Project name

Extra info

Contents Page

Retrospectively I have divided my NEA project into 18 sections, links to each one are below.

Contents Page

In order to help the marking of this NEA Project, I have compiled the set of Strands and listed which page the marker may want to look at to find evidence of each. The pages which should be particularly looked at for each Strand are in **bold**.

CONTEXT RESEARCH

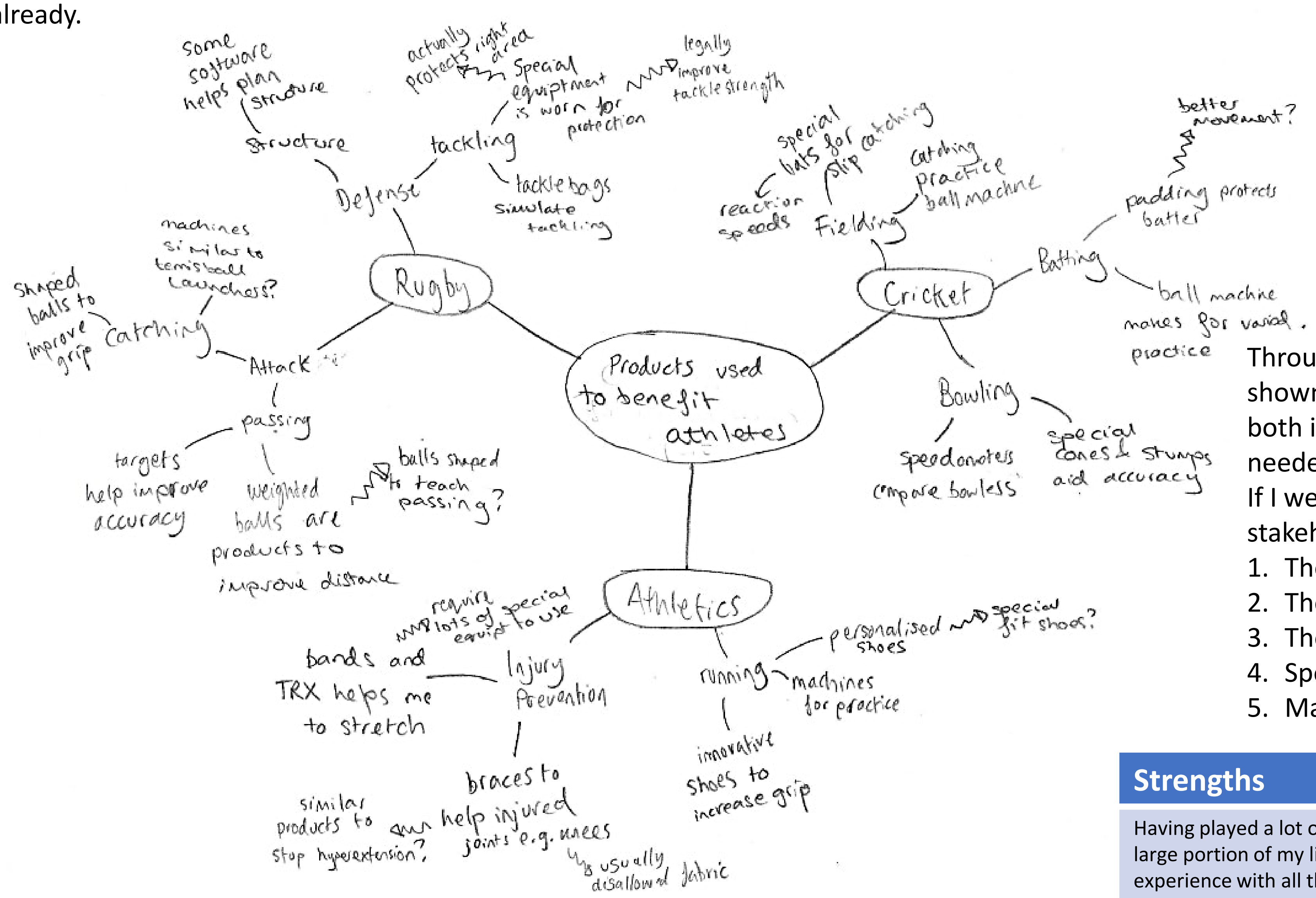
For my NEA project I will need to find a problem to solve. In order to find a problem that is worth solving, I am first considering a wider set of problems. I decided to begin with analysing three areas that are close to me (sports, success of cafés, and aiding developing third-world areas) so I can work towards a design brief for this product.

SPORTS

Sport has been a large part of my childhood and so I have a lot of experience with a wide range of sporting activities. Currently still playing rugby and cricket for my local clubs as well as having a personal trainer to help me with sprinting for athletics. My contact with so many people makes this a strong context to choose. I have an incredibly large stakeholder base, both in users (players), customers (coaches) and retailers (sport shops I regularly visit).

Throughout my sporting career I have encountered many problems that have been solved with the use of certain products such as using a ball machine to practice my batting against when there was no one to help, with more products shown in the spider diagram below.

My wealth of experience with sport also means I am aware of the downsides to choosing this as my project context: there are a lot of companies and a lot of different products. While there have been lots of different problems requiring solving, due to the incredible number of people who play these sports, the market is inevitably saturated with products already.



I extended my research by asking my rugby coach about areas that needed innovation as well as products that were already being used.

Through my experience, the largest vacancy for products is in injury prevention, as shown briefly in the spider diagram. I could think of a solution to almost all problems both in training and in matches and from my own time playing the sports, I have needed better equipment for injuries and protection the most.

If I were looking at injury prevention in rugby, for example, my target market and stakeholders could be:

1. The player – likely someone who gets more injuries i.e. a forward
2. The physio who will help administer and use the product/system for the player
3. The coaches who supervise the player and potentially buy equipment
4. Sports professionals who can approve and recommend the equipment
5. Manufacturers in how easy the system is to produce large scale

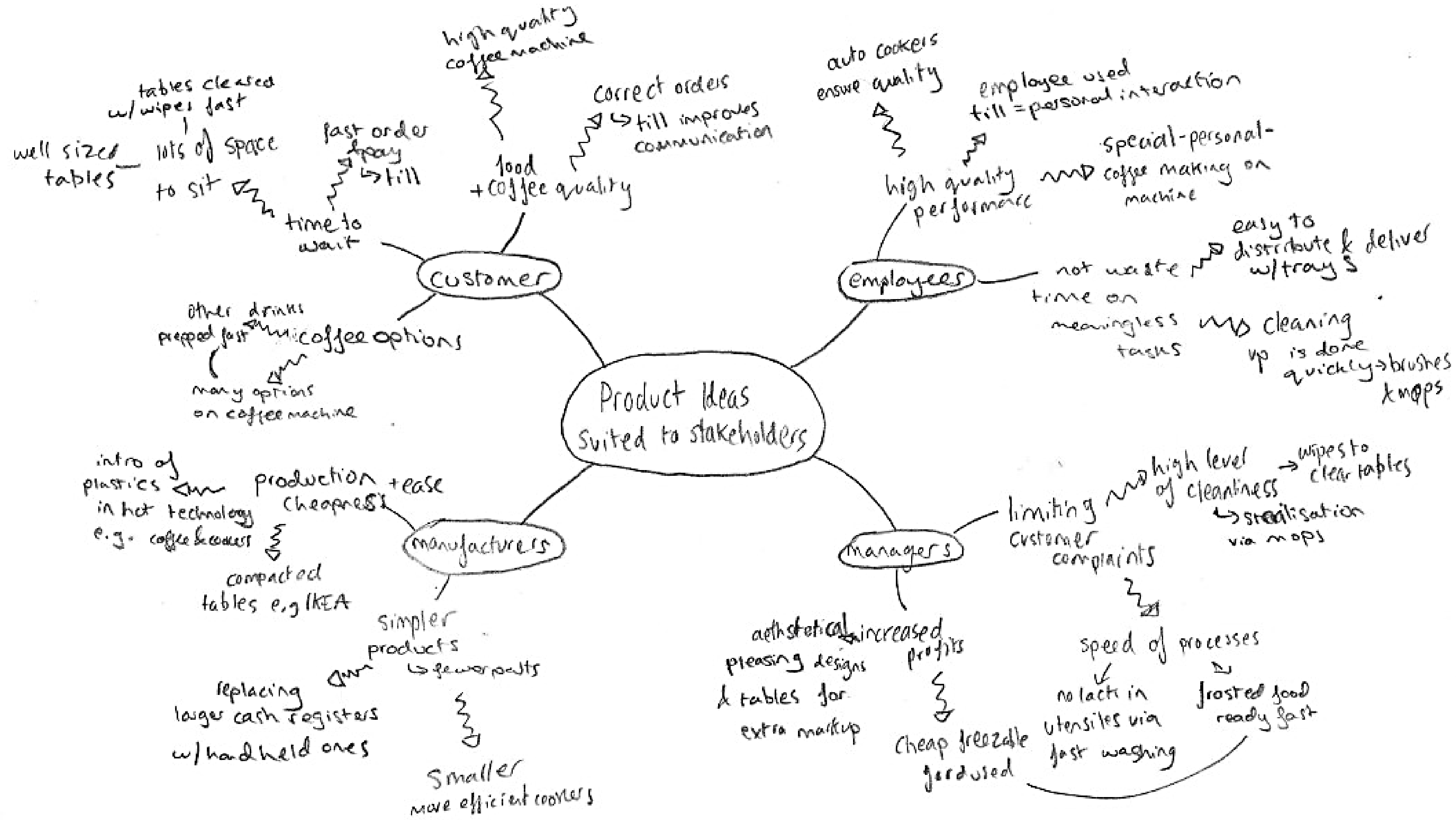
Strengths	Weaknesses	Opportunities	Threats
Having played a lot of sports for such a large portion of my life, I have experience with all the areas I discussed in the diagram above, making me a reliable primary stakeholder. On top of this, as I still play, I have an incredible base of people whom I can also ask about my ideas, all of which I have strong relations and proximity to.	Due to the incredibly large user base, it would be more difficult to design products that would be able to be used by the 5-95%. This is especially evident in rugby with the massive range of body shapes and sizes.	My most likely opportunity lies in injury prevention as mentioned. For this there are many different types of injury that I can look at. Outside of this, there are a wide range of project areas but few actual problems that require solutions.	As clearly shown on the diagram, there is already a heavy saturation of products in this industry and upon initial analysis with a stakeholder we found it difficult to gather many ideas for projects.

CAFÉ PRODUCTIVITY

Over the past 7 years, my mother has run a few local cafés with the help of many loyal workers, even including both my sister and half-sister. Throughout this time I have witnessed many problems, great and small, which have injured the performance of the cafés. Many have been solved while many more have been somewhat mitigated but still remain to hinder the workers and displease the customers. Even amidst the great feedback the café gets, much can and should be improved.

When I asked my mum about this she used her experience to discuss with me the possibilities of taking improvement of the café as my NEA project. What I found from this talk is more clearly demonstrated in this spider diagram below.

Although, reviews were good and there was great customer satisfaction, it was clear to myself and my mum that the café lacked productivity. There was loss of money due to an inefficient work model, that needed to be better in order to increase profits. When I asked another separate small café owner, they agreed with the diagram I had made and the necessity to increase productivity in order to increase profits.



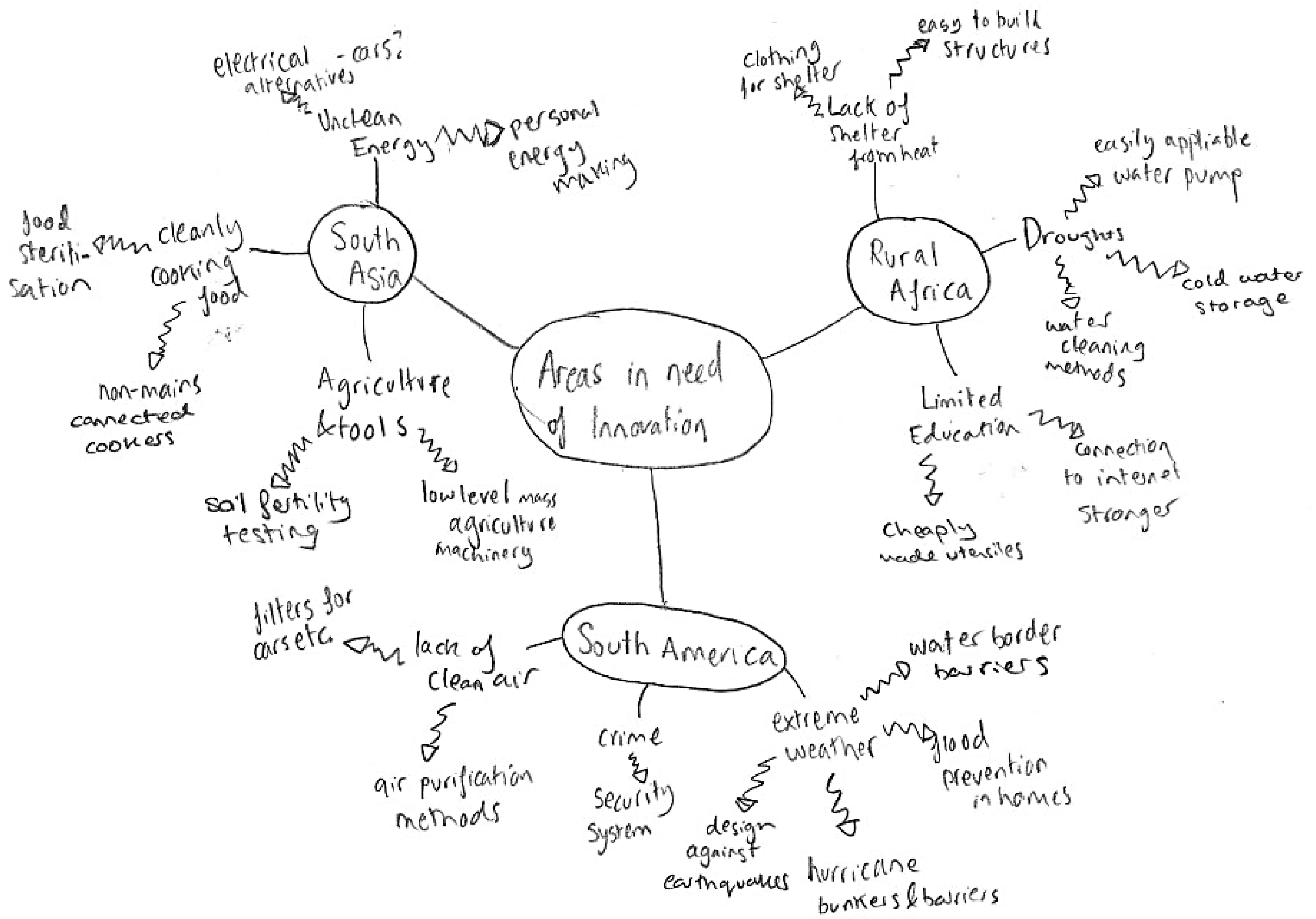
Unlike looking into sports, there are a very wide range of areas that can be improved and I could already think of a few general ideas to solve problems. I split up the ideas by stakeholder so I could see the overlap between different people's requirements for the product I would design.

As already demonstrated, I have a large base of people I can talk to about the production of this project if I were to undertake it on all levels of stakeholder (even manufacturers as the managers have ties directly to those they purchase machines and food from). These stakeholders are easy to access and talk to, to get creative feedback.

Strengths	Weaknesses	Opportunities	Threats
It could be regarded that as everyone I know has been to café before, that everyone would be a stakeholder in some way. Additionally, I have very good sources of information close to me in my mum and sisters. It is also very easy to visit the place of use for this context and even test out parts in real life at cafés locally.	Most of the products used in cafés are expensive and have a high level of workmanship that I must reach.	There are many requirements for a café so there are clearly lots of areas that I can innovate. Even developments made in smaller areas that large companies are not focussing on can result in improvements to productivity.	There are a large number of manufactures who make products for cafés. This means most problem areas are being worked on by large teams of designers already.

DEVELOPING 3RD WORLD COUNTRIES

Even in the developed world we now live in, there are many countries in much worse circumstances that require aid. We in Britain are incredibly privileged to live in the area we do and be able to support ourselves in such a way that those in impoverished areas cannot. This is why this context requires innovative work.
The spider diagram below groups a continent/sub-continents and outlines what part of our usual daily life do the poorer parts of those areas not have and so need. As I have not had primary experience with those I would be designing for, I used secondary research via North Eastern and Global Justice among other websites.



Stakeholder-wise, this would be quite a difficult task to take. Being an A level student at school, I will not be able to travel to any of the mentioned areas or similar areas in other places around the world. The closest to these areas in Britain are not nearly as impoverished and still not close enough to me to be able to have a good close relationship with in order to conduct lots of primary research.
While this is a large downfall, there are clearly a very large need for innovation in these areas and it took little time to think of a wide range of ideas. If I did take this forward as my chosen NEA project I would likely look to flood prevention and water barriers, or air filtration as those are two smaller tasks I could contribute toward with testing that I can do myself without need for travel. Any development in any of these areas, however, would be of great help to bettering the lives of those in impoverished areas.

Strengths	Weaknesses	Opportunities	Threats
This product would have a chance at providing very useful change to the project area, being the most morally good context to pick. Moreover, the charity websites have a wealth of good information to use for my designing.	Testing of ideas would be difficult as I would have to fully recreate the country conditions in which the product will be used in.	There are an incredible number of opportunities discussed all of which are incredibly diverse. Additionally, the more tools that my workshop has are more advanced than those in the poor areas so I can have a great contribution.	This context has the obvious downfall of low access to stakeholders. While I can talk to charity workers, I can only use secondary research. Also I will never know if my products would work as I can never use it in the environment it would be designed for.

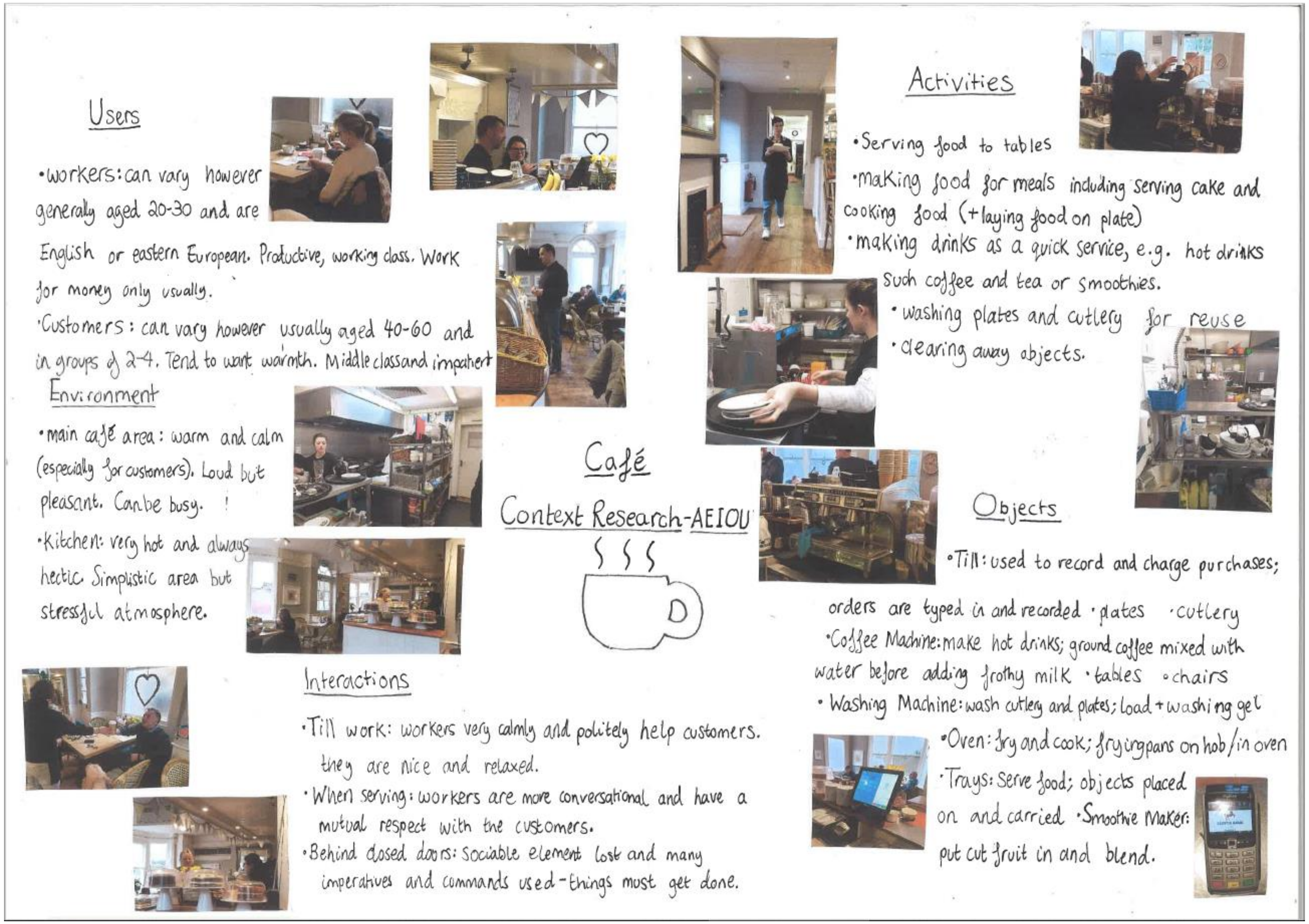
After carefully considering the three context areas I chose, I have decided to go forward with improving the productivity of cafés. In my SWOT analysis of looking into sport, there was a clear lack of opportunities and few things I could work on. What this would mean is that I would have a greatly restricted number of routes I could take and there would be a good chance of being forced to design a product that would have little value and not help many people, simply as I had no other options.
Alternatively, the problem with making something to mitigate the hardships of those in developing countries is that I am lucky enough to live in a first-world country and so know little of their struggles. As I do not personally know much about the problems these areas face, I would need a very strong stakeholder base, which I cannot achieve due to budgetary and time restrictions as well as me being an A level student. It was clear that my second chosen context area – café efficiency – had a good blend of close and reliable stakeholders as well as a wide range of opportunities for me to try to solve. Even though there are large companies tackling more expensive problems cafés go through, there are still lots of problems I can attack, large and small, that could benefit the productivity of a café. Therefore I believe this context area to be that which I can realistically have the most positive impact.
From here I can more closely process the problem area to decide what problem needs solving. I will devise more analytical questions and conduct more specific research in order to find what the greatest downfall in efficiency independent cafés will tend to have. From there I can write a design brief and begin to devise a solution.

CONTEXT RESEARCH

To truly understand what could improve a café's efficiency, I need to conduct research across the area. This research will start general and get more specific as I find out more information and narrow down my options for innovation and development. Thus I will begin with a wide AEIOU research as shown below before going on to Behavioural Mapping and Surveys to fully grasp the possibilities of this context area and working out what task I intend to improve for my NEA project.

AEIOU EXPLORATION

AEIOU research is my first form of primary research which I will use to set a basis of knowledge about my chosen context. From this research I should be able to understand how a café works and what opportunities there are for exploration. I plan to find activities that can be made more efficient, to learn about the atmosphere and environments I will be working in, what interactions must be in mind and improved upon, which objects I can innovate and how I can improve user experiences. AEIOU research will allow me to work on to more specific research about the café later on.



CONCLUSIONS

- All people want fast and good quality hot drinks from the coffee machine.
- While drinking, they wish to feel warm and welcomed.
- Most people also come for either simple small meals/snacks or more often full lunch meals with their drinks.
- Mostly, workers want to make food and drink as quickly however easily as possible.
- It can be inferred that workers are obliged to be nice to customers as forced confrontation to ensure customer satisfaction.
- Work is always done at the till and coffee machine while work is <u>almost</u> always done at the oven and washing machine while less so at other stations (e.g. smoothies).
- Only more experienced workers can work the till and oven especially while any and all workers can do washing and serving.
- The stressful environment would be calmer (especially in the kitchen) with easier objects to use as well as fewer processes that need to be carried out.
- There are tasks outside of the use of objects such as laying food on to a plate and clearing up tables.
- All tasks must be done collaboratively to orchestrate the production of a dish/drink in an efficient amount of time for the buyer.

BEHAVIOURAL MAPPING

Over the course of 2 hours I monitored 4 workers and their paths. In doing so I mapped where they went and gave rough estimates for how long they spent in certain places as represented by larger dots. The workers are all different types of people for a diverse range of research.

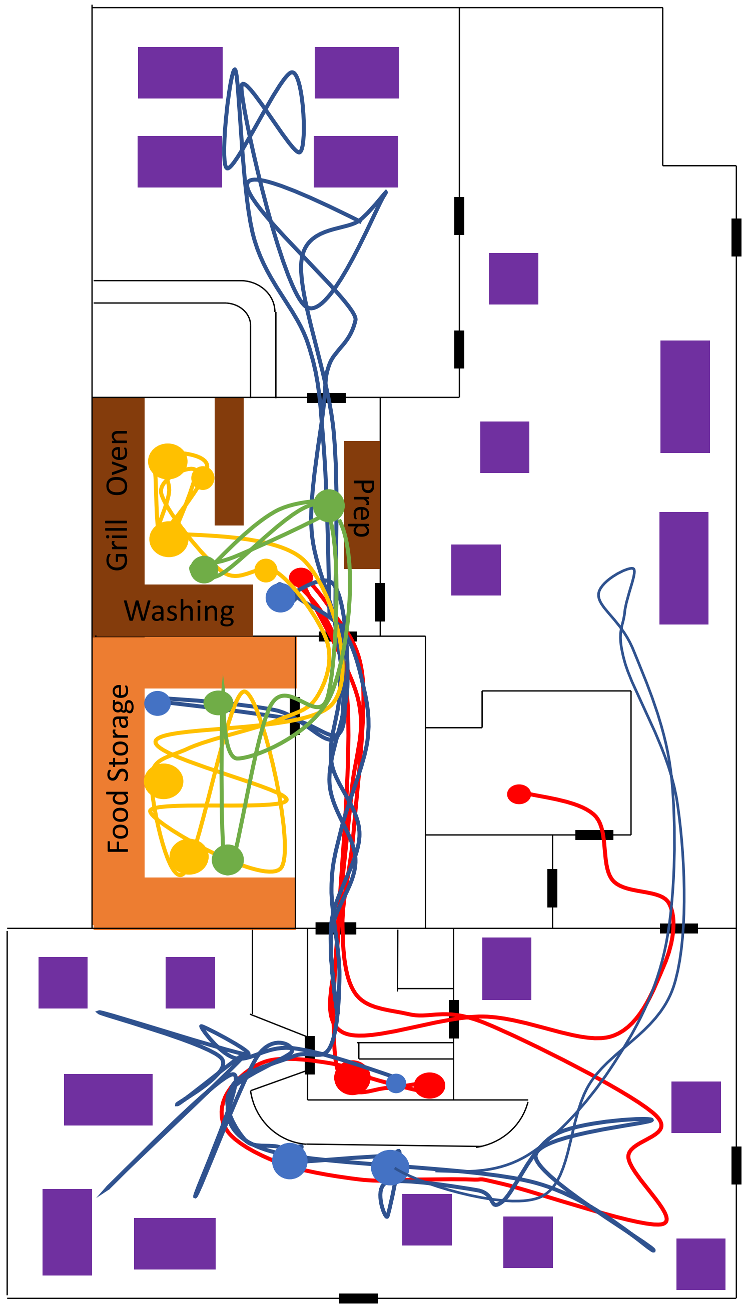
In addition to this I did short character studies for the workers. Each of their paths are different colours as shown.

Amelia Tomlin (19)
- Worked 4 years
- English
- Middle class
- Part time, works for money

Bela Veres (40)
- Worked 4 years
- Hungarian
- Poor background
- Full time work/career

Paula Martyr (58)
- Worked 3 years
- English
- Working class
- Part time work, in spare time

Fiona Park (65)
- Worked 2 years
- English
- Soon to pension end of work
- Full time "simpler job" before retirement



Most visited places/actions per person in order:

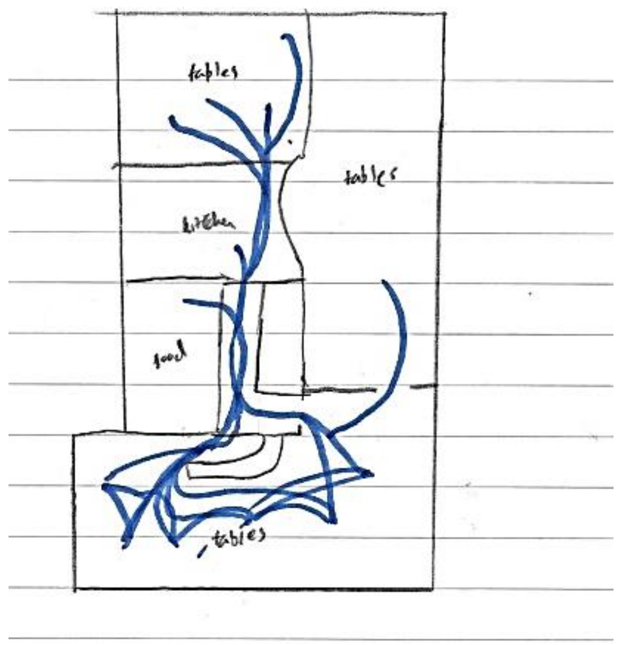
1. Coffee making
2. Till work
3. Toilet
4. Picking up food

1. Picking up coffee
2. Picking up food
3. Making smoothies
4. Picking up drinks

1. Preparation of food
2. Retrieving from freezer
3. Defrosting
4. Washing up

1. Cooking on oven
2. Cooking on grill
3. Collecting ingredients
4. Giving food for delivery

In order to reach this data I documented the movements of the four workers. I chose a Sunday to be the day to document them as it was always the busiest day of the week. On the first Sunday I documented Amelia for two hours and then Bela for two after that. The next Sunday I did the same for Paula and Fiona. Over the course of this time I would loosely tail them and draw upon a layout where they had gone and for roughly how long (an example is shown below). From my four separate drawings I comprised the one on the left, in order to demonstrate which places had the most traffic and what would benefit from an efficiency upgrade in the café to reduce difficulty for workers when it was busy.



