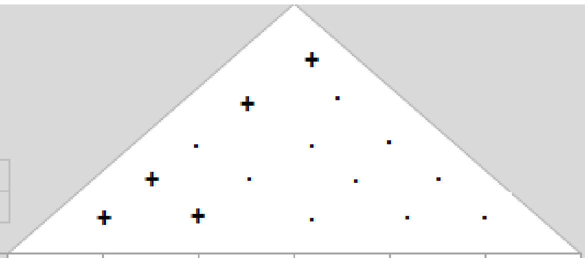
**Table 5.2, Quality Function Development Method**

Correlation:

| + | . | - |
|---|---|---|
| Positive | No-correlation | Negative |

Relationships:

| 9 | 3 | 1 | |
|---|---|---|---|
| Strong | Moderate | Weak | None |



| | 1: low, 10: high | Desired direction of improvement | ↓ | ↓ | ↓ | ↑ | ↓ | ↑ | |
|---|---|---|---|---|---|---|---|---|---|
| | Customer importance rating | Specification → / ↓Requirements | Number of Parts < 75 | Size < 500 x 350 x 120 mm^3 | Weight < 4.2kg | Ratio of accessible parts | Production Cost < £300 | Electric parts enclose | Weighted Score |
| 1 | | **Performance** | | | | | | | 0 |
| 6 | 7 | Extracting enough amount of coffee | | | | | | | 0 |
| 7 | 6 | Light weight | 3 | 9 | 9 | | | | 126 |
| 8 | 9 | Compact | 3 | 9 | 3 | | | | 135 |
| 9 | 7 | Comfortable to carry | | 9 | 9 | | | 1 | 133 |
| 10 | | **Safety** | | | | | | | 0 |
| 11 | 6 | No sharp parts | | | | | | | 0 |
| 12 | 10 | Electrical components enclose | | | | | | 9 | 90 |
| 13 | 8 | Dust and dirty prevention | | | | | | 3 | 24 |
| 14 | | **Accessibility** | | | | | | | 0 |
| 15 | 6 | Easy to build/ Simple Design | 9 | 3 | 1 | 9 | 1 | 1 | 147 |
| 16 | 8 | Possible to buy parts in store. | | | | 9 | 1 | | 81 |
| 17 | 8 | Parts available by CAD files | 1 | | | 1 | | | 16 |
| 18 | 7 | Less number of components | 9 | 3 | 3 | 3 | 3 | 1 | 142 |
| 20 | | **Inexpensive** | | | | | | | 0 |
| 21 | 7 | Low production cost | 3 | | | 1 | 9 | 1 | 44 |
| | | Technical importance score | 191 | 237 | 171 | 162 | 98 | 141 | 938 |
| | | Importance % | 20% | 25% | 18% | 17% | 10% | 15% | 107% |
| | | Priorities rank | 2 | 1 | 3 | 4 | 6 | 5 | |

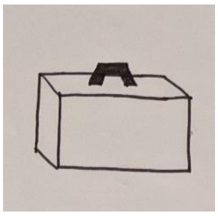
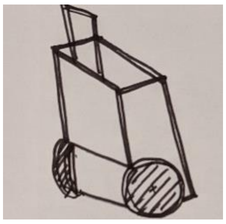
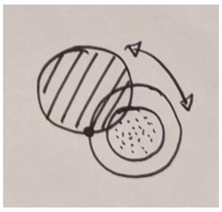
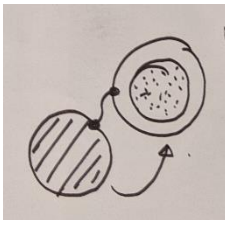
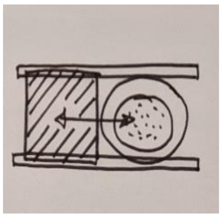
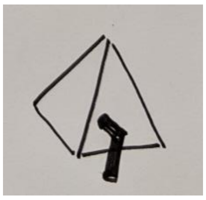
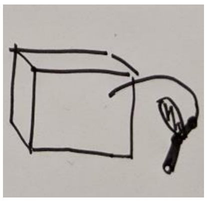
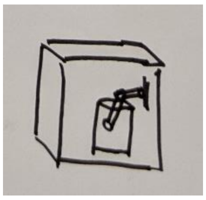
# 6 DESIGN CONCEPTS

On this part, the design ideas and concepts were brainstormed and selected. The design ideas of each component were brainstormed based on their function. At least more than three ideas were listed on each category. Then, the plans were evaluated by using the QFD method and selected based on the resulting score the concept gets.

## Concept development

The conceptual design of each function has been brainstormed. Then, the ideas have been organised in Table 6.1 with the brief drawing and explanation of the principle.

