SIMPLE SORTING

Innovation Group Design Final Report

Contents

1. Introduction

Half of the plastic that has ever been generated has been produced in the last 13 years. If these recent trends continue, it is estimated that 26 billion tons of plastic will be produced in the next 30 years. To reduce these environmental impacts the radical way of thinking needs to be changed, by optimising the use of this material and increasing its life cycle through reuse and recycling [1]. Statistics show that 15% of waste that arrive at recycling plants are non-recyclable or highly contaminated [2]. Thus, making it difficult for waste management facilities to be accurate during the recycling process, which results in wasting time, money, and labor.

Promoting proper waste management, by combining education models and appropriate technologies, is a key contribution to sustainable development. The aim of the project is to overcome these difficulties by developing a self-sorting machine with the implementation of artificial intelligence. The goal is to separate recyclables from non-recyclables, thus preventing the presences of unwanted waste at recycling plants beforehand.

Once the purpose and design of the product was chosen, a questionnaire was conducted for primary research regarding the potential market of the automatic recycling bin. The research concluded that Universities are the best potential market for the sorting machine as on average Universities in the UK spend £250,000 a year on waste management and a potential market size of £1.08 million was estimated.

Simple Sorting was designed, developed and tested by group Pangea according to the Universities needs and demands by incorporating Google Cloud Vision API. This was achieved by developing design evaluation criteria and costumer competitive assessment, which concluded that Simple Sorting would be designed to be eco-friendly and highly affordable compared to existing products on the market. To satisfy these requirements Finite Element Analysis was used to determine which material was most suitable for this design and to understand the service life of the product, which came to 10.3 years.

Group Pangea developed a prototype which demonstrated the ability of Simple Sorting to sort different types of waste according to recyclable or non-recyclable. This was achieved with the Google AIY Vision Kit which operates by means of image recognition. An evaluation plan was developed to understand if the final prototype would have met the design criteria establish at the beginning of the project.

Finally, a Manufacturing and Business plan were developed for Simple Sorting, concluding that the manufacturing location would be established in China, the market location would be focused initially at UK universities, and gradually expand to Europe. The financial model estimated that profit is made after the second year of operation by selling bins at a feasible price of £380 with a monthly subscription fee of £15.

1.1 Team

Basualdo Asllani

Sophie O'Byrne

Yuhong Wang

Miriam Said

Nilay Yavas

TEAM MEMBERS	TASKS AND RESPONSIBILITIES
Nilay Yavas Industrial Engineering	Nilay is the team leader of Group Pangea. Responsibilities include the main point of communication between the group members and the course lecturer. This consists arrangement of meetings and weekly reporting. Further responsibilities include the development of the business and manufacturing plan, risk analysis and feasibility evaluation of the Simple Sorting bin.
Sophie O'Byrne Mechanical Engineering	Sophie is responsible for the fundamental background research. This includes research on the essential problem, current market and competitors for simple sorting. Sophie was also responsible for the risk assessment for MechSpace and producing House of Quality design Matrix for the evaluation of the prototype.
Miriam Said Mechanical Engineering	Miriam's tasks include the development of the CAD designs and the connected Finite Element Analysis to gather information about the hardware system, such as ideal materials and geometry. Miriam was also responsible for the image recognition coding with python and TensorFlow.
Yuhong Wang Electrical Engineering	Yuhong responsibilities consist mainly on the electrical framework of the bin. This includes the development of the electrical circuit and the establishment of the electrical system on the initial prototype, such as the connection of microcontroller, camera and computer, as well as the coding for the motor mechanism.
Basualdo Asllani Physics	Basualdos is responsible for the Image Recognition design part. This includes fundamental research on the image recognition technology and the justification and evaluation on the chosen concept, technology and mechanism.

2. Background Research

2.1 Questionnaire Results

A questionnaire was conducted for primary research regarding the potential market of waste management. The questionnaire also aims to understand the main problems that occur at the start of the recycling process, how and why manual sorting is inefficient and often incorrect [appendix 2]. The questionnaire is comprised by 8 questions, the total number of participants were 73, mostly students. From the answers given, two main point were concluded:

1. *Recycling on campuses:* The questionnaire results show that more than 35% of students do not recycle on regular basis. 40% of the respondents eat at the university cafes on campus. 60% of the respondent are not willing to spend more than £10 on an automatic sorting machine, which on average cost £ 200 to 500. Based on these results, the potential market has been narrowed to focus on recycling on campuses, instead for individuals.
2. *Automatic sorting Machine:* The questionnaire results show that 35% of the respondents throw their waste in any bin. Only 3% rated their knowledge on recycling a 4/5. 60% of the respondents recycle mostly bottles and food packaging. These results show a high demand for an efficient and automated sorting system.

2.2 Problems with Recycling & Management

Plastic production has increased exponentially in just a few decades, from 1.5 million tones 1950 to 322 million tons in 2015 [3], Figure 1. With the increase in production, there has been a consequent increase in plastics waste. In Europe, waste-to-energy is the most widely used way to dispose of plastic waste, followed by landfill. Of all plastic waste generated, the European average for recycling is only 30%, with very large differences from country to country.

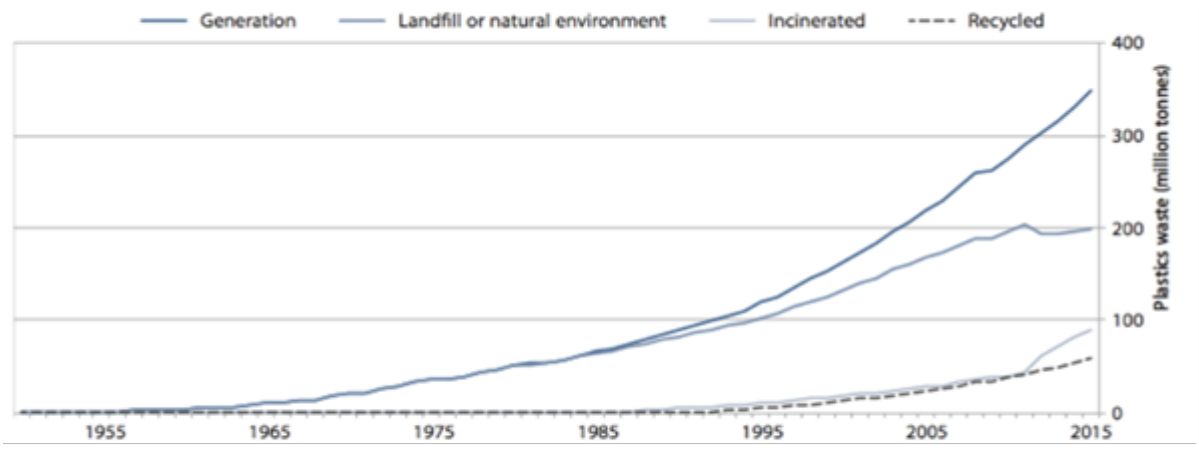

Figure 1: Increase of plastic waste over the years

Half of the plastic collected for recycling is exported for treatment in countries outside the EU. The reasons why it is exported include the lack of facilities, technology or financial resources to treat the waste locally. It has then become urgent to find other solutions.

Such a small percentage of plastic recycling in Europe means big losses for both the economy and the environment. It is estimated that 95% of the value of plastic packaging materials is lost in the economy after a very short first use cycle, as only 30% is recycled (Figure 2). Every year the production and incineration of plastics in the world emits approximately 400 million tons of CO2. Some of these emissions could be avoided by more effective recycling.

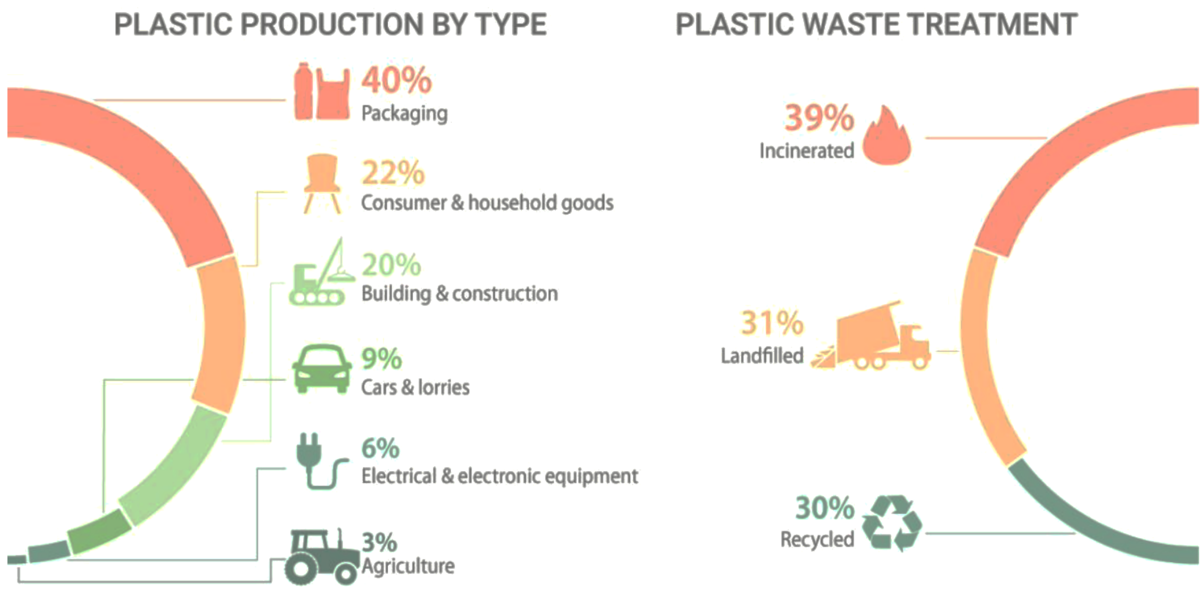

Figure 2: Plastic production and waste treatment (EU)

The biggest problems that interfere with the recycling process of plastics are [4]:

Quality and Price: Concern of quality and price of recycled products when compared to brand new products. Plastic processors need a large quantity of recycled plastic, production must meet very strict control specifications and the price must remain competitive.

Diversity of Plastics: Since plastics are easily adaptable to the individual needs of each producer, the diversity of raw plastics materials further complicates recycling processes, which affect the cost and quality of the final product. In the plastic bottles alone there are two types of plastic, the polyethylene terephthalate (PET), used for the actual bottle; and polypropylene (PP), used for the cap [5]. As a result, demand for recycled plastic amounts to only 6% of the total demand for plastics in Europe.

Separating Waste incorrectly: Recycling plants are fundamental, but one of the biggest problems in separating waste is linked to the presence of different types of waste [6]. The process of incorrect waste separation is causing the deadlock in waste management. Recycling plants that receive this mix of recyclable and non-recyclable materials, end up disposing recyclable materials.

The UK government has implemented some policies to tackle these problems [7]:

- Waste Hierarchy: consider methods of recovery
- Diversion of waste from the landfill
- Increase Recycling
- Reduction of waste from the economy
- Controlling Hazardous Waste
- Shared Responsibility

The Government also introduced Landfill tax which is used to encourage alternative means of waste disposal such as recycling. Every year this tax increases, introducing an increase of 80£ per tonne of waste in 2019 [8].

2.3 Market Potential

Further research was conducted based on the high interest of waste sorting at University campuses to understand the market potential of sorting machines.

The research concluded that many Universities in the UK spend on average £250,000 a year on waste disposal, depending on the number of students attending the University. For example, the University of Exeter spends around £500,000 a year on waste disposal, with a total number of students of 30,000 [9]. The University of East Anglia spend an average of £260,000 per year [10] with a total of 15,000 students, whilst Newman University produces a cost of £16,000 per year, with a number of students of 3,100 [11]. The city of London alone spends an average of £2bn a year [12].

The results from the questionnaire also show that none of the participants sort their waste accurately 100% of the time, when using the recycling system of UCL, [Appendix 2]. In fact, the UCL bin system (Figure 3) shows three different compartments: Non-recyclable waste, mixed recycling, food only [13]. This bin signage can be very confusing and often result in the student to dispose of waste incorrectly causing frustration. Which is causing the above-mentioned problem of incorrect waste sorting. For example, non-recyclables in the recycling bin will need to be manually sorted, or the non-recycling bin will contain recyclables that will be brought to landfills and burnt, producing unnecessary pollution.

Figure 3: A3 signage for UCL's slot bins

From the data researched above, its apparent that a sorting machine would be beneficial for the UCL waste management strategy to achieve the following:

- Improve the process of sending the waste to be recycled by removing the large-scale sorting stage implemented in recycling facilities.
- Cutting costs such as labour, which will result in decreasing waste management costs.
- Meet the goal of UCLs sustainability strategy of reducing waste per person by 20%, by 2024, with the aim of increasing the recycling rate to 85% [14].
- Maintain UCL reputation of "First Class award by People & Planets University League" which ranks UK universities on their environmental and ethical performance.
- Comply with the UCL Environmental Sustainability Management System (ESMS), certified under ISO14001 [15].

2.4 Market Competition

Primary research on existing products on the market was conducted to evaluate current competition in Table 1.

What's on the Market? [16] [17] [18] [19]

Table 1: Existing products on the market comparison

	TrashBot	Oscar	R3D3	BIN-E
Cost	– $ 100,000 to build prototype	– 90-115 €	N/A	– £430+ subscription fee of £107
Location	– Convention centres – Commercial buildings – City stadiums – Institutions – Transportation facilities	– Small facilities – Households	– Restaurants – Cafes – Small institutions	– Households – Office environments
Advantages	– Mobility – Quality construction – Cloud bin which enables to detect more items	– Touchless Sensor – Compact and space saving – Volume capacity of 45 litres	– Sorts and compacts can, cups and plastic bottles	– Waste compression – Fill level control – Data processing in the cloud

Disadvantages	– -High purchase and maintenance cost – -Not yet on the market (prototype testing)	– Location only for small facilities – Can't detect types of plastic or Food	– Only detects a small amount of waste items	– Not yet on the market – High purchase cost – Can't sort food
Disposal Time	– 3 seconds per item	N/A	N/A	N/A
Maintenance repair	– High	N/A	N/A	– High
Type of waste	– Plastics (PP, PE), Food, General waste	– Separates recyclable to non-recyclable	N/A	– Plastic, Paper, Glass and Metal
Sorting Mechanism	– AI and cloud connected robotics system, uses cameras and sensors	– AI with help of machine learning algorithm, uses image recognition camera	– CSR engagement, compression process	– AI technology and data processing to sort and compress waste
Accuracy	– 90%	N/A	N/A	– 95%

2.5 Technical Research

For this project, a system must be created that can differentiate between recyclable and non-recyclable materials. In order to achieve this, a type of recognition system had to be selected to classify the waste items. For this purpose, different technologies, such as AI image recognition, near-infrared technology and a barcode scanner was researched. The comparison is done to understand which technology was most suitable for the mechanism of the sorting machine, specifically on university campuses, shown in Table 2.

Table 2: Waste Sorting Mechanism and Technologies Comparison

	How it works	Advantages	Disadvantages
AI	– Detect faces, logos, image attributes and labels. – A selected image will be scanned by the API and the object in	– Large database (Over 1 million photos to compare to), thus allowing a 91% accuracy.	– Detection accuracy is not as high as other sources

(Google Cloud Vision API) [20]	the photo will be categorized, using googles database.	– Google provides a camera, that links directly to the database. – Camera only takes up 5% of total volume	– Relatively expensive (each camera costs £70 RP)
Near-Infrared Technology (NIR) [21]	– Infrared radiation is shone on sample, deflected radiation picked up by scanning spectrometer and information is fed to an artificial neural network.	– 99% accuracy as each material is categorized based on its wavelength. – In house database created which reduces costs by £1000's in the long run.	-Takes up 15-20% of design volume due to detectors involved. -Very expensive: scanning spectrometer costs £3000+ -Original database can take several hundreds of hours to create – not feasible
Barcode scanner [22]	– Item is scanned by user and the scanner uses a database to determine which compartment to open.	– 100% accuracy as item will be identified exactly	– Products without barcodes cannot be identified – Not practical for user, time consuming

3. Design

3.1 Design Evaluation Criteria

Based on the research completed above, design evaluation criteria were defined to specify on the functional requirements that this product needs to meet, in order to be competitive on the market. These criteria are categorized in manufacturing, performance and operational requirements (Table 3).