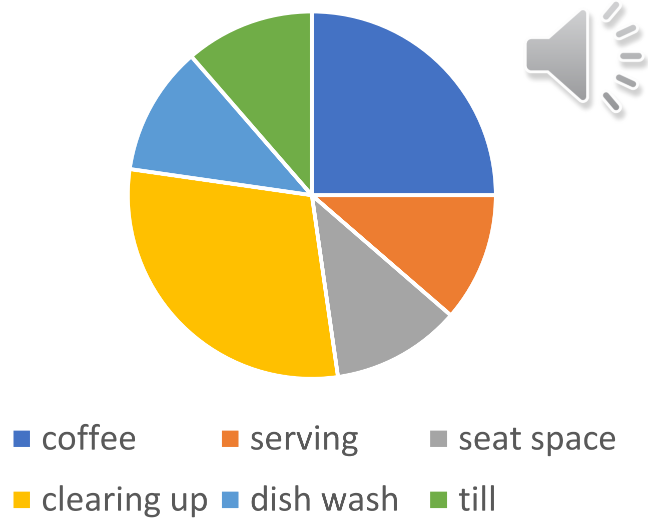
From this information, a range of conclusions can be drawn. Firstly it is clear the greatest traffic occurs in the kitchen and the path between the counter and kitchen. Additionally, almost all the time spent by Bela Veres is around the tables (where he would serve and clear away). Now that I have lain out the data, it is easier to tell that the places that would most benefit from an improvement in efficiency would be between the kitchen and till, and the table tasks done by Bela. Moreover, significant time is spent by Paula and Fiona travelling to food storage, but also in the preparation of the food once cooked.
While I would have liked to have made a time lapse of all the workers to improve upon the accuracy of this test, it was deemed unlikely that everyone could agree to being filmed. Instead, I will devise a few questions for some workers to get their insight on how they work. Currently, the possible areas that I might focus my coursework on would be:

- Speed of clearing away
- Speed of serving
- Increase efficiency of food preparation
- Work at the Till faster
- Information transfer kitchen to Till
- Improving food storage

SURVEYS

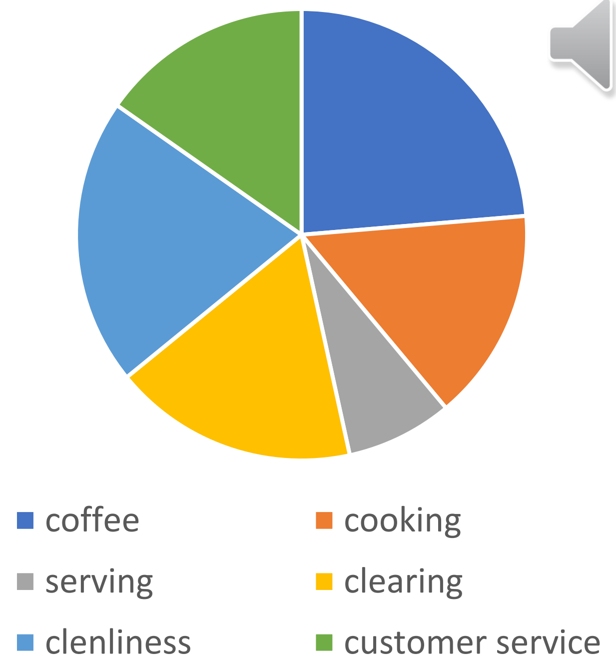
First I needed to extract info from the employees of a cafe about what they think will best improve efficiency in the café. I asked the following questions listed below. From this data I was able to generalise the answers to corresponding project areas as shown in the pie chart below. Elaborations on the responses are in the section →

1. Where do you spend the most time?
2. What do customers complain about most if at all?
3. When the day is stressful, what processes are hard to do?
4. What was the hardest to learn to use?
5. Which individual job do you dread doing if any?



I then asked further questions to the manager, Szilvia Horath. These were designed to give a better more accurate overview of the happenings around a café as a whole to more precisely pin point what could be improved. Exactly the same, answers were generalised below in the pie chart and expanded on in the same paragraph.

1. What is the most difficult activity to teach new workers?
2. What skills do workers need to have to work in this job?
3. What do workers, in your opinion, spend the most time doing?
4. What do you pay the most attention to during stressful or busy hours?
5. What do you believe is most important in providing a good experience to customers?



With this data illustrated in the pie charts and the in depth paragraph at the top I can perform SWOT analysis on my possible project area options →

From my two surveys I was able to narrow down further my options. At the back, experienced workers were hard to find, this could perhaps be due to either a lot of workers are needed or the machinery is difficult to use. These can be solved with machinery being more automated or easier to use respectively. However, only well experienced are employed, meaning once they are employed the work is done to a high standard and speed. In the front, customer interactions are the most time consuming and efficiency limiting. For example serving food and drinks, using the till and cleaning up after them. It was explicitly said that faster hot drink making and faster table clearing would help the most during the most stressful hours. While the coffee machine was one of the most stressful elements of the day for workers (as the machine is quite slow), it was expressed that it is of great importance that each coffee can be personalised for each customer's needs and desires (patterns, dietary preferences, etc.). Workers also have difficulty finding space for new customers as it takes time to prepare each table for new people and they lack space. Therefore I have been led to the decision that I should take a further look into cash registers, and automated cleaning for their reduction in time for unnecessary customer interaction, and the coffee machine to produce coffees with less interaction with the user to make coffees faster and improve customer satisfaction.

Cash register

Strengths	Weaknesses	Opportunities	Threats
With customer interaction taking up the most time, innovation of the till could make work at the front much quicker, leaving workers more time to make or serve drinks. An improved till would benefit not only front workers, but also help kitchen workers, passing info faster	• May require high level of programming • I will suffer from an inefficiency of circuitry compared to large manufacturers	• Automatically counting coins and notes • Easier to use/ better UI • Sending messages to the kitchen via internet • Little competition or variation in market	• models currently in use unlikely to be replaced by café owners • Intricate trialling and testing already taken out by large companies

Coffee Machine

Strengths	Weaknesses	Opportunities	Threats
The coffee machine is an integral part of every café. An improvement in this area would ease the constant need to make coffees, improving efficiency, and reduce stress. Ultimately, faster serving would also increase customer satisfaction	• Many components with likely difficult moulding • Limited manufacturing methods available • Existing models very expensive	• Other models very expensive • Often quite slow and inefficient • All model very similar thus room for improvement	• As an old product, companies have a lot more experience testing

Automated Cleaning Products

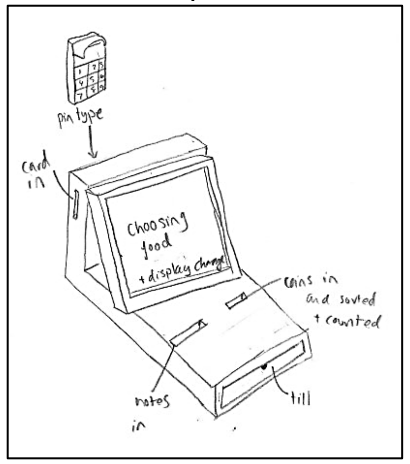
Strengths	Weaknesses	Opportunities	Threats
By automating table cleaning, or cleaning of any other utensil either somewhat or fully, incredibly increases efficiency of customer flow, allowing new customers to be seated almost instantly after the previous have left, rather than everything having to be cleared and wiped every time. This may also reduce as many employees required. Even more importantly, cleanliness would be improved, especially important with the recent coronavirus outbreak.	• Cleaning must be done thoroughly to ensure cleanliness • Current cleaning systems very cheap so this would be much more expensive in comparison	The only type of product in this area are cleaning sprays which require someone to use them with a wipe to clean the tables, therefore there is no current products that automate this task despite the clear need for one. Similarly, other things like cleaning milk cups from the coffee machine is a process that has to be done perfectly while it inconveniences the coffee maker as it stops them making more coffees	• Current manual products used by all cafés so large innovation must be made

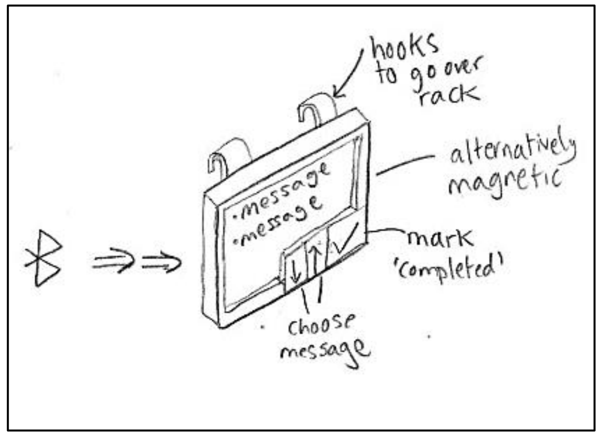
Now primarily considering cash registers, making coffee and clearing tables, I wanted to do some extra research around the subject to gather a greater understanding of all the different contexts to make a decision based of my knowledge of the opportunities present within the area.

CONTEXT 1 – CASH REGISTERS

The first of my contexts considered is improving cash registers. Through research at my mother's café, I found that there were inefficiencies with interaction time spent when the customer pays, as well as mistakes being made about the communication between till workers and kitchen workers.

To increase the speed of ordering, I briefly sketched a possible idea that would count money for the employee. Similar to an ATM or self-checkout, notes and coins could be input through slots (as well as even the card), for the till to count up by itself. Software can then calculate the change required before dispensing. This should increase the speed in which the money exchange is done.





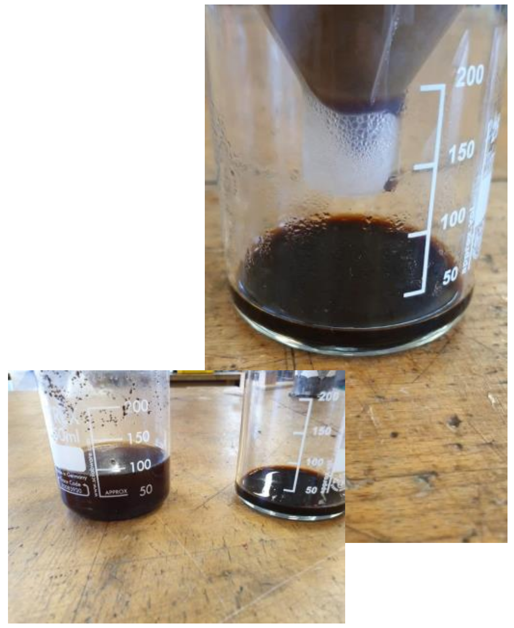
The second opportunity discussed could perhaps be solved with a Bluetooth system. Often the communication problem that the café workers had is the till worker not writing enough detail on the note which they give to the kitchen workers. A way to solve this is to have all information entered into an electronic till before being sent electronically to a receiver in the kitchen. This way it would be far harder to make mistakes and would also save time sending the order information.

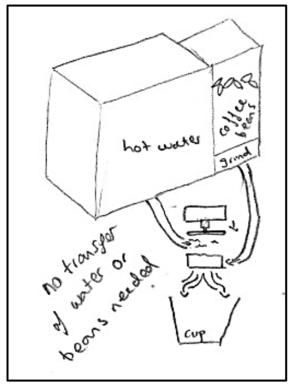
To assess the suitability of these ideas and thus this context as a whole, I spoke to other café owners. The feedback was not what I had been expecting: I quickly found that there were already EPOS cash registers which had receiving screens that would help communicate information to the kitchen. This means the Bluetooth idea had already been used and designed to completion. Additionally, the café owner discussed that the counting of the money at the till takes very little time, and most tills calculate change required. Even if I were to go through with this idea, most of the time used at the till is due to customers and employees talking, and removing that would directly infringe upon the atmosphere and cosiness of independent cafés.

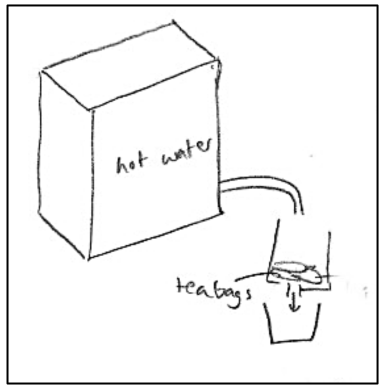
CONTEXT 2 – COFFEE

Next, due to the large amounts of time spent on making coffees and other hot drinks, the second context is coffee machines. I had to first understand different ways of making the hot drinks before being able to derive any possible progress I can make with these devices. Powder can be added to hot water in instant coffee however in cafés they used different methods: diners would often use cafetieres to press coffee grounds to allow water to be pressurised and infused with coffee, similar steps are taken by Moka pots where the water runs through coffee grounds as steam.

When I tested the quality of coffee I compared the process of infusing water with coffee versus with grounds against adding powder and filtering out. Filtering out coffee powder was very fast and made 100ml of drinkable coffee in only a few seconds, however powder was not perfectly filtered and the coffee was very weak and disappointing. Alternatively, filtering the water through grounds led to an incredibly strong coffee however took many minutes to procure 20ml of, with a video right. The process was sped up by about 4 times when adding pressure to the water, as well as using less coffee in the filter (even still giving a strong coffee).





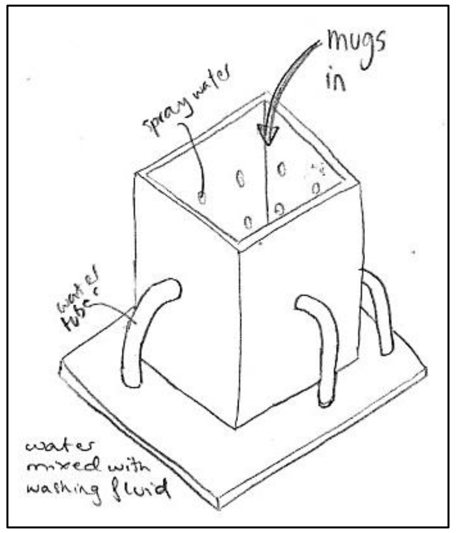


From here I put together a few preliminary designs, which used hot water and automatically ground coffee beans fresh for use to pressurise water and push it through the grounds to infuse the coffee taste. However, when talking to stakeholders it was discussed that the process I designed was closer to coffee machines than I had originally perceived. A similar design for Tea that I drew up was also discounted by the stakeholder as not a fresh way to make tea well.

Despite discussing in detail the potential faults of coffee machines or making hot beverages, it was clear that neither of us could come to any reasonable innovations to improve the creation of these drinks.

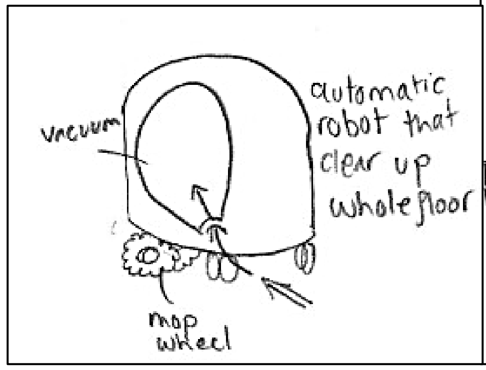
CONTEXT 3 – CLEANLINESS

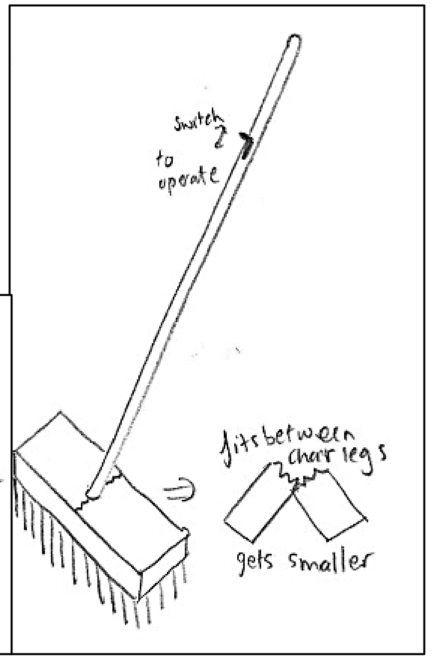
The final context I decided to look into is improving cleanliness around the café, this option has a much wider variety in it than the other two contexts. It was made evident through the questionnaire and contact with my stakeholders that time needed to be saved around the cleaning of objects in order to increase the productivity of the café. As mentioned, workers need to clean tables to prepare for next customers, as well as clean all utensils used by the previous customers. Additionally, a Global Pandemic has recently begun, going cleanliness even more importance.



For initial idea sketches I thought back to how employees of cafés mentioned they would have to clean utensils very fast to put them back into use. As utensils are loaded into a dishwasher, there will always be the dilemma between wasting water and using a half-full dishwasher, and waiting until it is full but having to wait a long time to wash the utensils. An alternative, therefore, could be to wash utensils quickly one-by-one as shown in the sketch to left. This product in particular could wash individual mugs using water jets in the side that could then drain out at the bottom. There could also be many similar products.

As well as utensils, the café area itself needs cleaning. This could be to prepare for new customers, or perhaps to clean something that had been dropped on the floor. In little time I briefly considered two designs that can simplify the cleaning of the café floor both to save time and to improve the depth of cleaning. To be able to clean in a wider range of areas, a broom could have the property of being able to get smaller in width so that it can fit through small gaps and clean more spaces, such as smaller gaps under chairs and tables. A second solution might be with a product that automatically cleans without the need for a worker. It would be suitable for a range of litter and food that may have been spilt on the floor.





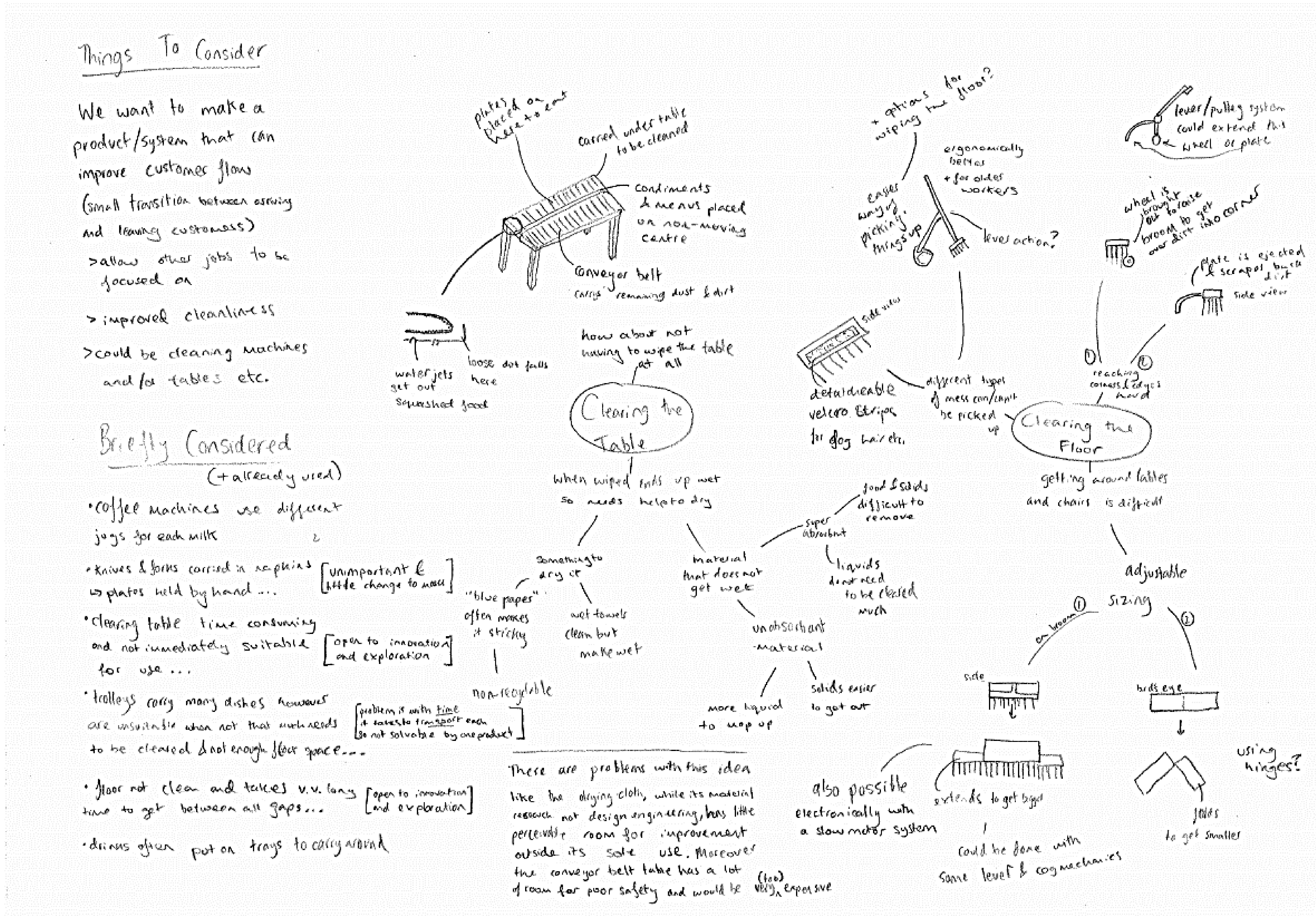
While these are only briefly thought about ideas and first time sketches, they demonstrate the large variety of opportunities that this context has. Of the three contexts considered, this is especially important as of the World Health Crisis of Coronavirus. For this context, my stakeholder base would also refine itself: I could speak to health professionals to gather data about hygiene regulations etc.

Recapping the Data

Before progressing on to working on a design brief, I need to evaluate all the information I have found as well as decide on a context to take forward. AEIOU research gifted me an understanding of the working of cafés to allow me to decide to use Behavioural Mapping to find what can increase efficiency. While this path mapping research highlighted that a lot of time was spent making coffees and taking orders, it was soon revealed that a lot of wasted time could be attributed to a build up of cleaning by all of the staff in small amounts each (hence it not being evident from the tracking). The previous AEIOU page also revealed who my stakeholders were, and so helped to construct a solid questionnaire for them. This new data outlined a clear group of contexts to me to build on that from the behavioural mapping – coffee making, cash handling, and cleanliness. The research done into these contexts over the past two pages has denoted that improving cleanliness and efficiency of cleaning is likely the best choice of the three. This decision is primarily driven by the lack of innovation in the context currently, and so there are many opportunities. I believe this context will allow me to explore a wider range of creativity of ideas.

In order to begin constructing A design brief, I need to intricately analyse the context and discuss with stakeholders the best way to contribute to the productivity of cafés. Shown right is me talking with my stakeholders about our ideas, which are shown on the next page.

To check that cleanliness in the café workplace is a suitable context, I need to consider a wide range of options and see if innovation could be possible. Additionally, I can work out what part of café cleanliness I can work on.



From the method of exploration I had just tried, I was able to extract what user requirements there are in the realm of clearing and cleaning. With the help of expert analysis and ideas, I found the roots of problems within this area and which parts actually needed innovation.
The primary two areas we looked at the most were (1) clearing a table and (2) cleaning the floor. For them to have an impact on a cafés efficiency and proficiency, certain innovations must be made. As there was such a strong range of ideas for cleaning the floor in a better way, whereas wiping the table seemed more like material science not design engineering and also had less room for improvement, I decided to proceed with the floor.

Thus the problem area I have decided to proceed with is cleaning the floor. Current products for this were labelled as hard to use and very time consuming. When used to clear up mess made in the café it would take far too long (thus getting in the way of customers) and would be very hard to use at the end of the day when cleaning the floor. An innovation made must ease the clearing of the floor to allow it to be done quicker so workers can move on to other more important tasks rather than be overly worried about the cleanliness of the café. This improves customer flow as well as customer satisfaction.

As discussed in my analysis, there are a range of important user requirements within this area:

- All places on the floor must be able to be reached
- All forms of mess/dirt must be able to be cleared
- The floor must be made cleaner by the product
- Comfortable and easy to use
- All mess/dirt must be efficiently collected for easy disposal
    - No unnecessary strain placed on the user
- Versatile for use in any café whatever the floor plan
    - All cafés can buy and use this product and even places that are not cafés
- Will not harm or have negative effect on the floor or objects it touches
    - As to not hurt the aesthetics of the café nor cause economic damage

Design opportunities to explore and solve for this problem area that I have in a more condensed form are as follows:

- Making the cleaning element versatile to all floor shapes
- Cleaning corners and edges of rooms
- Make dirt easy to pick up quickly without necessarily having to go to pick it up yourself

To get a strong understanding of the use of my product I need to study the location of its use. Of course I have understood the floor plan of cafés however I have not yet considered the state and condition of the floor nor fully comprehended the surface I will be working to improve. The floor may look like: [write about details of the floor, type of things on the floor, what objects to clean around, types of surface I am cleaning].

Design Brief

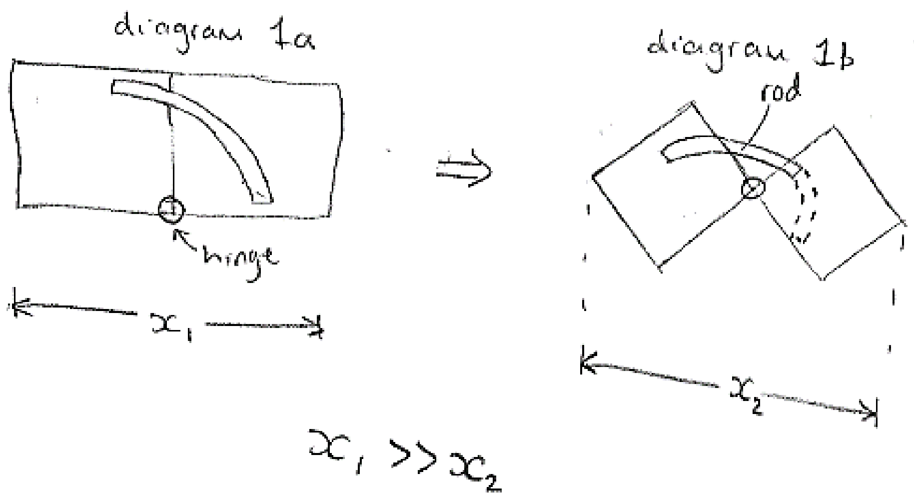
My design will be one that solves the need for a higher level of cleanliness in cafés while also improving speed of customer flow.

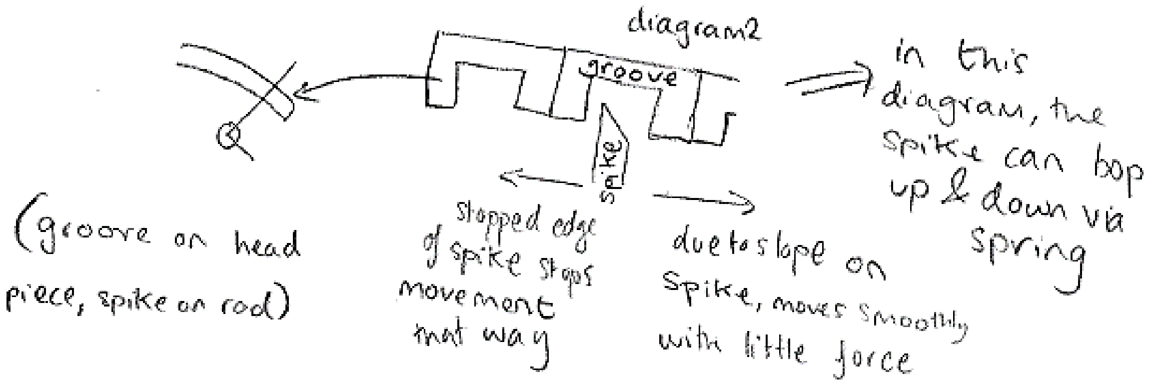
To do this, I will make a product which lets employees cleans the floor of a café quickly and efficiently by being versatile and easier to use than existing products. Its use during workhours would allow the main seating area of the café to be used to its maximum capacity with a greatly reduced transition period between customers and its use after hours would maintain a clean and safe environment.

PRODUCT ANALYSIS

	AESTHETIC	COST	CUSTOMER	ENVIRONM-ENT	SIZE	SAFETY	FUNCTION	MATERIALS	ANALYSIS
Japanese Eto Broom 	Eto brooms are very old looking, fashioning a long brush and shorter wooden handle which has a curled end. The brush is held together via woven strings. It has bland colour and no aesthetic features.	The intricate hand-woven Eto broom costs up to £20 to manufacture so retails at up to £40. However, unauthentic machine made brooms can be sold for £10 only.	Eto brooms were intended for dustier areas and poorer people. They were made by villagers for themselves. Their longer, sharper bristles capture the dust blowing everywhere. The added wiry sharpness of the bristles is ok as users would not have polished floors	As it was for villagers, the Eto Brooms are made with locally sourced materials like wood sticks and wood strands, thus they are very recyclable and so environmentally friendly.	The brush would be about 300x70mm and up to 400mm tall. The handle would vary more but usually would mean that the whole broom is around 1.6m tall.	As they were not made to be sold on a mass market, there is little consideration towards safety. Bristles are wiry and relatively sharp and have many parts loose which could inflict pain.	The Eto broom is made exclusively for brushing things to another place. The things brushed are damaged and thrown aside however this allows them to clean effectively & quickly. Their specialty is dust via dispersion.	Tend to use Maple wood for the handle but varies depending on the region due to availability. The bristles are made in many different ways but commonly they are the veins of large plants that have been cut down.	Despite being unsafe in some ways, the Eto broom is effective at its job. It is environmentally friendly and suitable for dustier areas. Due to the construction, it is not suitable for mass production.
Long handled dustpan and broom 	A more colourful plastic design, this makes use of a short brush on a long handle. In addition to this the dustpan has a long handle too. The minimalist design has only as much material as required and is all on colour.	These brooms cost around £15-20 however due to their manufacturing methods of polymer moulding it can cost as little as £1 to manufacture plus the cost of materials.	These brooms are made for regular households. Their lightness means anyone including children can use it, while its ability to be compacted allows for easier storage. The small bristles are made to be soft against the floor to stop scratches. It can also be used by those with back problems, by sporting a long handle	Although polymers are made from oil which's extraction and use is harmful to the environment, by using a one-material-design and thermoforming plastic, the product is easily recycled for reuse of materials.	For these brooms, they might only be 250x40mm with bristles being less than 100mm long. With the handle added in, these brushes are generally around 1.8m tall.	There is little need for safety precautions on this product due to its simplicity and few parts. Soft edges stop one from being cut and the bristles are not too sharp to inflict any possible damage or pain.	This brush is suitable for collecting lots of dirt and dust, etc. in order to wipe it away. It collects mounds of the dirt on floor. This is especially effective when paired with the dustpan which can be held from standing position and can hold onto the dirt while more is collected. Fold for easy storage.	These brushes' handles are made of fully nylon that can be extrusion or injection moulded. The bristles are often made with PET as they are soft but still rigid enough to collect dirt.	This design attempts to balances the need for hard bristles to be effective but soft enough not to be damaging to anything. It is safe and recyclable. The only thing it lacks is that its PET bristles are not rigid enough to hold dirt making it less effective.
Folding dust mop 	Having mechanisms built in, the handle and end have more intricate design and detailing including hinges and ball joints. Colour coding designates different parts of the product making this product stand out more.	Costing only £10-15, the folding dust mop is better value for money as while containing mechanisms, is made of cheap, easily formed materials like thermoplastics that are easily assembled.	Closely resembling a wet mop, the tassels on this product are soft on the floor and are for building owners wishing to clean smaller bits of dirt and dust. Its inability to effectively wipe larger dirt makes it unsuitable for cleaning at home, only at a place where perfect presentation is necessary (e.g. café).	Although parts can be recycled such as the aluminium rods in mechanisms and the thermoplastics used, this product is not easily recycled due to its permanent joining of parts. Also manufacture is energy inefficient	By default the dust mop is around 400x110mm with a depth of 30mm however it can be folded to reduce it to 300mm wide. Similar to the modern brush, they are usually around 1.8m.	Despite having many mechanisms in it, the dust mop successfully stays safe. Many different cases and material pieces cover the mechanisms so hands are no stuck in it. Plus the tassels are soft	Being very shallow, the dust mop is best for collecting small particulates such as dust. The dust is collected under the mop to be swept to another location. This mop has the added feature of its sides folding in, which can make it smaller to fit in smaller spaces.	With many parts there are lots more materials. Plastic parts tend to be nylon while aluminium rods are used for the mechanisms and synthetic cotton or nylon fibres.	This mop's versatility let it be used in many different floor plans, however the lack of depth means it can only polish, not clean larger dirt or mess. The mechanisms provide strong user interaction however contribute to an inability to recycle.

The in depth analysis of cleanliness in cafés led me to the opportunity of innovating the broom or cleaning utensil to make it more versatile for a wider range of areas. What this meant is that the product can easily go between any chair or table legs it interacts with to speed up the cleaning process. Hence I need to spend time attempting to design a broom/mop head that can change its size.





This design would have a hinge that allows two halves of the head of a broom split and move independently. This allows the width to decrease – letting it go through smaller spaces. For this design I decided to also add a way of allowing the broom to keep its position. I adopted a ratchet type system as shown in diagram 2. When the two broom parts split apart, the rod (which is fixed in the left head part of diagram 1) slides out of the right head part – this is represented by movement to the right in diagram 2. What diagram 2 illustrates is that this sliding is easy and smooth as the spring on the spike allows it to sink down to slide to the next groove. A stop motion representation of this can be found here. Because of the shape of the spike, it cannot move backwards to the left (according to diagram 2). What this means is that the broom can have a default position of no split – held there by a spring – but once the spike is stuck in a groove, the head will instead stay in that position.