**Table 6.1, List of Conceptual Design**

| | Options 1 | Options 2 | Options 3 |
|---|---|---|---|
| Method of transportation |  Handle |  Wheel |  Strap |
| Dirt prevention device for grouphead |  Rotating slide cover |  Fitting cover with string connection |  Sliding cover |
| Steam wand |  Fitting steamwand |  The tube extended steam wand with grip |  Steamwand and container inside the housing |

## Concept evaluation by QFD

Each organised part concept was combined into a sketch to demonstrate the initial options of the prototype design. These concept prototypes were evaluated by the QFD method. For the transporting method, the strap was chosen. For the grouphead cover, the fitting cover with string connection was selected. Finally, steamwand was planned to extend its tube and add grip on to it.

**Table 6.2, Concepts evaluation by QFD**

| | ↓Requirements | Weighted Score | Handle | Wheel | Strap | Rotating cover | Sliding cover | Fitting cover | Directly connected steamwand | Lined Steamwand | Steamwand inside |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Performance** | 0 | | | | | | | | | |
| 1 | Extracting enough amount of coffee | 0 | | | | | | | | | |
| 2 | Lightweight | 126 | | | | 4 | 3 | 4 | 4 | 3 | 3 |
| 3 | Compact | 135 | 4 | 2 | 4 | 4 | 3 | 4 | | | |
| 4 | Comfortable to carry | 133 | 2 | 4 | 3 | 3 | 3 | 3 | 2 | 3 | 4 |
| | **Safety** | 0 | | | | | | | | | |
| 5 | No sharp parts | 0 | | | | | | | | | |
| 6 | Electrical components enclose | 90 | | | | | | | 4 | 4 | 2 |
| 7 | Dust and dirty prevention | 24 | | | | 3 | 3 | 3 | 2 | 2 | 3 |
| | **Accessibility** | 0 | | | | | | | | | |
| 8 | Easy to build/ Simple Design | 147 | 4 | 2 | 4 | 4 | 2 | 4 | 3 | 4 | 2 |
| 9 | Possible to buy parts in store. | 81 | 3 | 2 | 3 | 3 | 2 | 4 | | | |
| 10 | Parts available by CAD files | 16 | | | | 4 | 2 | 4 | | | |
| 11 | Less number of components | 142 | 4 | 2 | 4 | 3 | 2 | 4 | | | |
| | **Inexpensive** | 0 | | | | | | | | | |
| 12 | Low production cost | 44 | 4 | 1 | 4 | 3 | 2 | 3 | | | |
| | | 938 | 2381 | 1586 | 2514 | 2968 | 2114 | 3191 | 1619 | 1773 | 1456 |

Based on the calculated values by QFD, strap, fitting cover and extended steamwand with grip have been chosen for the basic concepts for the prototype.

# 7 MANUFACTURING DESIGN

After the design concepts were chosen, the prototype was begun to build. The rapid prototype was focused on building a working model. Then, based on the experience gained from the prototype, the final prototype was planned to build. All the decisions were justified by comparing available options, especially using the QFD method.

## 7.1 Prototyping

**Figure 7.1, Briefcase [37]**

The main body frame was chosen to use a briefcase because it was relatively inexpensive and had handle on it. According to the result of the concept evaluation, the strap was chosen. Nevertheless, the handle was included on the case, thus the hand was used rather than installing the strap.

University technicians advised to use the original pump housing structure. This advice was given because of the difficulty of controlling the pump vibration. Therefore, for the prototype, the pump housing was made through reverse-engineering the original structure of the pump housing to minimises the pump vibration.

Rather than redesigning the grouphead from the prototype, the existing grouphead was mounted onto the briefcase by using the additive manufactured holder. As Figure 7.2 shows, the CAD models were designed by Fusion360 to 3D printed.

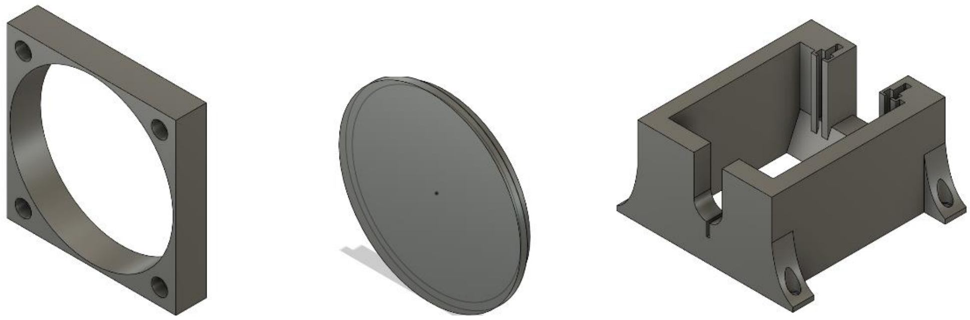


**Figure 7.2, Grouphead Holder, Grouphead Cover, Pump Holder.**

### Additive Manufacturing the parts

Additive manufacturing is an automotive manufacturing device which creates the product layer-by-layer with Computer-aided design (CAD) file. It can use various kind of materials, such as plastics, metals, etc. The University of Sheffield provides two types of AM devices from student workplace. The two kinds of AM were FDM (Fused Deposition Modelling) and SLA (Stereolithography). FDM and SLA have different operating methods, so they have various advantages and disadvantages. The differences are listed in Table 7.1. In this project, FDM was chosen for manufacturing parts due to the low cost, which can increase the accessibly as an opensource project, and the relatively low design requirement for dimension accuracy.