Table 3: Design Evaluation Criteria

Category	Criteria	Requirements
Manufacturing	Size	Max 1 x 1.50 x 0.5m (indoors)
	Material	Properties - Non-corrosive / stainless / moisture protected - stiffness resistant, high toughness - sustainable and lightweight - durability
	Weight	Max. of 80 kg
	Modularity of design	Detachable parts for easier and cheaper maintenance
	Cost	Maximum of 400 pounds for prototype production
	Assembly time	10 to 14 days
Performance	Capacity	Required load of 120l x 3
	Speed	Processing time 30-45 seconds
	Reliability	Ability to sort 6 different waste items into 2 categories
	Accuracy	Min. 80%
Operational Requirements	Power Supply	230 V 50 Hz
	Maintenance	Maintenance service twice per year
	Lifetime / warranty length	Usability for up to 10 years

Initial Design Sketches

Based on the criteria above, initial design ideas were created that were based on different technologies as presented in Table 2, section 2.5 and mechanisms for the item sorting process. These sketches include rotating, sliding and pushing mechanisms as shown in Figure 4:

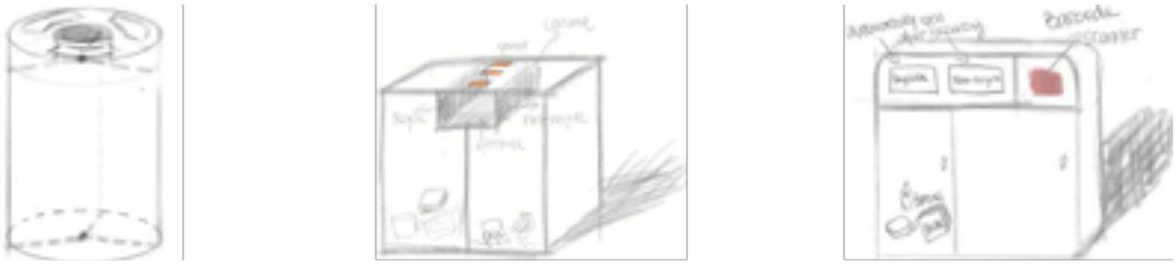

Figure 4: Initial concept sketches

Initial Design Concept

The initial identified design concept was created based on infrared technology, in order to achieve a cheaper product than current competitors on the market using AI technology. The sorting mechanism was created as a modular system with an integrated sliding mechanism, detachable to different bin sizes. (Figure 5)

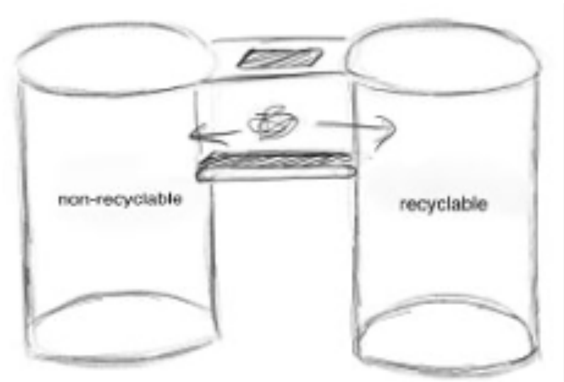

Figure 5: Initial design concept (NIR Technology)

After detailed analysis, it was clear that the planned infrared technology could result in many problems of detecting different waste items. In order to improve the classification of different waste items, several further detectors would have to be incorporated. Another factor was the volume consumption of the sorting mechanism, as it would take up to 20% of the bin compartments. A further issue is that there is only one compartment to put the waste in which would result in longer waiting times.

Evaluation of Technology

In order to create the optimal sorting system design, both, system technology and sorting mechanism options were decided to be compared in a weighted matrix design table (Table 4 and Table 5). The technology selection matrix in Table 4 is based on different criteria, such as feasibility, costs, accuracy and processing time. The evaluation of technologies is based on the research made in Section 2.5.

Table 4: Technology selection matrix

Selection Criteria	Criteria weighting	Smart Bin (with infrared technology)	weighting x rating	Smart Bin (with Cloud vision API)	weighting x rating	Barcode Scanner (internally built)	weighting x rating	Barcode Scanner (externally built)	weighting x rating
Feasibility	10	7	70	7	70	6	60	5	50
Accuracy	8	9	72	7	56	9	72	8	64
Market Potential	8	8	64	9	72	6	48	6	48
Costs	9	6	54	5	54	8	72	7	62
Competition	6	8	48	6	36	4	24	5	30
Life Cycle	7	6	42	7	49	7	49	6	42
Time for Completion	8	6	48	8	64	8	64	8	64
Volume Consumption	8	4	32	8	64	8	64	9	72
Aesthetics	5	6	30	8	40	5	25	8	40
Total		460		505		478		472	

The weighted rating of all potential technology systems resulted in the smart bin with image recognition using AI. This technology promises a quick and accurate process, with low volume consumption of the sorting compartment.

Evaluation of Mechanism

The mechanism selection for the moving compartments is based on different criteria, such as complexity, maintenance and volume consumption. (Table 5)

Table 5: Mechanism selection matrix

Selection Criteria	Criteria weighting	Rotating Mechanism	weighting x rating	Sliding Mechanism	weighting x rating
Complexity	8	10	80	7	56
Costs	9	8	72	6	54
Maintenance	7	7	49	8	56
Time for Completion	7	8	56	8	48
Volume					

Consumption	8	8	64	6	48
Aesthetics	5	6	30	8	40
Total		351		302	

The mechanism for the waste sorting was chosen to be a rotating compartment due to the simplicity of the movement, the time for completion and the low volume consumption.

Updated Design Concept

There were several issues linked to the initial concept design. The underlying issues were the infrared technology and the sliding mechanism as it created issues with volume, feasibility and price. By utilizing the above selected design options based on the selection criteria a new and improved design concept was established. A clear process of how the simple sorting bin works is shown in the flow chart (Figure 6).

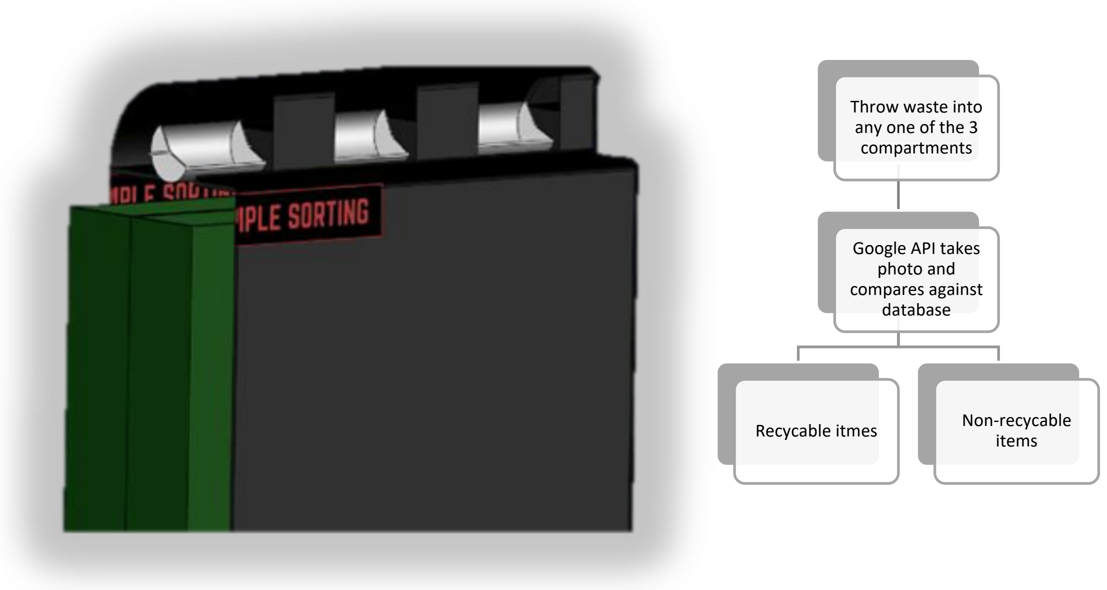

Figure 6: Final design concept

An AI powered camera (Google Cloud Vision API), will be placed above each of the compartment interiors to eliminate the issues created by the first design. This camera has dimensions of 25cm x 10cm x 10cm, hence the overall size of the bin was able to be reduced by 15% in overall volume – in comparison to the first design. Moreover, this new design simultaneously increased the number of compartments for consumers to use by 3x, therefore increasing feasibility and reducing the average time spent by the customer, from an average of 10 seconds to an average of 4 seconds. Additionally, infrared technology requires an entirely new database, whereas with the vision API there is a large Google database already in place that can be used to complement the device. This significantly streamlines the electrical design for the product, reduces the cost and therefore increases the overall feasibility.

3.2 Design in comparison to the market

A costumer competitive assessment (House of Quality) was made in order to understand what features of Simple Sorting would be more feasible compared to the existing products on the market described in Chapter 2.4. The graph in Figure 7 shows the customer requirements against costumer rating. The overall score of Simple Sorting came to 36/45 vs. the market average of 32/45. Based on this assessment and on research of the already existing products, Simple Sorting will be designed to be eco-friendlier and more affordable in order to meet customer requirements compared to the market competition.

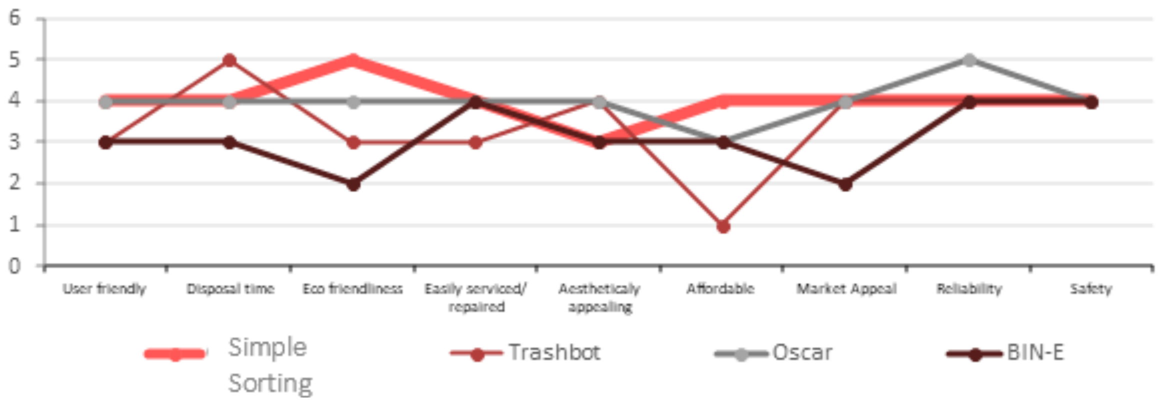

Figure 7 - Costumer Competitive Assessment

Table 6 compares the market assessment of existing products against Simple Sorting, based on the location, affordability, functionality, market appeal, and technology. This comparison indicates which features Simple Sorting will incorporate compared to the market competition in order to meet the market demand.

Table 6 - Competition vs Simple Sorting Market Analysis

Competition vs Simple sorting		
Aspect	Competition	Simple Sorting
Location	Mainly focuses on household and small facilities.	Designed to fit at Universities (canteens and cafes)
Affordable	High costs	Simple sorting will be made of components in a lower price, whilst satisfying the consumer demand
Functionality	The market competition shows that only one input compartment is incorporated into the designs.	Simple sorting will achieve a better processing speed by incorporating 3 compartments in the same bin.
Market appeal	Most products use bright tone colours, clean and	Simple sorting will be designed with dark colour, so that is appears professional and unique. The

	simple, with a cylindrical shape.	product will be shaped as a cube to occupy less space.
Technology	Best performance is achieved via image recognition	Simple sorting will use the same Technology mechanism to guarantee high quality performance.

3.3 Rotating Mechanism

The simplistic design in which this bin sorts out plastic incorporates one rotating mechanism that operates a movable compartment. The movable compartments rotate clockwise (90°) or anticlockwise (-90°) to drop waste into their target compartment, either recyclable or non-recyclable. Figure 8 depicts this mechanism.

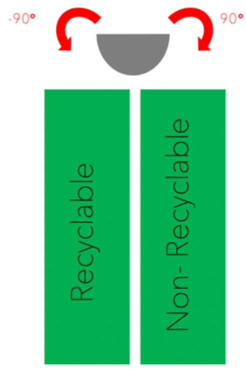

Figure 8 - Rotating Mechanism

The device chosen to operate the movable compartments is a servo motor. A servo motor precisely rotates a shaft to a pre-defined position. This position is defined in a control signal sent to the servo motor from the image recognition mechanism. A standard servo motor comprises a power, control, and ground wire. There are different types of servo motors such as; DC, AC, Brushless DC, Positional rotation, Continuous rotation and Linear. The chosen type to operate the bin is the positional rotation servo motor.

As mentioned above, a positional servo motor rotates a shaft in reference to a previously defined position. It is the most common type of servo motor and it rotates a shaft rotates in about 180°. Continuous rotation servo motors offer a 360° rotation unlike the typical 180°. This type of motor is essentially the same as a positional rotation servo motor, except this type offers open-loop speed control instead of closed-loop position control. Although this type of servo motor allows greater degrees of freedom, it is not essential for this particular project. As seen in Figure 8, the movable compartment only needs to rotate about a 180° axis, therefore the use of a continuous rotation servo motor is deduced to be unnecessary correspondingly due to its high cost. Figure 9 displays the positional servo motor installed onto movable compartment shaft. As seen in Figure 9, one servomotor will control one movable compartment. Circuit diagrams in the next section will display how these servo motors are integrated.

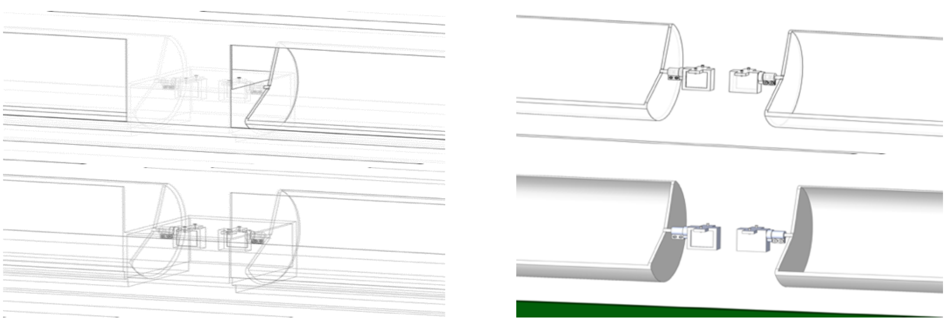

Figure 9 – Positional Servo Motor Installed onto Movable Compartment Shaft

3.4 Electronics Design

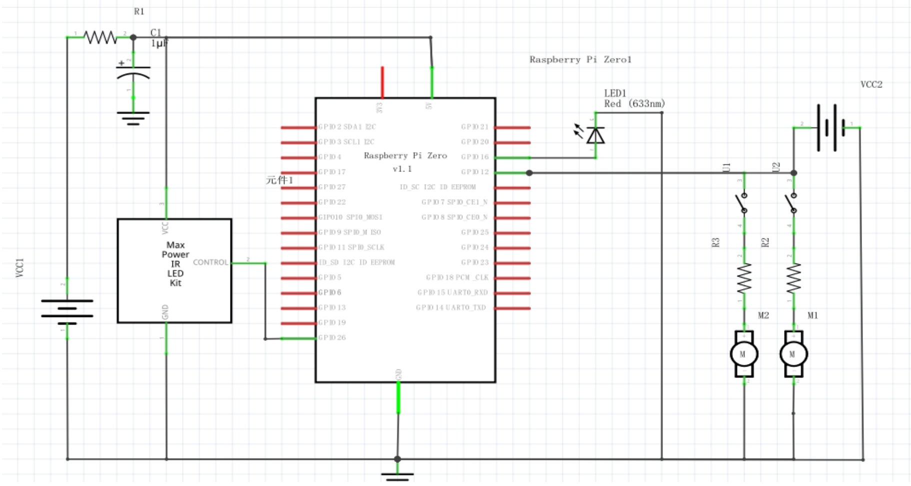

Figure 10: Circuit diagram

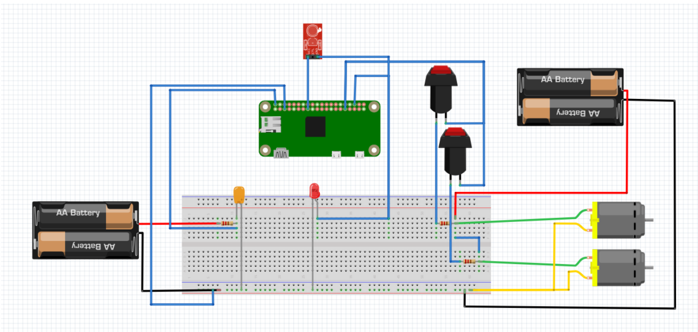

Figure 11: Circuit Diagram

Figure 10 and 11 represent the circuit diagram of the simple sorting bin. The camera acts as a sensor to take a picture of the target item. In order to transfer the image, the main processing part of the system - Raspberry Pi and Vision Bonnet - is connected with the camera. Raspberry Pi is responsible for receiving and sending images, and the Vision Bonnet deal with the image recognition process, by using the trained neural network. The neural network will be utilized for the purpose of distinguishing recycle and non-recycle waste. Then the result will be sent back to decide the desired direction of servo motors and placing the item into the correct bin. Resistance of R2 and R3 are used here to prevent motors from overheating.