I then went to test my ideas in physical form to see if this may be a suitable solution.

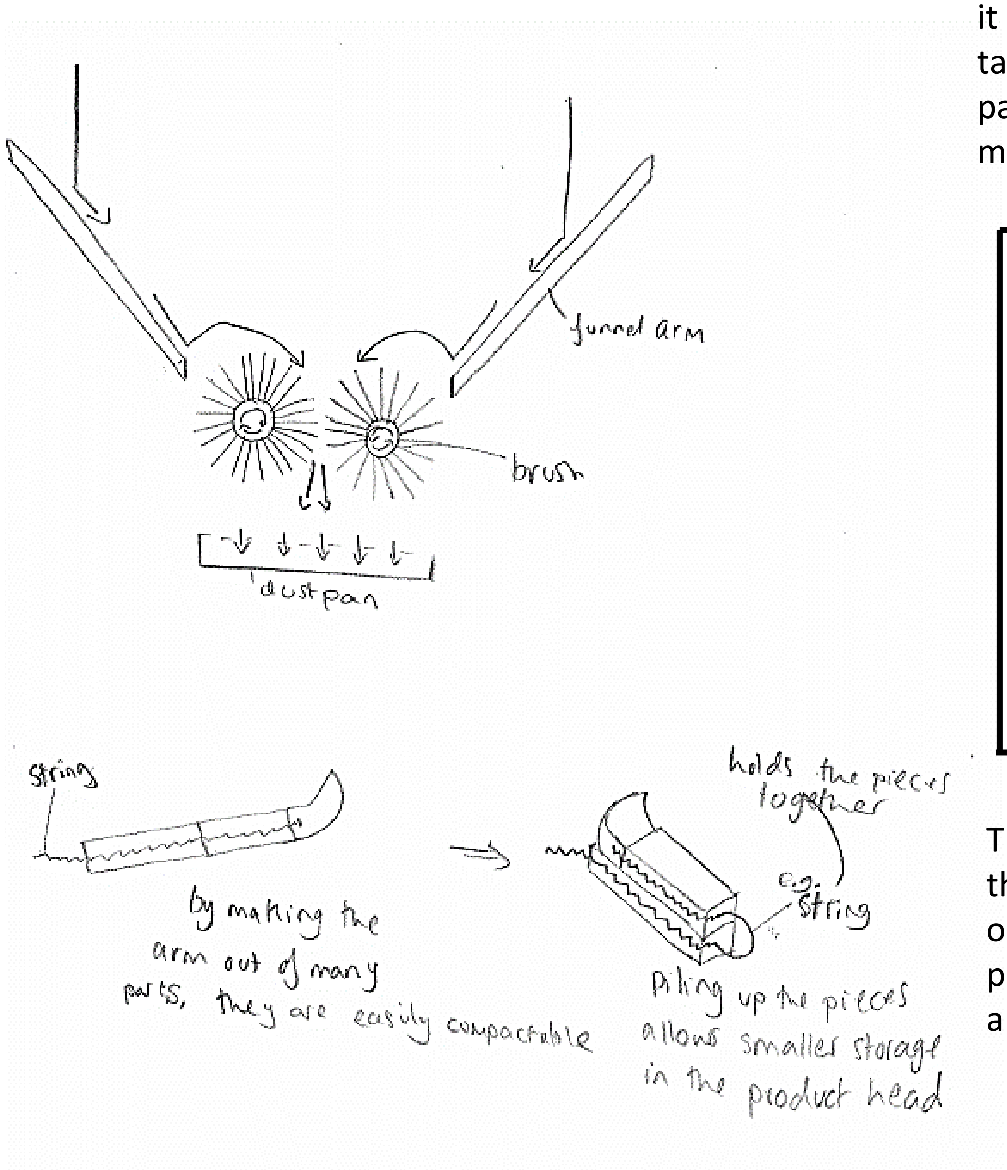
I went about making very basic shape models to start using plywood and the laser cutter. I made the two head pieces 250mm long each with the rod to connect them:

As shown, when split apart, the rod slides out of the right-hand piece and the whole head gets less wide, however I did notice the width only decreased about 30mm.

In order to decrease the width substantially (to 350mm), a very large angle had to be used which the rod could not accommodate for.

While the use of the hinged joint seemed to work, the ratchet-like rod mechanism did not allow enough of a split to create a useful reduction in width. If this exact mechanism was used, the rod would have to stretch farther than 90° to over 180° (to reach the minimum width) which is neither possible, as it would go back into the left-hand piece, nor aesthetically pleasing. The hinge can perhaps be used again, however the rod rachet must be abandoned for another solution.

Rather than starting with a large head that gets smaller, there is also the option of a small head that can get larger. In this case it would be designed to fit between any table or chair legs and when cleaning a large open space, can be extended to increase its area of effect.



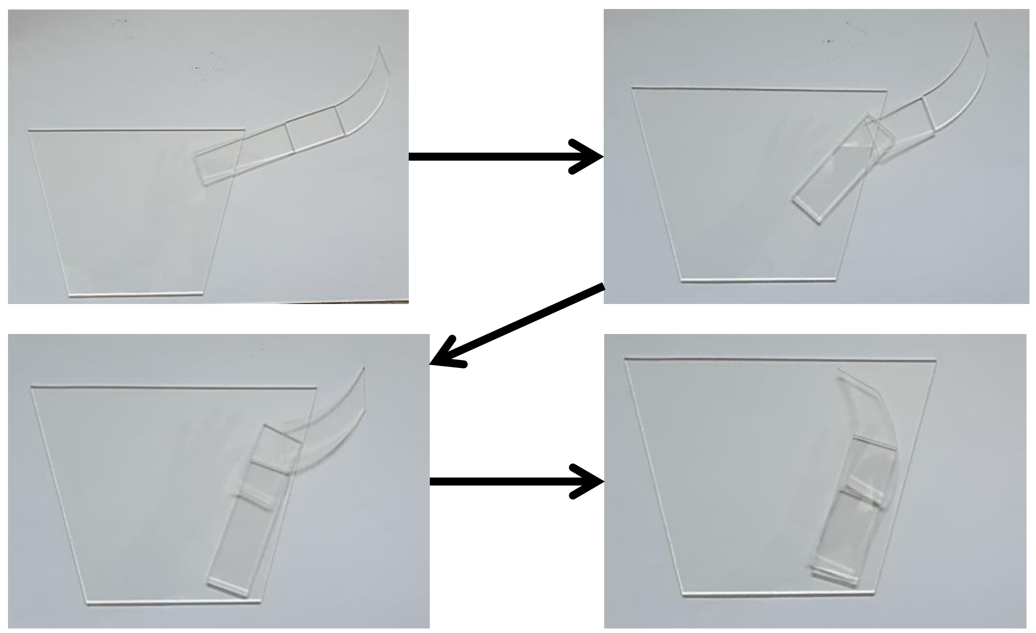
To make the task of increasing width easier, I thought of the idea of having extendable arms that collect debris and funnel it towards the middle where the actual brush is. To aid this system, I researched other ways of sweeping and ended up taking inspiration from road sweepers – two spinning brushes will collect any and all debris and force it backward into a pan (either in the head or separate and behind). For the area of effect to increase, therefore, the funnel arms will just move more objects into the path of the spinning brushes.

Road Sweepers

We can take a lot of inspiration from the vehicles used to clean roads for the product that cleans floors. They are used to clean dust and dirt as well as litter, water and stones; their use can be closely linked to the cleaning or dirt, litter, spilt fluids and food pieces. The road sweeper is designed to suit this by pulling objects with two rotating brushes at the front to collect debris, while a cylindrical brush behind pushes that which is collected into a container. Other models use Mulching fans to collect larger rubble without having chance to flinging it away like the spinning brushes do.

This method does, however, rely on the storage of the arms within the head. There therefore needs to be a way that the arms can be made to make a large extension outwards while also being able to be stored in a compact manner. I opted to make the arm into many connected pieces tied together. This method means that the arm pieces can be piled or sorted in a smaller space than they would take up if one piece, which is important as ideally the arms will be able to stretch far wider than the original head width itself. The pictures (left) also illustrate the use of this design.

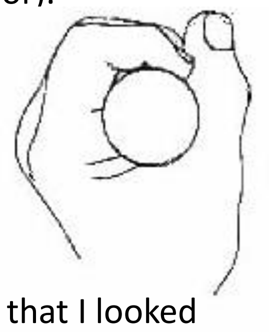
After making this basic shape model with laser-cut acyclic, I realised the need for depth in the arms. In order to funnel objects, the arms need to be at least half as high as those objects. To move all the objects it will collect toward the brushes in the middle, the arms would need to be fully solid and extend to the floor. As, for example, a sandwich package may be around 200mm tall, the arms will need to be at least 100mm tall and arm pieces of that height could not be stacked in a small space. Additionally, it is clear from the physical testing, it would be very difficult to manoeuvre the arm pieces to be side by side as to not take up much space.
It seems there is a way this design could work and in theory it is a good route to take, but due to the complications in fitting the arms, it is important to also consider a range of other options. One part of this design which is very useable even if the arms are not, are the automatically rotating brushes and potentially in built dustpan.



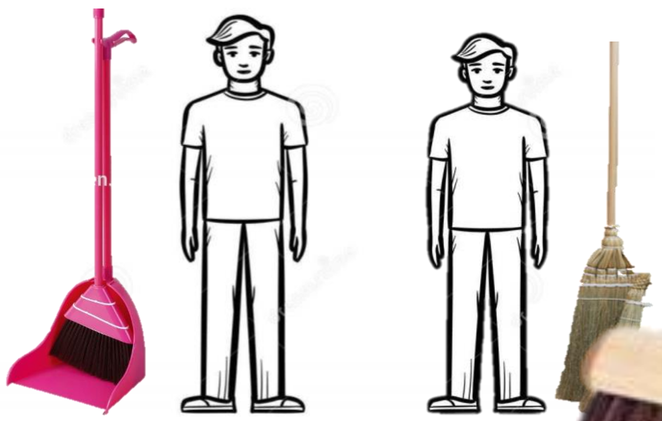
ERGONOMICS & SIZING

The handle of the cleaning tool must be able to be comfortably held as well as allowing the product to be easily moved around. To fulfil its full effectiveness, the design must be easy to hold in a range of different positions, allowing it to be used by a range of people and in a range of situations (easily cleans under tables as well as clear floor).

In terms of width this would be likely easiest if the handle was as large as the average hand's grip. This would mean it could be held normally with comfort while still not being too big or small to hold at a larger angle.



For length I can cite the other similar designs that I looked at in the product analysis. The old Japanese broom averaged around 1.6m whereas new Western brooms being 1.8m. I believe this is reflective of the average heights of the areas in those eras. At the primary time of the Eto broom's use, average height in Japan was 1.65m and in USA now it is 1.75m. Therefore I should choose to keep my product in line with those statistics and model my design's height around average height in the UK.



According to the OCR Anthropometric data the 5% to 95% for adults >18:

- Male Height:1.63m – 1.86m
- Female Height: 1.51m – 1.73m
- Male Finger Length: 64mm – 80mm
- Female Finger Length:60mm-74mm
- Male Thumb Length: 44mm-58mm
- Female Thumb Length:40mm-53mm

Using the formula [circumference = π x diameter] and adding the thumb and finger lengths to get the circumference we can work out:

- Male Grip Diameter: 34mm – 44mm
- Female Grip Diameter: 31mm – 41mm

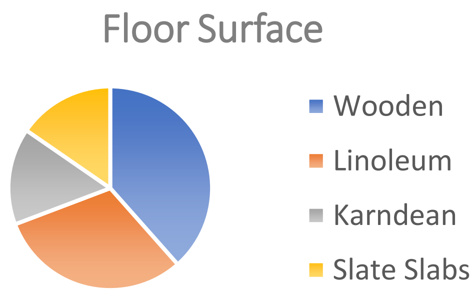
Having looked at the adjustable dust mop in my product analysis as well as my consideration of mechanical output during previous detailed analysis, I should prepare ergonomic exploration on how a person might interact with those mechanisms. The possible ways of manually activating these mechanisms may be a button or sliding lever.

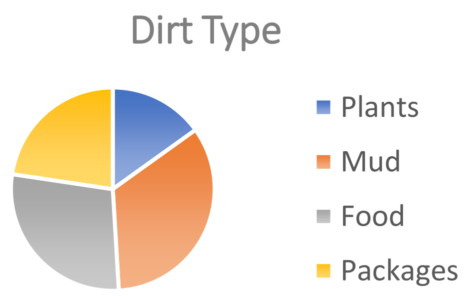
For a button, most likely it would be circular and sized around the width of a thumb to be comfortably pressed. For the sliding lever, again the width should be modelled around the width of a thumb, however the length should be something close to the length of the final bone on the thumb.

For a comfortably grip that would let the lever or button be pressed without moving too much, I need to know where the user might place their dominant hand. To work this out the best I will test with potential users:

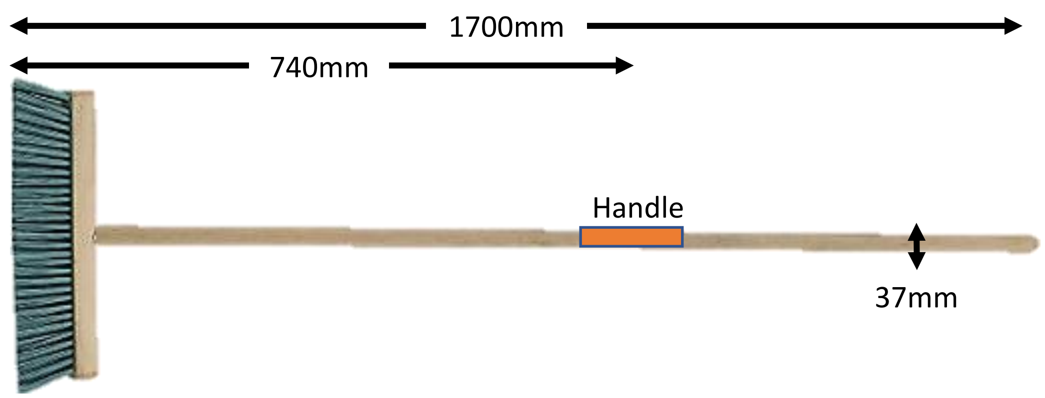
Measuring with a tape measure, potential users had their grips at 680, 740, and 780mm away from the head of the broom.

To work out how big the head can be, I need to understand what areas it is most likely to be cleaning in most often. From there I need to know if it should be able to get larger or smaller to fit other spaces it is likely to be used in. I can find floor data out simply by asking experts and potential users where they would intend to use a product like this:





My mother and sister are two people of very different ages and positions at the café however both have to sweep the floor periodically. Thus I asked them some questions about what surfaces they clean, and what things they need to clean up. The results of the short questionnaire are represented in the info graphs shown. It was expressed that outside, slate slabs where with gardening debris was cleaned with stiffer (likely unflagged) bristles. Inside surfaces required soft bristles where food and mud from people's shoes, in addition to packets and other larger rubbish. Wood and Karndean are both relatively sensitive so need to be treated carefully by bristles. Moreover, the three indoor surfaces have larger debris and so are less likely to need flagged ends.

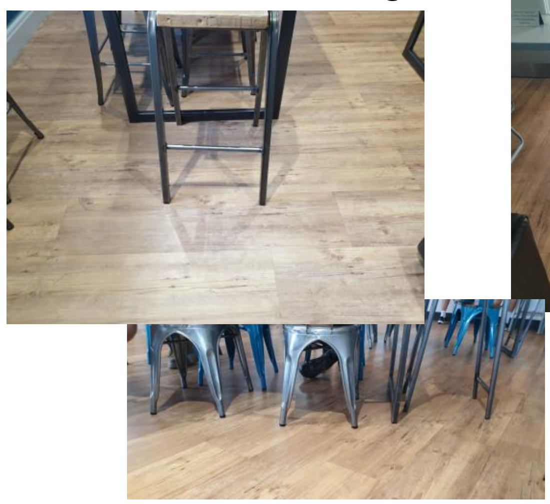


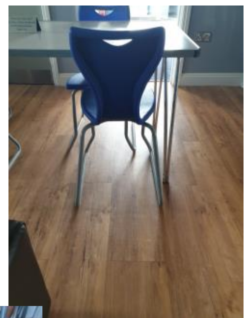
Even while there is are international quarantine restrictions, I went back to school in September, however school was not how it previously was. Communal areas had us wearing masks and there was always social distancing where possible. After lessons we would sanitise our hands and the tables and chairs we had used, all to reduce the spread of Coronavirus. Despite these changes, schools seem some of the least affected places.
Across the country, many cafés, restaurants and bars have had to shut, along with the café I had primarily used for my research, Thyme at the Park. Similarly, many other small business cafés had closed and even many chains have shut down a lot of their buildings. During this period cleanliness is even more imperative than it ever has been and thus my project is even more important than it once was.

This dramatic change in our daily lives has forced me to revaluate the decisions I have made – it is imperative I spend a long time discussing with my stakeholder what I can do to help them the most in these troubling times. As the customer needs change, I will need to remake a design brief to cope too. One side effect of the covid-19 restrictions is and will be the reduction in social spaces. I believe hospitality institutions will become more functional and objective. For example, there will be a reduction in social coffee shop locations in favour of more simplistic cafeterias for simply buying food, eating and leaving (as opposed to spending time with many people). A good way to understand an institute such as this, we can take cafeterias as a reference:

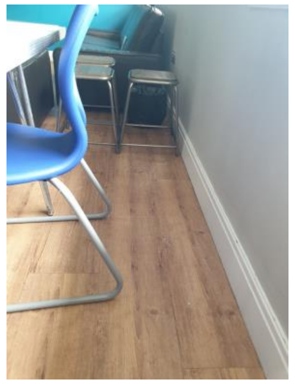
A brief look at my school cafeteria revealed a few key differences between them and cafés:

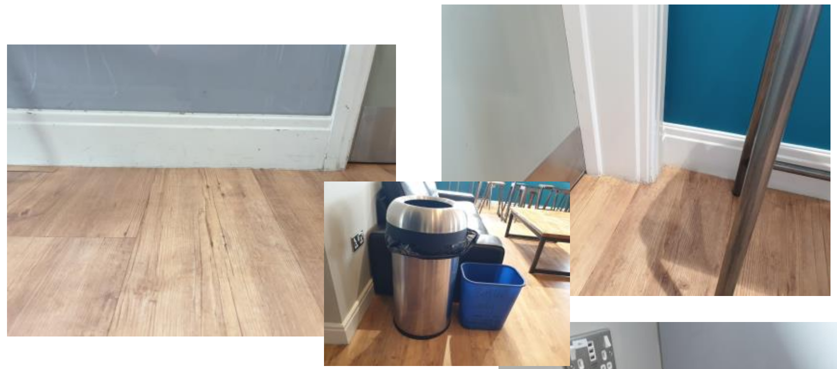
- Fewer workers
    - Less time to dedicate to tasks that are not currently deemed necessary
- Less emphasis on the quality of hospitality, more on the quality of food
    - Effort toward cleaning is lower due to the reduced need to please the customer outside of the food they eat
- Cheaper food due to weaker service
- Tables and chairs are very often different from each other
    - Far more different widths than previously anticipated
- Little effort toward cleaning past clearing
    - i.e. less "spot-less" as cafés. This means it can be assumed there will be more dust and micro-organisms across the floor. As the coronavirus outbreak continues, this will have to change



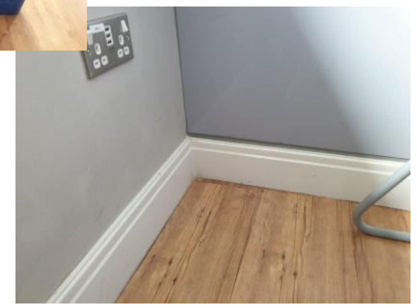


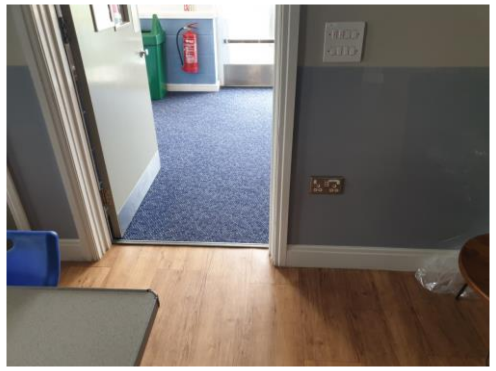
In cafeterias there are a very wide range of gap sizes making it hard to adapt to in the previously named methods





Lower aesthetic requirements mean that there can also be very unpredictable corners and objects that previous designs could not accompany for.





The cafeteria I used for reference:

While I was happy with some of the ideas I had gathered together for the broom that I had previously looked at, there are some problems that I had clearly failed to consider. These problems were perhaps ignorable when considering cafés however, if we consider cafeterias too then they must be addressed.

- There are many options other than brooms for cleaning floors
- There was too much emphasis on reaching different areas easier, not enough on actually making the floor there any cleaner
- The depth of my ideas only stretched to making the task of cleaning the floor less difficult, not actually necessarily less time consuming nor more thoroughly (which is what I set out to achieve)

It is important to clarify that my target is not cafeterias, I am merely using them as a reference to more easily understand the ways in which cafés will change over the coming years.

This is why I need to consider a wider range of ideas to solve this problem. How I should go about this is by first rewriting the Design Brief to encompass more than just one group of solutions…

Since the coronavirus outbreak has changed the way cafés are run and used, the problem area for cafés has changed slightly. As mentioned, there is a more important emphasis on cleanliness and a necessity to keep customers distanced and away from each other. Thus I need to amend my design brief to accommodate for that. Additionally, the design brief heavily limited my scope of solutions to manual brooms or mops and that needs to be changed.

For a café to stay open, it needs to be at the height of cleanliness, speed is merely a bonus now.

Could be employees or automatic

For my NEA project I intend to produce an innovative design that solves the need for a higher level of cleanliness in cafés while also improving speed of customer flow. To do this, I will make a product which lets employees cleans the floor of a café quickly and efficiently by being versatile and easier to use than existing products. Its use during workhours would allow the main seating area of the café to be used to its maximum capacity with a greatly reduced transition period between customers and its use after hours would maintain a clean and safe environment.

More important that cleaning is done thoroughly

With the social distancing rules in place, this max capacity is far reduced

Things need to be cleaned at the end of the day too

Current cleaning utensils range far more than my original design brief limited me to. It is also important to consider solutions with electric components such as vacuum cleaners, while also understanding the capabilities of cleaning robots such as the Roomba. One should think of products that work in ways that are not held in two hands like how single-hand-held vacuums can replace larger vacuum cleaners. Additionally, there should be an effort made toward sterilising the floor to ensure it will not aid the spread against coronavirus and other diseases. I looked to the 'Food Standards Agency' for what requirements a café has towards cleanliness, this should direct me toward a Design Brief that outlines a solution that fits within FSA standards.

MANAGE IT

- Make sure no food or dirty plates etc. are left out at night – these are a source of food for pests.
- Make sure that checks for pests are carried out regularly.
- Put reminders of when to check for pests in your diary.
- If you have a pest contractor, keep a record of their contact details and visits in your diary, as well as any feedback or action points they recommend. Make a note of when you have carried these out.

Under pest management it highlights a need to clear all physical dirt and food to stop attraction of such pests. This is reiterated later on when talking about areas to clean:

SAFETY POINT	WHY?
Cleaning needs to be carried out in two stages. First use a cleaning product to remove visible dirt from surfaces and equipment, and rinse. Then disinfect them using the correct dilution and contact time for the disinfectant, after rinse with fresh clean water if required.	Chemical disinfectants only work if surfaces have been thoroughly cleaned first to remove grease and other dirt.

It is mentioned that surfaces can only truly be sterilised once completely void of 'visible dirt'

SAFETY POINT	WHY?
Items that do not touch food are not as high a priority but they should still be cleaned effectively. Examples include dry storage areas and floors.	This prevents dirt and bacteria building up in the kitchen. It also removes any food which has fallen on the floor, which can attract pests e.g. mice and cockroaches.

There is also a lot of similar information about a need to take 'food waste into the bin before washing' the floor, and a need to 'wash surfaces thoroughly' each day.

Revised Design Brief:
I will design a product that quickly clears a floor space so that it is ready for sterilisation. The product should maintain a clean working place and thus reduce the spread of diseases in social spaces such as cafés.

Before moving forward so hastily as I did before for brooms, I need to first analyse what methods of cleaning are already in place. From there I have then concluded the advantages and disadvantages of each method so that I can find out what direction I should take for cleaning floors the best.

[What is on the floor?]

- packages
  - large e.g. crisps & bottles
  - small e.g. chocolate bars, sweets
  - glass pieces / shards
- food
  - pieces of food (slices?)
  - crumbs of food
  - food squashed to floor
  - stickiness of solid drink
  - spilt drink

Could damage vacuum later if picked up
→ manual pick up?

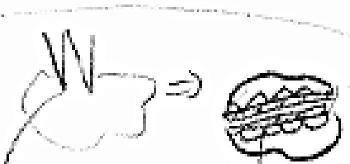
too large for normal vacuums to pick up
manual pick-up?

Can this be vacuumed?

dyson vacuum used a r=17mm semi circle but also had a gauze like structure to limit it to 4mm widths

spilt drink ✓
crumbs - only if small? ✓
if no gauze, always ✓

Solid parts can be scraped off



leaves accumulations of scraped solid (can be vacuumed)

how sharp? Will this damage floor?

can these scrape the majority of stuck drink w/o touching floor? ie. sharpness not an issue

Can we pick up without human hands?

[Current Method]
(According to workers)

→ pick up w/ hand
→ pick up (can be swept) dustbrush
→ dustpan & brush "
butlers brush
→ sweep - in group
→ sweep or vacuum
→ sweep then mop
may not work ⇒ scrub, pick up
→ mop up
→ mop up

A complaint about the vacuums is having to plug them in + other hassle.

Only times of large mess will things be cleared up during the day
- packages
- food ⇒ sometimes is missed
⇒ as to not embarrass the customer, may leave it
- always liquids as they are hazards

some of these protocols may change w/covid

automation in general reduces contact time between workers and customers during the day

Mop

CAN	CAN'T
• sanitise floor	• solid pieces
• spilt drink	• packaging (any)
• sticky floor	• squashed food

Pan & Brush

CAN	CAN'T
• Small packages	• liquids
• food pieces	• sticky floor
• crumbs	• deep clean
• [some] squashed food	

Vacuum

CAN	CAN'T
• crumbs	• sticky floors
• small packs	• large solids
• small solids	• deep clean
• liquids	
• squashed	

End of Day Routine
- chairs often upturned
- pick large by hand & butlers brush
- vacuum everything
- mop everything

To gather the majority of the current information for this page, I spoke to two senior workers at a café where I recorded one of my conversations with them. From the analysis and idea illustrations I have made here I can begin making and testing basic models of the systems that can solve the problems listed.

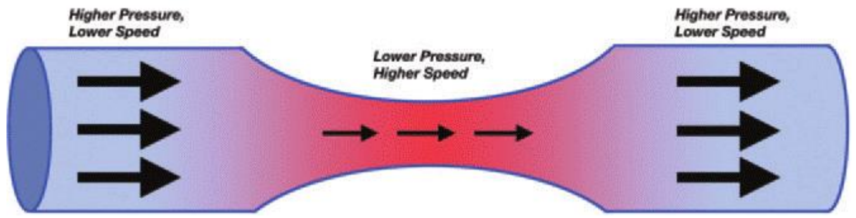
Having completed a very comprehensive analysis of the methods of cleaning currently used in cafés, I noticed a clear theme that almost all the cleaning done was either with a brush or by hand. I discussed in great detail on this page that in the future, contact between customers and employees will have to decrease dramatically, and this instance is no different.

A solution to this is the possible automation of this task amongst others. Upon initial thought this might be to make a rover or robot that can clean the floor of some types of debris, potentially being AI or being controlled by another worker. I asked my stakeholder for her thoughts.

My stakeholder enjoyed the prospect of minimising the close-contact time between worker and customer – especially after such a thing as the coronavirus pandemic. It was emphasised that the robot should live up to replacing a worker as much as possible, including clearing all as many forms of mess as possible. It was clear there had to be a decision between vacuums and sweepers. She expressed that a way of navigating would be ideal too – giving the example of bump sensors but also the prospect of actual navigation of the room. It was clear that there was not a conclusion on whether the stakeholder would want it to be used in the day or afterwards, so I will need to revisit that with her after gathering some ideas to discuss.

The Roomba is an incredibly popular household cleaner, used for cleansing floors of dust and dirt. The Roomba makes use of a spinning brush with a vacuum inside it to collect the dirt, in a very similar system to larger vacuums.

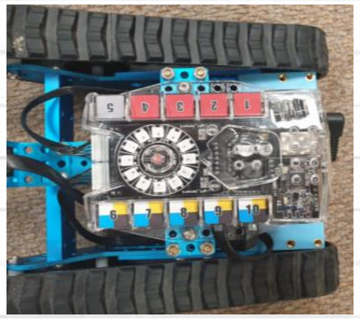
A vacuum works by spinning a turbine/fan to blow air in a certain direction; a second entrance is added and connected so that it paths in the same direction, this way air will also flow through this new entrance. The entrance is made a smaller area than the exit (due to Bernoulli's Principle as shown) so dust can be picked up efficiently, the Roomba uses this theory.



Additionally, Roombas have a rotating sweeper (in the top left of the photo) that helps sweep dust into the brush to be picked up.

The Roomba moves using a set of two wheels that permit movement linearly, and turning, and is balanced using a rotating wheel, or sometimes a caster wheel. The path of the Roombas movement is very simple too, travelling forwards until it comes into contact with a surface so it knows to turn (as sensed using bump sensors on the front).

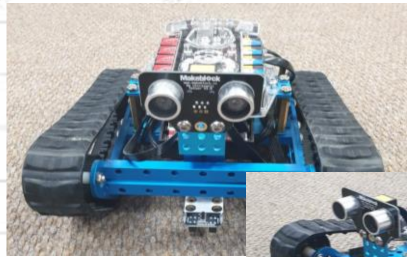
Makeblock mBot Ranger is a buildable programmable robot. It makes use of a specialised Arduino which can be controlled via an app.



The Arduino board connects to many sensors to be able to navigate its surroundings as accurately as possible.

A high level of ~~of~~ circuitory and coding involved has allowed it to be driven either manually, or be coded (via simple block-coding) to follow routes and respond to stimuli.

The robot, when coded, can use ultrasonic waves to detect objects ahead as well as LDRs and Sound Sensors to travel toward or away from those stimuli. In addition, a gyro-scope can help the robot balance while staying still and turning.