**Table 7.1, FDM vs SLA [38]**

| Type | FDM | SLA |
|---|---|---|
| Device | <br>Ultimaker 2+ Extended | <br>Prusa MK3S |
| Precision | Relatively low | Relatively high |
| Postprocessing | Need to remove supports | Need to remove stick resin by alcohol |
| Cost | Low cost<br>1kg of filament is around $25 | Relatively high cost<br>2.5L of resin is about $60<br>Platform $100 |
| Recommended situations for using | Rapid prototyping<br>Low-cost models manufacturing<br>Hobbyists<br>When precision is not important | When precision is important<br>When it does not require high durability<br>For creating moulds |

FDM not only shows the high-cost efficiency but also it is the most popular AM process, which occupies 69% of AM technology usage [39]. For this coffee machine project, one of the essential requirements will be the accessibility of the resources, so this project will focus on using FDM rather than SLA.

Due to the layer-by-layer operating principle and the limitation of the nozzle shape, to make reliable FDM results, there were several vital points to consider while designing the CAD file and printing it [40].

1. 1.2 to 1.5mm thickness support structures are required when the angle of the edge is lower than 45 degree.
2. Minimum wall thickness is 1.5 to 2mm due to the size of the nozzle.
3. Thicker the better with the strength, but it increases the required time and cost. Thus, it is crucial to find a design that provides both enough strength and efficiency.

4. Result of the FDM comes out with slightly smaller than the original CAD file. Therefore, when designing a hole, the dimension of diameter should be increased by 3% up to 10mm.
5. Perpendicular thread needs to be avoided, and the recommended thread angle is 29 degree with 0.8mm minimum thickness.
6. The upward-facing surface has the best surface finish, and curved design shows less surface finish.
7. It is better to change the hole's orientation into a vertical direction to avoid support usage.
8. Infill rate is one of the essential factors when using FDM. It shows the density of the inside parts, so higher the stronger but higher requires more time and cost.

**Result of the Additive Manufactured parts**

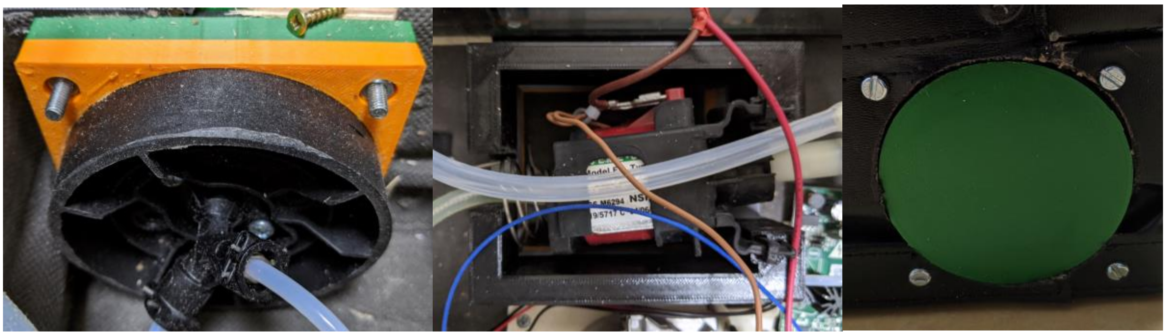


**Figure 7.3, Printed Parts: Grouphead Holder, Grouphead Cover, Pump Holder.**

Used Additive manufacture machine: Ultimaker 2+ Extended
Material: PLA

After comparing the FDM and SLA, the FDM was chosen to be used for printing out the parts. There was some concern about the quality of the printed parts. As an article [41] reported that FDM is not reliable enough.

**Assembling parts**

Before assembling the parts, the silicon tube was purchased from the online store for replacing the short silicon tubes. The university workplace provided the bolts and nuts, so they were not required to be bought.

Four different holes were made on the briefcase. A hole for the grouphead was built on the bottom right side of the briefcase by a 40mm radius hole saw. 8mm diameter holes were made on the right side of the briefcase and the top-right side of the plane. The right-side hole was for the knob, and the top right-side hole was for the steamwand tube. The fourth hole was made for the IEC connector. This hole was made by drilling the hole and then cutting into the desired shape by using the fret saw.

The three different sizes (100x80, 80x80, 40x40 $mm^2$) of plywood were made and fasten on to the briefcase. Each plywood was jointed onto the briefcase with two screws. The control board was glued on to the 100x80 plywood by glue gun. The thermoblock was fastened onto the 80x80 plywood with one screw. The knob parts for switching the steaming function was fastened on to the 40x40 plywood by two screws.

The grouphead which was extracted from the original coffee machine was fitted with the grouphead holder. Then, the grouphead was fixed on to the grouphead hole on the briefcase by four sets of bolt and nut.