The Printed Circuit Board (PCB) Design is presented in Figure 12. PCB is produced with reduced wiring and assembling errors. It saves equipment maintenance, debugging and inspection time. The usage of PCB largely increases labour productivity and reduced the cost of electronic equipment.

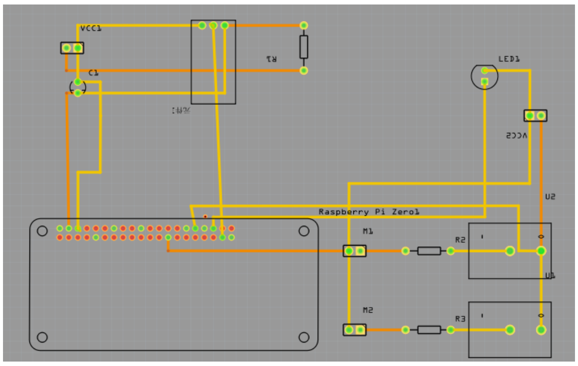

Figure 12: PCB Design

3.5 Mechanical Framework

Bin measurements

Measurement of the bin were chosen on the basis of general bin dimensions in the UK. The average bin capacity varies with the type of bin it is. Outdoor wheelie bins have an average capacity of 60-240 litres whereas indoor bins vary from 15-50+ litres. [23]

Computer Aided Design (CAD) Model

SOLIDWORKS® was used to model the bin. Table 7 displays bin compartments corresponding with its chosen measurements.

Table 7 - Component Dimensions

Part	*No. Parts*	*Height (h)*	*Length (l)*	*Depth (d)*
Exterior	1	114 cm	110 cm	40 cm
Interior Compartments	2	90 cm	108 cm	19 cm
Movable Compartments	3	12 cm	25 cm	12 cm

Figure 13- Exploded view of Recycling Bin

4. Modelling and Analysis

4.1 Material Selection

Appropriate materials for each component of the device must be chosen to ensure maximum function ability. The following sections outline a material selection technique comprising the investigation of material properties, advantages and disadvantages of common materials in addition to the use of Finite Element Analysis to determine appropriate component materials. Table 8 displays the advantages and disadvantages of common materials.

Table 8 - Advantages and Disadvantages of Common Materials

Material	Advantages	Disadvantages
Steel	– Strong and hard – can withstand high loads – Cheaper than Aluminium Alloy	– Very Heavy which is unnecessary for this application, especially for transportation purposes – Corrosive – unless stainless steel or painted with non-corrosive coating which is more expensive
Aluminium Alloy	– Malleable – can be shaped with ease into desired shapes – Lightweight – about 2.5 times less dense than steel – Noncorrosive – does not rust (although this bin is set to be placed indoors, items placed inside the bin can cause corrosion)	– Not as hard or strong as steel. However, has a good strength-weight ratio – More costly than steel but cheaper than stainless steel
High Density Polyethylene (HDPE)	– Hard and resistant to impact – Subjected to temp. of up to 120° C – Does not absorb liquid – Highly resistant to chemicals – Easiest Plastics to recycle – High strength, Durability – Resistant to mildew and corrosion – Light weight, High Quality	– Flammable – Sensitive to stress cracking – Difficult to bond – Poor weathering resistance
Polypropylene (PP)	– Affordable, Light – Chemical Resistance – Good Fatigue Resistance – Bad conductor of electricity and classified as an insulator	– High thermal expansion coefficient – Difficult to paint as it has poor bonding properties – Susceptible to oxidation – Difficult to recycle, only 1 % is recycled

4.2 Mechanical Modelling

Finite Element Analysis

Finite element analysis was used to determine a suitable material for the manufacturing of the bin. This process is further described throughout this section.

Mesh settings:

Table 9 shows the general mesh settings applied to the whole model. Whilst table 10 visualises the extra setting applied to the separate components.

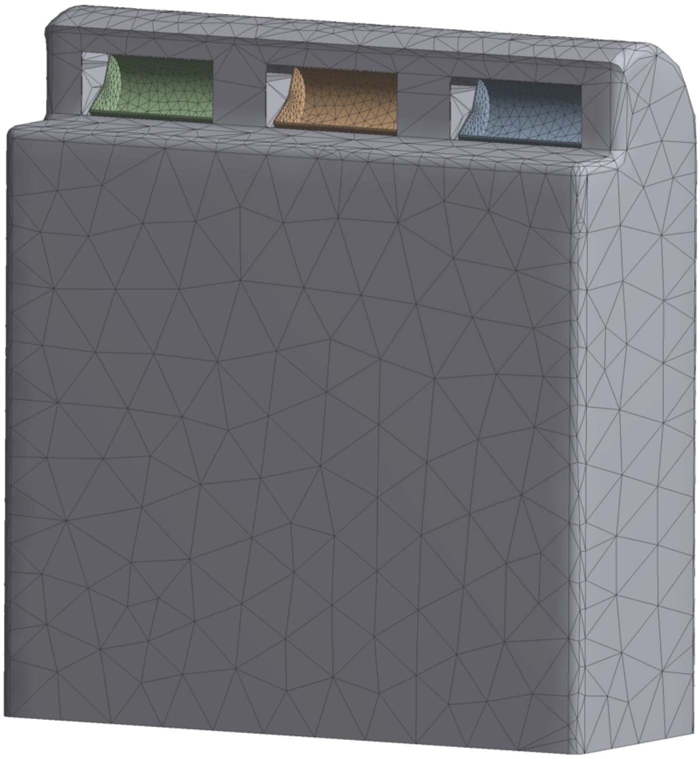

Figure 14 – Model mesh

Table 9 - General mesh settings

Mesh Setting	*Value*
Size Function	Curvature
Min Size	0.005mm
Max Tet size	0.1
Relevance Center	Course

Table 10 - Individual mesh settings

	Interior Compartments	*Movable Compartments*
Mesh Setting	Face Sizing	Face Sizing
Size Function	Uniform	Curvature
Size	0.08mm	0.0175mm

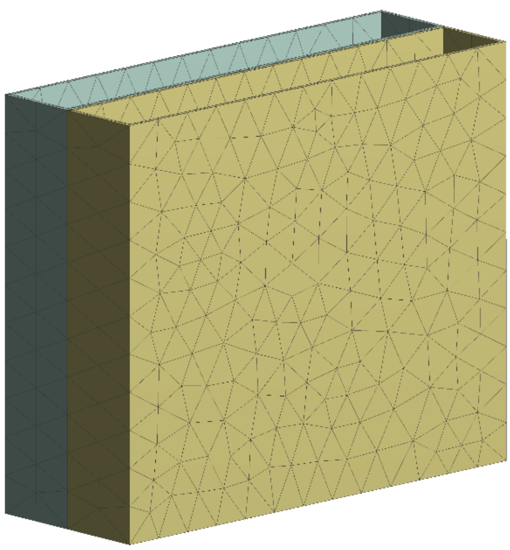

Figure 15 - Interior Compartments

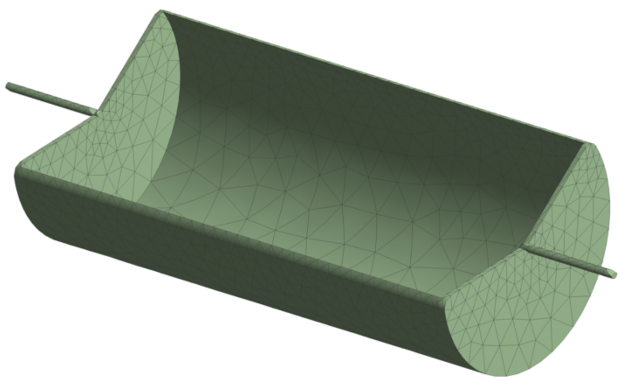

Figure 16 - Movable Compartment

Load settings:

To model the bin appropriate loads were applied to different components and analysed for each material. 750N and 10 N were applied to each interior compartment and the movable compartments respectively. Results of maximum deformation and equivalent von-mises stress are visualised in Table 11.

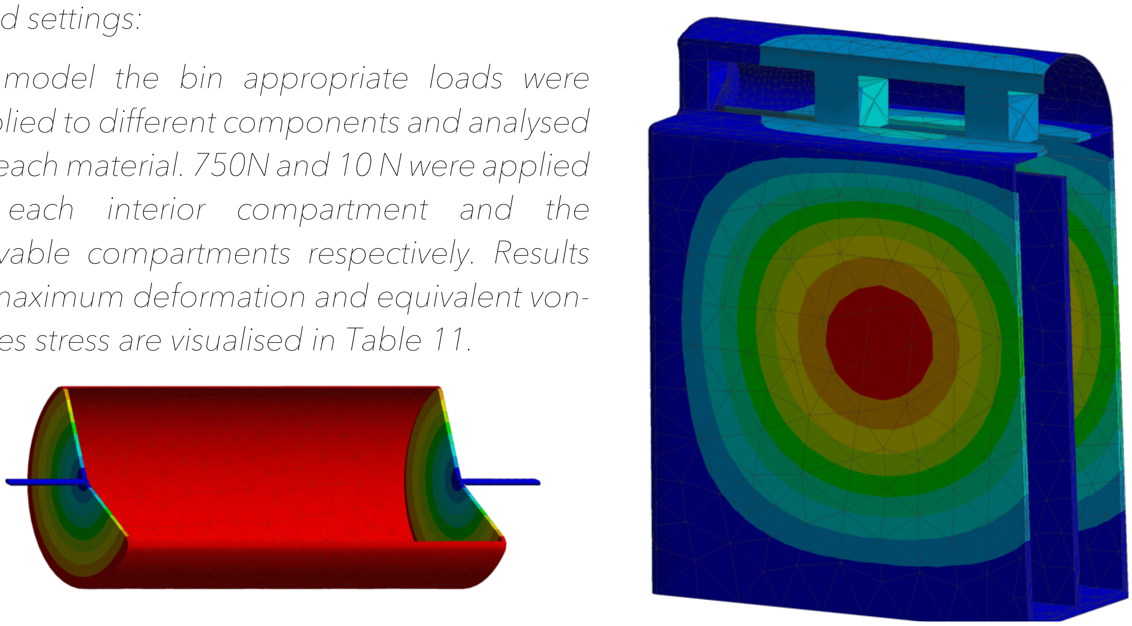

Figure 17 – Total Deformation

Material Selection:

Table 11 – Material selection process

		Interior Compartments		Movable Compartment	
Material	Total Mass (kg)	Maximum Stress	Maximum Deformation	Maximum Stress	Maximum Deformation
HDPE	60	6.8434e5	0.0013789	0.067109	0.067109
Aluminium	173	7.2833e5	0.000026169	1.2437e8	0.015619
Steel	491	7.392e5	0.000009638	1.2305e8	0.0057012

Maximum deformation and stress were found to be appropriate for all three material choices. However, due to the significant difference in weight in addition to the appropriate material properties mentioned in the previous section, Polyethylene and Aluminium were further pursued in this project. Each Interior compartment has a capacity of 34 Litres, resulting in a total bin capacity of 68 litres. In accordance with these results, it was concluded that the following components would be manufactured with the corresponding materials shown in Table 12.

Table 12 - Component Material

Component	*Material*	*Mass (kg)*
Exterior	HDPE	36.418
Interior Compartments	HDPE	23.257
Movable Compartments	Aluminium	0.443
	Total Weight	60.118

4.3 Fatigue/Design life Analysis

ANSYS was further used to determine the design life of the device. ANSYS does not provide the necessary material properties for this analysis therefore specific fatigue characteristics for each material were attained from further research. Fatigue parameters of metal components were determined using the Uniform materials Law [31] whilst fatigue parameters of polyethylene (HDPE) were found using a research paper cited in reference [32]. In addition to this, an alternating stress R-Ratio curve was required. This curve was provided by ANSYS for Aluminium alloy however additional data was acquired to compile an alternating stress curve for HDPE using reference [33]. The inputted parameters are summarised in Table 13.

Table 13 – Cyclic Fatigue Material Parameters

Cyclic Material Parameters	Aluminium Alloy	HDPE
Strength Coefficient (σ_f')	517.7 MPa	0.085 MPa
Strength Exponet (b)	-0.095	-0.043
Ductlilty Coefficient (ε_f')	0.35	0.23
Ductlity Exponet (c)	-0.69	-0.78
Cyclic Stress Coefficient(K')	499.1 MPa	55 MPa
Cyclic Stress Exponet (n')	0.11	0.055

Once the model was prepared, the design life could now be determined, using the same constraints and loads mentioned in the previous section in addition to the calculated Equivalent von Mises Stress. Figure 18 visualises the Fatigue life of the different components. It can be seen that the minimum fatigue life occurs on the HDPE interior compartments and exterior with a minimum amount of cycles of 629370. It was assumed that the bins would be loaded for approximately 7.5/hours a day. This therefore gave a minimum design life of 3747 days or *10.3 years*. In comparison to other Bin manufacturers, this design life is suitable as it exhibits comparable figures. The design life could be increased by the exchange of component materials however this would lead to the increase in overall device weight which is not desirable for this application.

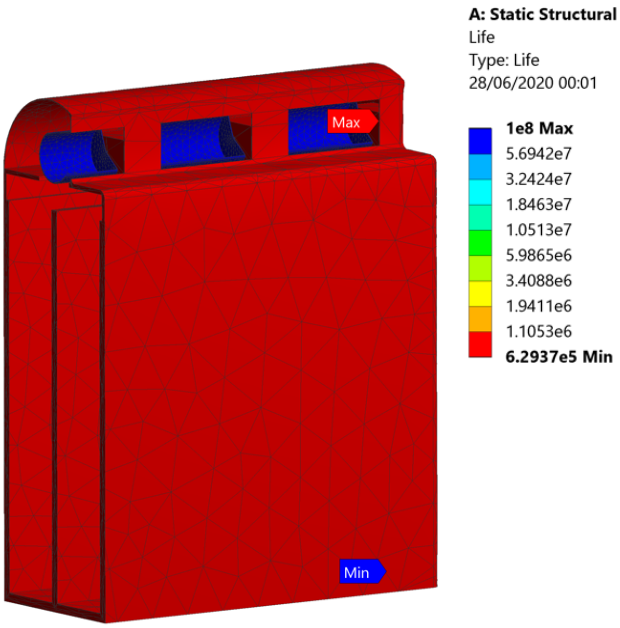

Figure 18 - Fatigue Life

5. Prototyping

5.1 Prototyping Plan

Theoretical Design

- Model Sketches
- Detailed Prototype Specification
- Material Selection for Prototype
- Design the electrical circuit

Prototype Construction

- Construct the physical structure of prototype
- Build and connect the electrical circuit of prototype
- Program the code for image identification and model execution

Prototype Tests

- Standard Mechanical and electrical testing
- Functionality test
- Improvement of the prototype

The theoretical design of the prototype is completed in the sections above. The prototype construction was planned to be carried out at MechSpace based on the components list in Table 14, with a total prototype cost of £363.80.

Table 14: Components list for prototype

Component	Qty	Price per unit	Total	Supplier
Raspberry Pi Microcontroller	1	£44.69	£44.69	CS Components UK
Raspberry Pi V2 Camera	3	£20.33	£60.99	CS Components UK
Capacitive Proximity Sensor	3	£45.00	£135.00	CS Components UK
Arduino T010051 Digital Continuous Servo Module	3	£12.03	£36.09	CS Components UK
Capacitor	6	£3.45	£20.70	CS Components UK
Resistor	6	£2.40	£14.40	CS Components UK
LED light	3	£2.00	£6.00	CS Components UK
Long Flex Cables	3	£1.20	£3.60	CS Components UK
Battery AA	1	£8.60	£8.60	CS Components UK
SD Card (4 GB)	1	£18.83	£18.83	CS Components UK
Aluminum Sheets 1mm	40X100cm	£7.60	£7.60	Aluminum Warehouse UK
Polyethylene Sheets 2mm	250X250cm	£1.23	£1.23	Direct Plastics UK
Polyethylene Sheets 2mm	250X250cm	£6.16	£6.16	Direct Plastics UK
Total price	£363.80			

5.2 Prototype made to date

The prototype made to (Table 15 and Figure 19) was created using a standard shoebox and fixtures. The AIY kit was installed at the top of the shoebox enabling to capture images of the desired object, and it is able to connect with power supply from top. Google Cloud Vision API was used alongside the specified code in Appendix 3 [24] to detect on different types of waste. These properties will aid in the judgement of recyclable vs non-recyclable waste.