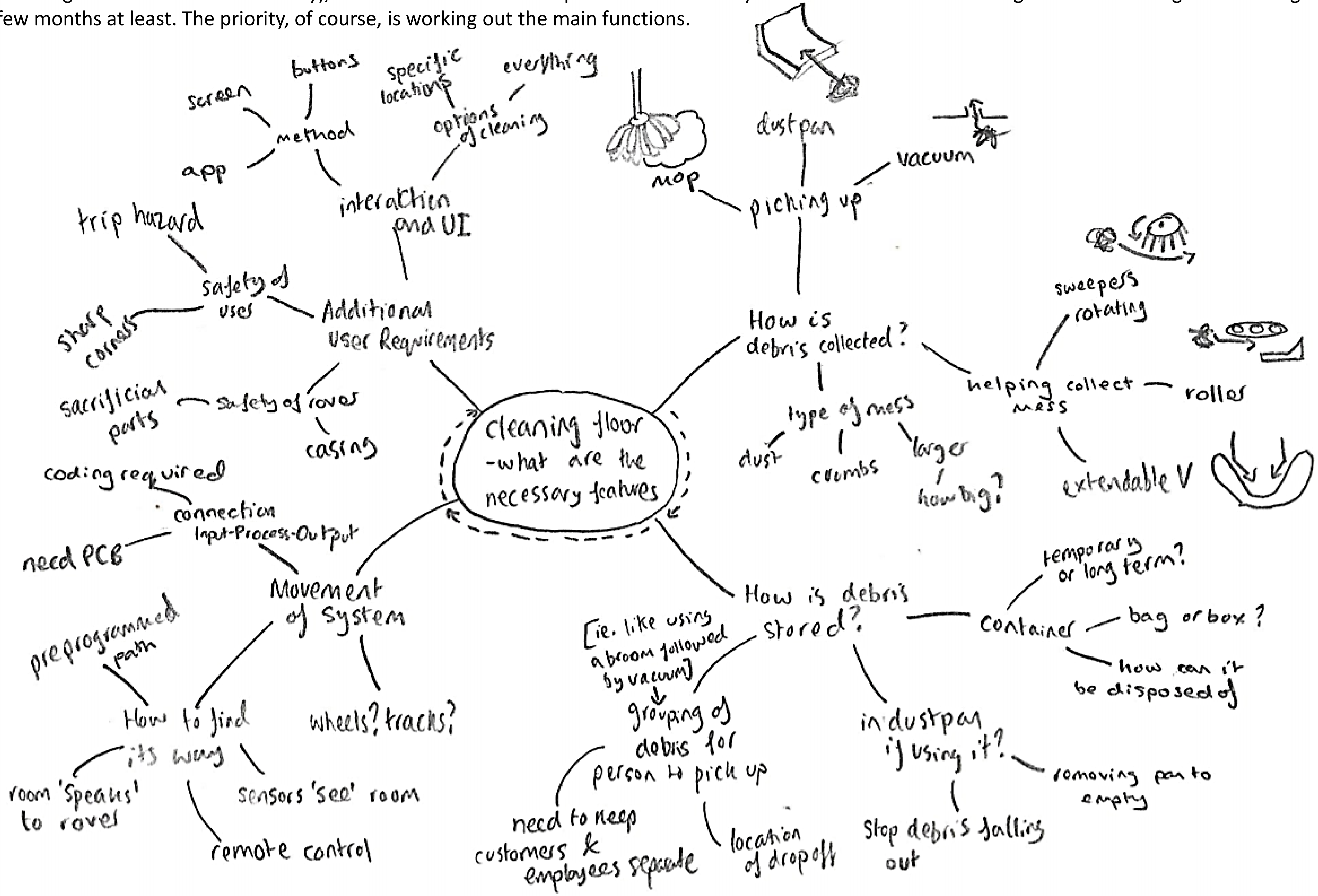
Even with all this functionality, the mBot is only 200x170x120mm so can fit in all the chair gaps previously mentioned. A specialised version of a product like this can remove certain parts such as the industrial wheels or a lot of the Arduino sensors and wires.

The possibility, by having both driving and programming options, of using the robot to take a pre-planned route is a very present one. Some roombas will bump into surfaces and rotate ~~accordingly~~ accordingly but in a place with many chair and table legs, this will cause a lot of unnecessary travel. Alternatively, a robot like this can be driven a planned route that it remembers and can drive itself – or follow lines on the floor.

While I am interested in the prospect of using a small vacuum cleaner, it is an unrealistic desire for a small robot to be able to house one powerful enough. A Roomba, and even some vacuum cleaners are built to pick up dirt and very small objects, not anything like the debris that I discussed with my stakeholder. After reasonable research I found it hard to find any vacuums that were called 'quiet' that were nearly as quiet as they would need to be in a social space like a café too, disappointingly. It is very unlikely I will be using vacuuming as a primary function.

Current Plan and Elements that need to be looked at

I have now decided that I want to design a robot that can clean the floor and replace the need for an employee to do it and be around customers a lot. A rover of this function elements that will all need to be explored before I can reach a full design solution. Those areas are functional (how is debris collected and stored), movement related (including how the rover finds its way), and other user-centric requirements like safety and UI. These are all the things I will be working on and designing over the next few months at least. The priority, of course, is working out the main functions.



While the process of vacuuming may not be suitable for this project, sweeping is still very viable. In normal cleaning, butler's brushes and dustpan brushes are both used to clear a wide range of shapes and sizes of debris in a café. To take the hundreds of years of the use of brushes in such restaurants as evidence, this is most likely the best method of collection of debris. Even if I have decided on automated sweeping, however, there are still many ways to do even this…

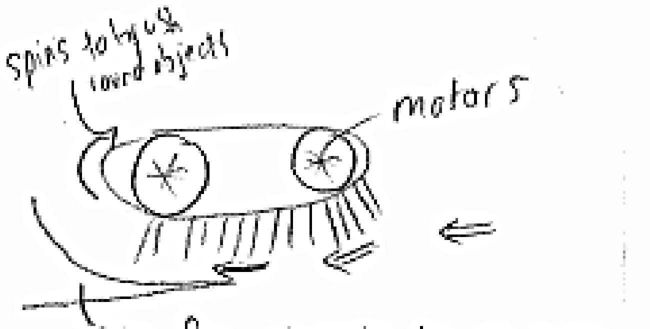
Dust Pan and Brush

takes time to pick things up

and in Covid, it is important

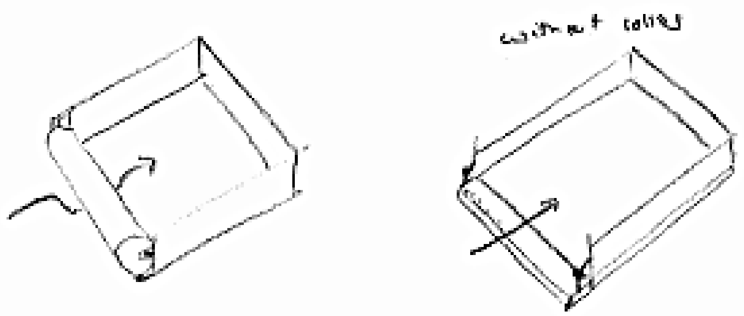
to get as much as possible ⇒ make brushing easier

Idea – brush moves automatically



For the sake of testing I can simply do one motor ⇒ smaller conveyor

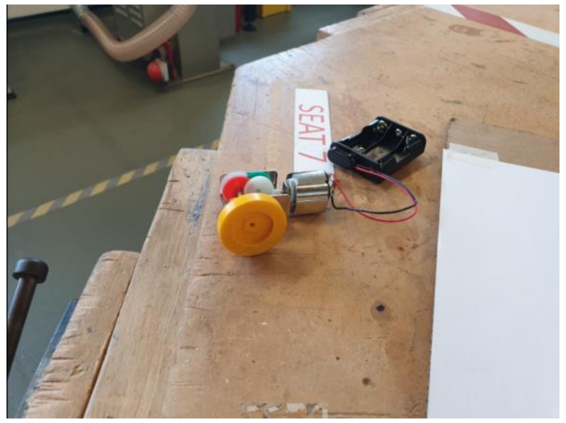
this should check whether the concept works



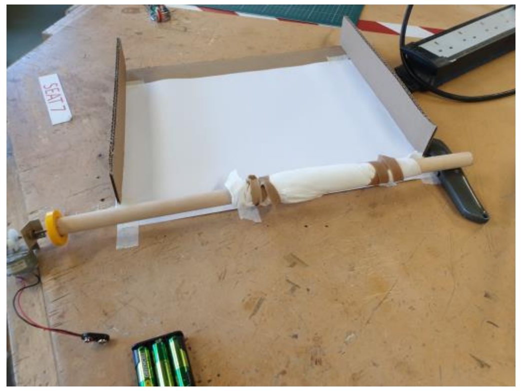
This would stop workers touching things that had been touched by customers

By attaching a roller to a motor, I could make this designed model easily by covering the roller with materials. Rather than going straight to using bristles, I used thick, rough cloth – held with rubber bands – to sweep things.

The sweeper would then brush objects into the pan behind it (currently made of cardboard) so the objects could pile up as more and more were collected.



Once I thought it was complete, I realised that the dowel piece was rolling the wrong way as shown here and when I switched it round to the other direction I quickly noticed that the movement of the dowel made it roll off of its support and away this clip.



To stop this problem I then created small cardboard brackets that would hold up the dowel on either side to stop it rolling away (demonstrated here). This meant that I could try it out with a few objects.

The primary thing that affected the use of this auto-brush now was its grip on the objects it picked up.

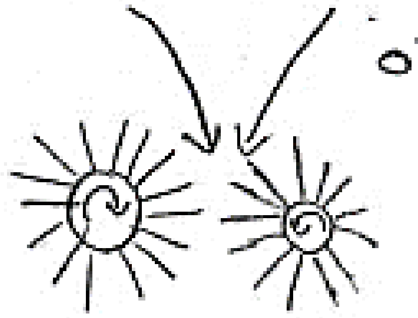
If the cloth managed to fully touch the object, it did seem to be picked up, however the cloth was not very close to the table-top and so smaller objects could not be collected. An alternative to the cloth therefore could be short bristles which allow larger debris to be picked up despite still being able to interact with low down smaller objects.

While working on this first sweeper design, I noticed that it would only be able to pick objects up that are directly ahead of it and not in a wide area, unlike vacuums which work for more of an area-effect. This was also true for previous designs such as on this page. As previously established, it was unwise to use a vacuum, however this first design made it clear that I should find ways to pick up debris from more than linearly ahead. This reminded me of the road sweeper design that helped funnel debris from a wider area, something I filtered into the next design…

Another way to sweep is via taking the design of road sweepers. I had previously used this for broom designs.

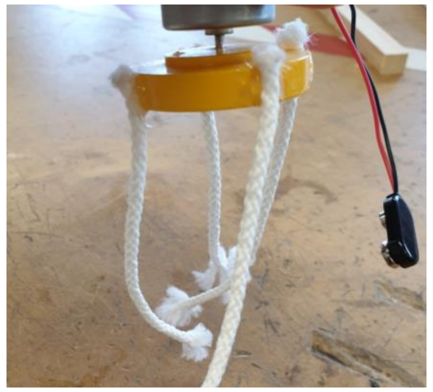
The idea of referencing road sweepers is mentioned [here](#)

Bird's Eye View



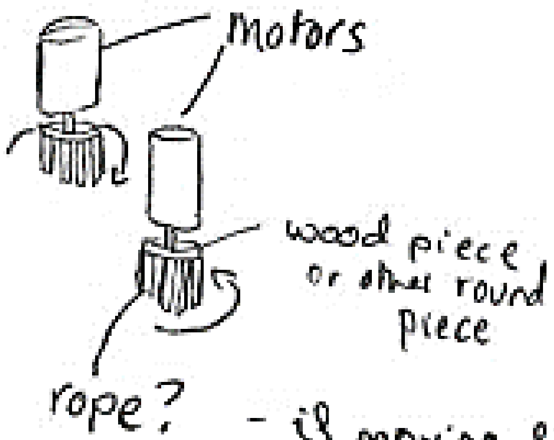
objects get brushed into centre and backwards

First I attempted creating a small quick test using small rope pieces, hot-glued to spin on a DC motor. I was impressed to see that this worked practically. The link to the video of the rope sweeper is here. While it did work, the rope sweeper only had application in small, very light objects.



Due to the rope's flimsiness, it spins perpendicular to the motor rod. What this meant is it could only move objects that had a small weight distribution. I tried the sweeper against my eraser and

y erase … aser was more easily
as close … e sweeper hit.
he mid … distributed closer to the
s effect … msiness was a problem was
l pieces … o be swept by such a weak
ted its … tion to this would be to use
nt leve … e a sweeper with more
robust bristles that can hit a wider range of objects and sweep them back:



- if moving fast enough the rope can perhaps provide enough force to move larger objects. If this is not the case, I can try bristles.

First stripping a brush, I glued brush bristles to a
ttach to a motor. As
attaching the bristles
nd 30 degrees (videos
ust on the links). At
he outside (on the 0
became evident that
es and stick the

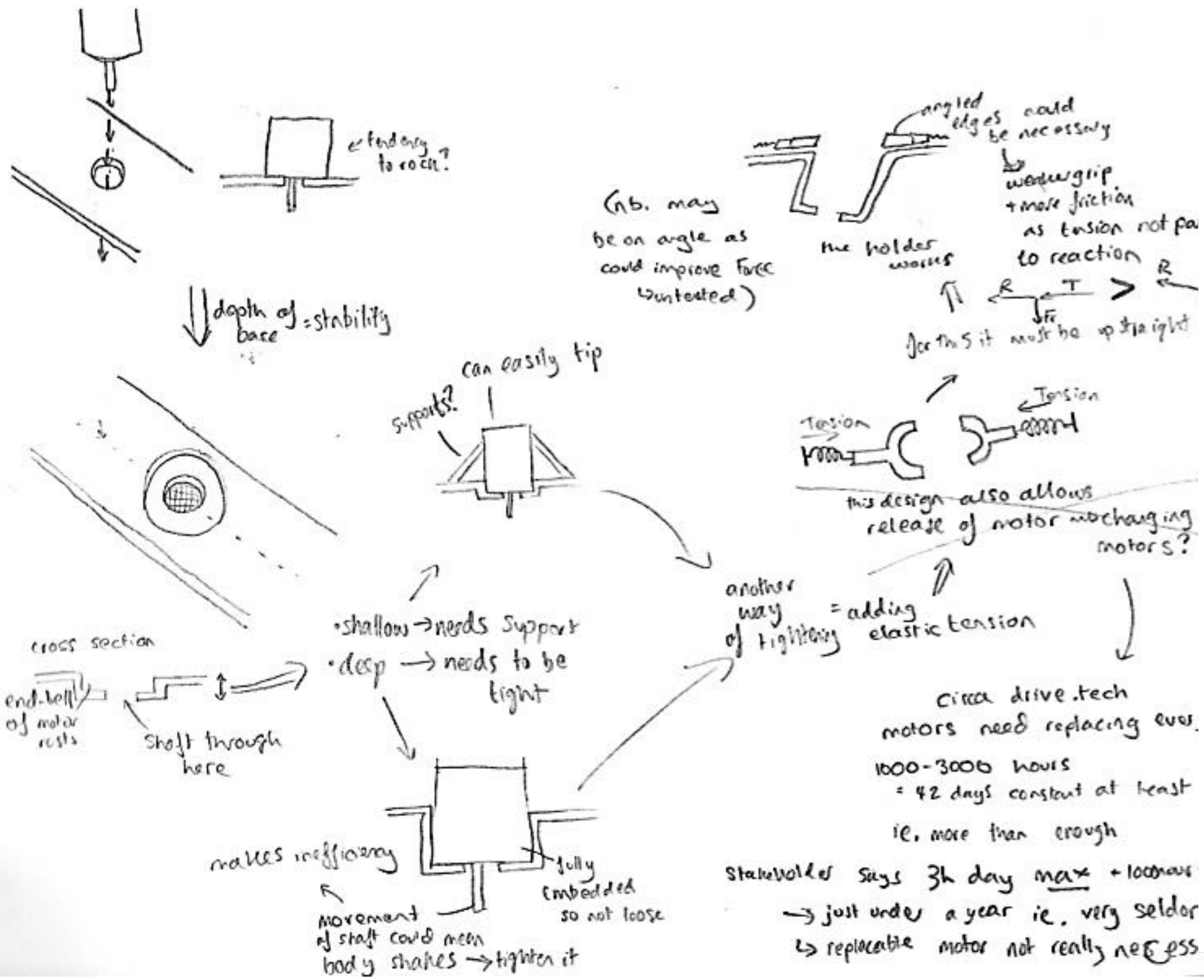
The results of this test showed that despite their smaller size, the real bristle brushes did not fail to sweep the dust in the videos back and seemed to work just as well as the rope brush did. Additionally, there was less spread in terms of the direction of the dust. The differences between the effectiveness of real bristle versus rope is quite subtle when it comes to dust, so a more suitable test might be for larger objects. For this test I could refer back to the previous test where the rope sweeper attempted to sweep similar weighted objects with different centres of gravity. Additionally, the angle of the bristles gave the sweeper a larger area of affect without having to spin faster or sacrifice any significant force – 30 degrees was appropriate

In this it was clear that my thesis was correct and the stronger bristles had a better effect than the rope. Most likely I will be moving forward with the bristles however it is important that I take note of the usefulness of the rope's greater area of coverage in comparison.

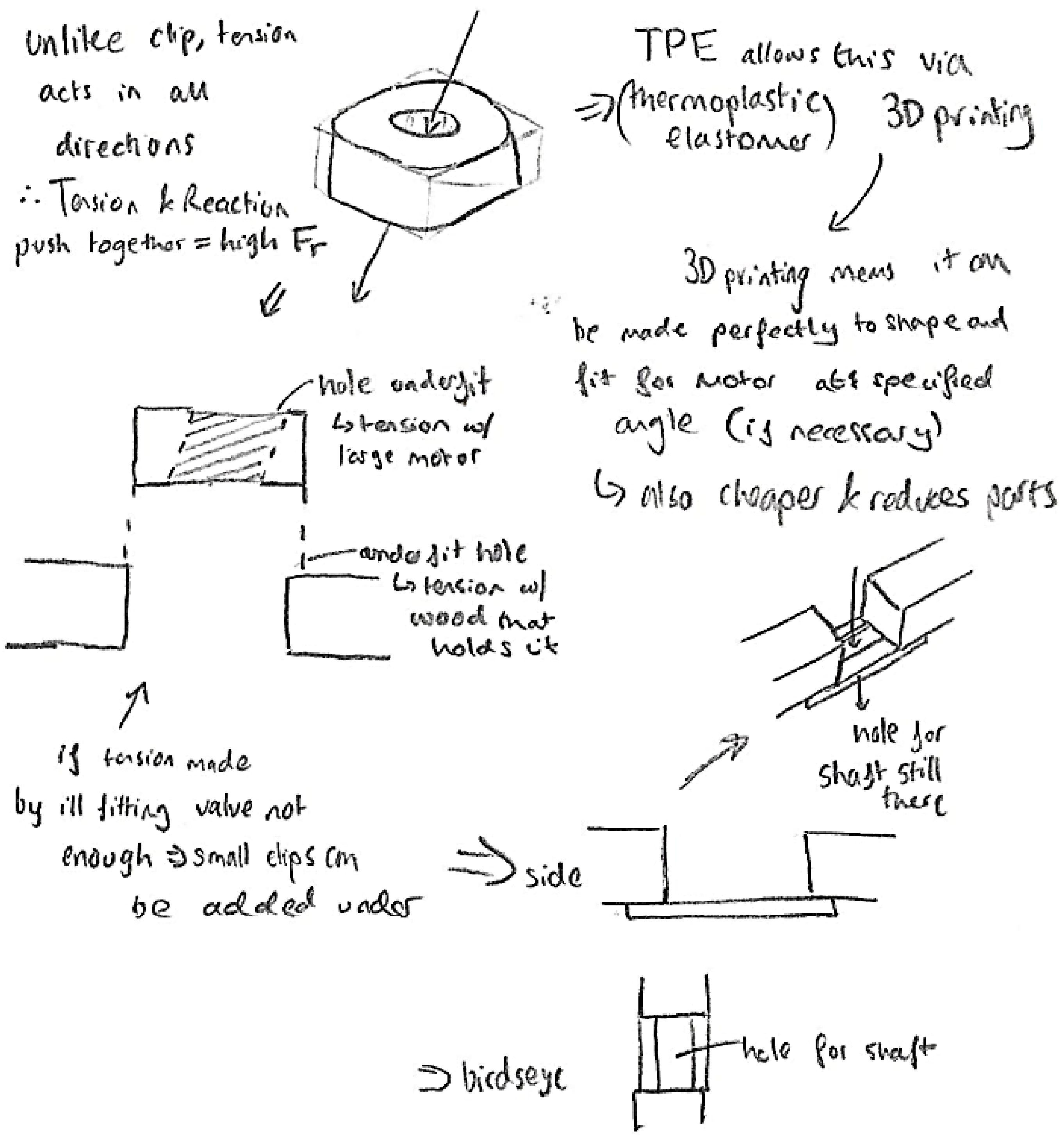
Mounting the Motor

To implement these motors onto a design, I need to figure out a way to mount them onto the chassis. This would mean stably holding the motor in place while allow the motor shaft to connect to the brush below it. The mount must not inhibit the spinning of the brush and the best effort possible needs to be made to reduce vibrations of the motor body to reduce inefficiencies. As to keep the motors in as good shape as possible, some sort of cushioning would be ideal too.

In the videos on the previous page, there was a little bit of thought put into having the sweeper spin on an angle, i.e. the motor not pointing straight down. While more investigation into the usefulness of this can be done later, it might be good to reach a possible design that allows for the motor to be at such an angle.



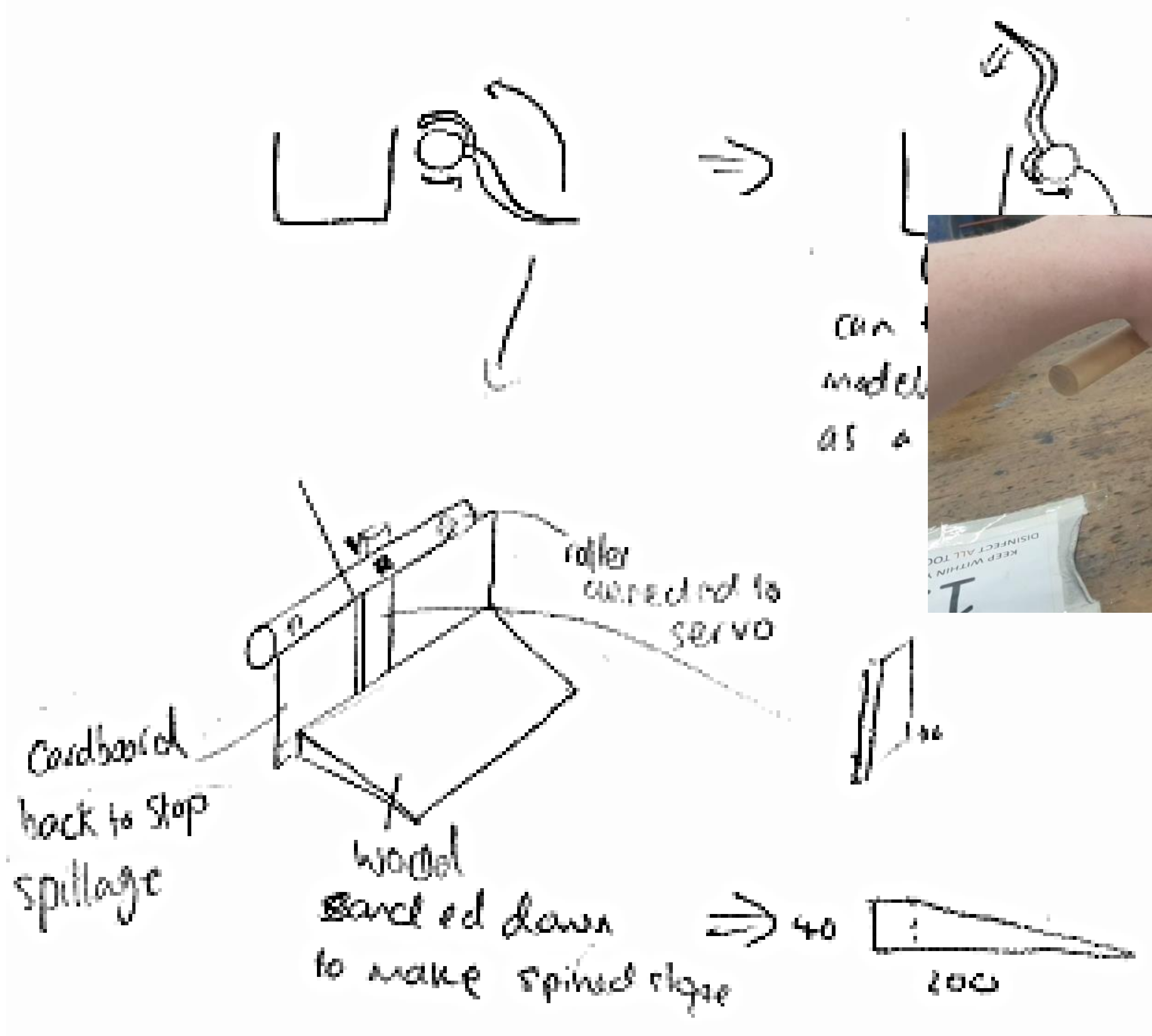
Another way of using tension to hold the motor in place Using interference fit

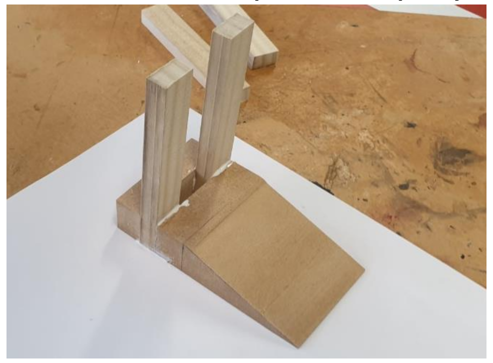


SCOOP MODEL 1

While the brush can help collect the loose pieces of food, food that is stuck to the floor is harder to clean up. One potential idea I referred to in the stakeholder discussion, on this page, was to scrape it up and then collect it. This current page will refer to doing that with a scooper, that can also help collect debris picked up by the sweeper(s) too. These scoopers would be rotated back using a servo or similar motor.

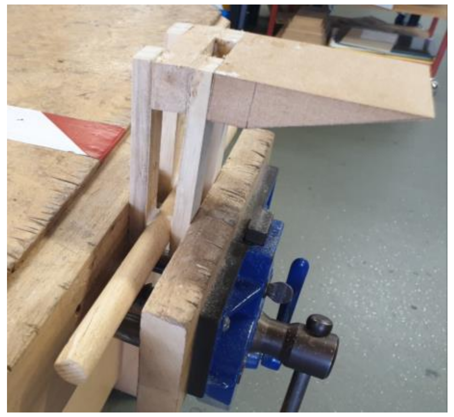
In the case of this, a low down automatic sweeper ~~may~~ may not be suitable. Perhaps an automatic way of picking things up could work





As there will be lots to clear up on every working day, the pan that debris is brushed on to will fill up very fast. To refresh the pan, it could perhaps up turn itself and tip all the collected objects into a separate container so it can then collect more.

To get this to work I decided to make a surface that can be spun over by a servo motor. I used a shallow slope for the 'pan' to make the front edge pointy (to help objects be pushed on to it).



...mpty spots with pieces of cardboard, ...s fit for testing – I just had to 3D print a bracket to securely hold the design in place on the servo motor that I will use.

With the completed model, I then had to conduct testing. For this to be a viable scoop, objects needed to be able to be pushed on to the ramp easily, and also stay on the ramp. As seen in this video, potential debris like water bottles quickly fell off due to the slope. Additionally, I was interested in seeing how this scoop model dealt with finer things like crumbs and dust. Shown in the picture, the MDF was very rough so would stick to crumbs a lot. While this wood was not in any way finished, it was clear That there would be far less problem using something like metal or plastic for the scoop material. An additional problem that is mostly associated with woods is the large weight of this. While I have not tested it yet, this scoop would definitely be too large a weight with too high a moment distribution to be comfortably carried by a servo motor (never mind the debris it carries). An improved scoop would be lighter, flatter, and potentially have a sharper edge.

By making this model with wood, it is important that the many risks associated with any processes are noted before hand.

The use of any tool in a workshop first requires safety goggles, and a trained professional to ensure full safety measures are maintained. Some woods, can give off lots of dust. This dust, especially in cheap modelling woods like MDF, can be very fine and therefore be harmful if inhaled. This can pose a high threat if continuously working with such woods, but has a lower risk when done for individual models such as the one I am doing. Nevertheless, a simple safety precaution to deter any potential hazard like this is to wear a protective face mask.

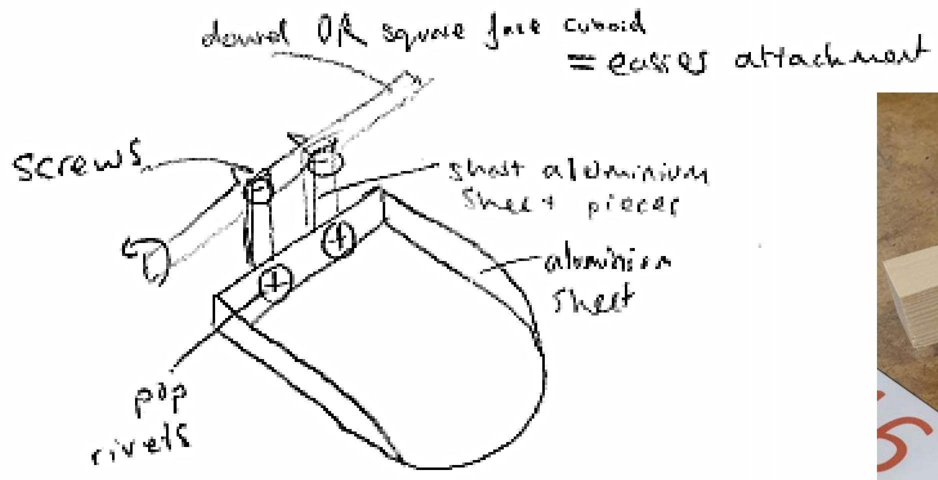
SCOOP MODEL 2

The wood in this case takes a lot of effort to make smooth and is very difficult to shape. The alternatives, plastic and metal, are far more shapeable with better working properties

Additionally wood is far heavier than plastic and metal (if used as a sheet). Perhaps instead I could replicate a shovel or spade

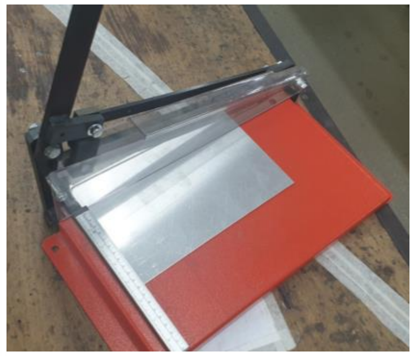
this has a sharper point and will not need to collect things on a slope like the wood model from before

Aluminium sheet being bent to make walls and sharpened to make the point would be a good start



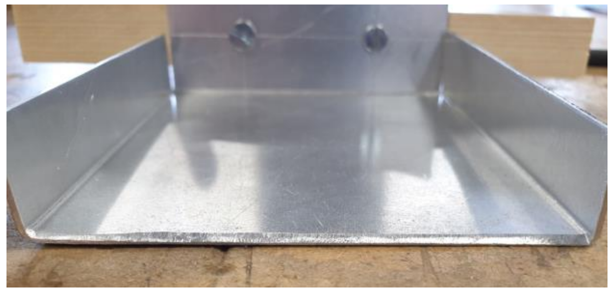
Shovels can have many different forms. According to this website, rounded shovels are more used to dig into things while flatter ones tend to be scooping things from off of a harder floor. Additionally, the edge of the shovel is conditioned for the size of the objects it will be picking up: ranging from sharp edges for compressed finer particulates and flatter block edges for loose pieces of dirt. These ideas can be roughly translated to this context where I would likely look to use a flat headed, sharp edge shovel to be best for scooping off the hard floor and to pick up the wide range of debris (as I want to pick all types, all the way down to fine dust) respectively.

The second model made corrects the problems of the first. Using the design choices of a shovel (as shown left), I could make a scooper that is more suitable for scraping and picking up stuck food/drink. This was possible using metal (Aluminium in this case).