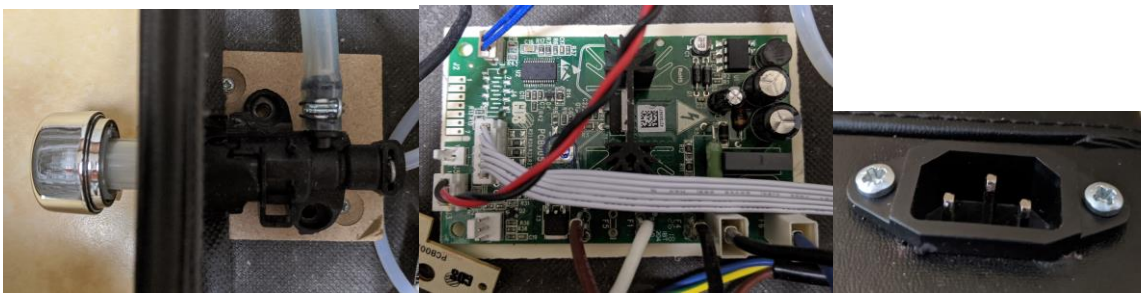


**Figure 7.4, Steamwand Controller, Control Board, IEC C13**

The thermoblock was fastened on to the plywood by screw. The pump holder was tightened on to the briefcase by using four-screw. Then, the pump was mounted on to the holder. A part holding a water tank was extracted from the original body by sawing and fasten onto the briefcase by using the glue gun and screws. IEC female connector was fixed onto the briefcase with two screws.

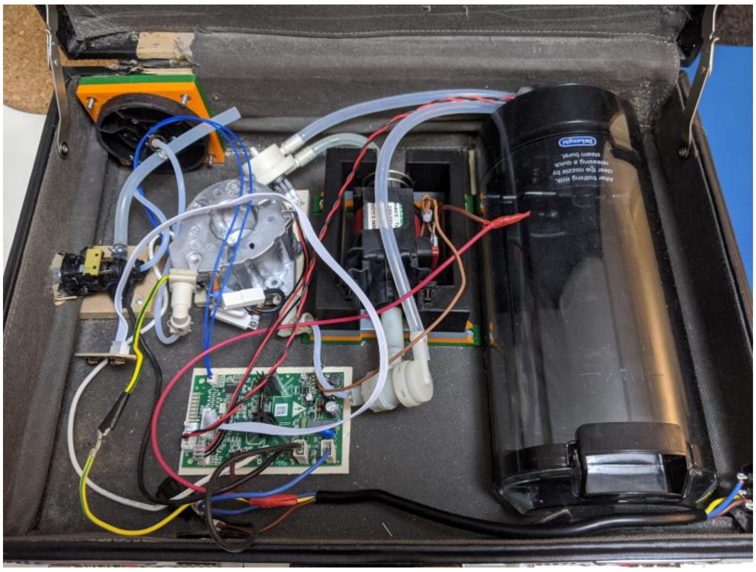


**Figure 7.5, Inside the Prototype**

All the electric wires and water tubes were connected by following the original way from the De'Longhi espresso machine. For the IEC connector, the power cables including plus, minus and ground were soldered on to the IEC female connector with the correct match.

### 7.1.1 Testing and Discussion

The result of the prototype was compared with the original espresso machine. Based on the targeting specifications, the weight and the number of parts had been successfully decreased. The weigh had been reduced from 4.2kg to 4.0kg, and the Number of total parts has reduced from 75 to 58. The size of the machine has reduced, and the shape of the device becomes simple. Therefore, the espresso machine became more convenient to carry and manufactured.

Before manufacturing the prototype, there was some concern with using additive manufacturing. The tolerance of the grouphead cover for adequately fitting on to the grouphead hole was concerned due to the limitation of dimensional accuracy. FDM has weak strength comparing to other AM process. Thus, there was also a concern that the strength of the result is not enough to bear the vibration or applied force on the parts. However, the actual result was strong enough to bear the force applied by the screw.

The holder on the briefcase was convenient and strong enough to bear the weight of the device. Thus, replacing the strap to holder was reasonable decision. There was an issue with the electrical parts enclose because the original water tank was not sealed. This issue was planned to be improved in the final design.

The espresso machine worked well. It showed the same performance compared to the original product. However, there were still more parts that need to be replaced by the opensource hardware. In addition, the university students from the workplace gave a feedback that the machine looks like a bomb. Therefore, referring to those result and feedback, the final design was structured.

## 7.2 Final Design

Based on the experience, which was obtained from the prototyping, the final design was planned. Unfortunately, the final design could not be manufactured because of the university facilities shutdown due to the COVID-19. Nevertheless, the final design was planned. In this section, the IEC connector was reselected, the briefcase was replaced by a laser-cut acrylic case, the water tank was redesigned.

### IEC connector

From the prototyping, the IEC C13/C14 was installed for safety issues. However, the IEC connector was chosen without any research about the difference between each type. It was just installed due to the recommendation by the technicians. The further research about IEC connector was done lately. Through this research, the problem that IEC C13/C14 was not suitable for the espresso machine was recognised.