Table 15: Prototype specification

Weight	800 g
Dimension	25cm x 10cm x 10cm
Operational time	5 seconds
Disposal size	N/A
Cost	Electrical Component: £ 85 Shoe Box and Fixtures: £5

Figure 19: Prototype

The AIY kit

The Google AIY Vision Kit is the core component in the product. It is used for the purpose of image recognition, it includes camera, led, buzzer, Raspberry Pi Zero WH, Vision Bonnet and other mechanical and electronic components. All these components are provided separately, shown as Figure 20.

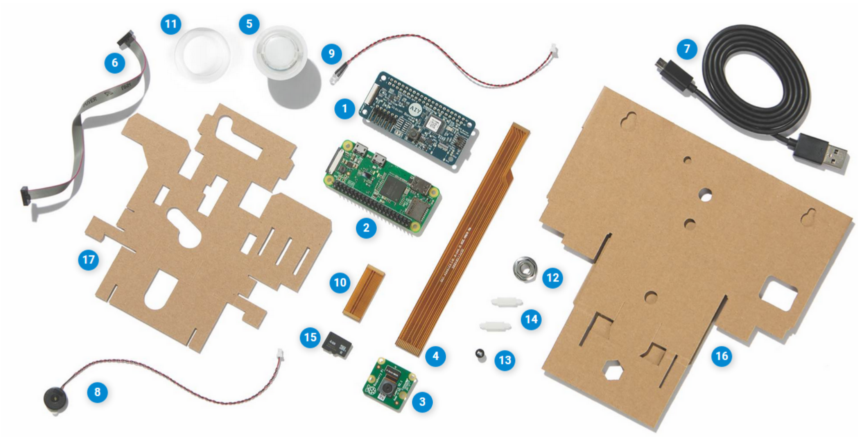

Figure 20: Google AIY Vision Kit

The main advantage of this kit is that it has already been implemented with neural network models for basic tasks such as object detection, joy detector and image classifier. Apart from that, the kit can also be customized to recognize more kinds of objects via training a new Tensor Flow model. Detail instructions about its constructing process and coding programs are all provided on its website. Python API library is also provided on their website to help with various features creation modes of Vision Kit.

AIY Kit Working Principle

The neural network in AIY Kit includes 3 types: MobileNet, MobileNetV1 + SSD, SqueezeNet. All of these neural networks are based on Convolutional Neural Networks (CNN). CNN has been one of the core algorithms in the field of computer vision for a long time, but it is mainly used to deal with complicated projects on computers. It has superior advantages for processing images as it uses one or more convolutional layers to extract important information from images. MobileNet produced by Google provides a compact and efficient CNN model which is more suitable for mobile or embedded devices. The most contributing point is that MobileNet adopts the depth wise separable convolution, while it takes only $\frac{1}{N}+\frac{1}{D_k^2}$ amount of calculation than the traditional convolution [25].

Raspberry Pi Zero WH

Raspberry Pi Zero WH, Figure 21, provides the basic structure for the image recognition function. The microprocessor on the chip is ARM BCM2835. The Raspberry Pi Zero WH has 2*20 pins for input and output usage. Each pin has its different function. The schematic in Figure 22 shows the pin used by Vision Bonnet and other components.

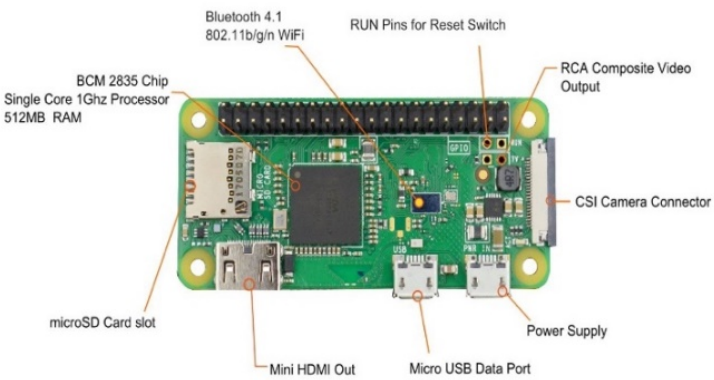

Figure 21 - Raspberry Pi Zero WH

PIN NAME	FUNCTION	Vision Bonnet		FUNCTION	PIN NAME
	3V3 power	1	2	5V power	
GPIO 02	I2C SDA	3	4	5V power	
GPIO 03	I2C SCL	5	6	Ground	
GPIO 04	GPIO	7	8	UART TXD	GPIO 14
	Ground	9	10	UART RXD	GPIO 15
GPIO 17	GPIO	11	12	I2S BCLCK	GPIO 18
GPIO 27	GPIO	13	14	Ground	
GPIO 22	GPIO (Piezo buzzer)	15	16	GPIO (LED button)	GPIO 23
	3V3 power	17	18	GPIO	GPIO 24
GPIO 10	SPI MOSI	19	20	Ground	
GPIO 09	SPI MISO	21	22	GPIO	GPIO 25
GPIO 11	SPI SCLK	23	24	SPI CE0 (Myriad)	GPIO 08
	Ground	25	26	SPI CE1	GPIO 07
GPIO 00	I2C (EEPROM)	27	28	I2C (EEPROM)	GPIO 01
GPIO 05	GPIO	29	30	Ground	
GPIO 06	IRQ (Pi to Myriad)	31	32	PWM0	GPIO 12
GPIO 13	IRQ (Myriad to Pi)	33	34	Ground	
GPIO 19	GPIO	35	36	GPIO	GPIO 16
GPIO 26	GPIO	37	38	GPIO	GPIO 20
	Ground	39	40	GPIO	GPIO 21

Figure 22 - Functions of Raspberry Pi Zero WH pins

The desired input power supply should provide 2.1A and 5V for Raspberry Pi. Lower or higher supply might cause the *corruption* of Sd card. The input supply voltage needs to be justified by resistance and rectified any possible AC value by capacitance. Two servo motors work at rated condition, powered by the voltage supply. They rotate in the opposite direction. Raspberry Pi chooses the rotation direction and which motor to motivate based on the result of image recognition.

Vision Bonnet

AIY Vision Bonnet is a low-power vision processing unit capable of running neural network models on-device, enabled with Intel Movidius MA2450 processor, Figure 23. It can enhance the visual processing ability of Raspberry Pi Zero WH. For future improvement, extra GPIO pins on the Vision Bonnet can provide control to LEDs. Apart from that, GPIO pins are suitable for servo controlling, as they are performing pulse-width modulation (PWM) more precisely than the Raspberry Pi by on-board MCU controlling.

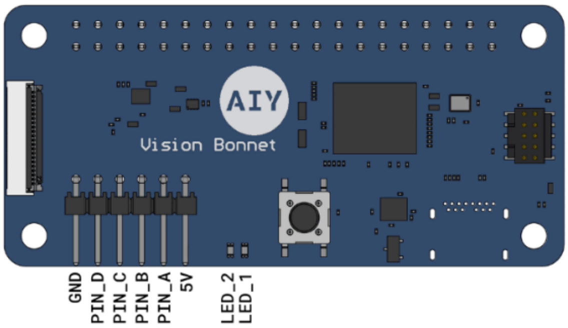

Figure 23 - Vision Bonnet GPIO pins

Physical Body Constructing Procedure

The procedure of the construction of the AIY kit is shown in figures 24-26. Figure 24 displays the camera and buzzer that are embedded in the internal frame cardboard. Figure 25 shows the inner box including camera, Raspberry Pi Zero WH and Vision Bonnet. The final product is shown in Figure 26.

Figure 24.

Figure 25

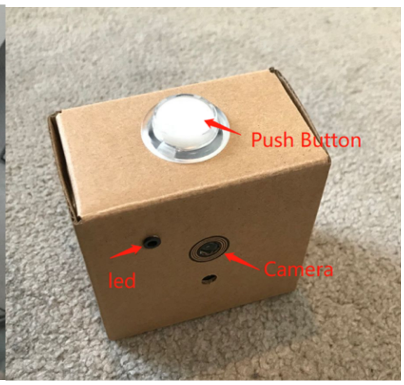

Figure 26

Classification Dataset:

The basic classification dataset is shown in Table 16, which lists the common items appearing in the UCL campus. This dataset is mainly focused for campus recyclable materials. Different datasets should be created for 'Simple Sorting' in different places. Based on this dataset, the prototype will sort it into appropriate parts.

Table 16 - Classification database

Common Labels	
Recyclable materials	Non-recyclable materials
Paper	Dish
Bottle	Snack

Cup	Flowers
Book	
Plastic	
Box	

5.3 Prototype Test

As shown in Figure 27, the result of testing for the image recognition is successful. The physical structure of prototype is reasonable for supporting the kit and connecting with power supply. The prototype shows a good performance in tests. The camera is facing downwards for capturing items in an appropriate distance and position. Different labels are presented when detecting different items. We planned to test the whole prototype connecting motors together for sorting the items. However, due to the COVID-19, this test did not carry out as we expected.

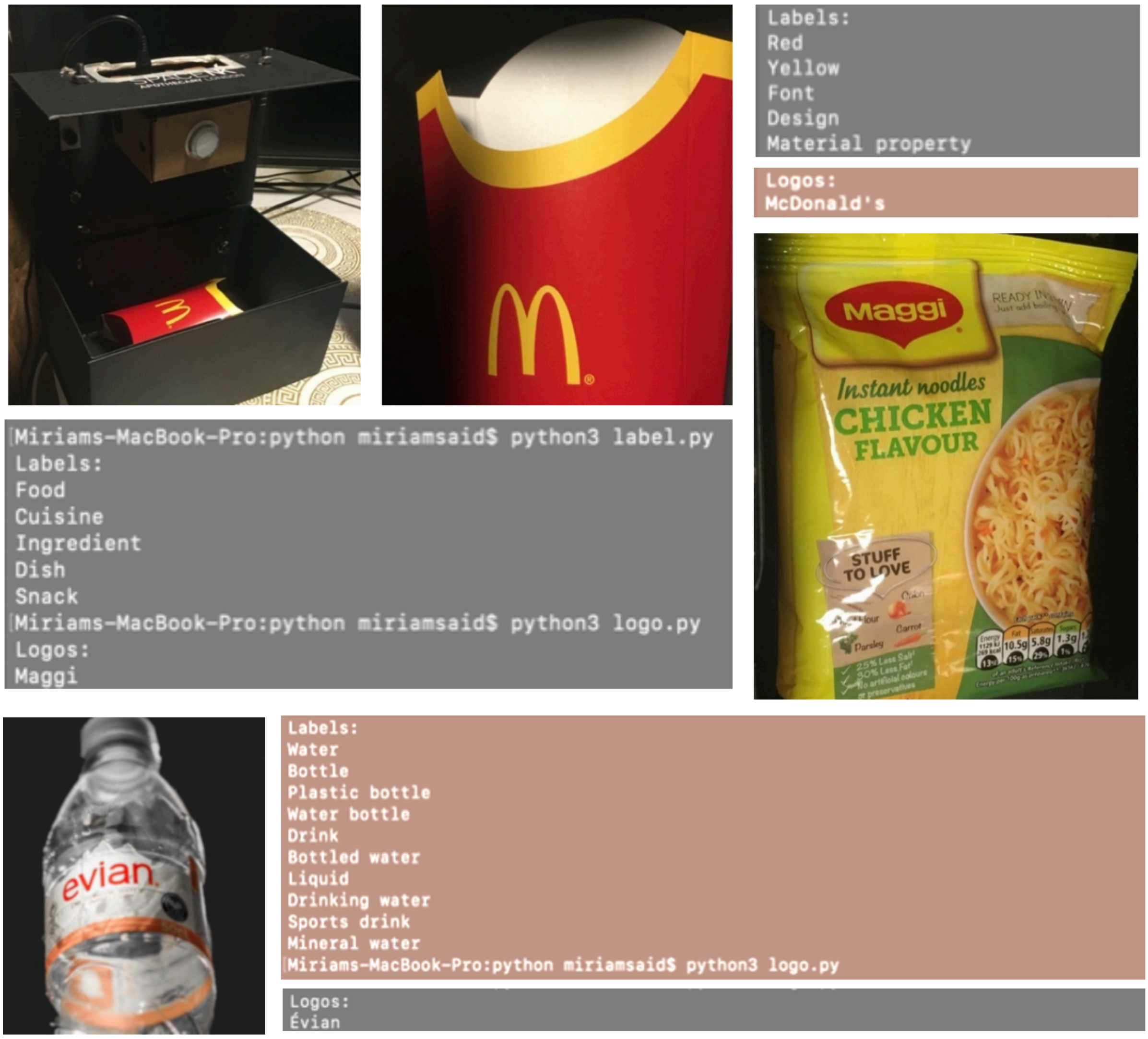

Figure 27: Label and Logo results for different types of waste

5.4 Evaluation of Prototype

5.4.1 Testing Plan

Table 16 - Testing plan Electrical and Mechanical components

	Part	Testing
Electrical Component	Camera (sensor)	– Check for dust
		– Check that the camera can detect different items
		– Set lens on manual focus
	Raspberry Pi (receives and sends images)	– Check that cables are properly connected
	Microprocessor chip	– Check that the chip has enough memory
	Vision Bonnet (image recognition process)	– Verify connection between Vision Bonnet and camera
		– If not working, reboot the Pi and run
Mechanical Component	Rotating Mechanism servo motor	– Check if motor receives signal
		– Check load, phase failure, air duct obstruction, power supply
		– Check if motor rotates accordingly (± 180 °)
	Shaft	– Check if shaft is properly connected to motor
	Bin compartments	– Check that bin compartments can slide and move freely when need to be emptied
	Fixtures	– Check that fixtures are all stable

5.4.2 Prototype Performance Evaluation Criteria

By referring to the initial evaluation criteria in the design chapter, the final prototype created was measured against this initial design criteria to determine if all the designed features of the machine were met. Table 18 shows all the features from the design evaluation criteria together with the costumer competitive assessment. Table 18 was made to understand if the features satisfy the final prototype.

Due to the product being a very basic prototype, the goal for the first part of the assessment was to make a prototype that would be able to detect any type of object. Consequently, the final goal would be to detect specific types of objects and create a product that would be able to sort them accordingly.

As can be seen in Table 18, the functional requirements of the final prototype meet the customer requirements of being *affordable* and *Eco-friendly*, which was an established in the design criteria. One of the customer requirements that may cause an issue it the *Easily Repaired* criteria. In order to satisfy this costumer criteria, maintenance service should be implemented once a year, with the price included in the subscription fee, which is mentioned in the business case.

Table 17 - Design Evaluation Criteria

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<tr><td></td><td></td><td></td><td></td><td>Column #</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
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<tr><td>2</td><td>||||||||| |||||</td><td>14.93%</td><td>10</td><td>Disposal Time</td><td></td><td>X</td><td></td><td>✓</td><td></td><td></td><td>✓</td><td></td><td>✓</td><td></td><td>X</td><td></td><td>✓</td><td></td><td>✓</td></tr>
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<tr><td>4</td><td>||||||||| ||</td><td>11.94%</td><td>8</td><td>Easily serviced / repaired</td><td>✓</td><td>✓</td><td>X</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td></td><td>X</td><td>X</td><td>X</td><td>✓</td><td>X</td><td>✓</td><td></td></tr>
<tr><td>5</td><td>|||||||</td><td>7.46 %</td><td>5</td><td>Aesthetically appealing</td><td>✓</td><td>✓</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>✓</td><td></td><td></td><td></td><td>✓</td><td></td></tr>
<tr><td>6</td><td>||||||||| ||</td><td>11.94%</td><td>8</td><td>Affordable</td><td>✓</td><td></td><td>✓</td><td>✓</td><td></td><td></td><td></td><td></td><td>X</td><td>✓</td><td>✓</td><td>✓</td><td></td><td>X</td><td>X</td></tr>
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<tr><td>9</td><td>||</td><td>2.99 %</td><td>2</td><td>Safety</td><td>✓</td><td>✓</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td>Weight Chart</td><td>|||||| |||</td><td>|||||</td><td>|||| |||</td><td>||| ||</td><td>||| ||</td><td>|||</td><td>|||||| |</td><td>||| ||</td><td>|||||| |||</td><td>|||||| |||</td><td>|||||||||</td><td>|||</td><td>|||||||</td><td>|||||</td><td>||| ||| |</td></tr>
</table>

6. Manufacturing Plan

6.1 Materials List

The sizes and materials for each component are taken from Table 7, in section 3.5 and table 12 in section 4.2 to calculate the required sheet sizes.