To cut the Aluminium in the first place, I utilised a Guillotine. When doing metal work, there are a few safety precautions I had to be aware of. First, all physical work in a workshop should be done while wearing safety goggles to protect eyes from any and all rogue objects that can damage sight such as dust or shavings from metal cutting. Additionally, another trained individual being around can help reduce chances of something like being caught under the blade. If a cut is acquired, the cut should be cleaned first with water and bandaged to reduce bleeding, utensils should be cleaned before re-use.

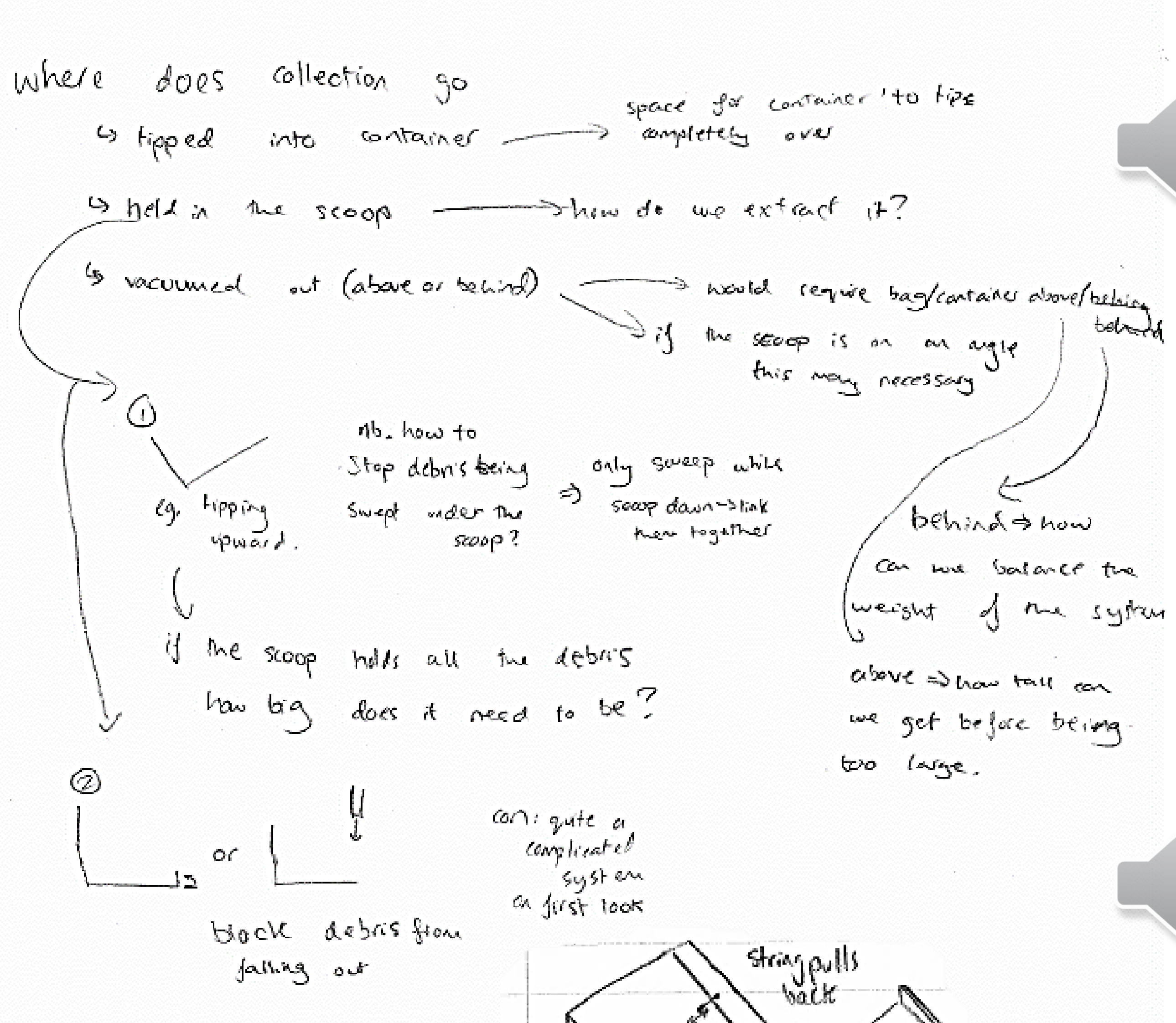
After cutting using a Guillotine, I began bending the metal to shape with a bench folder, I could use a rasp to get the sharper edge I desired. Additionally, following shovels, the flat base would mean that objects could be held more stably.

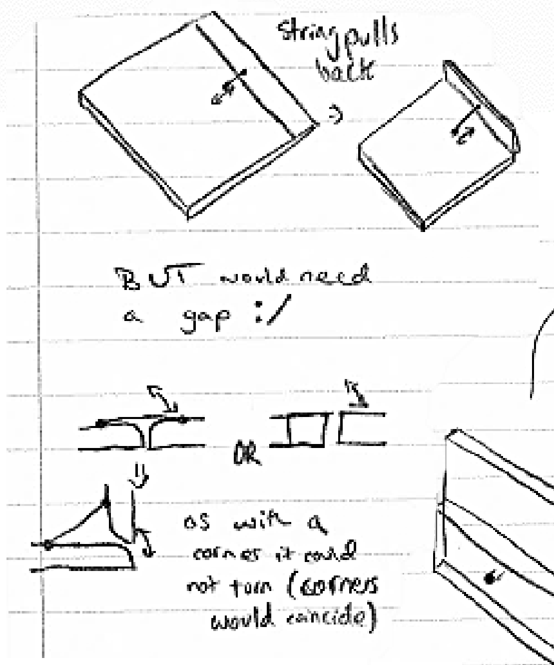


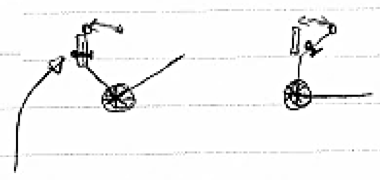
Despite its higher functionality, this model is also lighter – being half the weight of Model 1 as shown below. Additionally, video comparisons shown here and here prove the increased effectiveness of the shovel shape if I were to go forth with the idea of using a scraping scooper, a sharp, flat shovel would be the better choice.

Therefore, the best choice to move forward with is using a shovel-like shape. There would be a heavy emphasis on a sharper tip to ensure objects can be picked up easily, and an initial preference for the use of a metal.

While the scoop can collect the debris, there needs to be a way of storing it until it can be taken out by a person to dispose it.







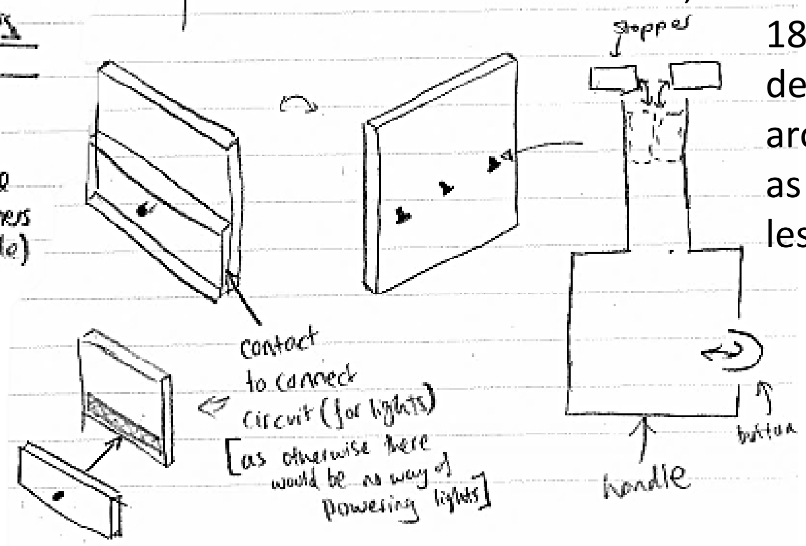
For the third idea, vacuuming out would not be ideal as, while dust and dirt can be collected, a vacuum could not really have a large enough entrance to collect larger objects like packages and food.

According to screwfix's options, a small vacuum bag might hold around 9 litres of debris and be emptied every other week (cite following audio clip) usually with a maximum use of no more than 2 litres full of dust. According to a test I did on dust pans I had at home, dustpans will tend to hold around ¾ litres– tending to be emptied once per day. When I asked my stakeholder, she confessed that vacuum cleaners were usually used once every evening against dustpans' many times throughout the day. The dustpan was said to very rarely be anywhere near full, and that larger solids were more often picked up by hand. A frequently used product such as this, being filled with primarily large solids, will likely need to be consistently emptied and would have a reasonable chance of being daily too. From this I can extrapolate that I might want a container to hold around 2-3 litres in order for it to be emptied weekly. I asked my stakeholder what solids are picked up the most in her opinion and she gave me the following list:

- Mud, glass, straws, small food pieces with dustpan and brush
- Cartons, napkins, packaging with hands

As this product would aim to reduce the contact of employees to customers, both of these lists of objects would need to be cleared. If the container were not big enough, then the larger objects like packages (which cannot mould to their container) will stack, so the container would have to be quite large in its bird's-eye view.

A plastic water bottle, likely the tallest solid object that could be picked up, is usually between 170 and 200mm tall, so 180mm wide scoop should be wide enough to hold one (as the bottle likely would not be perpendicular to the scoop. The container should follow suit with its width too. Next, the container's other axis might be at least 120mm to ensure the size for the plastic water bottle, unless something suggests a smaller or larger size should be used, I think 150mm is a good dimension to start with. If the container is 180x150mm then it would need to be 70mm tall to reach the desired volume. (n.b. as OCR Anthro data says hips for adults are around 400mm, the gap between legs of a chair may be as little as little as 300mm so the width of the whole product must be far less than this in order to fit in between if necessary)



The methods I designed here to allow use of the scoop as the container itself are incredibly complex. At least until a simpler method arises, I should proceed as if I must use a container.

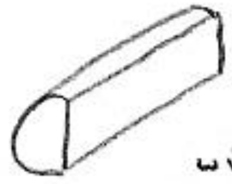
Summary:

Scoop will collect debris that will be tipped into a container behind it. The container will be 180x150x70mm while the scoop needs to also be 180mm wide.

Technical Design – Servo motor and Scoop

Now with a grasp on the size of the scoop, as well as the function I want it to serve, I can design a system that builds upon 'Idea 2' from [this]() page. It is imperative I keep the design as simple as possible and fall in line with previously specified needs such as a smooth surface for debris to be tipped into the container, and design for a metal scoop. The final design reached is show bottom right.

• amendment ⇒



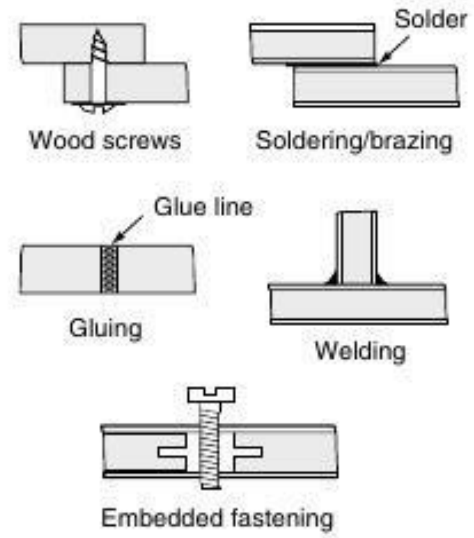
$\frac{2}{3}$ cylinder with flat face will be easier to attach scoop to

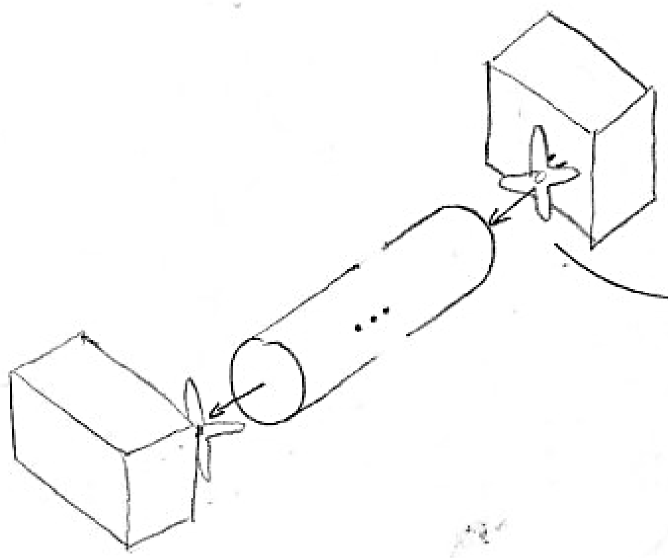
→ if not possible, full cylinder fine but not preferred

→ preference scoop has shape:

not

↳ aids tipping into container





connection: servos typically come with parts to attach (e.g. the 4 prong star shown)

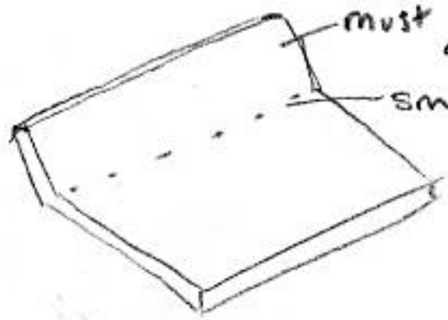
⇓

① make own servo connector
or
② make attachment to existing connector

⇓

due to difficult shape of servo pin

② would likely be an easier option



smooth = no screws like in test scoop

↳ under assumption of use of brass ⇒

If the cylinder were made of a metal, brazing or welding may be a good, flush join to use. If they are dissimilar materials, however, an adhesive like epoxy resin would be necessary.

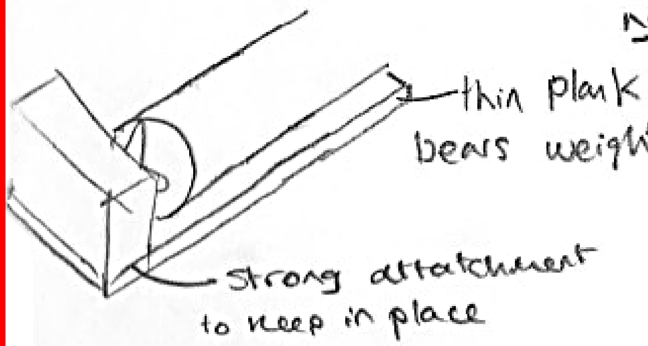
Servo motors tend to have poor capabilities when it radial loads (in this case, weight)

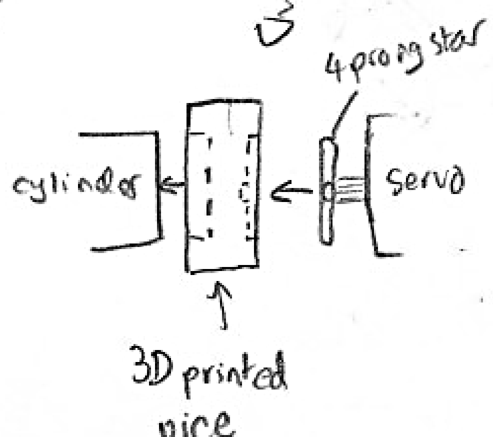
↳ piece beneath cylinder to hold it up

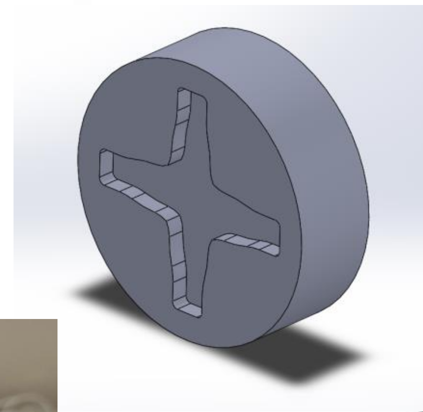
nb. plank should be lubricated somehow

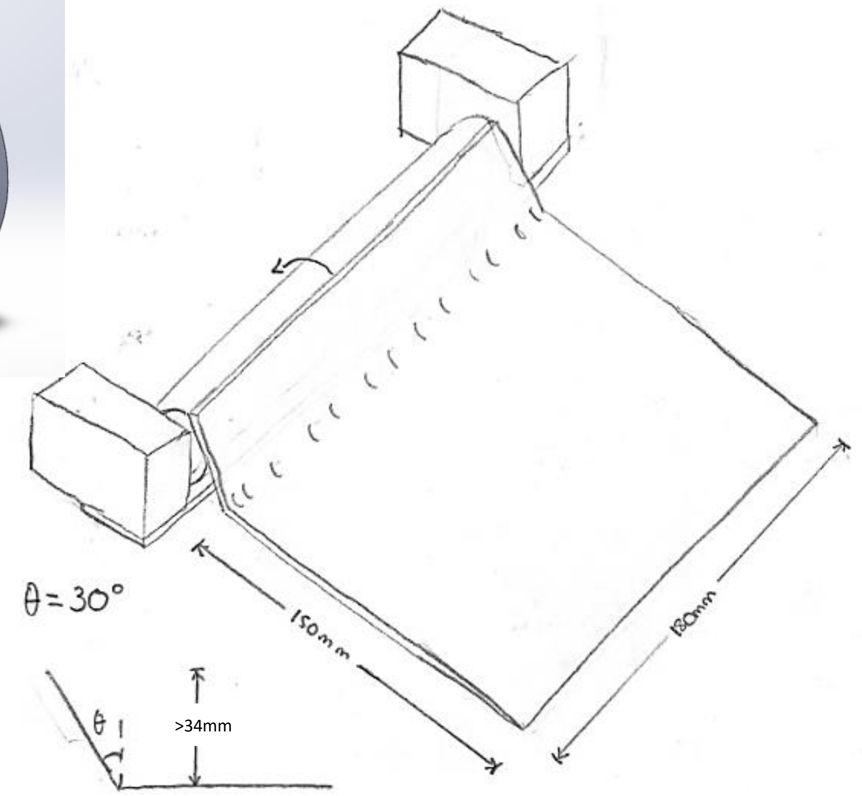
⇓

nylon?

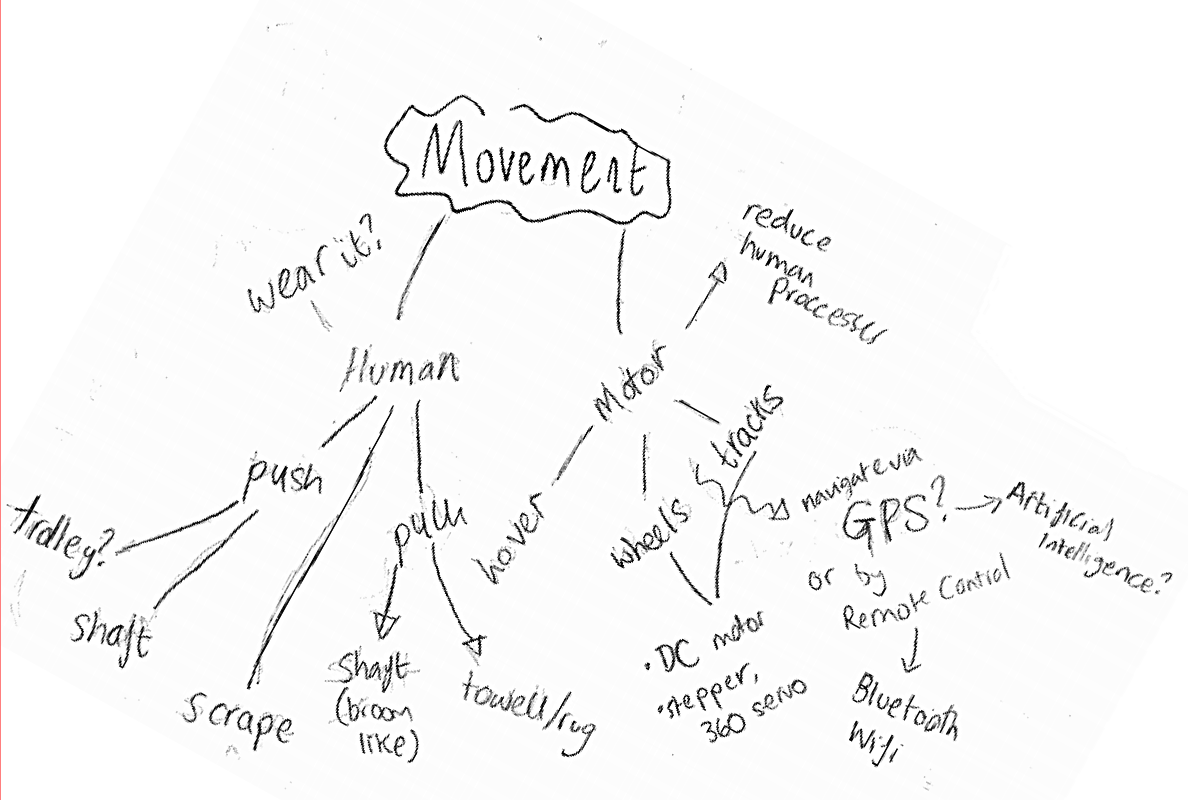


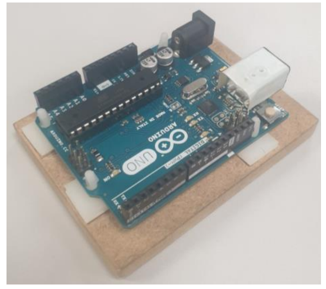






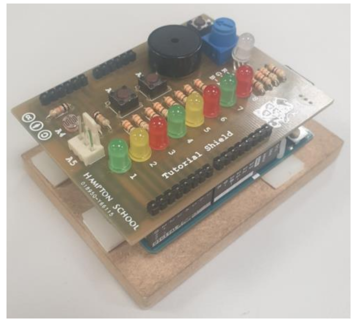
With a rough scope on how my chosen product might pickup, store, and dispose of debris, I need to begin analysing the method of movement I will use.
Cafés have many tables and chairs that will need to be avoided, as well as any people who may be walking around, these will need to be avoided. While avoiding these obstacles the product must be able to clean around and under tables, as well as in open space.





To get the movement to work I had to code the controller for them. I did this using an Arduino microcontroller that I wrote code for in C#

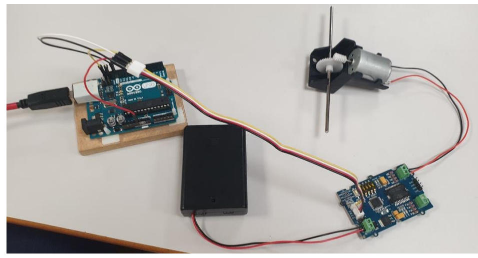
For testing reasons, I constructed the code using a previously made LED shield in which I could use different lights to signify different outputs. I could also use the buttons and dial on the shield for inputs.

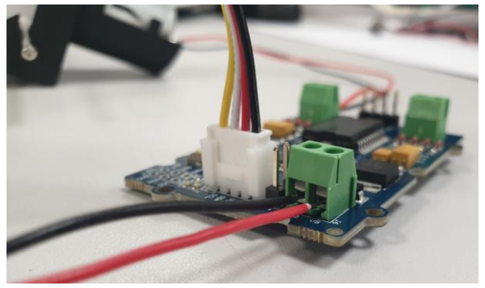


I coded the system so that it one button could be for forward and one button for backward, then the dial (A1) could pinpoint the direction of the movement. The lights represent movement as noted by the comments.
Once I had got this to work, I could build the system that would actually power a motor instead of lights.

```
void setup()
{
  pinMode(1, OUTPUT); // R forward
  pinMode(2, OUTPUT); // L forward
  pinMode(3, OUTPUT); // R backward
  pinMode(4, OUTPUT); // L backward
  pinMode(8, OUTPUT); // check

  pinMode(A3, INPUT); // move backward button
  pinMode(A2, INPUT); // move forward button
  pinMode(A1, INPUT); // direction dial
  float dial = 0;
  int direc = 1;
}

void loop()
{
  digitalWrite(8, HIGH); // check on
  float dial = analogRead(A1);
  int direc = map(dial, 0, 1023, 0, 100);
  if (digitalRead(A2) == HIGH) // forward
  {
    digitalWrite(1, HIGH);
    digitalWrite(2, HIGH);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
  }
  else if (digitalRead(A3) == HIGH) // backward
  {
    digitalWrite(1, LOW);
    digitalWrite(2, LOW);
    digitalWrite(3, HIGH);
    digitalWrite(4, HIGH);
  }
  else
  {
    digitalWrite(1, LOW);
    digitalWrite(2, LOW);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
  }
  if (direc <= 15) // turn left
  {
    digitalWrite(1, HIGH);
    digitalWrite(2, LOW);
    digitalWrite(3, LOW);
    digitalWrite(4, HIGH);
  }
   else if (direc >= 75) // turn right
   {
    digitalWrite(1, LOW);
    digitalWrite(2, HIGH);
    digitalWrite(3, HIGH);
    digitalWrite(4, LOW);
   }
   else
   {
    digitalWrite(1, LOW);
    digitalWrite(2, LOW);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
   }
}
```

After analysing the options, it is clear that to reduce human interaction, automated motors are necessary. Examples of motor options would be DC motors, Servo motors or perhaps Stepper motors. The requirement is a strong torque as well as a relatively precise turning cycle. Stepper motors use precise angular turns and high torque (via OrientalMotor), however DC motors are also worth considering due to their frequent use in products like this.
Technology professionals at seedstudio discussed that both motors are very good at slow speeds while both can be very precise. Additionally, DC motors tend to be very efficient and far quieter than Stepper motors are. Out of DC motors, brushless have almost no noise compared to brushed DC motors, however they are far more expensive. Talking to my teachers, who are themselves professional Engineers, agreement was found with Brushed DC motors being the ideal option due to price and the fact that these DC motors are as precise as I will need them to be.





The system connected the shield to the Arduino via Breadboard wires and also soldering the battery and motors to the shield. To test the system I had put together I wrote some test code for one motor as shown. At first the code could not run however I soon learnt it was due to not having enough power; once a 9V battery was connected, the system ran smoothly. With the circuitry working, I can take note of the parts required and save creating the final code until I have built the chassis.

```
#include "Grove_I2C_Motor_Driver.h"

#define I2C_ADDRESS 0x0f

void setup()
{
  // put your setup code here, to run once:
  Motor.begin(I2C_ADDRESS);
  Serial.begin(9600);
}

void loop()
{
  // put your main code here, to run repeatedly:

  Motor.speed(MOTOR1, 50);
  delay(1000);
  Motor.speed(MOTOR1, -50);
  delay(1000);
  Motor.speed(MOTOR1, 20);
  delay(2000);
  Motor.speed(MOTOR1,-70);
  delay(500);
  Motor.stop(MOTOR1);
  delay(1000);
}
```

To get the product to move, there will need to be a chassis. This chassis must hold all the parts of the system while fitting certain design requirements of size and form. Before deciding on the shape of the chassis, therefore, I must be aware of the parts required.

Brushes

According to rapidonline.com the motors at school work at 6-15V which have torques of 400gcm which is about to 0.04 Nm. With the current 60mm diameter of the brushes this gives 4/3N of force provided meaning they can push objects of just under 300g (as there are two brushes). Although this is not a perfect calculation, it roughly illustrates that these motors alone should be able to brush all the debris without difficulty, even at their small size. If the heaviest object weighed 200g, then the brush could have a diameter no larger than 80mm to maintain the force necessary (however that assumes that only the end will hit it, so 200g will be more than manageable if it is a large object). More specific detail can be looked into at a later date but it is important for the chassis design to note that a motor of this size is large enough and no extra electrical components are required to increase torque.

Motors for Wheels

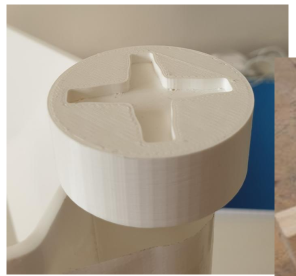
Previously looked at was the Makeblock mBot Ranger. In this design there were DC motors with gear boxes attached as shown in the picture which were 50x50mm with a 30x30mm cut-out. Each motor drives a wheel at the back which drives two more wheels at the front using tracks. The mBot weighs around 800g and likely can push a lot more weight than that. A short test (VIDEO) was done to see how much extra weight that is: when pushed against a weighing scale, I found that the mBot pushed with 1.45kg of force before recognising it was overloading and stopping. This means the mBot's two DC motors could push with around 22N of force while using a step-down gear box and 9V (6 1.5V batteries). Given the high range of speed of the mBot that would not be necessary with my product, the force produced can likely be higher (especially modifying the gearbox). Therefore I would recognise that no extra parts than this would be needed and motors of this size would be useful for my design

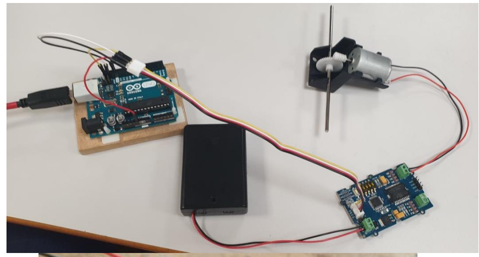
Other Wheels

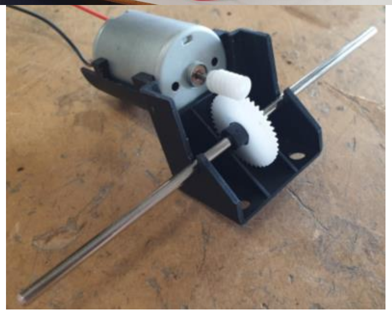
Each motor for the wheels should be able to provide the necessary force to move the device when empty, therefore two motorised wheels is enough to ensure sufficient power in all cases. No matter the shape of the chassis, two wheels will not suitably balance the design, therefore I need to be aware of other wheel options to add. A simple balancing mechanic, similar to that of a car, would be to have free-moving wheels ahead of the motored wheels. Moreover, tracks can be added to connect them to increase grip on the floor like the mBot did, however this is usually for softer surfaces that my product will likely never come across. A method from some Roombas is using caster wheels. These would be suitable for multidirectional movement but are good as they are very easy to add: they require very little support and space. For example, if a wheel is at the front it could get in the way of the brushes, but a caster wheel has more flexibility in its placement due to its small size.

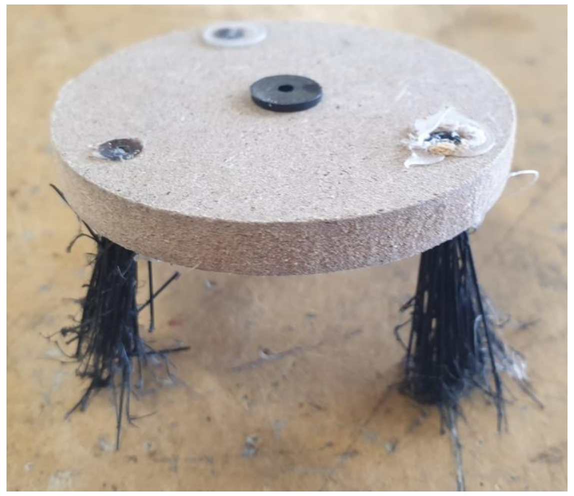
The included parts will therefore need to be two sweepers, the scoop, the servo to spin the scoop, the storage container, the wheels (and their motors), the power supply for the system and finally the circuit board for the system. My current thinking is that the circuit board will be above all the other parts on a separate platform. Moreover, any potential sensing equipment (similar to the bump sensors on the Roomba or ultrasonic sensors on the mBot) will be mounted on the casing and so should not impact the choice of shape for the chassis.

This design is currently under the use of a 180x150mm container, and a 180mm wide scoop. To decide the length of the scoop we need to consider the height boundaries of the product, this is because the scoop will have to be rotated upwards to tip debris into the container. The OCR Anthropometric data dictates an average lower length of 430mm for adults, meaning that chairs are likely usually around 350-400mm high – my product needs to fit under this with ease. As the container had a size of 150mm, this would be a fair size for the scoop too, that still should allow the design to fit well within the limits of height.