IEC stands for International Electrotechnical Commission. Based on their agreement, a lot of electrical components have been standardised. One of the standard rules is IEC 60320, and it specifically represents the power supply connector for household or its related devices. IEC 60320 has several different types, and they are composing a couple by female and male type connectors. Each connector has different durability for current, voltage and pin temperature. Those differences are listed in Table 7.2. Apart from C15/C16 and C15A/C16A, all the other connector shows 70 degrees of maximum pin temperature. However, for the espresso machine, the heated water reaches up to more than 90 degree Celsius. This indicates that the C13/C14 connector cannot bear the water temperature of the espresso machine. Therefore, the C15/C16 or C15A/C16A type must be used for this project. Besides, the C15/C16 connector is commonly used for an electric kettle. Thus, it will also be suitable for the espresso machine [42].

**Table 7.2, IEC 60320 [42]**

| Connector (female) | Appliance inlet (male) | Configuration Female/Male | Earth contact | International | | North America | | Max. pin temp. (°C) |
|---|---|---|---|---|---|---|---|---|
| | | | | Max. current (A) | Voltage (V) | Max. current (A) | Voltage (V) | |
| C1 | C2 | | No | 0.2 | 250 | 10 | 125 | 70 |
| C5 | C6 | | Yes | 2.5 | 250 | 10 | 125 | 70 |
| C7 | C8 | | No | 2.5 | 250 | 10 | 125 | 70 |
| C9 | C10 | | No | 6 | 250 | / | 125 | 70 |
| C13 | C14 | | Yes | 10 | 250 | 15 | 125/250 | 70 |
| C15 | C16 | | Yes | 10 | 250 | 15 | 125/250 | 120 |
| C15A | C16A | | Yes | 10 | 250 | 15 | 125/250 | 155 |
| C17 | C18 | | No | 10 | 250 | 15 | 125/250 | 70 |
| C19 | C20 | | Yes | 16 | 250 | 20 | 125/250 | 70 |
| C21 | C22 | | Yes | 16 | 250 | 20 | 125/250 | 155 |
| C23 | C24 | | No | 16 | 250 | 20 | 125/250 | 70 |

## Redesigning a Housing

There was a feedback from other students while working inside the workplace. Two students said that the product looks like a bomb because of the black colour briefcase. There were some changes made in appearance of the final design. Moreover, the briefcase was only supplied by the Irish online shop, which is not internationally reachable. Thus, the briefcase was redesigned to be manufacturable at home instead of purchasing.

**Table 7.3, Final Design Concept Development**

| | 1st prototype | Option 1 | Option 2 |
|---|---|---|---|
| Housing | Briefcase | Laser-cut acrylic | 3D printed housing |
| Water tank design | Original parts from the espresso machine | Plastic bottle using a check valve | bladder water tank |

For replacing the briefcase design, the new design was planned to use laser-cutting or 3D printing method. The laser-cutting was chosen for manufacturing the new housing. This decision was made by comparing the benefits of each method by the QFD method, as shown in Table 7.4.

As Figure 7.6 shows, the housing was designed by Fusion360. The connecting parts were designed with zigzag pattern to increase the contacting areas between components to improve the strength of the bond. The estimated mass of the machine case was 2,035 g which is 410g lower than the briefcase. The screw holes were not drawn on the initial CAD file because of the concern of the unperfect location matching between holes and components. The screw holes were planned to be added on the CAD files after manufacturing and measuring the exact location of the holes. 900 x 600 x $5mm^3$ acrylic sheet needs to be cut by a laser-cutting machine. Each part was planned to be adhesive by plastic weld glue to prevent whitening of the plastic sheet by other types of glue.

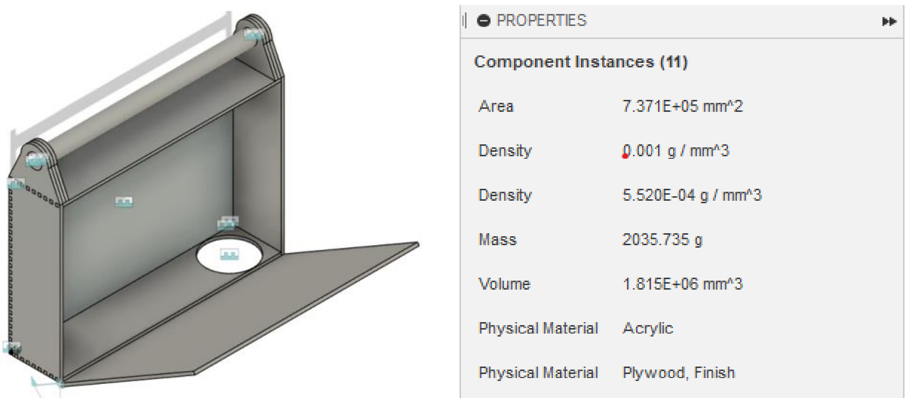



**Figure 7.6, Computer Aid Design of the Acrylic Housing**

## Redesigning a Water Tank

For the water tank, the prototype used the original parts from the De'Longhi machine. Unlike other components, the housing cannot be purchased individually from the online parts store. Therefore, the water tank was redesigned with using parts that are easy to purchase or obtain from other resources.