Table 18 - Plates size for each Compartment

Component	Material	Quantity	Size	Total	
Exterior	Polyethylene 2mm	2	110X114 cm		200X230
		2	40X114 cm	114X80	
		2	110X40	110X80	
Interior Compartment	Polyethylene 1mm	4	108X90 cm		200X300
		4	19X90 cm	80X90	
		2	19X108 cm	40X108	
Movable Compartment	Aluminium 1mm	3	25X38 cm	75X38	40X100
		6	12X12 cm	24X36	

6.2 Product Parts List

For the manufacturing of the Simple Sorting bin a complete parts list was created in Table 20. Further to the initial prototype the parts list in Table 14, section 5.1, it includes all components for the mechanical and electrical framework of the final product, as shown in Figure 28.

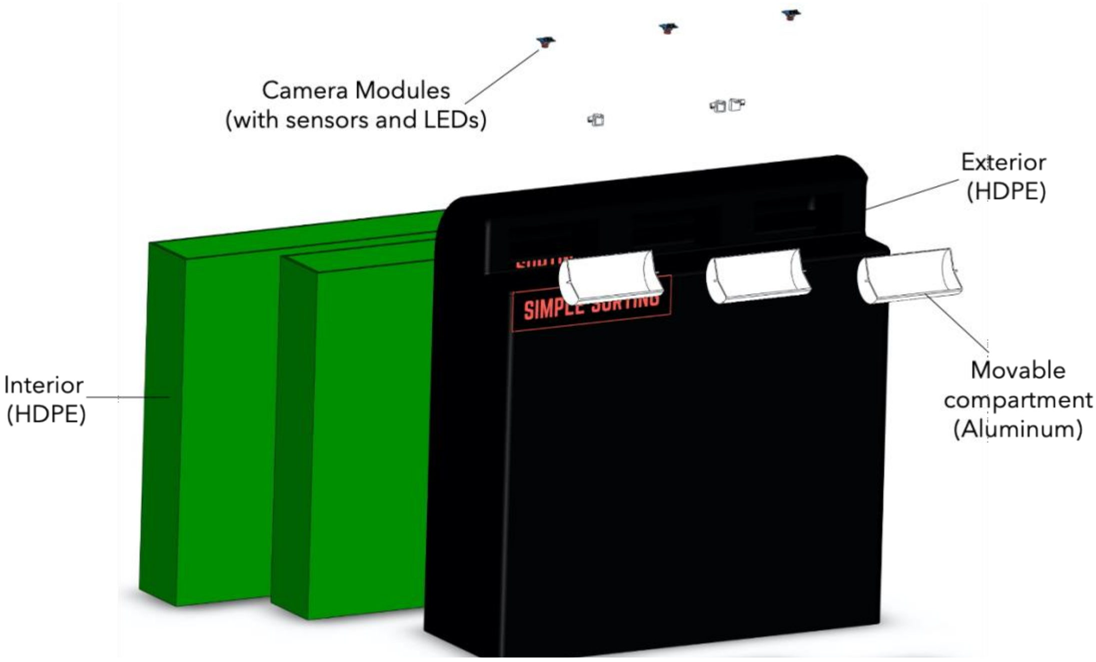

Figure 27: Exploded view of the bin

Table 20 – Parts list

Component	Qty	Price	Total	Supplier
Miniature 240V SPDT Vertical PCB Slid	3	£8.00	£24.00	Dongguan Heart Electronic Technology Co., Ltd.
MX298 sensor HD 16mp Camera module	3	£10.50	£31.50	Guangzhou Sincere Information Technology Ltd.
LED light module	3	£0.10	£0.30	Shenzhen Yuanzheng Energy Technology Co. Ltd
Capacitive Proximity Sensor	3	£3.50	£10.50	Shenzen Samcen Automatic Equipment Ltd.
Positional Servo Motor	3	£4.00	£12.00	Dongguan De Sheng Intelligent Technology Ltd.
Wires and Cables	1	£2.40	£2.40	Henan Jinshui Wire and Cable Co Ltd.
Aluminum Sheets 2mm	1	£3.20	£3.20	Shanghai Hanwei Aluminium Industry Co., Ltd.
HDPE Sheets 2mm	1	£4.50	£4.50	Dezhou Plastics Co., Ltd.
HDPE Sheets 10mm	4	£13.50	£54.00	Dezhou Plastics Co., Ltd.
Price per Bin	£ 142.40			

The complete manufacturing cost per bin was calculated to be £ 142.40.

6.3 Manufacturing Location

For the choice of the manufacturing location, there are different factors and requirements that need to be considered. These requirements were split up into manufacturing, infrastructure and further requirements. For the manufacturing location, the UK was not included due to very high manufacturing costs. The chosen locations were China and India, due to their expertise in IT manufacturing (Table 21):

Table 21 – Manufacturing location

	China	India
MANUFACTURING REQUIREMENTS		
Labor Costs	*($27.50/day)*	*($4.86 /day)*
Further Costs	Lower overheads, higher logistic costs	Lower overhead, higher logistical costs

Production Capability & Efficiency	Established manufacturing facilities: high volume and high efficiency (114 M employed)	Manufacturing industry focuses electronics (strong in R&D) (73 M employed)
INFRASTRUCTURE REQUIREMENTS		
Nearness to the Market	Located far from the market	Located far from the market
Nearness to source of material	China is the monopole of IT manufacturing, high number suppliers available in China	India has very raw metal production for manufacturing such as steel and HDPE
Infrastructure facilities available	yes	yes
FURTHER REQUIREMENTS		
Safety requirements and legal regulations	Safe production law since 2015	Factories Act 1948

In direct comparison, the ideal manufacturing location was chosen to be China, hence the high quality and efficiency of production and the cost-effective labor. At the same time China has established a qualitative manufacturing industry with focus on innovation, including similar technologies, such as AI, VR and image recognition.

6.4 Supply Chain

The market is geographically located in the UK. Initially UK universities will be targeted as Simple Sorting customers. Therefore, a Warehouse is needed in a UK location for distribution to further customers.

The supply chain can be presented as shown in Figure 29. Initially, the supply of raw materials (aluminium and polyethylene) and electronics will be done in China. The distribution company (e.g. DFS Worldwide) will carry out the logistical transport to UK. The initial distribution of the product is planned via University Institutions as wholesale distribution. The distribution can be adapted retail distribution in a later stage of the product.

Figure 29: Supply Chain

Further detail on production, processing and assembly can be found in figure 30. The headquarters in London will be in charge of sales and production planning which includes order management and production schedules. The manufacturing workshop and procurement will be located in China, whilst procurement through Chinese suppliers will be managed in London headquarters.

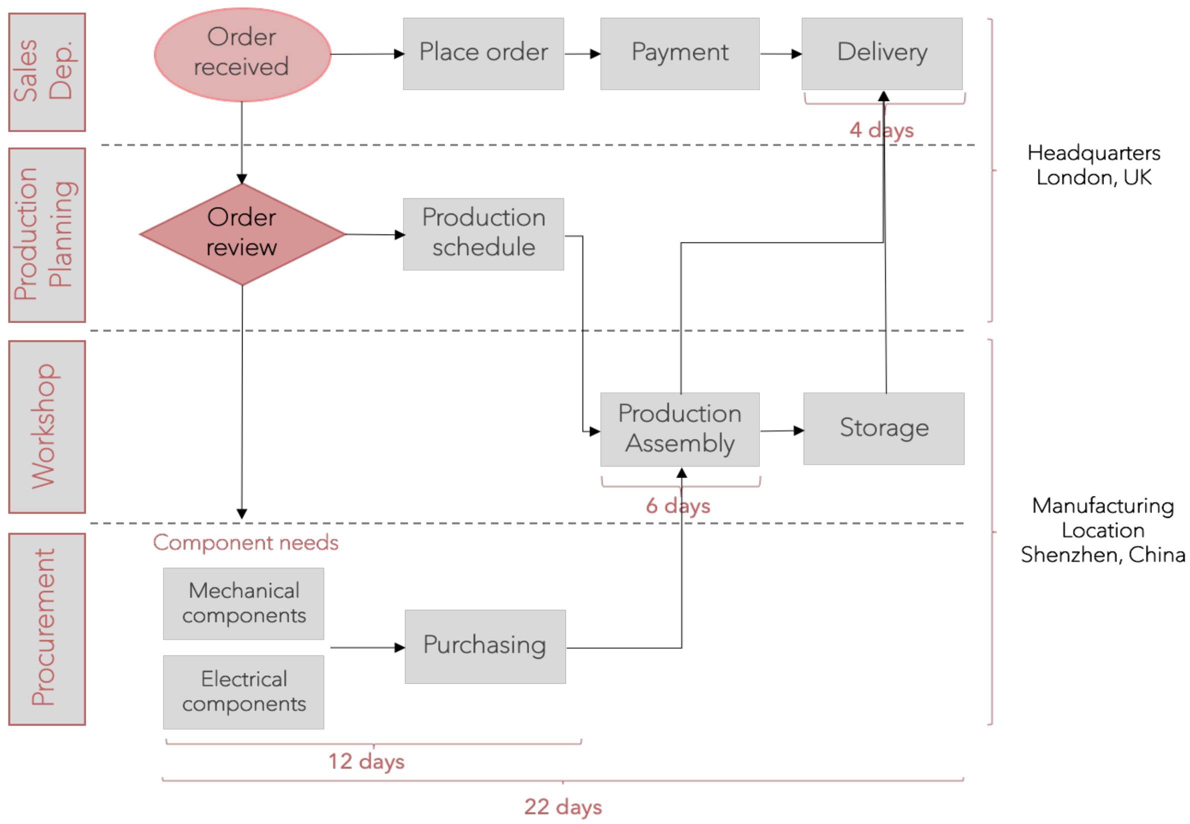

Figure 30: Production and Assembly Plan

7. Business Plan

7.1 Product

The Simple Sorting Bin is an automated smart waste sorting system that will be located in communal places, such as University Campuses and Office buildings, to sort waste by differing between recyclables and non-recyclables with the use of image recognition technology. The product is designed to adapt to the same size and capacity requirements as for current bins.

7.2 Market and industry

The PESTLE-analysis (Figure 31) displays the high opportunities for the simple sorting bin. As the industry of waste management and recycling is severely growing. This is a result of political and legal factors that are demanding an improvement in recycling technologies and providing state funds. At the same time a major social movement towards ecologically friendly behavior is seen.

POLITICAL

- United Nations Sustainability goal 8: sustainable consumption and production patterns (resource efficiency, waste management)
- EU Target for recycling 75% of packaging waste by 2030 [1]
- Importance of waste management sector in the UK is rising

ECONOMICAL

- €2.61 Billion Recycling bin market size in Europe
- Universities spend an average of £250,000 per year on waste management
- £4.7 million government fund launched to drive up the recycling [29]

SOCIAL

- Increasing level of awareness regarding plastic waste issue (environmental consciousness)
- 86% of public favours eco-friendly products [30]
- UK recycling rate from households was 45.7% in 2017 [28]

TECHNOLOGICAL

- Increasing development of AI technology (image recognition, machine learning) can pave the way for this product
- Competitors such as Bin-e, TrasBot and Oscar are too expensive for the public

LEGAL

- UK Environmental Protection Act 1990
- From January 1st, 2015, new UK waste regulations will require businesses to separate recyclable material (paper, plastic & glass) from other waste

ENVIRONMENTAL

- Environmental awareness (Pollution)
- Animal and Wildlife severely affected by the outcomes
- Laws regulating environmental pollution, Recycling (Environmental Protection Act)
- Attitudes towards green/ecological products grow (88%)

Figure 31: PESTLE-analysis of Simple Sorting

7.3 Market size

Placement of bins in on-campus cafes and libraries. We assumed that around 30% of the universities will be potential customers of the "simple sorting" bin. Potential next market Europe (2,725 Universities). A market size of £1.08 million in the UK is calculated with a potential of £19.6 billion on the European market. (see Table 22)

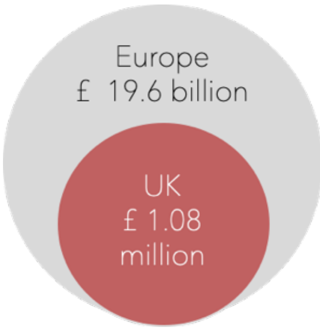

Table 22: Market Size Estimation

Average number of cafes on campus	10
Average numbers of bins in cafes	2
Average number of libraries on campus	20
Average number of bins in libraries	5

Number of UK universities	150
Potential placements for "simple sorting" (UK)	5.400 (30%)
Market size (with a turnover of £200 per bin)	£ 1.08 M

7.4 Financing Plan

The business will be initially financed by funding and/or bank loans. The planned pricing model, projected sales and revenues are presented in this section.

Funding

The simple sorting bin is an innovative and sustainable approach to recycling and is therefore subject to various funding opportunities. The EU Horizon 2020 provides funding of €5.5 billion for improved waste management which include waste prevention, reuse and recycling [26]. Various Venture Capitals, such as EMV Capital could be a potential lead investor in the first round, with previous lead investments in innovative recycling technologies [27].

Table 23: Projected Funding Amount

Round of funding	Amount raised in the round
Pre-seed	£ 300-500K
Seed	£ 1.2-1.5M
	TOTAL: £1.5-2M

A funding of £1.5-2M (Table 23) is expected based in two funding rounds from angel investors and venture capitals. Further funding rounds can be attempted after product growth on the market.

Marketing

To efficiently reach the target market of this product, the marketing is planned to focus on university fairs, brochures and newsletters, as well as online adds and search engine marketing. The network of potential customers is planned to be expanded by networking through angel investors. The focus is set on angel investors that have personal interest in recycling and waste management technologies.

Pricing Model

The pricing model was chosen to be a combination of a consistent product price and a monthly fee. The costs include the manufacturing costs in China which are variable to the number of products and are defined as *per bin*. These consist of material costs, calculated in the manufacturing plan in section 6.2, labor costs, specific to the chosen location and shipping costs. In addition, import taxes and delivery was included. Whilst the selling price remains the same over the years, a decrease is seen in costs, due to higher production numbers resulting in lower bulk prices from suppliers.

The product price is currently planned at £380 per bin with a subscription fee of £15 per month, as shown in Table 23. The selling price can be reduced in upcoming years due to lower manufacturing costs and higher sales volumes.

Table 23: Pricing Model

		2020		2021		2022
Selling Price (incl VAT)	£	456.00	£	456.00	£	456.00
VAT (20%)	£	76.00	£	76.00	£	76.00
Selling Price (excl VAT)	£	380.00	£	380.00	£	380.00
Subscription Fee	£	15.00	£	15.00	£	15.00
Total Fee	£	180.00	£	180.00	£	180.00
Total Price	£	560.00	£	560.00	£	560.00
Manufacturing Costs (CHINA)						
Material Costs (per bin)	£	142.20	£	115.00	£	100.00
Labour Costs (per bin)	£	30.00	£	28.00	£	27.00
Shipping Costs (per bin)	£	15.00	£	14.00	£	12.00
Import Tax (20%)	£	28.44	£	23.00	£	20.00
Delivery	£	20.00	£	20.00	£	18.00
Total Costs	£	235.64	£	200.00	£	177.00
Gross Profit	£	324.36	£	360.00	£	383.00
Gross Margin %		58%		64%		68%

It is assumed that Simple Sorting will sell 520 bins in the first year. An increase of manufacturing of 10% each year is required according to the sales forecast. The sales forecast for the Simple Sorting Bin assumes a 2% increase in sales each month, making a roughly increase of 27% over a year. One month prior to the start of the academic year a rise of 15% in sales is predicted. (Figure 32)

Figure 32: Sales Forecast

Profit and Loss

The financial modeling is based on a bank loan of £250k in the first year of operation. Possible funding and grant opportunities are not included in this model. The profit and loss forecast includes all main overheads, such as total salaries, warehouse and office rents, marketing, software and further costs. In combination with the sales forecast the overall profit over the three years is calculated. (Table 24)

Table 24: Profit and Loss

	2020	2021	2022
Sales (excl VAT)	£529,204	£768,810	£1,099,306
Cost of Sales	(£222,681)	(£274,575)	(£347,459)
Gross Profit	£306,522	£494,235	£751,847
Overheads			
Total Salaries in Store (Incl NI)	(£175,000)	(£305,550)	(£413,438)
Warehouse and Office Rents	(£114,171)	(£116,052)	(£118,141)
Marketing	(£8,400)	(£18,480)	(£30,492)
Software	(£219)	(£269)	(£579)
Utilities	(£4,906)	(£9,812)	(£14,718)
Other Costs	(£2,167)	(£4,000)	(£8,000)
Total Overhads	(£304,863)	(£454,163)	(£585,367)
EBITDA	£1,660	£40,072	£166,479
Depreciation	(£11,360)	(£23,760)	(£37,040)
Operating Profit (EBIT)	(£9,700)	£16,312	£129,439
Loan Interest	(£10,317)	(£8,221)	(£6,030)
Profit Before Tax	(£20,017)	£8,090	£123,410
Corporation Tax	£0	£0	£0
Profit after Tax	(£20,017)	£8,090	£123,410

According to the financial modelling the business will start making profit after the first year of operation. The monthly sales are compared to the monthly profit before tax over the three years (Figure 33). In relation to the sales the profits are increasing at a lower rate. Whilst the monthly total sales are more than tripled in month 36, from about £500K to £1M sales per year. The profit before tax has risen from negative numbers in the first months to £123K in month 36.