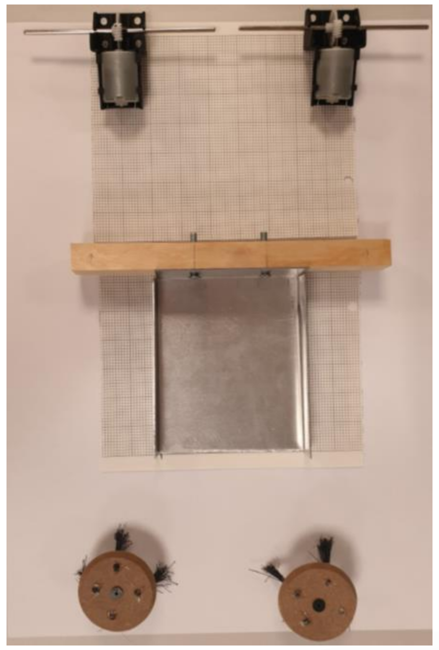




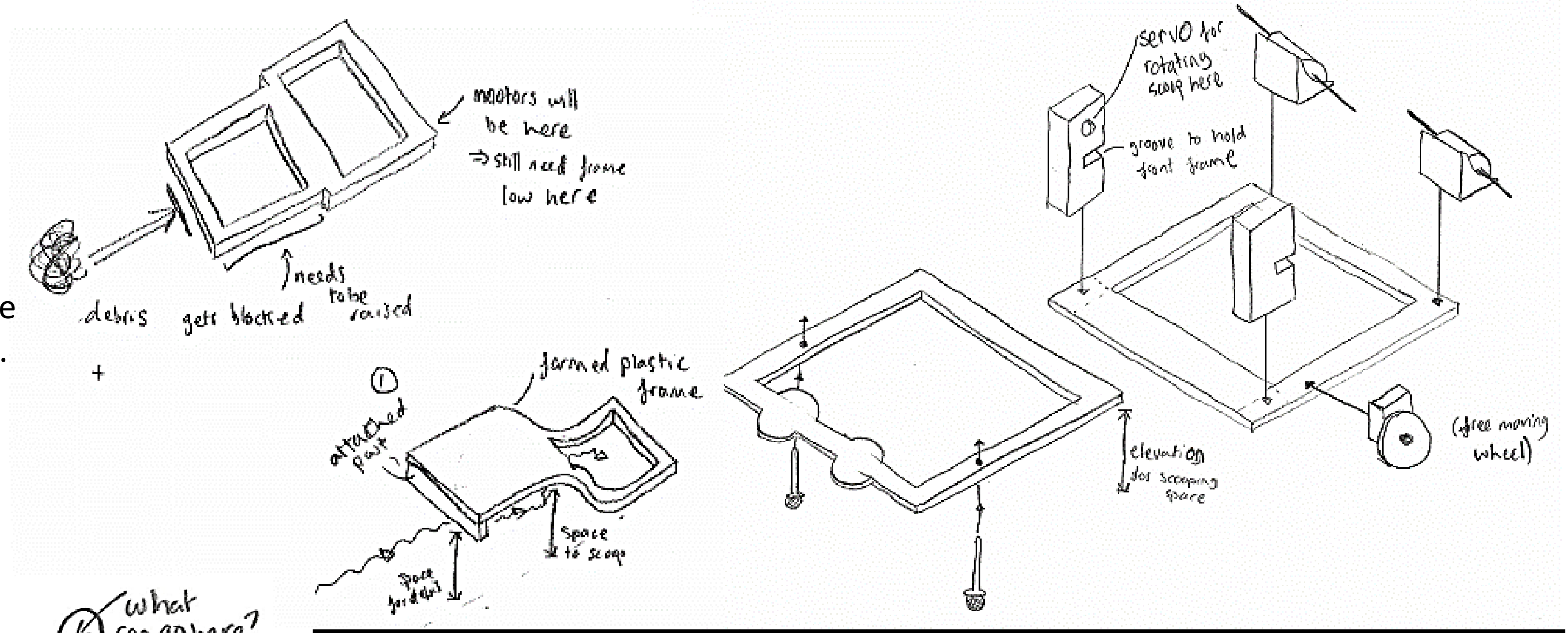


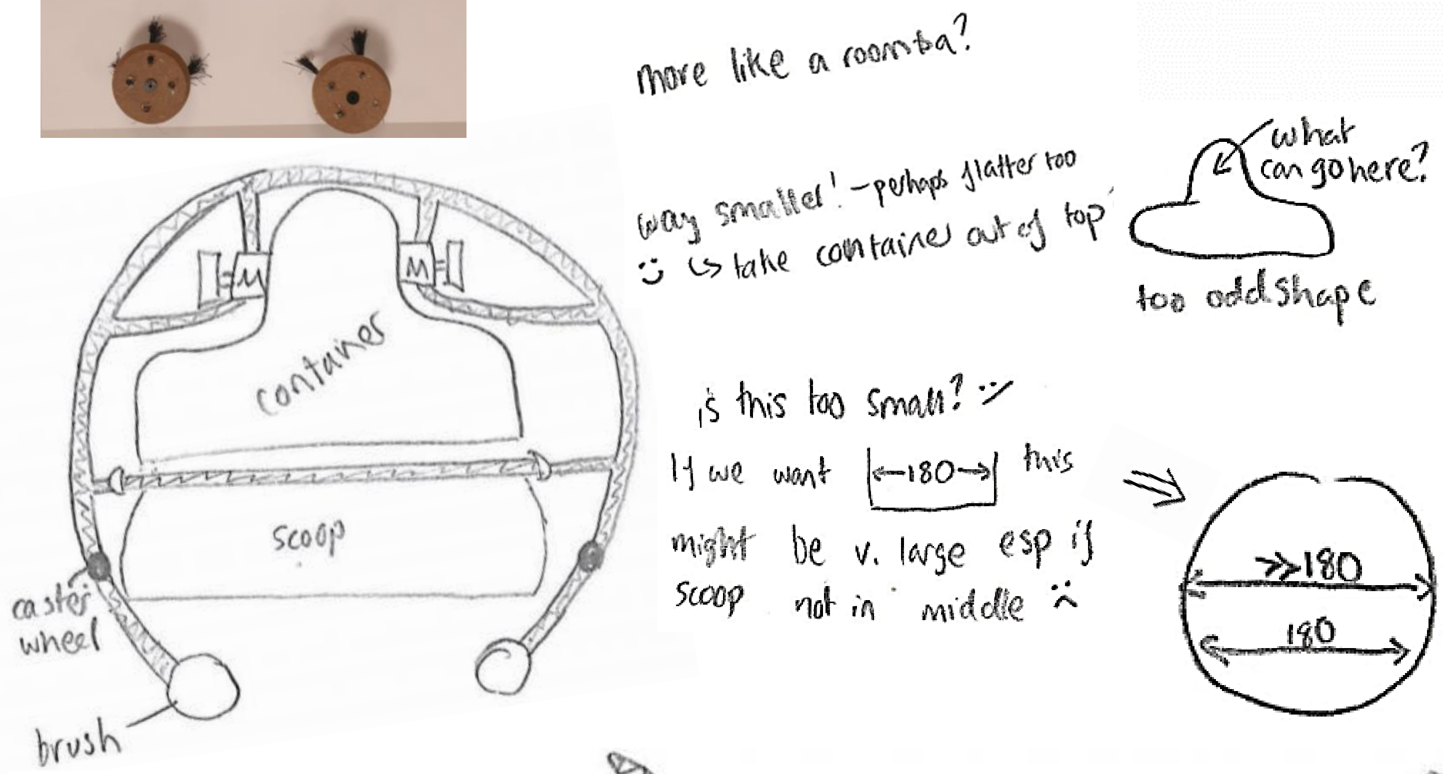
Deciding on a chassis shape is on the next slide

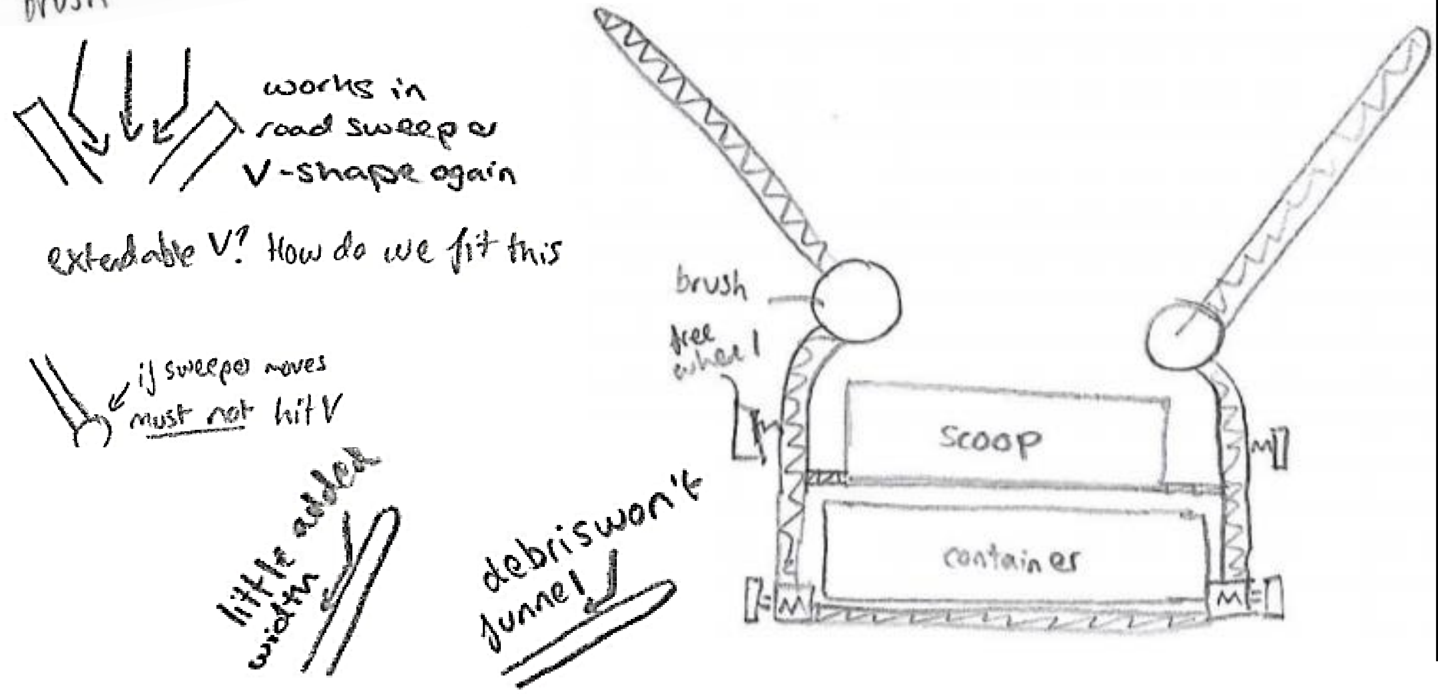
Chassis Designing



I first began by laying out the components in the rough overall positions they would need to be in. The most simple design was what I thought of first, which included just making a box frame about which the components could lie (shown right). Shown below those designs are some further ideas I thought of.







The exploration of these three diverse ideas showed me how many things there are that are still left unconsidered. Both the Circle and the V shapes have many extra issues to consider which is not ideal, especially when so many other important features have not been explored at all. Therefore, until I know more about which functional requirements I want and which specification points I am considering, I should stick to the simpler box chassis. This means I need to be quite prepared to make many changes to it as will be necessary.

A few changes were made, including ensuring the wheels and scoop were not too close as they would both need separate motors, and using the servos to raise the front so that the brushes can go underneath it (sweepers 80mm tall)

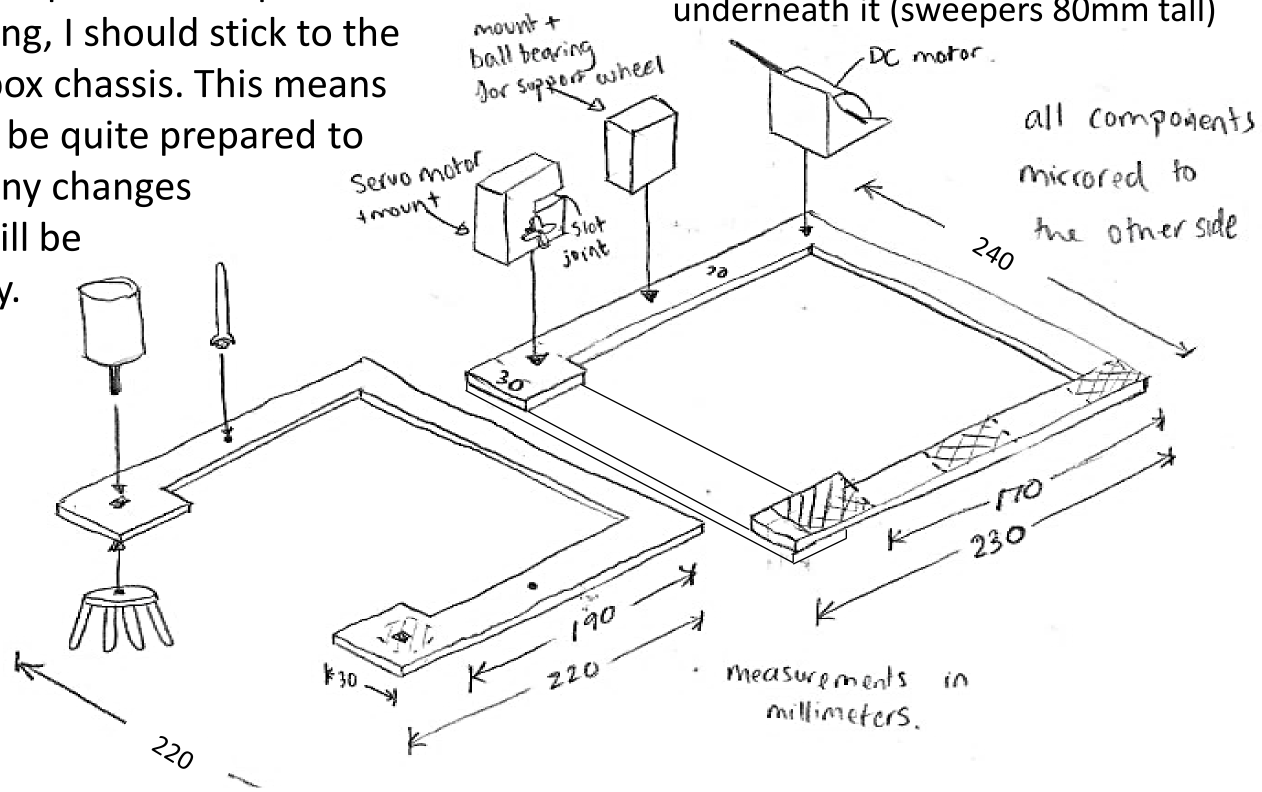


Fig. 1 shows the result of laser cutting the design I had made on the previous page. When I assembled the other components in the correct arrangement, I noticed the scoop's bar was trapped between the two halves of the chassis frame, restricting its movement. Even if this was a cylinder not a cuboid, it would be somewhat trapped. Therefore I had to cut out one of the pieces (see Fig. 2) with a Scroll Saw to get the chassis shown in Fig. 3. Fig. 4 shows the sketch of this design.

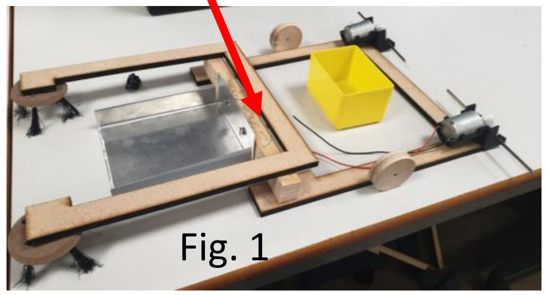
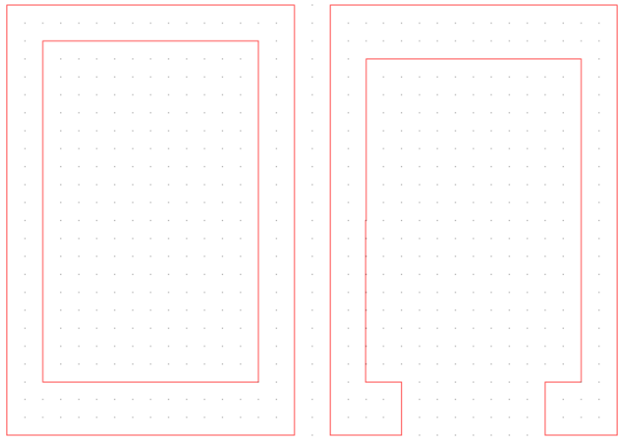


Fig. 1



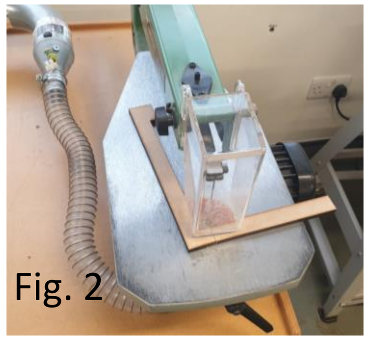
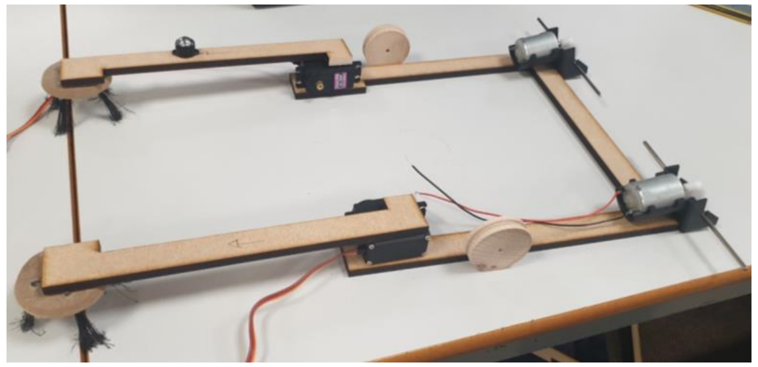


Fig. 2



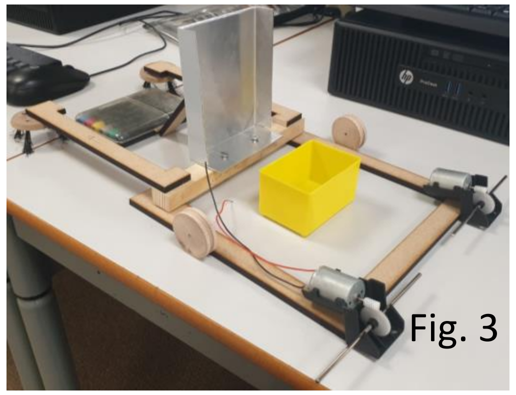


Fig. 3

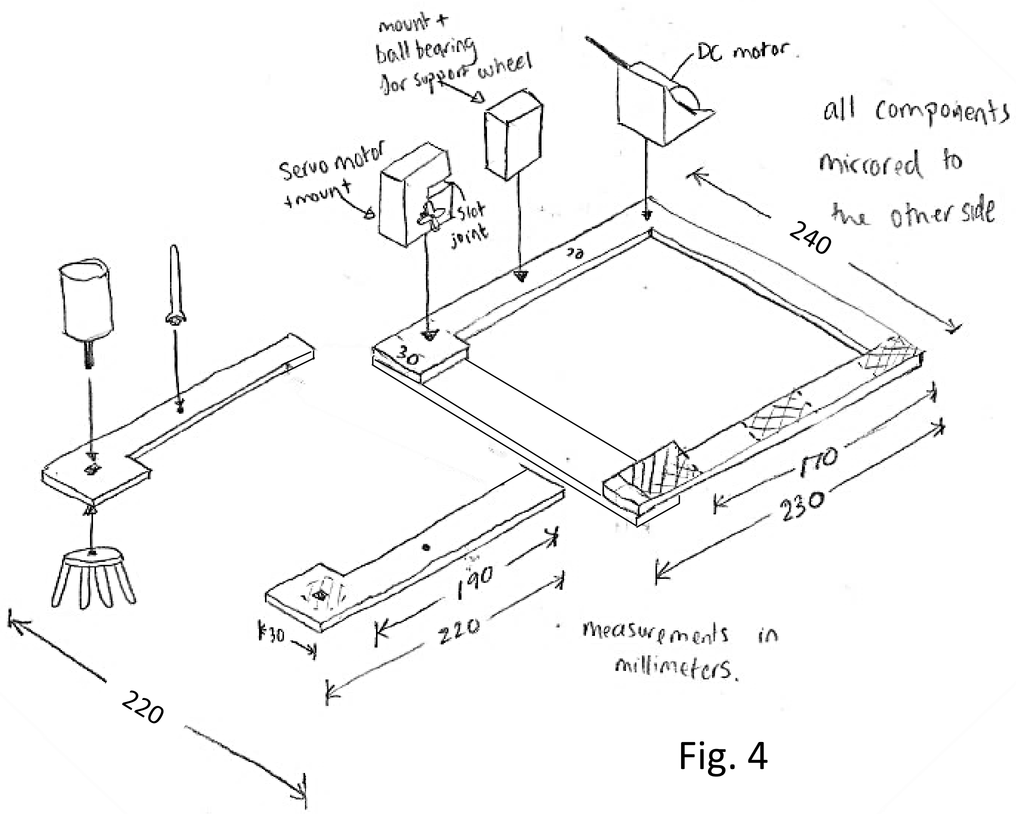
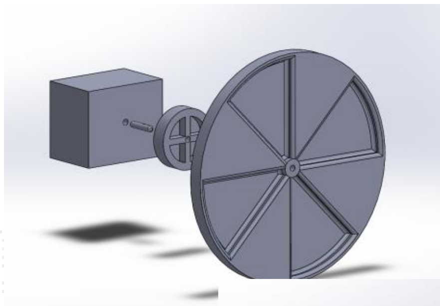
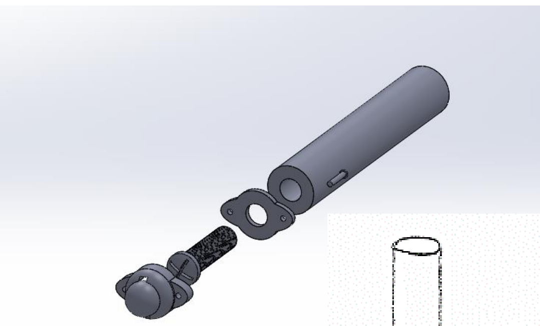


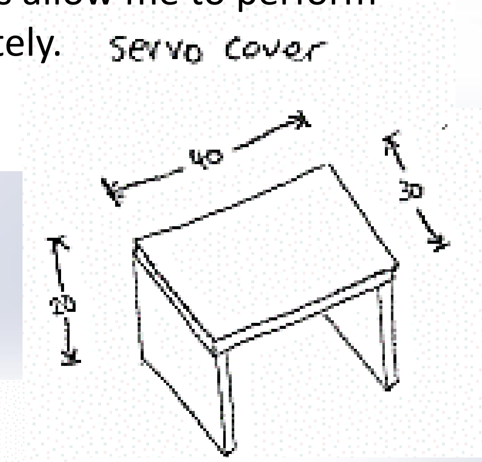
Fig. 4

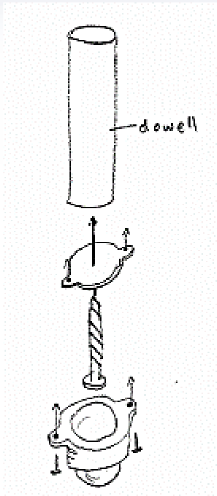
With limited access to the workshop due to coronavirus restrictions, I have decided to make a 3D model of the chassis and parts chosen so far. This should allow me to visualise the designing I am doing when put together, as well as allow me to perform iterative design, albeit remotely.

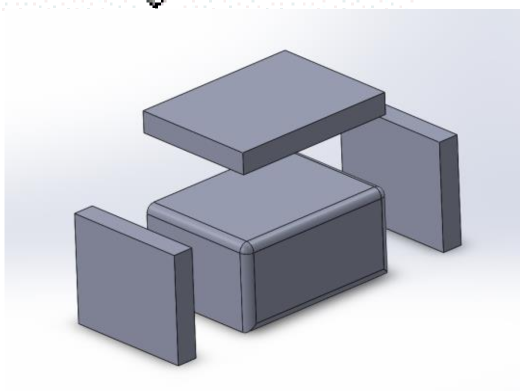


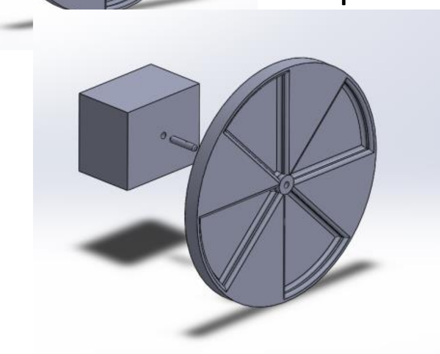
Before creating the model I designed simple ways to put the extra components onto the model. Them being the way to stilt the caster wheel, casing for the servo motor, and mounting the free-moving wheel. In a real prototype or sellable model, I would likely use a ball bearing to let the free-moving wheel spin, however for the sake of testing I would just use a loose fitting dowel (this is a 3D model so both can be represented to the left).

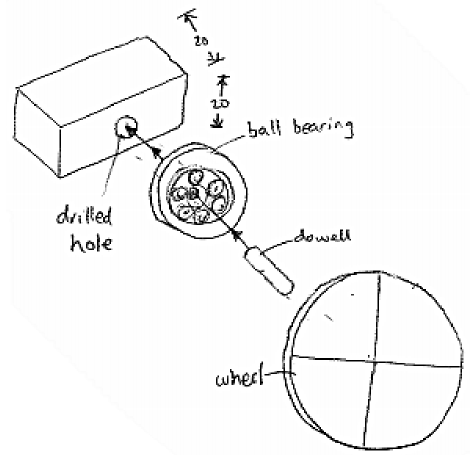




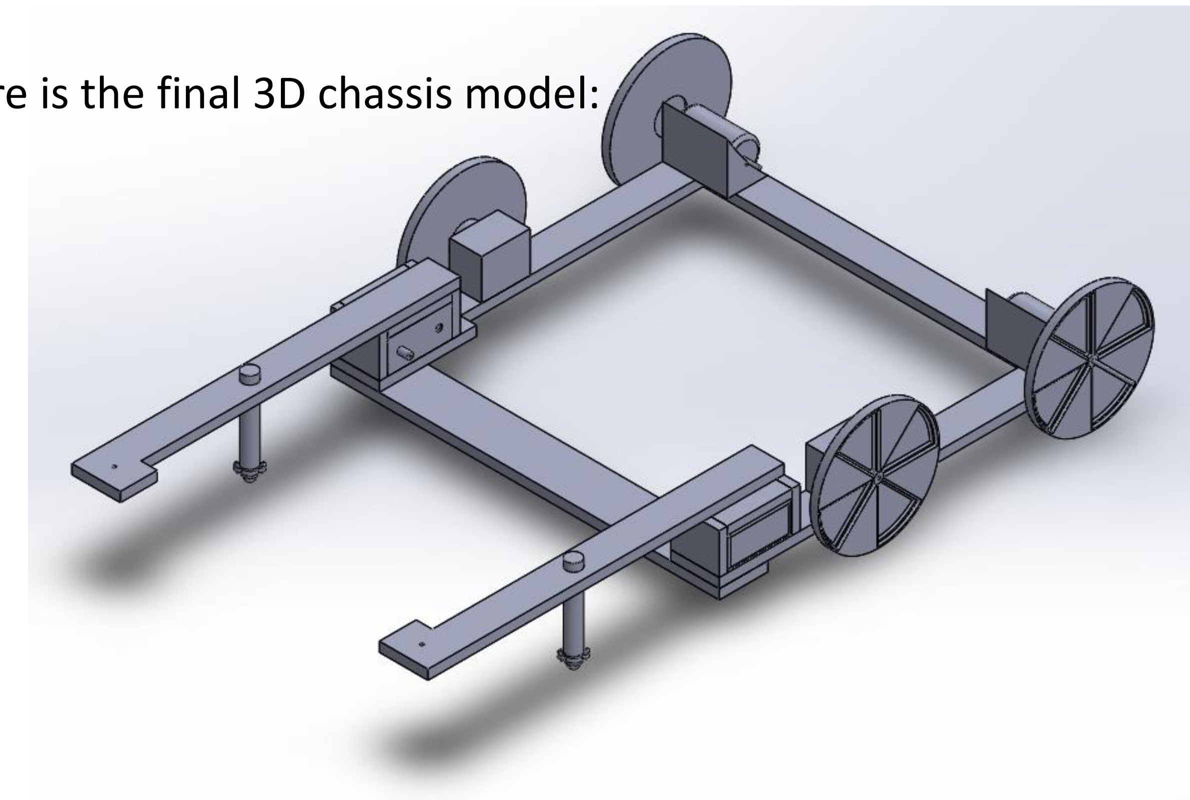




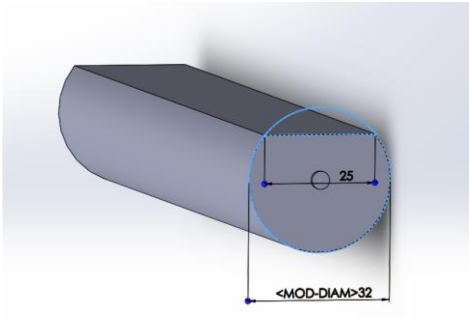


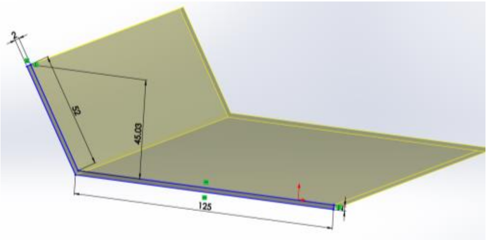


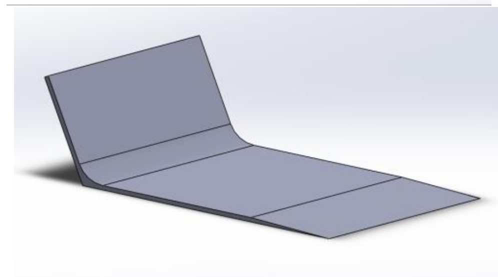
Here is the final 3D chassis model:



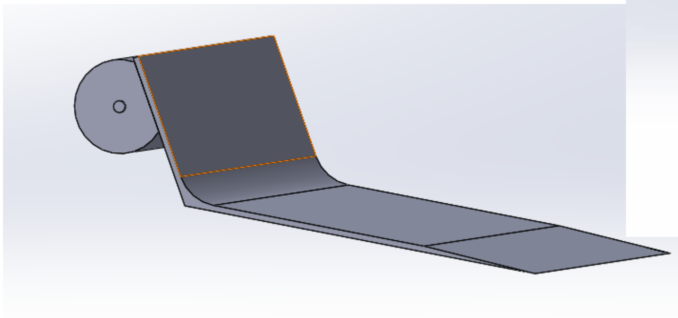
Now that I have a base model of the chassis, I can add the previously decided upon parts that make up the sweeper and scoop. This gives me my most up to date model, to scale and completely assembled.