There were two ideas. One was using a disposable plastic bottle with a check valve to sustain the pressure inside the bottle. This was important to sustain the pump function. The other idea was using a bladder water bag, which is shown in Figure 7.7, This idea can sustain the pressure inside by shrinking the structure. These two main designs were evaluated in Table 7.4 with QFD method. As a result, the Bladder water tank design was chosen.

**Figure 7.7, Bottle & Check valve [43, 44], Bladder Water Bag [45]**

**Table 7.4, Final Design Concept Evaluation by QFD**

| | ↓**Requirements** | Weighted Score | Briefcase | Laser Cut acrylic | 3D printed | Original parts | Bottle & check valve | Bladder water tank |
|---|---|---|---|---|---|---|---|---|
| | **Performance** | 0 | | | | | | |
| 1 | Extracting enough amount of coffee | 0 | | | | | | |
| 2 | Lightweight | 126 | | | | 1 | 3 | 4 |
| 3 | Compact | 135 | 3 | 3 | 3 | 1 | 3 | 4 |
| 4 | Comfortable to carry | 133 | 3 | 3 | 3 | 1 | 3 | 3 |
| | **Safety** | 0 | | | | | | |
| 5 | No sharp parts | 0 | | | | 4 | 4 | 5 |
| 6 | Electrical components enclose | 90 | | | | 1 | 4 | 4 |
| 7 | Dust and dirty prevention | 24 | | | | | | |
| | **Accessibility** | 0 | | | | | | |
| 8 | Easy to build/ Simple Design | 147 | 2 | 3 | 3 | 1 | 2 | 4 |
| 9 | Possible to buy parts in store. | 81 | 2 | 4 | 4 | 1 | 3 | 3 |
| 10 | Parts available by CAD files | 16 | | 5 | 5 | | | |
| 11 | Less number of components | 142 | 3 | 4 | 3 | 2 | 3 | 4 |
| | **Inexpensive** | 0 | | | | | | |
| 12 | Low production cost | 44 | 2 | 4 | 3 | | | |
| | | 938 | 1774 | 2393 | 2207 | 996 | 2505 | 3202 |

## 7.3 Final Design Evaluation

The final design was evaluated based on the specifications and requirements which were set at the initial step of the project process.

As shown in Table 7.5, the performance of the final design outstands the prototype apart from the cost perspective. The cost has increase about £20. However, the size, weight, accessibility of parts and electrical parts enclose have improved a lot. The size and weight have been reduced because of redesigning the housing with Acrylic. This has enhanced the portability of the espresso machine. Even though the total part number had not decreased dramatically, the accessibility of the parts has improved due to changing the water storage components. Therefore, the final design can be evaluated as a good design according to these improvements.

**Table 7.5, Evaluating Products based on Specification**

| | Original Machine | Prototype | Final Design |
|---|---|---|---|
| Number of parts | 75 | 58 | 57 |
| Size | 500 x 350 x 120 $mm^3$ | 440 x 323 x 102 $mm^3$ | 385 x 320 x 88 $mm^3$ |
| Weight | 4.2kg | 4.0kg | 3.6kg |
| Ratio of accessibility parts | - | 90% | 100% |
| Production Cost | £180 | £205.68 | £226.78 |
| Electrical parts enclosed | 100% | 70% | 100% |

**Table 7.6, Bill of Materials**

| **Prototype** | | | **Final Design** | | |
|---|---|---|---|---|---|
| No. | Part description | Materials | No. | Part description | Materials |
| **Original Parts** | | | | | |
| 1 | Large two-cup filter | STAINLESS STILL | 1 | Large two-cup filter | STAINLESS STILL |
| 2 | SUMP | STAINLESS STILL, ABS | 2 | SUMP | STAINLESS STILL, ABS |
| 3 | FROTHER | STAINLESS STILL, ABS | 3 | FROTHER | STAINLESS STILL, ABS |
| 4 | KNOB | ABS | 4 | KNOB | ABS |
| 5 | MICROSWITCH | | 5 | MICROSWITCH | |
| 6 | TAP | PLASTIC | 6 | TAP | PLASTIC |
| 7 | WATER TANK | TRANSPARENT | - | | |