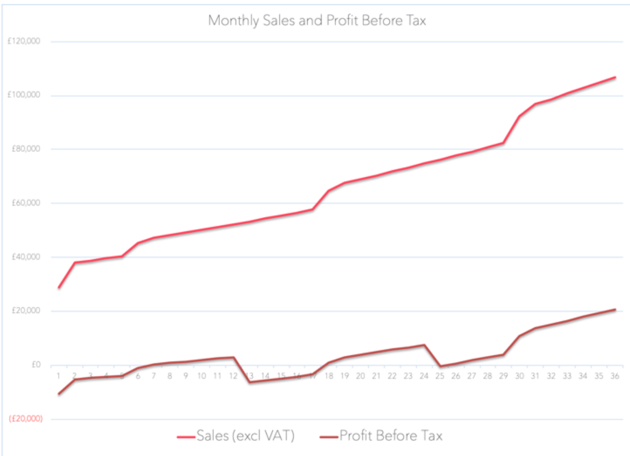

Figure 33: Sales and Profit

7.5 Risk Analysis

A risk analysis was carried out for both, product and business. The risk analysis is focused on different areas of the business, such as product market fit, product quality and budget, and evaluates the current situation (Table 25).

Table 25: Risk Analysis on Business

Area	Risk Level	Evaluation of current business	Recommendation
Product and Market Fit	2	– The acceptance rate of universities to employ this product is projected by 30%. – According to previous research, the targeted customer segment at universities (students, staff and professors) are acceptable of new sustainability measurements.	– Interaction with universities / possible markets
Product Quality	3	– Our initial prototype is working, as the items can be classified into recyclables and non-recyclables – There is currently no final prototype to test the moving compartments of the bin and evaluate performance – Occurrence of errors and quality concerns for final product is high	– Product testing of finalized bin
Team	2	– Our team covers builds a stable foundation by covering various areas such as mechanical, industrial and electrical engineering – Less experience in sales and marketing	– Expansion of team into other expertise
Funding and Budget	4	– The business is currently financially dependent on investors and bank loans – some Venture Capitals are specifically targeted at start-ups in the recycling industry, but continuous funding can be evaluated as critical	– establish strong relationship with potential lead investors
Short-Term Competition	3	– Currently low competition on the market due to an innovative product – But current competition more experienced since already on the market	– establish competitive advantage incorporation of further technologies (app)
Long-Term Competition	4	– Our product is not the first mover and cannot display clear competitive advantage to other competitors to ensure long-term stability	

The Business risk evaluation shows that the general product market fit has a low risk of failing due to high demand for waste management solutions but needs to establish competitive advantage to its competitors to grow on the market. Further risks are product is still investment dependent and the product quality can be affected by missing evaluation and testing and "proof-of-concept" of the final product.

8. Discussion

Technical Feasibility

The overall technical feasibly of this product in regards to technical resources and capabilities of our group is high but can be limited by several factors. The simple sorting bin uses machine learning to apply image recognition for waste items. According to our experiment, the classification works properly, and the error rate is low. Failure can be caused by the angle between camera and item, missing labels or disformed items, such as scrunched plastic bottles. Another technical issue can arise when updating the dataset, as waste types will differentiate for further locations. Whilst a bin on campus mainly needs to recycle bottles and food packaging, a bin in a theatre mainly deals with food waste and cups. A regular update can also be important to maintain or improve accuracy and efficiency. Another factor is that our current bin has two compartments for a simple and effective process which clearly limits the classification of items at the same time.

Economic Feasibility

Based on the Loss and Profit analysis of this product, it can be defined as financially feasible. This economic feasibility is mainly limited by the dependence on investment. The financial model is assumed on the basis of a £250k and a sales forecast with a steady but adequate increase to achieve profit after the first year of business operation. Due to the manufacturing location in China and therefore low variable costs, a high gross margin is assumed, and the product price is comparable to current competitors on the market. As this model assumes no funding or grant, additional investments would increase the economic feasibility and support R&D to improve the products quality.

Conclusion

The idea for this product was to construct an automated recycling bin that can be placed a public place due to better financing options, higher sales quantities and a wider target market. The product offers a solution for lowering the problem of recycling from the source of waste management.

The simple sorting bin proves technical and economic feasibility to be delivered onto the market, ensured by design modelling and analysis and financial modelling in this report. Improvement of accuracy, speed and dataset can further improve the product quality. The product has potential to rise on the market with adequate funding and investment opportunities. Financial predictions show that the UK target market can achieve a profit of £123k after the second year of operation, which indicates the significant opportunity that an expansion into the European market with an estimated market size of £20 billion holds.

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Appendices

Appendix 1 – Meeting Minutes

Department of Mechanical Engineering
MSc GROUP DESIGN

Group PANGEA - Meeting Minutes

Date: 22/10/19 + 23/10/19
Time: 13:00-14:30 + 12:00-13:00
Location: UCL
Duration: 1:30 h + 1h
Note Taker: Nilay
Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

Actions from last meeting

1. Aldo: current waste sorting (domestic)
2. Miriam: new sorting technologies (detecting plastic)
3. Molly: ocean/beach waste
4. Nilay: current global new technologies (comparison)
5. Sophie: current waste sorting (macro/bigger scale)

Discussion Topics

1. ocean waste = difficult scale for our group project
2. current international solutions act on bigger scale, such as recycle plants

→ Group mission = all plastic waste in UCL, considering the prototype, the domain in which this system will be enacted is in UCL which can portray success on a macro-scale. ("Plastic Only" – recycle bins)

→ similar to the concept of "Pfandautomaten" (recycle automats for plastic bottles using barcodes) in Germany, but considering all plastic products

→ AI system that gets info about the material (e.g. plastic) through scannable barcode/ QR-code / image identification

→ Research the possibility of sorting materials in other ways (density, color etc.)

3. Criteria for concepts: technical viability, desirability, usefulness

New Actions (with names of who will deliver)

1. Questionnaire (5 Questions from each member until this Friday → finish Questionnaire until monday)
2. Primary Research on concept (technical):
    a. Aldo/Miriam: scanning codes (how other companies scan different items e.g. fitness apps identifying calories etc.)
    b. Molly: ways of sorting waste by image identification
    c. Nilay/ Sophie: ways of sorting waste by material properties

Group PANGEA - Meeting Minutes

Date: 29/10/2019 + 31/10/2019
Time: 16:00-18:30 + 13:00-14:00
Location: UCL
Duration: 3:30 (total)
Note Taker: Nilay

Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

Actions from last meeting

3. Questionnaire (5 Questions from each member until this Friday)
4. Primary Research on concept (technical):
    a. Aldo/Miriam: scanning codes (how other companies scan different items e.g. fitness apps identifying calories etc.)
    b. Molly: ways of sorting waste by image identification
    c. Nilay/ Sophie: ways of sorting waste by material properties

Discussion Topics

First meeting
1. Sorting waste by material properties is mostly done through infrared or chemical processes
2. Technical viable concept for the group project: Identifying the polymers by codes (stamp on containers and packaging)

→ focus different types of plastic that are commonly used at UCL (water bottles, chips bags, food packaging etc.): PETE, PV, LDPE + non-recyclable Plastic?

→ Problem 1: at recycling plants (10-13 % of the plastic that is delivered, including plastic bags, is not recyclable)

→ Problem 2: how to sort food contaminated plastic?

Second meeting:

1. 5-3-5 Brain writing sheet (5 people, 3 ideas each in 5 min)
   → we came up with 60 different ideas – everyone had to favor two ideas from their sheet:

Miriam	Scan barcode of recyclable product – bin allocates product to compartment	Bin that can burn plastic – the emissions are captured by a machine to make clean air (e.g. Singapore)
Aldo	Barcode responsive – doors open up	Domestic bin that sorts waste using infrared
Molly	Use barcode to classify plastics	Circular bin that sorts out waste automatically (using barcode)
Sophie	Tube outside the apartment that directly sends plastic to recycling shop in the community	Infrared machine which detects different types of plastics
Nilay	Machine that can compress plastic to minimize waste size	Invent bacteria that eats plastic (chemical process)

New actions:

1. Finish up the Questionnaire:
   → Analyze and evaluate the results in the next meeting
2. Gather criteria to evaluate different concepts and weigh them (technical viability, usefulness, market value etc.)
   → Rate different concepts by using the chosen criteria

Group PANGEA - Meeting Minutes

Date: 7/11/2019 + 13/11/2019

Time: 12:00-14:00 +14:00-16:30

Location: UCL

Duration: 4:30 (total)

Note Taker: Nilay

Attendance: Aldo, Miriam, Molly, Sophie, Nilay

Late (by more than 10 minutes):

Absent: -

Actions from last meeting

3. Technical viable concept for the group project: possibility of Identifying the polymers by codes (stamp on containers and packaging)
   → focus different types of plastic that are commonly used at UCL (water bottles, chips bags, food packaging etc.): PETE, PV, LDPE + non-recyclable Plastic?
   → at recycling plants (10-13 % of the plastic that is delivered, including plastic bags, is not recyclable)

2.60 different ideas – everyone had to favor one from their sheet: 5 concepts were chosen

Discussion Topics

1. Evaluated different concepts:

Weighting Rating Matrix - PANGEA

		Rating		Rating		Rating		Rating		Rating	
Selection Criteria	**Criteria weighting**	**Bin sorting materials by scanning barcode**	**weighting x rating**	**Bin sorting materials by image scanning (AI)**	**weighting x rating**	**Bin sorting materials by infrared**	**weighting x rating**	**Bin burning plastics**	**weighting x rating**	**Bin sorting by chemical processes**	**weighting x rating**
Technical Viability	10	9	90	1	10	6	60	1	10	5	50
Usefullness	10	10	100	10	100	10	100	8	80	3	30
Restriction of products (-)	10	1	10	10	100	10	100	9	90	7	70
Processing time (e.g. sorting)	8	9	72	9	72	5	40	4	32	2	16
Market Size	7	6	42	10	70	9	63	2	14	1	7
Rival Products	8	8	64	2	16	6	48	8	64	8	64
Cost (-)	10	10	100	1	10	6	60	1	10	4	40
	Total		478		378		471		300		277

→

focusing research barcode scanning (478) and infrared (471)

→ decided on Sorting of recyclable and non-recyclable waste (bin with two different compartments) – biggest problem at recycle plants

2. Discussed most important result of questionnaire at UCL
    a. Majority (35%) of UCL students eating/buying food outside of the campus (consider to integrate products of shops around the campus) → barcode concept will restrict the products that can be disposed
    - Majority of disposed waste plastic Bottles and food packaging (95%)
    - Nearly 50% of UCL Student actually use recycling bins
    - favored Incentives to recycle: Money back or Tracking system ("xxx tones of plastic have been recycled")

3. Information considering bin design:
    a. Started design sketches by each team member
    b. → Considering usage patterns (x times used per day) /Tracking system once the bin is full?
    c. possibility of 2 to 3 bin "holes" to avoid people waiting
    d. Possible sorting mechanism:
        i. "box" that turns left and right (works as a closing mechanism at the same time)
        ii. "walls" pushing the item left or right
        iii. moving compartment
    e. Possible scan design:
        i. 360-scan for the barcode concept?
        ii. item moving 360 until scanner recognizes barcode?

New actions:

1. choose technology behind designed concept: infrared or barcode (research on cost, technical viability etc.)
2. decide on sorting mechanism / scan design
3. Work on the concept design (capacity, weight, height etc.)
4. Start with CAD

Department of Mechanical Engineering
MSc GROUP DESIGN

Group PANGEA - Meeting Minutes

Date: 21/11/2019 + 25/11/2019
Time: 13:00-14:00 +14:00-18:00
Location: UCL
Duration: 5h (total)
Note Taker: Nilay

Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

ACTIONS FROM LAST MEETING
Evaluated different concepts:
→ focusing research barcode scanning (478) and infrared (471)
→ decided on Sorting of recyclable and non-recyclable waste (bin with two different compartments) – biggest problem at recycle plants

1. Discussed most important result of questionnaire at UCL
    - o Majority (35%) of UCL students eating/buying food outside of the campus (consider to integrate products of shops around the campus) → barcode concept will restrict the products that can be disposed
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  - Nearly 50% of UCL Student actually use recycling bins
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2. Information considering bin design:
   - Started design sketches by each team member
   - → Considering usage patterns (x times used per day) /Tracking system once the bin is full?
   - possibility of 2 to 3 bin "holes" to avoid people waiting
   - Possible sorting mechanism:
   - "box" that turns left and right (works as a closing mechanism at the same time)

- “walls” pushing the item left or right
- moving compartment
- Possible scan design:
- 360-scan for the barcode concept?
- item moving 360 until scanner recognizes barcode?

DISCUSSION TOPICS

- Discussed sorting mechanism / technology

    - Infrared usually used to sort different plastic types such as PVC and PET
    - → technically viable for our process?
    - →current focus on “non-recyclables vs. recyclables”

    - Bar-code restricting range of products
    - People need to scan / place item towards barcode scanner
    - Is the technology “too simple”?