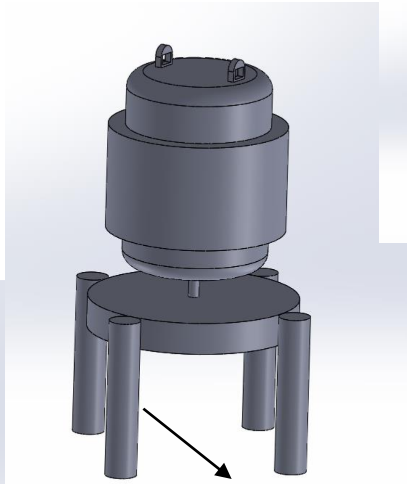




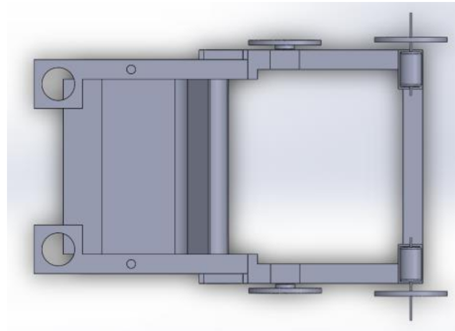
For the scoop I first had to make the respective cylinder and scoop as was specified on [this](#) page. I made sure the dimensions were a perfect fit to ensure the scoop would perfectly lie just above the ground with the tip touching the ground.

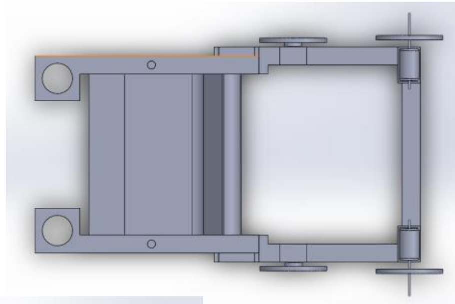


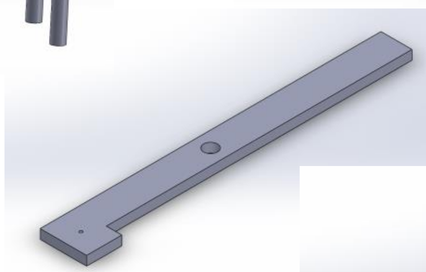
As mentioned on [this](#) page, the motor for the sweeper is going to be contained within a rubber piece that holds it tightly in the chassis for an interference fit. Product information dictates the motor body is 27.5mm diameter and 37.5mm long. I made the rubber piece 34x20mm to fit this sensibly.

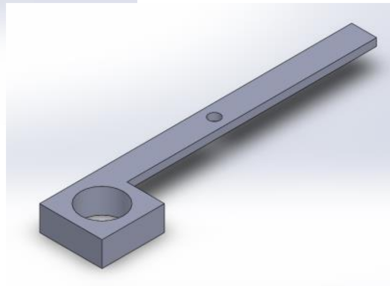


Small cylinders used as placeholders for rope (to avoid having to model rope)

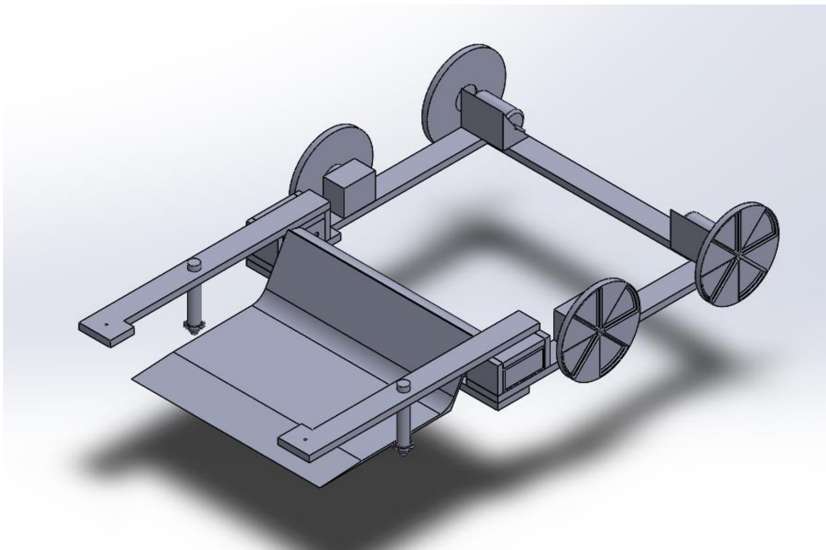




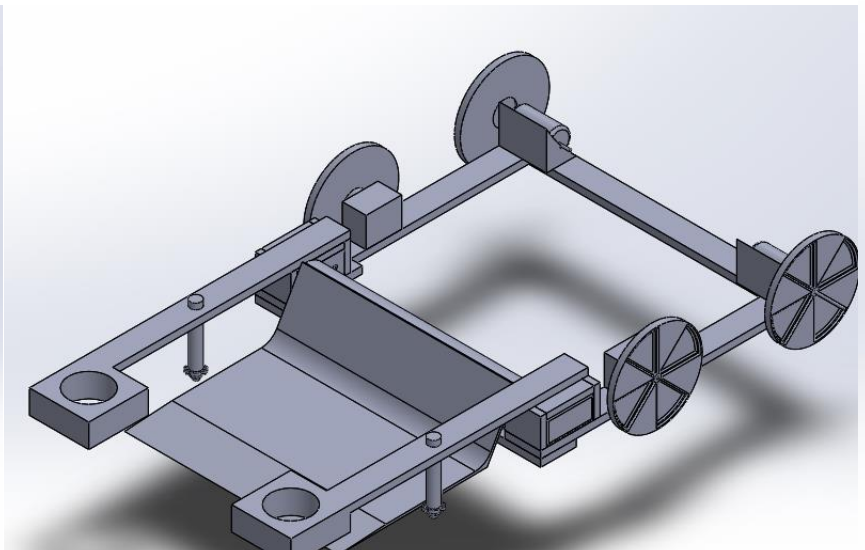




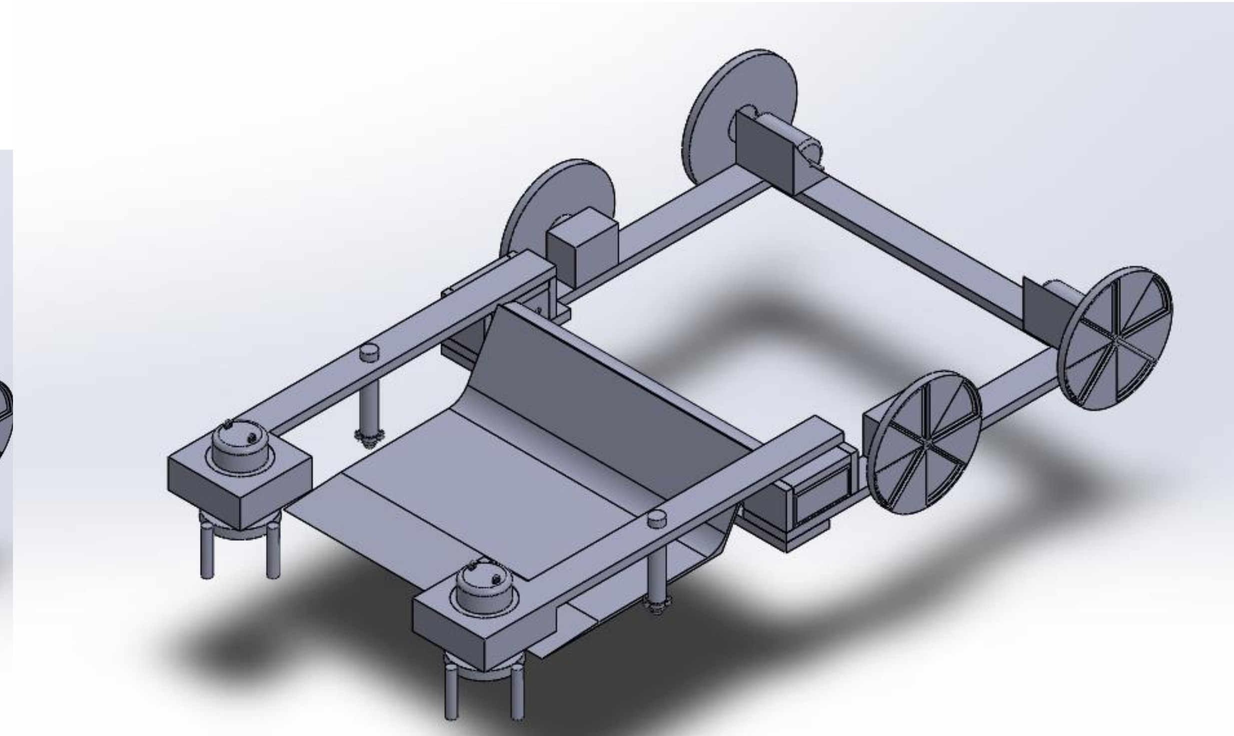
While implementing the hole for the motor I immediately realised the current size of the front chassis piece was not nearly large enough. The part circled was 30x20mm, not nearly big enough for the motor nor the rubber surrounding, so I arbitrarily increased it to 50x50mm which served far better. While doing this, I also increased the depth of this part to 20mm (from 6) to allow for the motor to be held with enough rubber to capture the majority of its body.
When I added the new chassis pieces to the front, it became clear they needed to be longer, so I changed them from 220mm to 250mm, a perfect fit.



Chassis + Scoop



+ new arms



Final model

Sensors

In accordance with the stakeholder discussion on this page, the product will mostly (if not always) drive itself. While in most cases, the cleaner will be able to travel around the café floor without interruption, there will inevitably be times when things are not where they are meant to be, meaning that sometimes chairs might be misplaced, or perhaps tables moved – the product must be able to react. Additionally, it may be possible for my product to sense larger debris so that it can efficiently position itself to pick up the objects best.

Important factors to consider are differentiating objects to avoid and debris to pick up, as well as correctly deciding how the path of the cleaner should be changed.

Sensing objects in the way

↳ table legs, chair legs, walls, threshold plates/strips

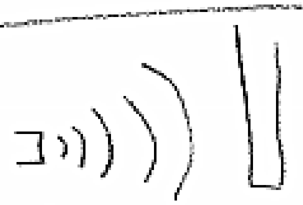
obstacles need to be sensed (in case they are in the way of the coded path)

pathing system
→ path can be set up in installation process & told to the robot

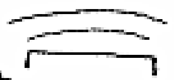
Sensor will need to be able to see object in time to react. It is ideal to know where the obstacle is (left, centre, right) and how big it is in order to efficiently avoid it. We also want to ensure that objects to pick up are not avoided

① sonar sensors
② uses pointers
③ camera / scanner –
④ "whiskers" – effectively bump sensing

①



✓ can tell if something ahead
✓ good distance perception
✓ can see proximity for all the way across robot



✗ cannot tell what object ahead
✗ does not know size very well
↓
perhaps a more accurate way could be to triangulate using two sensors. This can find distance and position ⟹

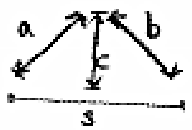
this needs hard testing to show it works

• another option is IR sensors however sun light IR can interfere.
• they are, however, cheaper.

②

✓ can tell if something ahead
✓ good distance perception
✗ cannot see all around only down one line of sight
✗ cannot tell size without having many sensors

distance, $\frac{1}{2}sc = \frac{1}{2}ab$



position:
as robot gets closer, distance difference between a & b is found

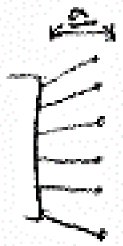
further to left (use trigonometry)

③

scanning codes can tell the robot what lies ahead. Special codes can tell info like size of object, type of object, etc.

Codes could be
• Bar Codes
• QR Codes

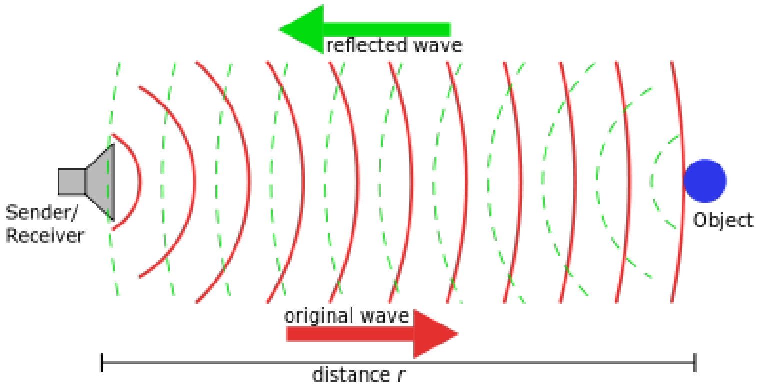
④



Similar to how roombas bump into walls and objects and can adjust their path, whiskers are physical sensors. If certain whiskers are hit, they can immediately know that the object is a distance away (shown in diagram), as well as where the object is

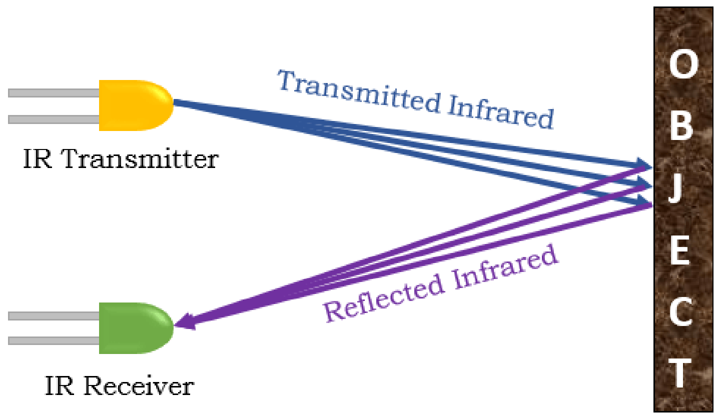
1 Just as was discussed on the previous slide, one option would be to use Ultrasonic sensors. They would be able to send a signal forward and then pick up that same signal again after a certain amount of time to deduce the distance between the sensor and the object.

Also mentioned was the use of two sensors in order to pin point the position of the object relative to my product. This is possible by using trigonometry to calculate the difference in path between the two Ultrasonic sensors and compare them to get that position.



The sensors would be placed on the outside of the design's casing, however much testing would need to be done to calibrate the position fix. This option would look good while being completely unobtrusive and still incredibly cheap.

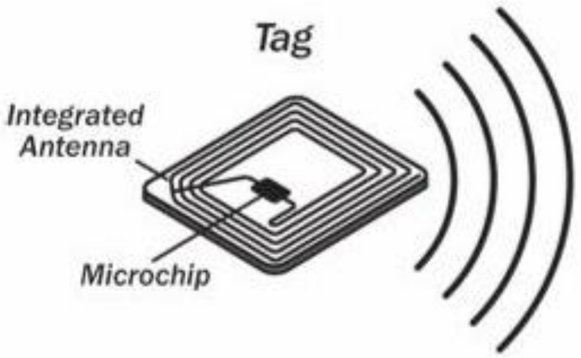
2 Very similar to the Ultrasonic sensor, the Infrared sensor sends a signal before receiving it back some time later, using the time difference to calculate the distance an object is from the sensor. The primary difference between the two sensors is the size of the signals. US sends diffracted waves of sound, therefore allowing the wave to reach many places and reflect off many things, IR however stays in a very tight line and will therefore likely only bounce off one object only. What this means is the IR sensor will be able to more accurately pin point where something is. Having multiple IR sensors would mean that a micro-controller could tell where an object is (by knowing which IR sensor picked up the object as well as how far away it might be. To do this, around 5-10 sensors might be placed across the front of my product, all facing forward.



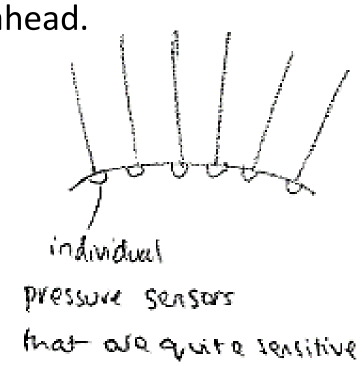
3 For an inexperienced coder such as myself, it would be impossible to make an AI which could tell the difference between a piece of food and a chair leg simply by looking at it, moreover this is a bespoke task so there is very little chance of importing code. A separate solution could be to make objects to be scanned so the controller can be told what object is what. The code would be wrapped around chair and table legs to distinguish them.

The simplest of code choices would be Barcodes or QR codes which we see daily. These codes are scanned with very simply build lasers so would be easy to implement. However, these types of codes are uni-directional, so the whole code would have to be visible to the scanner. Around a round chair leg, this would be difficult

An alternative might be RFID tags. When at close proximity with a sensor, they transmit information, such as the fact that it is on a chair leg. A way to implement this might be to use in conjunction with on of the other three sensors. This way, objects all around could be sensed by one sensor, and the presence of an RFID tag on those objects would subsequently differentiate objects to avoid (chairs) and those to pick up (debris).

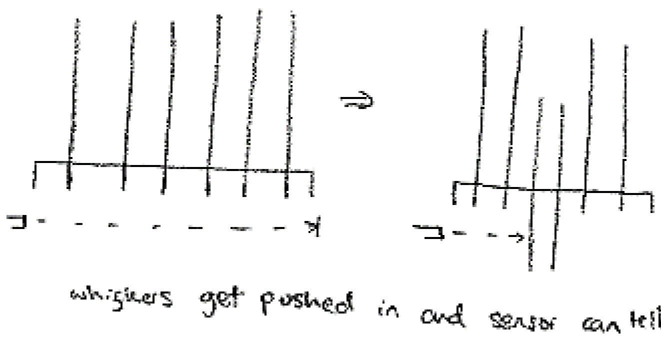


4 The Roomba's bump sensors tell the Roomba's microcontroller clearly that it has hit something so that it can turn. The product I am designing does not have the capabilities, however, to turn on the spot as easily, therefore needs to know of objects as early as possible. Despite this, a similar method can still be used. If the range of the bump sensors are increased, then this can be solved, the way to do this would be with whiskers. Whiskers would be flimsy as to let the product keep advancing, while also telling the microcontroller that there is an object ahead.



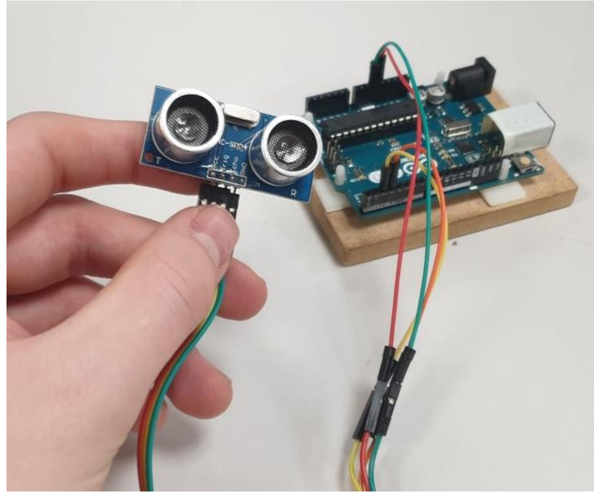
Method 1: whiskers all have individual pressure sensors. When a whisker is bumped, pressure would be exerted on the sensor and fed to the controller. The computer would therefore know that there is an object ahead, while also knowing the distance.

Method 2: one sensor sees movement of whiskers. In this one, whiskers are loose and can be pushed inwards, this would tell the controller that whiskers have been offset and there is an object ahead.



While the added accuracy may be a bonus in some designs, for this product it may end up meaning an object that is in front of the rover would be missed by the Infrared signals and so the rover would drive into the obstacle, the US sensor does not have this downside. Additionally, the US sensor is far cheaper and if the position fix idea works, then it would be an excellent solution to use. While the 'whiskers' are an interesting idea in theory, there are too many vital things holding it back, such as the expense of such small, precise pressure sensors, or the limitation of some whiskers being too short while others are too saggy. The possibility of using RFID tags or similar is too a very reasonable idea, one that has the possibility of implementation later.

Implementing an Ultrasonic Sensor



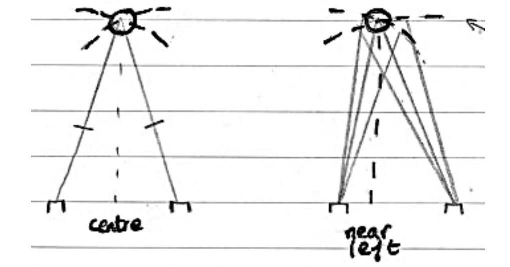
Initial trial coding allowed me to grasp the basics of coding with the Ultrasonic Sensor:

```
#define echoPin 2
#define trigPin 3

long duration; // duration of the sound wave
int distance;  // distance measurement deduced

void setup()
{
  // put your setup code here, to run once:
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  Serial.begin(9600);
  Serial.println("US sensor test:");
}

void loop()
{
  // put your main code here, to run repeatedly:
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);        // restarts sensor

  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);       // sends a signal c
  digitalWrite(trigPin, LOW);

  duration = pulseIn(echoPin, HIGH);
  distance = duration * 0.034 / 2;

  Serial.print("Distance of ");
  Serial.print(distance);
  Serial.print("cm");
  Serial.print("\n");
}
```

Idea 1

As discussed on the previous few pages, two sensors could be used to triangulate a position of an obstacle, this is called a position fix. For this I am taking inspiration from VOR Navigation aids in aviation. How it works is two sources send signals to a receptor – the receptors position can be known by working out where the signals should intercept. In aviation, this is done using directional interceptions (shown right), for this system, an interception would be found between the distances found by each ultrasonic sensor.

According to the product information, the angular range of this sensor is 15 degrees each way, therefore any distance found could be anywhere in that range. We can use this in the method described above and illustrated right.



beam reaches anywhere on edge of arc. Interception of arcs is where object must be

centre-front of bot: (0,0) ∴ sensors at (-11,0) and (11,0)

left sensor: $(x+11)^2 + y^2 = d_1^2$ || right sensor: $(x-11)^2 + y^2 = d_2^2$

simultaneous equation ⇒ gives (when y factored out): $x = \frac{d_1^2 - d_2^2}{44}$

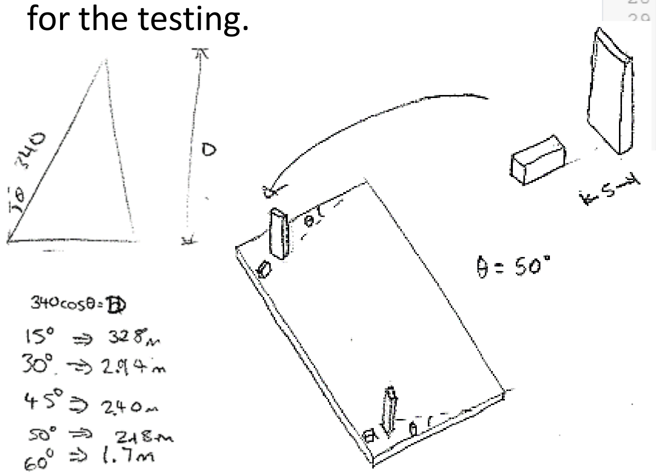
putting this back into initial equation gives [y must be +ive]

$$y = \sqrt{d_1^2 - 121 + \tfrac{1}{2}(d_2^2 - d_1^2) - \left[\tfrac{1}{44}(d_1^2 - d_2^2)\right]^2}$$

To test this I thought it best to make a rig to mount the sensors on. This way I can work out whether this is a feasible method of position fixing. Quick testing of code to the left showed the max distance the sensor could see was 3.4m, so I did a short plan of different angles of the sensors to use. I would say that 2m is more than enough space for the bot to react to an obstacle and move accordingly. Additionally, larger angles will lead to a larger difference in detected distances (therefore being more accurate), so I believe 50 degrees would be sufficient, at least for the testing.

```
#define echoPinL 2
#define trigPinL 3

#define echoPinR 4
#define trigPinR 5

import math

void setup()
{
    pinMode(trigPinL, OUTPUT);
    pinMode(echoPinL, INPUT);
    pinMode(trigPinL, OUTPUT);
    pinMode(echoPinL, INPUT);
    Serial.begin(9600);
    Serial.println("US triangulation:");
}

void loop()
{
    digitalWrite(trigPinL, LOW);
    digitalWrite(trigPinR, LOW);
    delayMicroseconds(2);

    digitalWrite(trigPinL, HIGH);
    digitalWrite(trigPinR, HIGH);
    delayMicroseconds(10);
    digitalWrite(trigPinL, HIGH);
    digitalWrite(trigPinR, HIGH);

    durationL = pulseIn(echoPinL, HIGH);
    dL = duration * 0.034 / 2;
    durationR = pulseIn(echoPinR, HIGH);
    dR = duration * 0.034 / 2;
```

```

    dLs = dL ** 2
    dRs = dR ** 2

    x = (dLs-dRs)/44;
    y = (dLs - 121 + 0.5(dRs-dLs) - (((dLs-dRs)/44)**2))**0.5;

    if (y < 120)
    {
        if (x <= -10)
        {
            slightright();
        )
        if (x >= 10)
        {
            slightleft();
        }
        if (-10 < x < 10)
        {
            fullavoid();
        }
    }
}
```



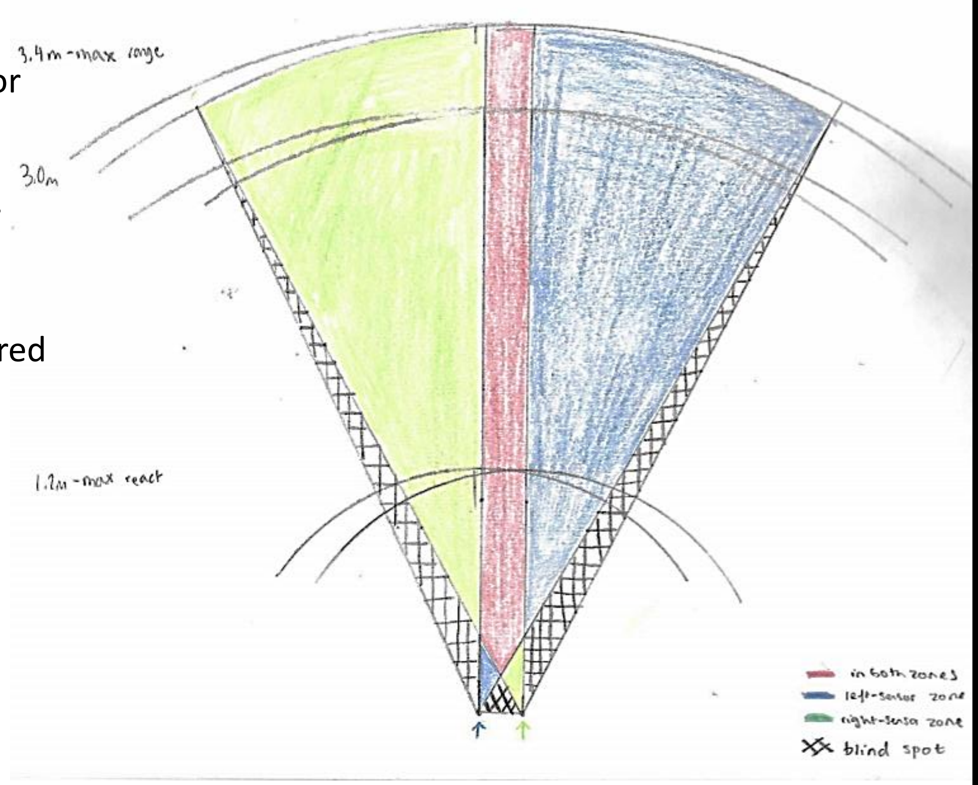
During coronavirus restrictions, I do not have access to the sensors in order to perform this test physically. However, rereviewing of when I began coding these sensors demonstrated how much I overestimated their accuracy. This method of position fix is so heavily reliant on the perfect sensing of distance of objects that I do not believe it to be a feasible method of ultrasonic sensors. This may work for a more expensive sensor that is very specific, but it is wiser to devise a separate idea that would not be too negatively affected by the imperfect distance sensing of these sound sensors.

Idea 2

A way which we can mitigate the effect of the limited accuracy of ultrasonic sensors is to instead use their area of detection to pin point positions. What is meant by this is that two sensors pointing across each other will have an area in which they intercept. By knowing which region an object is (shown below), the bot will know enough position information about the obstacle (does not need exact relative position, just whether it is on right left or centre), while it uses position detection from the sensors as a rough telling of how far away the object is – likely being characterised into regions too (somewhat shown by arc lines drawn). This should solve the problems with the previous idea.

How this would be used would be:

- Object detected at 1.2m by the right sensor (green zone)
    - Veer right slightly
- Object detected at 1.2m by the left sensor (blue zone)
    - Veer left slightly
- Object detected at 1.2m by both sensors (red zone)
    - Larger turn to the side for full avoidance
- Object detected at more than 1.2m
    - No action required



I believe this would be very good at ensuring the sensors had a full view of the surroundings, or at least as much as might be necessary. However, unlike what I had mentioned when doing loose testing on the left, much physical (and now YouTube as I do not have access to the sensors now) research as presented just how inaccurate the ultrasonic sensors are and how their readings fluctuate too much to give concrete distances.

This opens up the problem that is when there are two objects, one in the blue area and one in the green, that are about the same distance away from the sensors. I believe this occurrence would not be uncommon for a café as most of the obstacles would be chairs – which have two legs that could do just this. This would result in the program thinking there was only one object and that it was in the red area – meaning the product might turn to the side only travel directly into one of those obstacles. At this present time, the only simple solution I can think of without adding more sensors would be to ensure the bot is travelling quite slowly. When turning away to avoid the object that is believed to be in the red zone, the sensors will eventually have only one of the sensors see an object, at which point it will find out that there is only one object now in its path and that it is off to the side and not straight ahead.

This still does not solve the problem about distinguishing obstacles and debris (without RFID tags), so I will likely look at that after consultation with my stakeholder.

Coding this idea should also be much simpler to do, especially since it is not reliant on very specific values from the sensors:

The functions fullavoid(), slightright() and slighteft() are all placeholders what would be commands that would execute the evasive manoeuvres – this is not something ideal to do at this stage due to the limited ability to test the code physically and properly.

```
#define echoPinL 2
#define trigPinL 3

#define echoPinR 4
#define trigPinR 5

import math

void setup()
{
    pinMode(trigPinL, OUTPUT);
    pinMode(echoPinL, INPUT);
    pinMode(trigPinL, OUTPUT);
    pinMode(echoPinL, INPUT);
    //Serial.begin(9600);
    //Serial.println("US area watching:");
}

void loop()
{
   digitalWrite(trigPinL, LOW);
   digitalWrite(trigPinR, LOW);
   delayMicroseconds(2);                // reset sensors

   digitalWrite(trigPinL, HIGH);
   digitalWrite(trigPinR, HIGH);
   delayMicroseconds(10);
   digitalWrite(trigPinL, HIGH);
   digitalWrite(trigPinR, HIGH);        // get values from sensors

   durationL = pulseIn(echoPinL, HIGH);
   dL = duration * 0.034 / 2;
   durationR = pulseIn(echoPinR, HIGH);
   dR = duration * 0.034 / 2;           // distances found

  ratio = dL/dR;
  if (dL <= 120 or dR <= 120)           // when in a short range
  {
    if (0.8 <= ratio <= 1.2)            // distances roughly equal
    {
      fullavoid();
    }
    else if (ratio > 1.2)               // object only seen by right
    {
      slightright();                    // therefore object on left
    }
    else if (ratio < 0.8)               // object only seen by left
    {
    slightleft();                       // therefore object on right
    }
  }
}
```

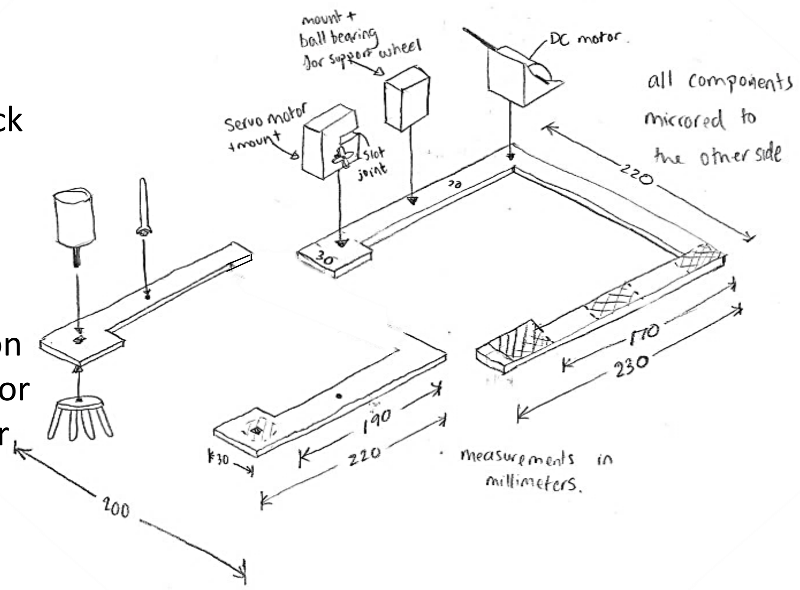
I think this idea works better, especially with the addition of the 0.8-1.2 ration range. This means the distance findings do not need to be perfect to still know there is one object dead ahead, while making it very unlikely to think two objects are one (as mentioned left). An extra benefit is that these values can be changed.