| | | | | | |
|---|---|---|---|---|---|
| | | PLASTIC | | | |
| 8 | O-RING | STAINLESS STILL | 7 | O-RING | STAINLESS STILL |
| 9 | TUBE LOWER | PLASTIC | 8 | TUBE LOWER | PLASTIC |
| 10 | TUBE DISTRIBUTING | STAINLESS STILL, PLASTIC | 9 | TUBE DISTRIBUTING | STAINLESS STILL, PLASTIC |
| 11 | SWITCH | | 10 | SWITCH | |
| 12 | GASKET | RUBBER | 11 | GASKET | RUBBER |
| 13 | TUBE DI=4 | SILICONE | 12 | TUBE DI=4 | SILICONE |
| 14 | FILTERS ASSEMBLY | PLASTIC | - | | |
| 15 | CLIP | STEEL | 13 | CLIP | STEEL |
| 16 | O-RING D=3.85 | SILICON | 14 | O-RING D=3.85 | SILICON |
| 17 | VALVE | ABS | 15 | VALVE | ABS |
| 18 | PUMP | | 16 | PUMP | |
| 19 | PROTECTOR | ABS | 17 | PROTECTOR | ABS |
| 20 | SPRING | STEEL | 18 | SPRING | STEEL |
| 21 | VALVE | ABS | 19 | VALVE | ABS |
| 22 | RING | STAINLESS STEEL | 20 | RING | STAINLESS STEEL |
| 23 | FLOWMETER | | 21 | FLOWMETER | |
| 24 | GASKET | ABS | 22 | GASKET | ABS |
| 25 | GASKET | ABS | 23 | GASKET | ABS |
| 26 | SUPPORT | ABS | 24 | SUPPORT | ABS |
| 27 | GASKET | ABS | 25 | GASKET | ABS |
| 28 | DOFFISER | STAINLESS STEEL | 26 | DOFFISER | STAINLESS STEEL |
| 29 | POWER SUPPLY CORD | | 27 | POWER SUPPLY CORD | |
| 30 | SENSOR NTC | | 28 | SENSOR NTC | |
| 31 | WIRING | | 29 | WIRING | |
| 32 | CONNECTOR | ABS | 30 | CONNECTOR | ABS |
| 33 | WIRING | | 31 | WIRING | |
| 34 | POWER BOARD | | 32 | POWER BOARD | |
| 35 | GENERATOR | STEEL, CUPPER | 33 | GENERATOR | STEEL, CUPPER |
| 36 | SPACER | STAINLESS STEEL | 34 | SPACER | STAINLESS STEEL |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5XD5.2XD7.9 NATURAL | | | | 5XD5.2XD7.9 NATURAL | | |
| 37 | GASKET | ABS | | 35 | GASKET | ABS | |
| 38 | CLIP | STEEL | | 36 | CLIP | STEEL | |
| 39 | BRACKET | ABS | | 37 | BRACKET | ABS | |
| 40 | CONNECTION | ABS | | 38 | CONNECTION | ABS | |
| 41 | TCO 192" | | | 39 | TCO 192" | | |
| 42 | TCP BRACKET | | | 40 | TCP BRACKET | | |
| 43 | CONNECTION | ABS | | 41 | CONNECTION | ABS | |
| 44 | TUBE PTFE DI=2 DE=4 | PTFE | | 42 | TUBE PTFE DI=2 DE=4 | PTFE | |
| 45 | TUBE PTFE DI=2 DE=4 | PTFE | | 43 | TUBE PTFE DI=2 DE=4 | PTFE | |
| 46 | TUBE PTFE DI=2 DE=4 | PTFE | | 44 | TUBE PTFE DI=2 DE=4 | PTFE | |
| 47 | SPRING | STEEL | | 45 | SPRING | STEEL | |
| 48 | CONNECTOR | ABS | | 46 | CONNECTOR | ABS | |
| **Additional Parts** | | | | **Additional Parts** | | | |
| 49 | Briefcase | | £16.49 | 47 | Plywood 100x80 | Plywood | - |
| 50 | Plywood 100x80 | Plywood | - | 48 | Plywood 80x80 | Plywood | - |
| 51 | Plywood 80x80 | Plywood | - | 49 | Plywood 40x40 | Plywood | - |
| 52 | Plywood 40x40 | Plywood | - | 50 | Grouphead Holder | PLA | - |
| 53 | Grouphead Holder | PLA | - | 51 | Grouphead Cover | PLA | - |
| 54 | Grouphead Cover | PLA | - | 52 | Pump Holder | PLA | - |
| 55 | Pump Holder | PLA | - | 53 | 900 x 600 x 5 Acrylic | Acrylic | £25 |
| 56 | IEC C13 | | £1.84 | 54 | Bladder Water Bag | | £7.99 |
| 57 | IEC C14 | | £3.35 | 55 | IEC C15 | | £6.99 |
| 58 | TUBE DI=4 DE=8 | SILICONE | £4 | 56 | IEC C16 | | £2.8 |
| | | | | 57 | TUBE DI=4 DE=8 | SILICONE | £4 |

'-' indicates supplied from university thus free

# 8 CONCLUSION

The aim of this project was designing an opensource espresso machine. Before thinking about manufacturing the device, the literature review was done to understand 'what is coffee' and 'how the coffee industry looks like'. Then, to address the project in a more engineering approach, the engineering design method, which integrates logical procedures for decision-making, was studied and applied. This method was beneficial because it is an exact way of how the engineers work in the industry to create or modify new products.