    - “PRISM” (“invisible barcodes”)
    - currently researched for plastic sorting (different types of plastic) in recycling plants that already use Near-Infrared scanners
    - → possible use for smaller scale of bins and broader sorting (recyclables and non-recyclables)
    - people don’t need to actually scan (other than normal barcodes)
    - faster and technically more viable than infrared
    - → Combining the favored technologies (labels and infrared)
    - using “intelligent labels” with fluorescent markers to identify with UV light detectors
    - Products would need to be “marked”

    - Worked out initial CAD-Concept of the “SIMPLE SORTING- BIN” with two different compartments (recyclable and non-recyclable)
    - Worked out design methodology and comparison to rival products, such as Trashbot and Oscar (sorting bins using AI technology)

NEW ACTIONS (Allocated different tasks for the initial presentation)

→ *2 minutes Video:* Miriam (CAD, features) , Aldo (Video design)

→ *build 5 minutes Presentation:* Sophie (Concept design + Background Research) , Molly (Modelling, Analysis + Prototyping) , Nilay (Manufacturing Plan + Business Plan)

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Group PANGEA - Meeting Minutes

Date: 02/12/2019 + 06/12/2019 + 09/12/2019+10/12/2019
Time: 12:00-14:00 +13:00-14:00 + 12:00-14:00 + 11:00-13:00
Location: UCL
Duration: 7h (total)
Note Taker: Nilay

Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

ACTIONS FROM LAST MEETING

MEETING 1 (02/12/2019)

- Nilay, Sophie, Molly: finalise all information that needs to be included in the presentation
- Miriam: finalise the cad and develop a video of it (product features features)
- Aldo: finalising all other parts of the video (problem, solution, summary)

MEETING 2 (06/12/2019)

- Allocate all parts to the different team members (1 minute each person)
- Nilay, Sophie, Molly: finalise the initial presentation
- Review Video (make changes and finalise)

MEETING 3 (09/12/2019)

- Rehearse final presentation
- Review video and finalise

MEETING 4 (10/12/2019)

- Final rehearsal of presentation

Department of Mechanical Engineering
MSc GROUP DESIGN

Group PANGEA - Meeting Minutes

Date: 17/01/2020
Time: 12:00-14:00
Location: UCL
Duration: 2h (total)
Note Taker: Nilay
Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

MEETING:

- ALLOCATION OF THE WRITING UP OF SECTIONS FOR THE MID-YEAR REPORT

1. Introduction
2. Background research (Sophie / Aldo)
3. Design (Miriam)
4. + Design of electric modeling (Molly)
5. Prototyping
6. Evaluation Section (Sophie)
7. Manufacturing and Business plan (Nilay)
8. Further work (Aldo)

- MADE TEMPLATE FOR REPORT ON TEAMS
- NOTED QUESTIONS THAT NEED TO BE ANSWERED IN THE REPORT

ACTIONS FOR NEXT MEETING:
Actions for the next week:

- Finalizing sorting concept (infrared) of the bin to further detail the CAD and electric modelling → (as prototyping, manufacturing etc. dependent on it)

Actions for the next two weeks:

- Each Member needs to start writing up their sections
- Note upcoming question that can be discussed in the next team meeting

Department of Mechanical Engineering
MSc GROUP DESIGN

Group PANGEA - Meeting Minutes

Date: 22/01/2020 + 28/01/2020
Time: 12:00-15:00 + 12:00-13:00
Location: UCL
Duration: 4h (total)
Note Taker: Nilay
Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

MEETING 1 (22/01/2020):

- Altered original CAD to a simplified prototype (reduction to one compartment that will move right or left) (Miriam, Nilay)
- Replaced Nir-sensor technology with camera for image recognition
- Familiarized with phyton coding for image recognition

MEETING 2 (28/01/2020):

- Compiling of write-ups for the mid-year report (Sophie, Aldo, Molly)
    - background research on plastic waste (recycling problem)
    - research on image recognition
    - design methodology etc.
- Discussion of parts list that is needed for the prototype: draft mode of parts list (Nilay, Miriam)

ACTIONS FOR NEXT MEETING:

- Finishing the risk assessment scheme for MechSpace (Sophie)
- Develop Gant Chart for mid-year report (Aldo)
- Electrical Circuit Planning (Molly)

- Finalizing parts list to order: materials, test samples, experimental consumables
- Finalizing Prototype costs from approved suppliers (Nilay, Miriam)
- Fill Purchasing Requisition Form and send to Dr. Miodownik (Nilay)

- Further write up for mid-year report (everyone)

Group PANGEA - Meeting Minutes

Date: 30/01/2020 + 03/02/2020 + 07/02/2020
Time: 12:00-13:00 + 16:00-17:00 + 13:00-14:00
Location: UCL
Duration: 3h (total)
Note Taker: Nilay

Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

MEETING 1 (30/01/2020):

- Finalized risk assessment for MechSpace
- Finalized parts list for first Prototype

MEETING 2 (03/02/2020):

- Finalized Block diagram and electrical circuit for prototype
- Discussion of purchasing equipment (Google AYI kit vs. Single parts trough RS Component)

MEETING 2 (07/02/2020):

- Compiling of write-ups for the mid-year report
- Purchased Google AYI camera that includes Raspberry Pi microcontroller and Raspberry Pi camera

ACTIONS FOR NEXT MEETING:

- Finalize FEA of prototype and decide for Materials (Miriam) → Materials list needs to be finalized for Manufacturing plan (Nilay)
- Finish write up of Image Recognition design part (Aldo)
- Finish write up of Background Research (Sophie)
- Write up of Electrical Framework (Molly)
- Coding for image recognition with Python (Nilay)

Group PANGEA - Meeting Minutes

Date: 19/02/2020
Time: 12:00-14:00
Location: UCL
Duration: 2h (total)
Note Taker: Nilay

Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

MEETING (19/02/2020):

- Received Parts (Microcontroller, Cables, Camera etc.)
- Assembly of the different parts of the Google AYI vision kit
- Compiled and discussed all parts for Mid-Year report that are done
- Discussed the missing chapters that need to be done by next meeting (Monday 24/02/20)
- Planned the complete prototype assembly with a box(e.g. shoebox) for next meeting (Monday 24/02/20)
- Discussion of python code for the image classifier (e.g. classification of labels)

ACTIONS FOR NEXT MEETING (MO 24/02/20):

Complete Mid-year Report (besides the prototype section, evaluation section etc.)

1. Introduction to the project and the team (outlining the roles of each members) (Sophie / Nilay)
2. Background research section (fully referenced) (Sophie)
3. Design chapter (including description of the design process, the design evaluation criteria, designs, CAD to date) (Aldo/Miriam)
4. Modeling and analysis section (describing the analysis, modeling of technical and financial aspects of the project to date) (Molly)
5. Prototyping section (describing the prototypes built to date) (Molly)
6. Evaluation section (containing a design matrix, product specification ect)

7. Manufacturing section (containing details of materials, processing, assembly, parts list, supply chain) (Nilay)
8. Business plan (evaluation of business case, finance projections ect..) (Nilay)
9. Further work section (tasks to do, gantt chart, group role/issues changes, contingency plans, ect..) (Aldo)

Department of Mechanical Engineering
MSc GROUP DESIGN

Group PANGEA - Meeting Minutes

Date: 24/02/2020 + 26/02/2020
Time: 14:00-17:00 + 11:00-15:00
Location: UCL
Duration: 7h (total)
Note Taker: Nilay

Attendance: Aldo, Miriam, Molly, Sophie, Nilay
Late (by more than 10 minutes):
Absent: -

MEETING 1 at MECHSPACE (24/02/2020):

Mid-Year Report:

- All members finalized their parts for the group report (Introduction, Background, Design, Modelling, Manufacturing and Business Plan)
- Parts were compiled to on Microsoft Teams

Camera Recognition:

- Camera configuration with Google API: Camera was able to detect objects on first try
- Alteration of code to waste detection with our waste dataset

Prototyping

- Brought the needed parts for the building of the first prototype to MechSpace and verified with Mechspace staff (Cardbox, fixtures, Google API camera)
- Finalized measurements for cutouts and drilling– verified with MechSpace staff

MEETING 2 at MECHSPACE (28/02/2020):

Camera Recognition:

- Finalized and tested the phyton code: Code is now able to identify different kinds of waste

Prototyping

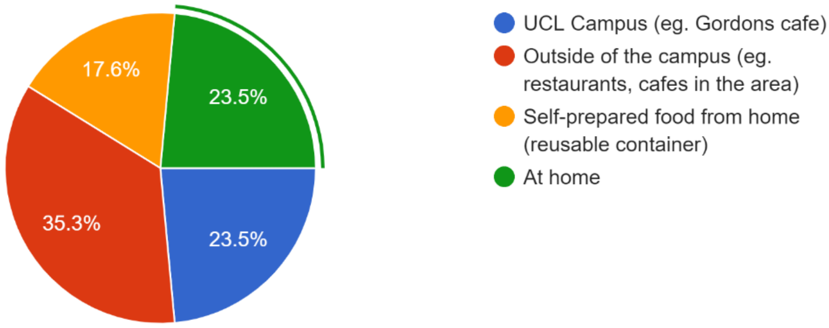
- Completed first Prototype in workshop (consists of one compartment with attached camera and (led lights))

ACTIONS FOR NEXT MEETING:

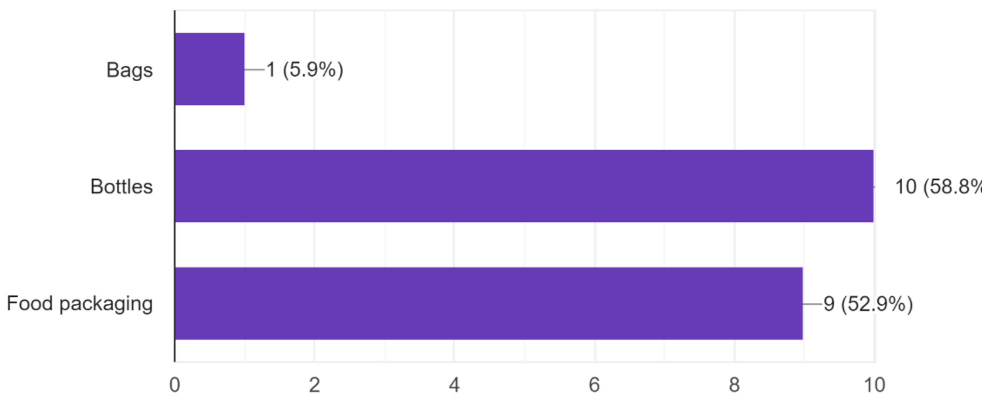
- Finalize and cut the Group Report to 20 pages for submission by 06/03/20
- (ADD evaluation section of the first Prototype)

Appendix 2 - Questionnaire

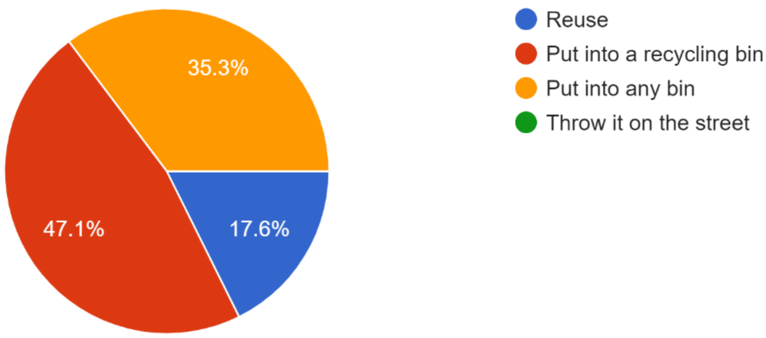
1. Where do you usually eat during the weekdays?
17 responses



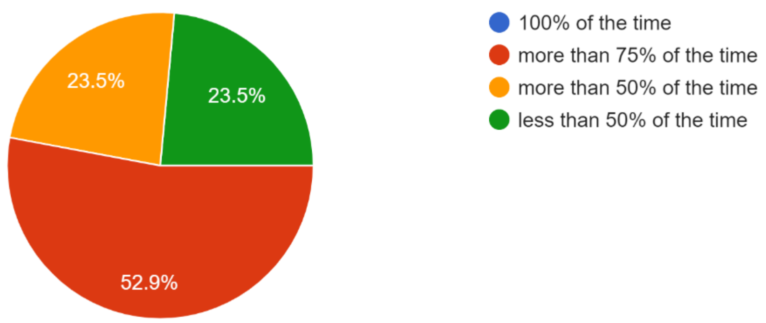
2. What are different types of plastic items you usually dispose at UCL?
17 responses



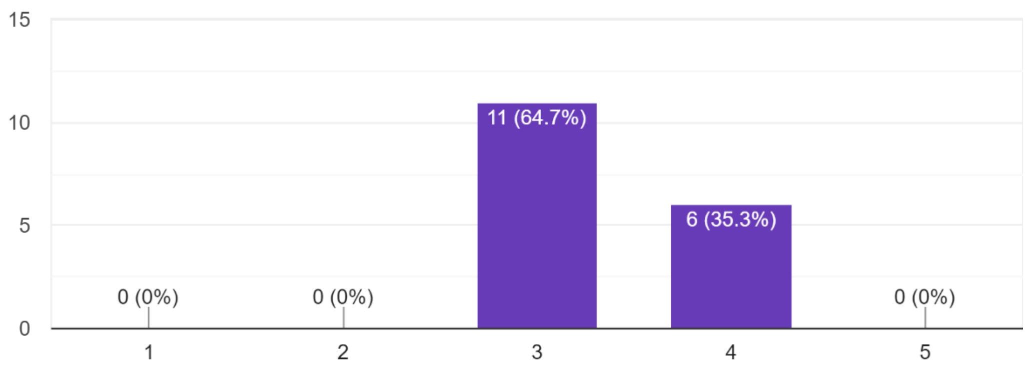
3. What do you do with plastic items once you finish using them?
17 responses



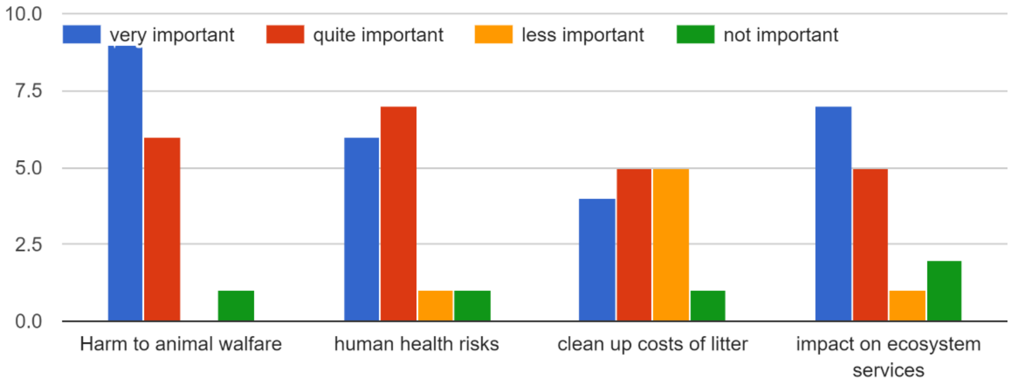
4. How often do you accurately sort your waste according to the recycling system visualised below?
17 responses



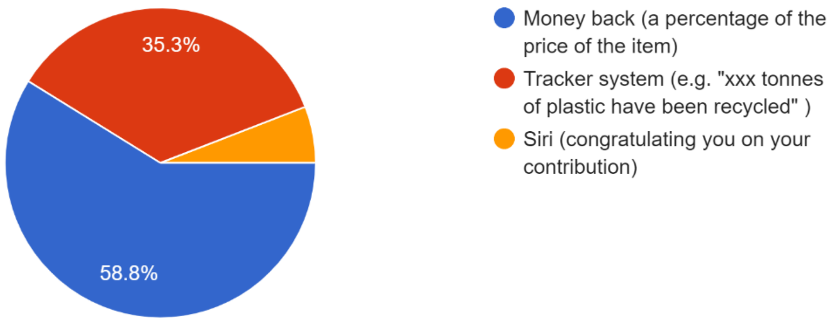
5. How would you rate your knowledge of Recycling?
17 responses



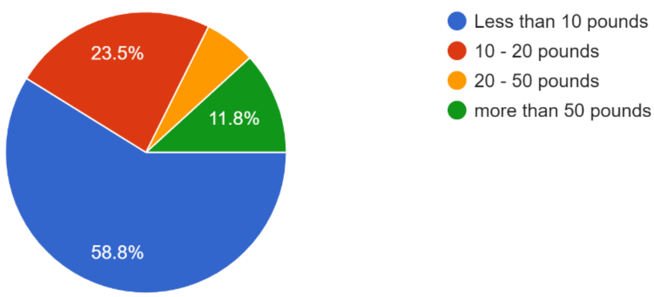
6. Rate how important you find the following issues and impacts linked to single use plastics?



7. Which of the following incentives motivate you most to recycle plastics?
17 responses



8. How much money would you be willing to spend for an automatic recycling bin?
17 responses



Appendix 3 - Code

Detecting labels

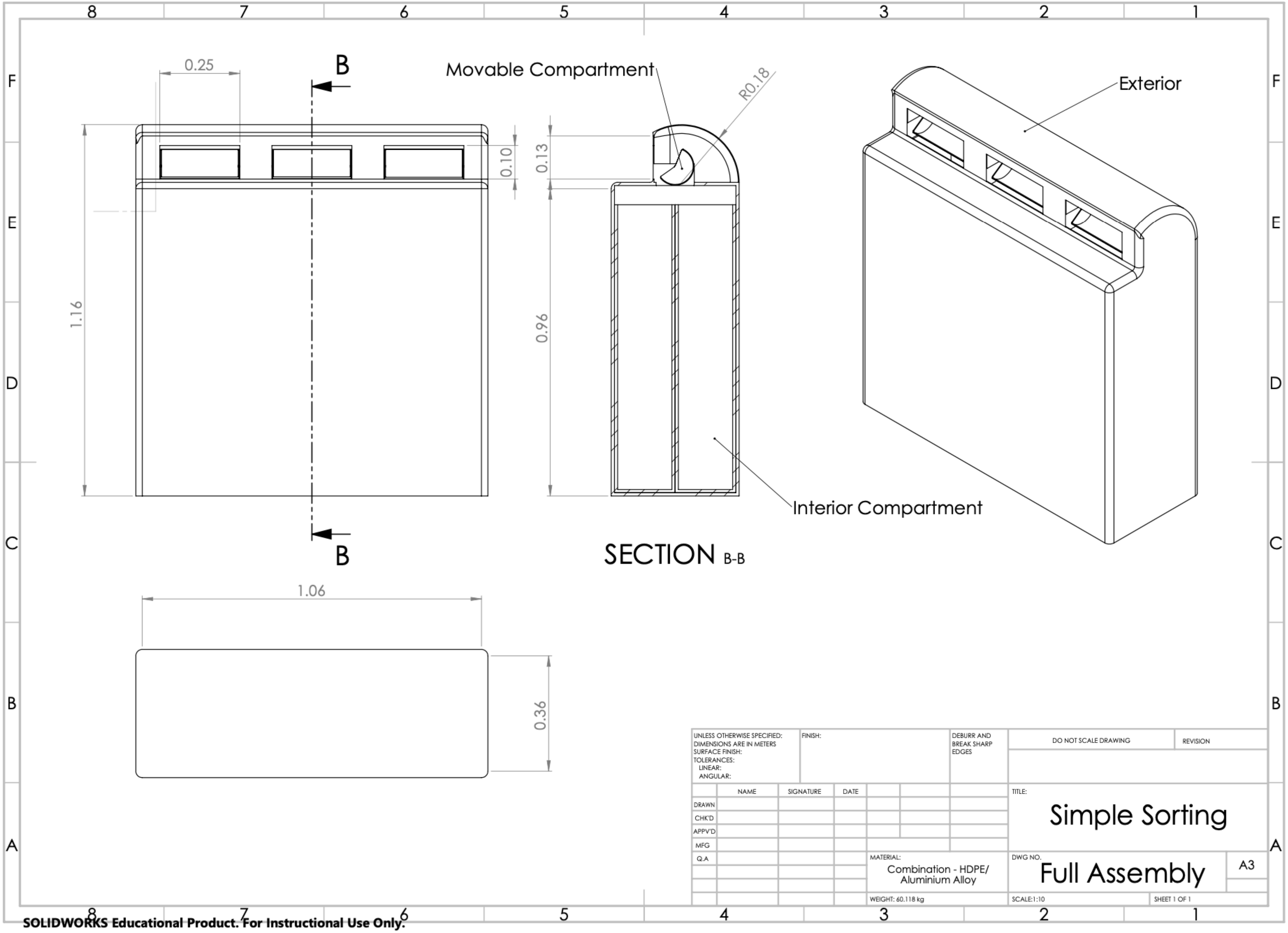
```
import io
import os

# Google Cloud client library
from google.cloud import vision
from google.cloud.vision import types

client = vision.ImageAnnotatorClient()

# image file
file_name = os.path.abspath('image.jpg')

with io.open(file_name, 'rb') as image_file:
    content = image_file.read()

image = types.Image(content=content)

# label detection
response = client.label_detection(image=image)
labels = response.label_annotations

print('Labels:')
for label in labels:
    print(label.description)
```

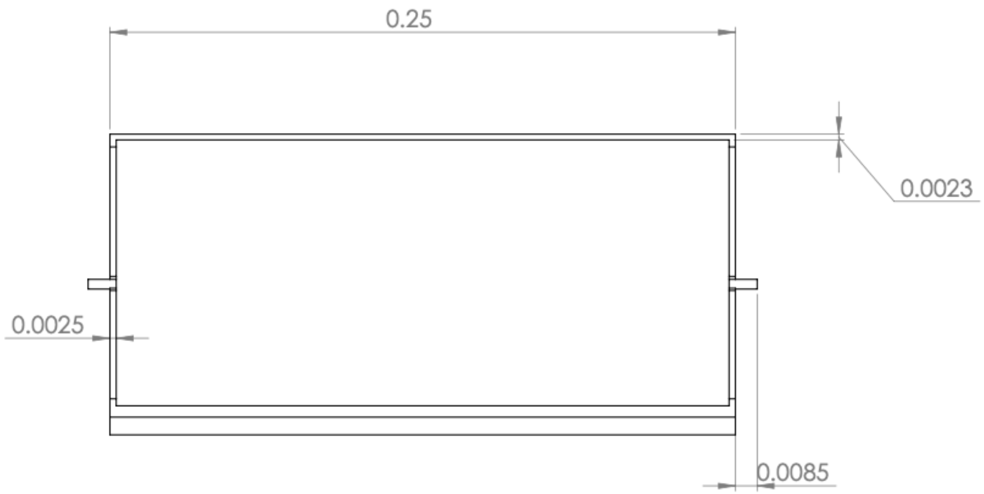
Detecting logos

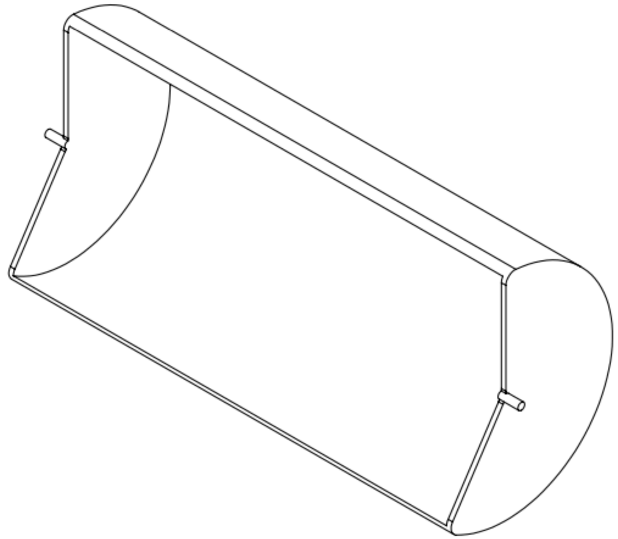
```
import io
import os

# Google Cloud client library
from google.cloud import vision
from google.cloud.vision import types

client = vision.ImageAnnotatorClient()

# image file
file_name = os.path.abspath('image.jpg')

with io.open(file_name, 'rb') as image_file:
    content = image_file.read()

image = types.Image(content=content)

# logo detection
response = client.logo_detection(image=image)
logos = response.logo_annotations

print('Logos:')
for logo in logos:
    print(logo.description)
```

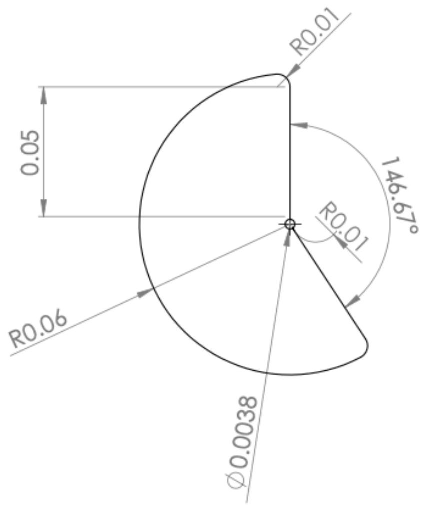
Motor rotation

```
from time import sleep
from gpiozero import Servo
from aiy.pins import PIN_B

# GPIO and PWM settings#
def init():
    GPIO.setmode(GPIO.BCM)
    tuned_servo = Servo(PIN_B, min_pulse_width=.0005, max_pulse_width=.0020)
    tuned_servo.mid()
    return

init()
# Find the desired labels
common = "bottle,water,box,paper,cup,card,book,fork,knives,plastic"
result = label in common


# Decision part and the rotation of motor.
if ( result == True):
   print ("This is a recyclable plastic!")
   tuned_servo.max()
   sleep(1)
    tuned_servo.mid()

else:
   print ("This is a non-recycleable plastic!")
   tuned_servo.min()
   sleep(1)
    tuned_servo.mid()
```

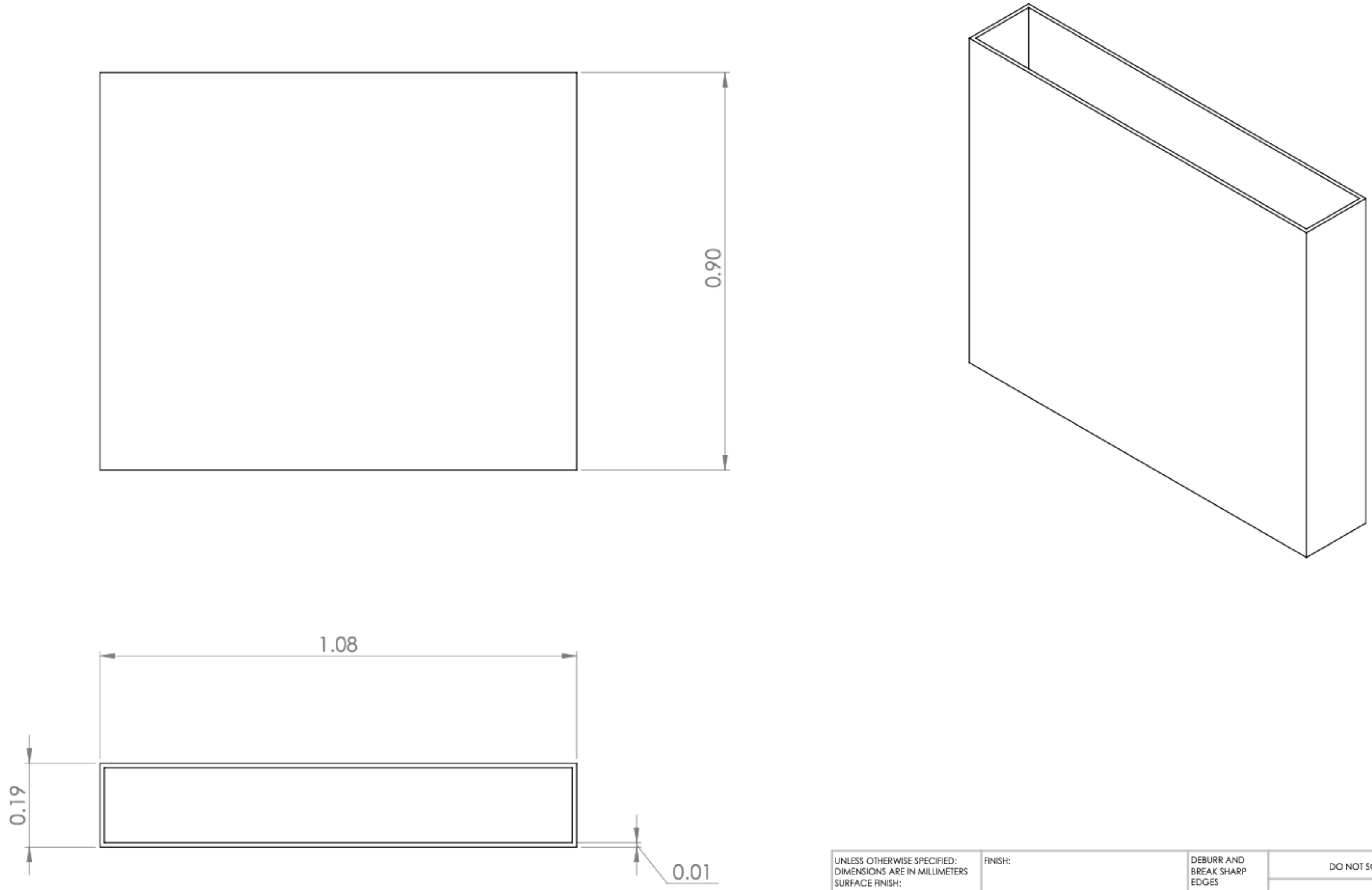

0.25
B
Movable Compartment
R0.18
Exterior
0.10
0.13
1.16
0.96
Interior Compartment
B
SECTION B-B
1.06
0.36
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN METERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Simple Sorting
MATERIAL:
Combination - HDPE/ Aluminium Alloy
DWG NO.
Full Assembly
A3
WEIGHT: 60.118 kg
SCALE:1:10
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



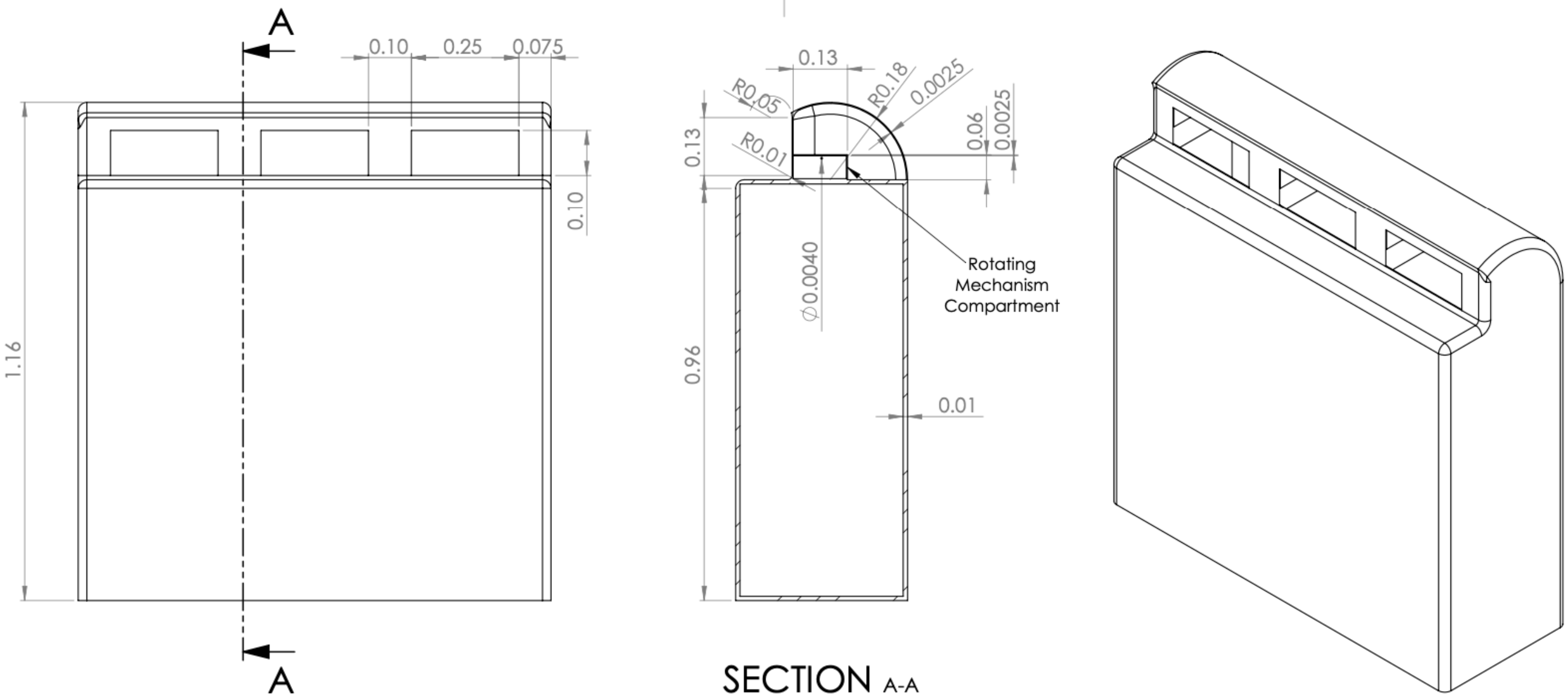




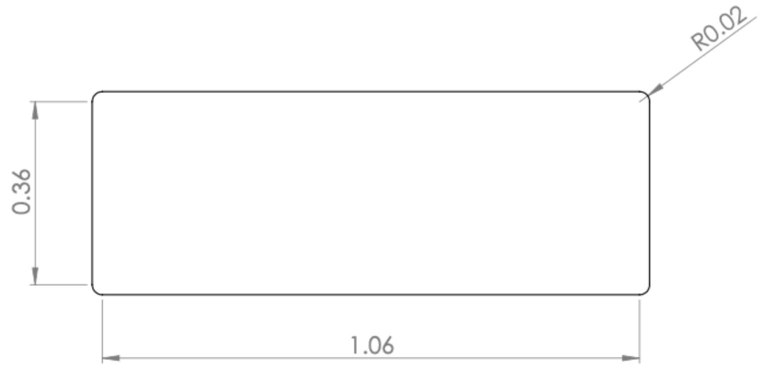
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE		TITLE: Movable Compartment		
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: Aluminium Alloy	DWG NO. MOVABLE1	A3	
				WEIGHT: 0.1475 kg	SCALE 1:2	SHEET 1 OF 1	



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE: Interior Compartment	
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: HDPE		DWG NO. Interior1	A3
				WEIGHT: 11.629 kg		SCALE:1:10	SHEET 1 OF 1



SECTION A-A



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN				Exterior	
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: HDPE	DWG NO. exterior1	A3
			WEIGHT: 36.418 kg	SCALE:1:10	SHEET 1 OF 1