This method started with the step for specifying the design requirements. The requirements were identified and prioritised by analysing the desire on the market. On the next step, the existing coffee machine was planned to be reverse-engineered, and the De'Longhi EC685M was chosen. The coffee machine was firstly narrowed down to compact espresso machine. This decision was made because of the compact design and the ability to extract many portions. Then, the extract De'Longhi EC685M model was selected due to the possibility of purchasing each component from the online store and accessibly to the device information. This machine was disassembled step-by-step with analysing the function and material usage. The main functioning parts were further studied to understand the principle of the machine clearly.

After the reverse engineering process was done, the specification was made based on the list of requirements. Then, the design concepts were generated by brainstorming. Through applying the requirements and specifications, the QFD table was made and applied to select the best ideas. Then, the rapid prototype was manufactured according to the chosen design concepts. The prototype was tested, and the result was reflected. Through applying the reflections, the final design was planned.

**Further improvement**

For the opensource approach, the process and CAD files were updated onto the online blog, and the follower was over 340 people. However, it was challenging to get live feedback and comment from the people. There were many things that need to be modified for opensource approach. One of the recommendations is to use a more active blog or online platform such as YouTube.

In some part of the design engineering process, it requires a subjective perspective for making decisions. The design process is often done by more than two people as a group to make the right choice. On this project, the opensource approach was used to overcome this limitation, but it was not sufficient to improve the design quality due to the lack of comments and non-real time interaction. Therefore, this project can be more effective if it can be a group project, or the opensource interacting is more live.

For the function of the device, though the new design was portable in size and weight perspective, the power source was not flexible or portable. It requires 220v voltage electricity. Thus, the new design plan can be changing the power source into a 12v car cigarette plug or using installing a batter inside the machine. The espresso operating switch was not installed on to the machine. Therefore, making a house can be a great further plan for this project.

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# APPENDIX 1. REFLECTION ON FEEDBACK TO PA REPORT AND GANTT CHART

The peer assignment report was submitted during the first semester of the final year. At the initial stage of the project, the title was 'Designing a unique shape espresso machine'. However, the reason and definition for creating a unique shape were not clearly defined. Also, the aim of creating a unique shape was not clear and certain. Thus, in the thesis, the title 'portable opensource coffee machine' was justified through describing the benefits of using the opensource and explaining the importance of portability by market research. Moreover, the need statement was written to clarify the aim of this project.

The initial report did not contain any picture or figures which can help to support the reader's understanding. Therefore, in the thesis statement, the visual materials were often used to help the reader.

# APPENDIX 2. COVID 19 IMPACT STATEMENT

After the second prototype's CAD file was completed, the university workplace was shut down because of the COVID-19. Thus, the practical tools, especially laser cutter, cannot be accessed. After this situation, all the project plan for the second prototype designing was unreachable. Thus, the second prototype design was renamed into a final design plan.

After the COVID-19 started to spread out in the UK. I went back to my home country. After arriving in Korea, the government guideline was to self-isolate for two weeks. Hence, I could not go out at all during this period. Thus, it was hard to focus on work due to unresolved stress.

# APPENDIX 3. MATERIAL PURCHASING LINKS

| | |
|---|---|
| **Original Machine** | |
| De'Longhi EC685M | https://www.amazon.co.uk/DeLonghi-EC685M-Traditional-Espresso-Machine/dp/B06WGTZ874 |
| **Prototype** | |
| Briefcase | https://www.viking-direct.co.uk/en/monolith-expandable-attache-case-in-black-faux-leather-p-3958911 |
| IEC C13 | |
| IEC C14 | https://www.amazon.co.uk/gp/product/B003OSUIRK/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1 |
| TUBE DI=4 DE=8 | https://www.amazon.co.uk/gp/product/B07T11QFHJ/ref=ppx_yo_dt_b_asin_title_o02_s00?ie=UTF8&psc=1 |
| **Final Design** | |
| 900 x 600 x 5 Acrylic | https://iforgesheffield.org/materials-prices/ |
| Bladder Water Bag | https://btrsports.co.uk/products/btr-hyrdation-bladder-water-bag-2l-bpa-free |
| IEC C15 | https://www.amazon.co.uk/Invero%C2%AE-Kettle-Monitor-Screen-Printer/dp/B01C4907OS/ref=sr_1_1_sspa?dchild=1&keywords=IEC+c15&qid=1588474996&sr=8-1-spons&swrs=0E5E6A0D3751FBD73DC85164E40A0988&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUExRFU1S0Y0SktLWVNPJmVuY3J5cHRlZElkPUEwNzMxMzQ0MkhOTkRKR0pRVDQ5UCZlbmNyeXB0ZWRBZElkPUEwNzUwODc1NjRURTg0Q1VYQk9QJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ== |
| IEC C16 | https://www.amazon.co.uk/Schurter-Rewireable-Condition-Socket-6110-3300/dp/B075MMTWMX/ref=sr_1_fkmr0_1?dchild=1&keywords=IEC+C15+c16&qid=1588474894&sr=8-1-fkmr0 |
| TUBE DI=4 DE=8 | https://www.amazon.co.uk/gp/product/B07T11QFHJ/ref=ppx_yo_dt_b_asin_title_o02_s00?ie=UTF8&psc=1 |