From here, any developments I want to make to my products design will need to be under heavy feedback and discussion from my stakeholder. I will do this using a slideshow presentation in which I pitch my current design and options for further development directly to my mum, the café owner (discussed more on the right). Before moving on to creating and pitching this presentation, I am first going to research, and try to reach a conclusion on, the method I will use to power my product – based on information about other products as well as the requirements of my system (discussed on the left).

Powering Methods

The components in my system that will require powering are:

- Two DC Motors for wheels at the back
- Two DC Motors for sweepers
- Two Servo Motors to lift the scoop
- Two Ultrasonic Sensors



According to previous research such as on this slide, the sweeper motors will look for 6-15 Volts, and while testing the code for the wheels, I found the motors for the wheels required 9 Volts for it to function as described on this slide.

Servo motors typically require 4.8 Volts but also very frequently come in 6V and 12V, most other Servos are either micro servos or far larger than necessary. As servo motors tend to have a far higher current requirement (1A to DC motors' unloaded 0.15A), 9 Volts can be stepped down with use of resistors in a circuit to donate the correct amount of power. A similar method can be used for the 5V Ultrasonic sensor.

The method of powering the system will be via disposable battery, or rechargeable battery. Renewable resources are hard to consider in this context due to the controlled environment the product will be used and the strict limitations of size and weight to abide by. I used an online comparison, here, to supplement my thought process. It is worth considering, the mBot had the ability to use either type of battery, which clearly shows how both are viable options. For actual cleaning products that serve similar functions to this product, Roombas make use of rechargeable batteries. Roomba batteries only last one cleaning cycle and are then recharged via mains electricity. Additionally they recommend you take the battery out if not using the Roomba for a while – this reduces the loss of capacity of them (it is an important to make batteries easily accessible for this). Vacuum's such as Henry Hoover and even Dyson Hand-held vacuums all also use rechargeable batteries. My impression is that rechargeable batteries favour products like this, that need a lot of energy, but will only require it in short bursts before being unused for a while longer – in which time it can recharge back to the full amount. Mains powered recharging batteries are the way forward, if not also for their lesser ecological output and cost over time for users.

Data about brushed DC motors is product information of the exact motors I used, servo motor info is from learn.adafruit.com, Ultra Sonic sensor info is also directly from the product previously trialled with.

Preparing for Stakeholder Presentation

So far up to this point, I have been able to test and develop methods of cleaning by myself for the most part. Using small bits of information from my stakeholder but primarily from inspiration from other products, I have reached conclusions on how I would want my designed product to work.
I have chosen the functions of the product based on the research with my stakeholder on this page, to best help cafés deal with the effects of the pandemic:

- Sweeper and scoop allow the product to pick up a great range of debris
- Development of motor-wheel system aids movement without human intervention with help of…
- Sensor system to let the product navigate by itself

To reach more conclusions on more features of the product, I am making a slideshow presentation in order to brief my stakeholder on the findings so far and my intended path, and to gather her ideas too. I intend to gather information on:

- Should it be used during day or after work-day → i.e. will product need to find individual debris by itself or to clean the whole floor at day's end
- Would the stakeholder potentially want UV lights → for sterilisation of floor
- Stakeholder opinion of RFID tag use → see this page
- Any features currently in use that are not necessary/ specific features they deem necessary
- Speak to other stakeholders about software requirements of the products system → this would be dependant upon if the bot is used at the end of the day or finds debris itself (for better explanation see the slideshow page it is discussed on)

This slideshow needs to match a product pitch, as this presentation would also have the purpose of advertising this product to the stakeholder.
Features to remember in a presentation like this are:

- Keep slides at one topic only – keep it simple
- Demonstrate the production process so far – problems and solutions made
- Illustrate competition of other products too
- Business model – be specific on market e.g. is it a premium product
- Interaction – making sure to get all the desired information as shown above

The presentation, as mentioned starts on the next page. The script for the presentation I used is on this page and the audio is on this page. The analysis of all the information gathered from this presentation also starts on this page.

Note: when presented, this slideshow was slightly larger, however it has been compressed a little in order for it to be more suitable for this NEA project folder. Nothing of significance has been removed.

Cafe Cleaner

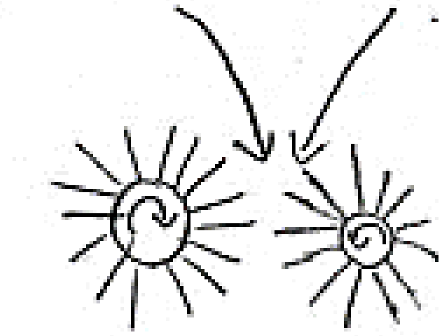
Stakeholder Update – Finishing the Design Process

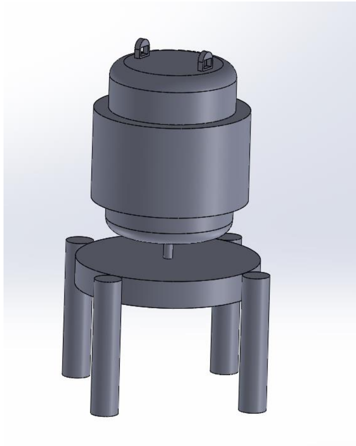
The Purpose I Wish to Fulfil

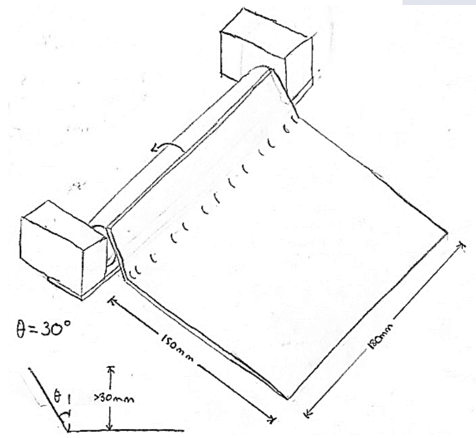
"I will design a product that quickly clears a floor space so that it is ready for sterilisation. The product should maintain a clean working place and thus reduce the spread of diseases in social spaces such as cafes"

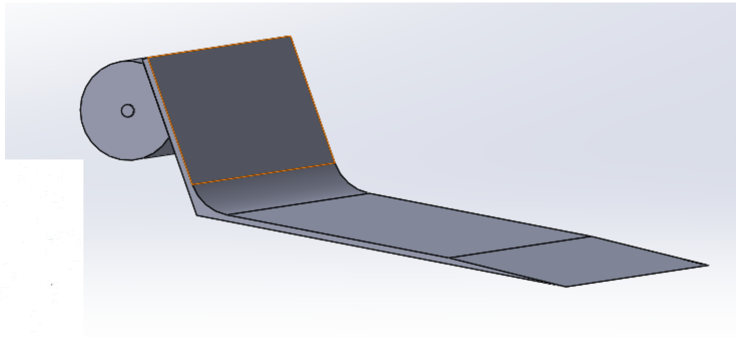
Cleanliness	Efficiency	Fitting In
• Manage mess that comes in both small and large sizes • Be able to cover all areas on the floor • Have facilities to store the debris	• Have a method of covering the floor efficiently • Not negatively impact the work done by employees • Reduce work required by employees	• Not disturbing customers • Having no ability to harm those in front of it

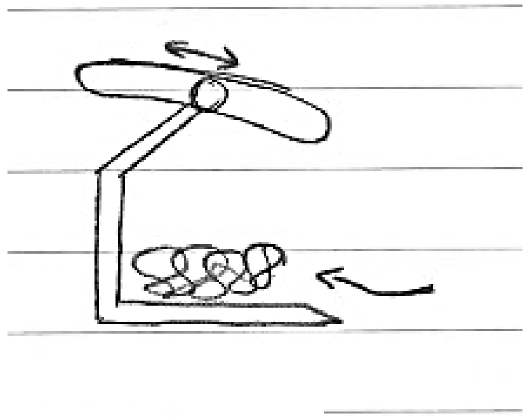
Development So Far

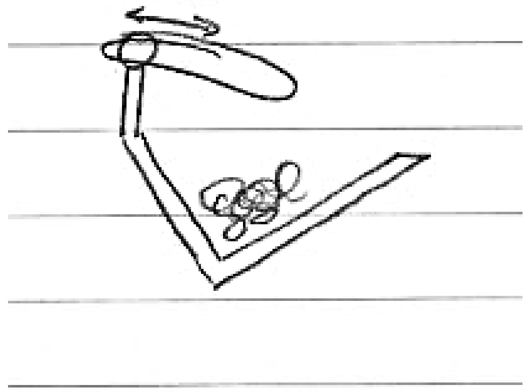


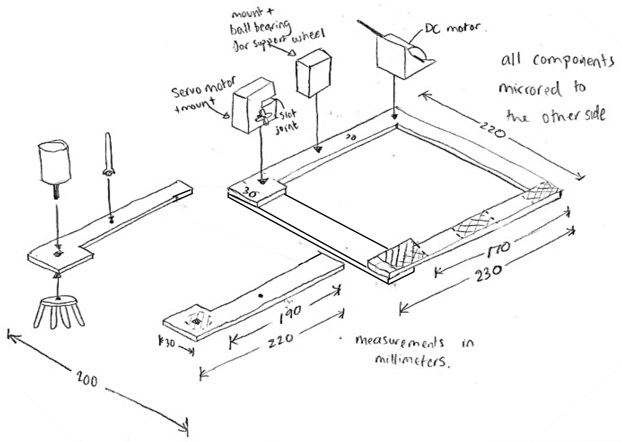


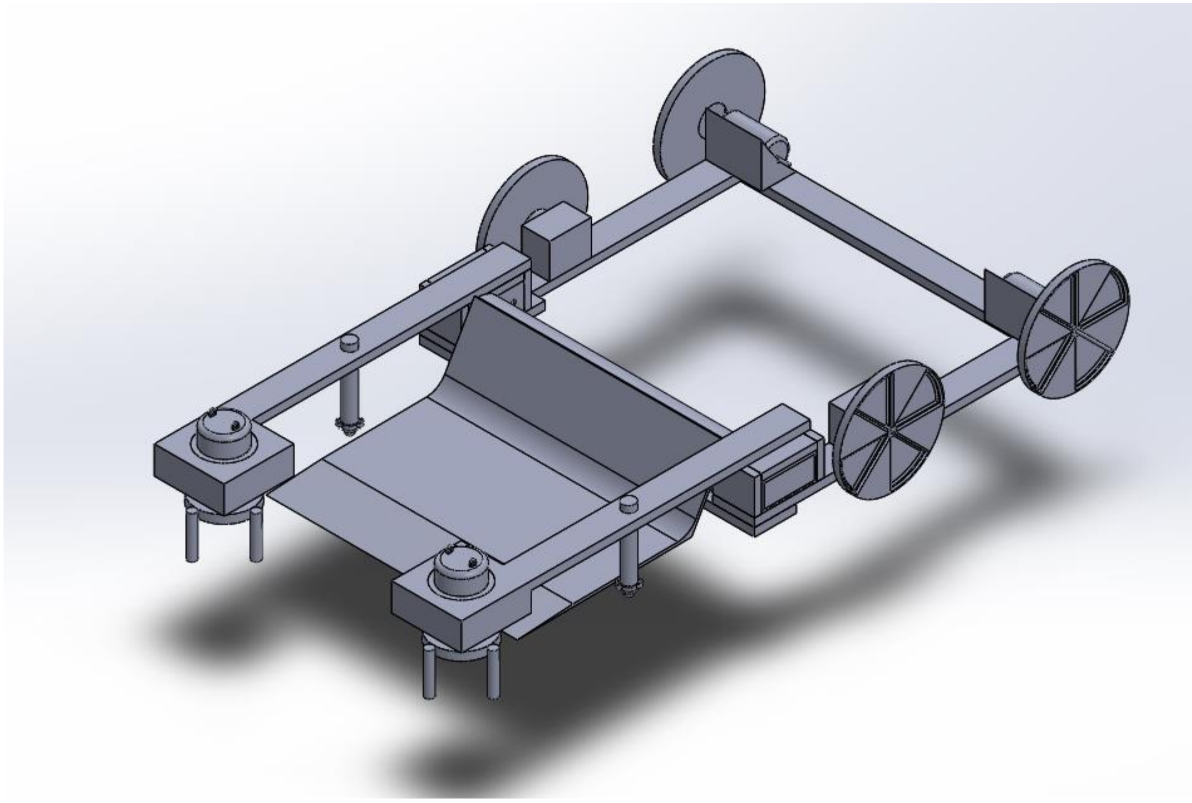


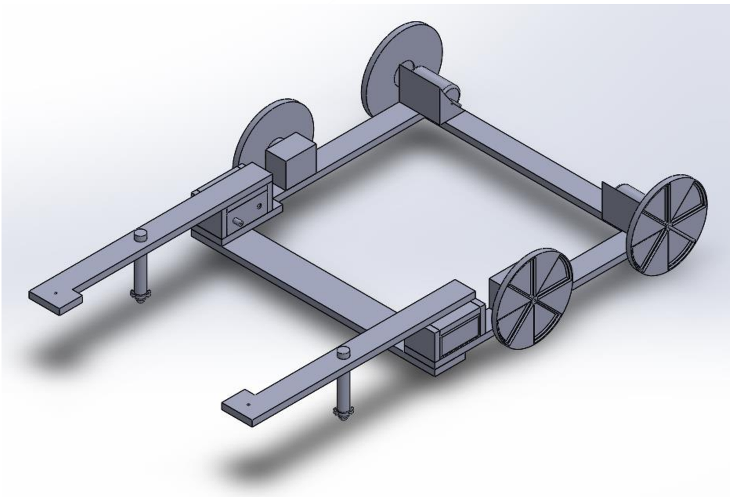








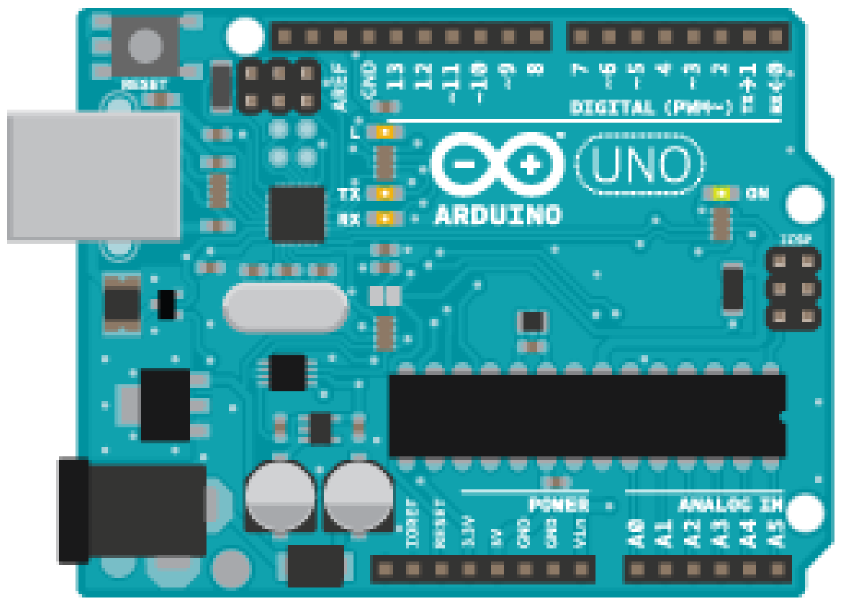


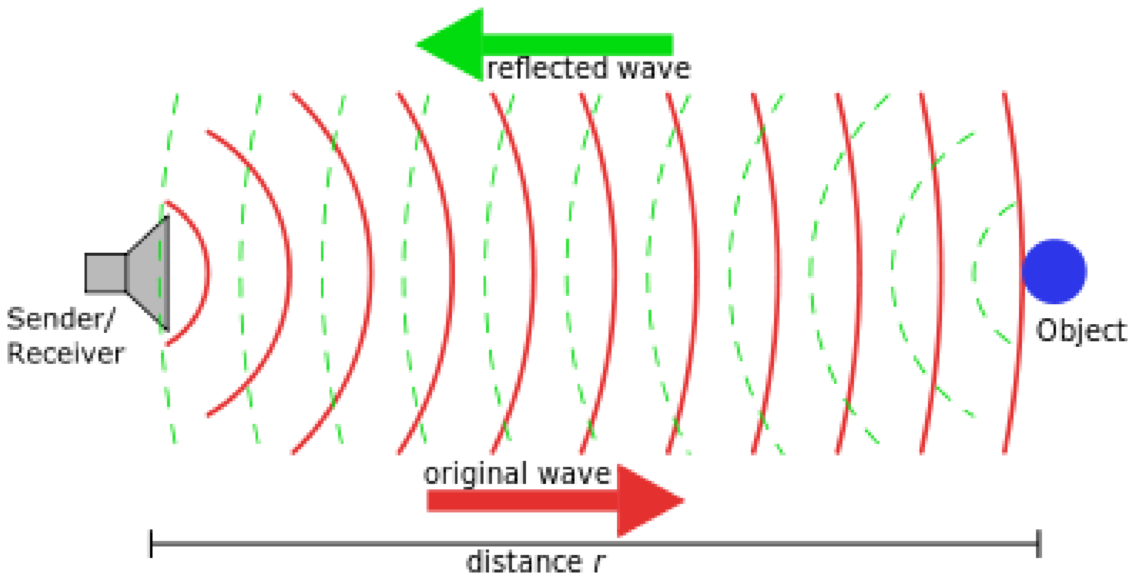


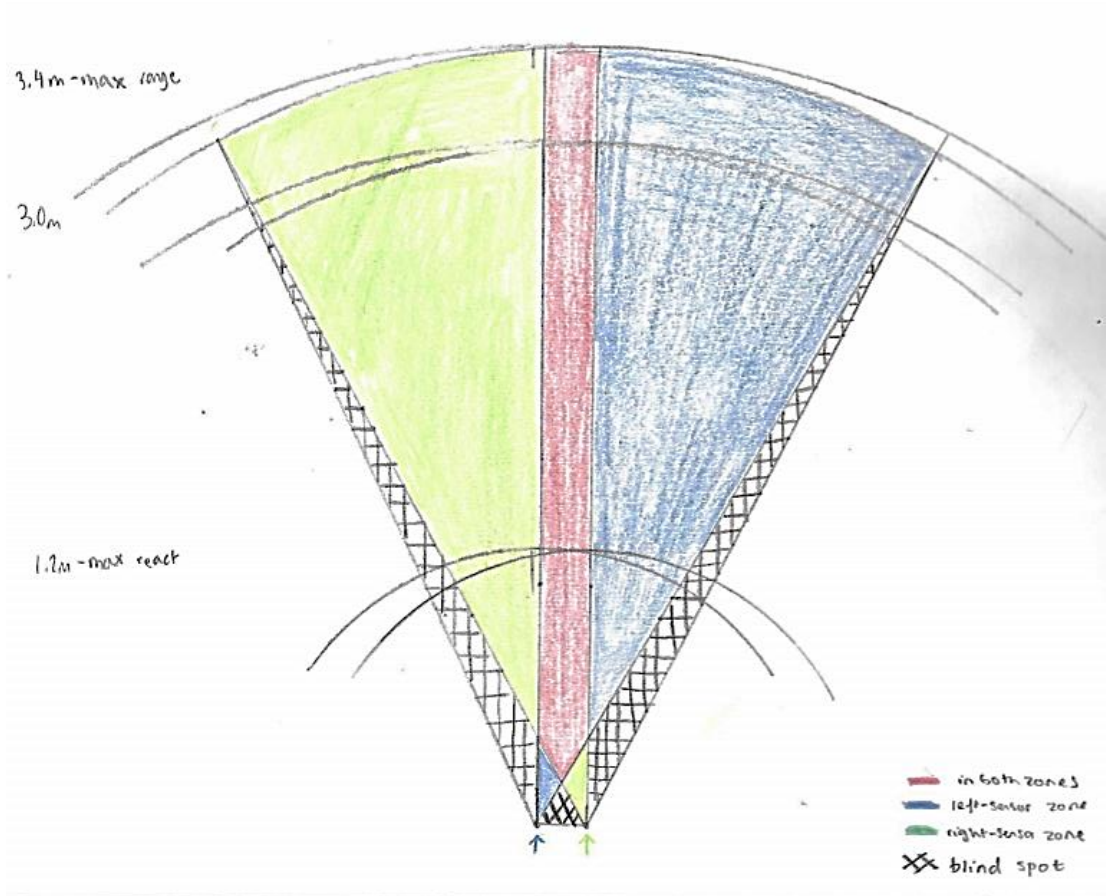
Cafe Cleaner

Development So Far

ARDUINO

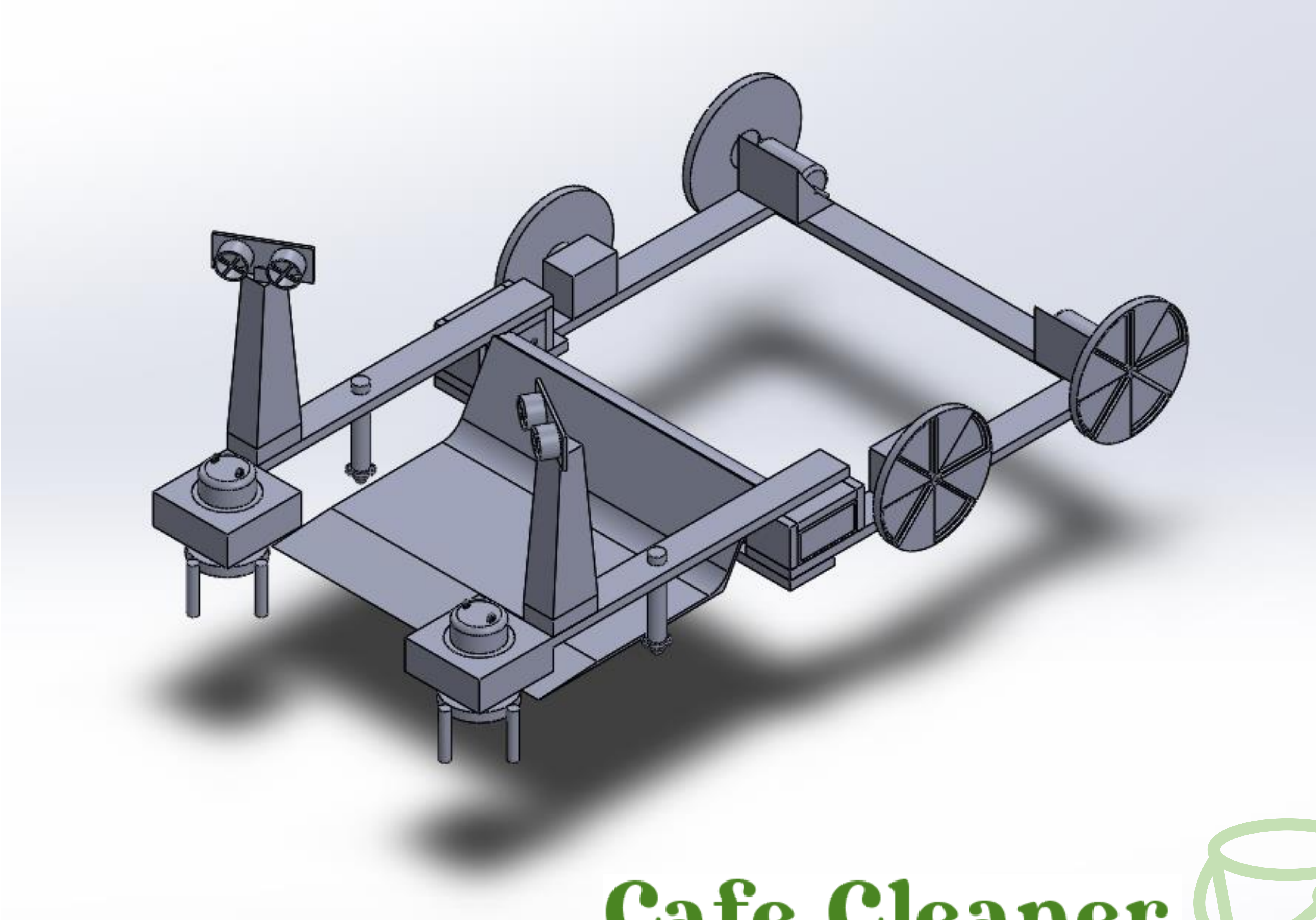






Cafe Cleaner

The Final Model

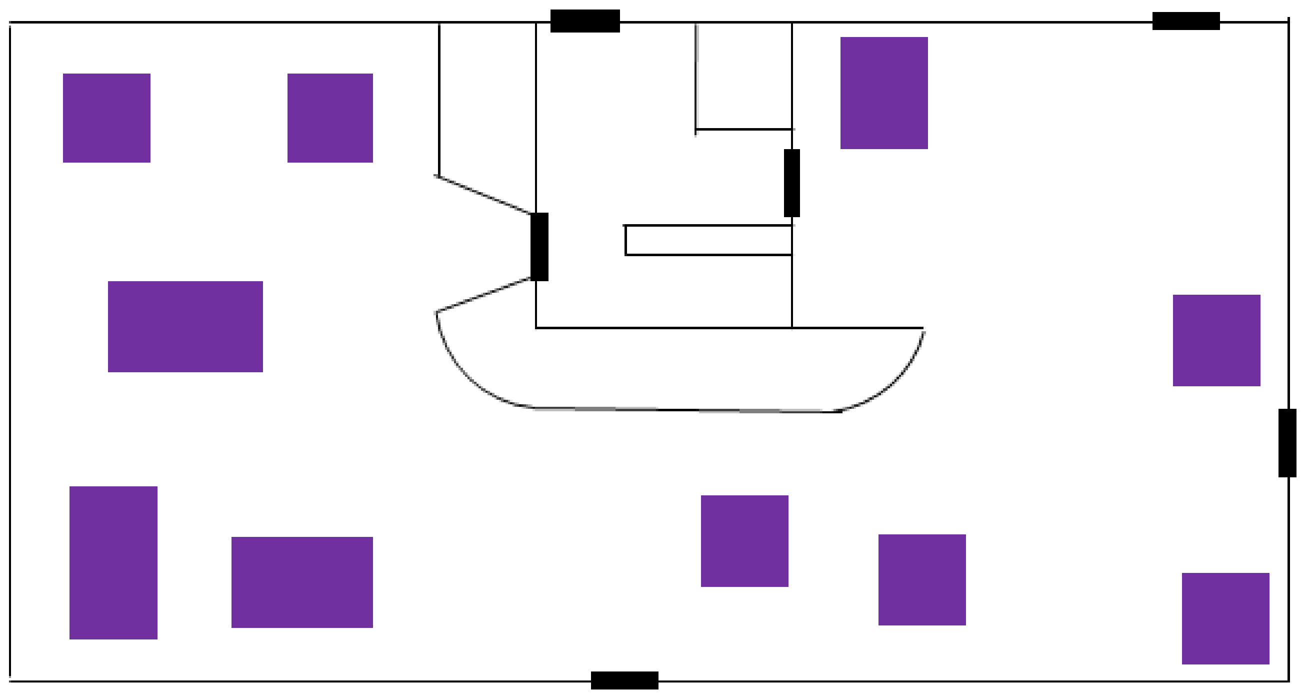


Software Requirements

£100 installation fee

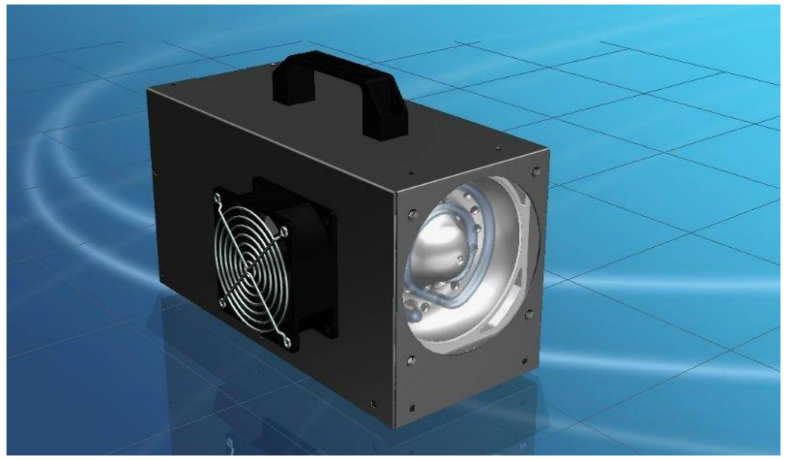
- Controlled by employee
- Path randomly
- Plan out its own path

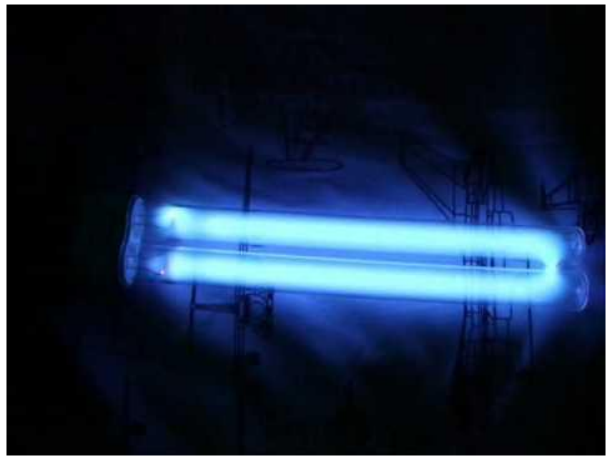
- Screen on the rover
- An array of buttons
- Bluetooth connection



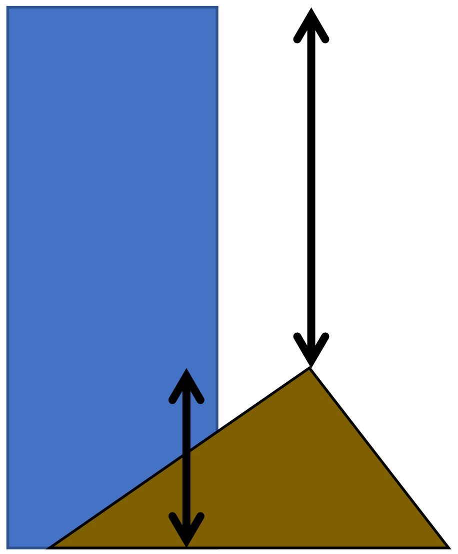
Further Feature Ideas

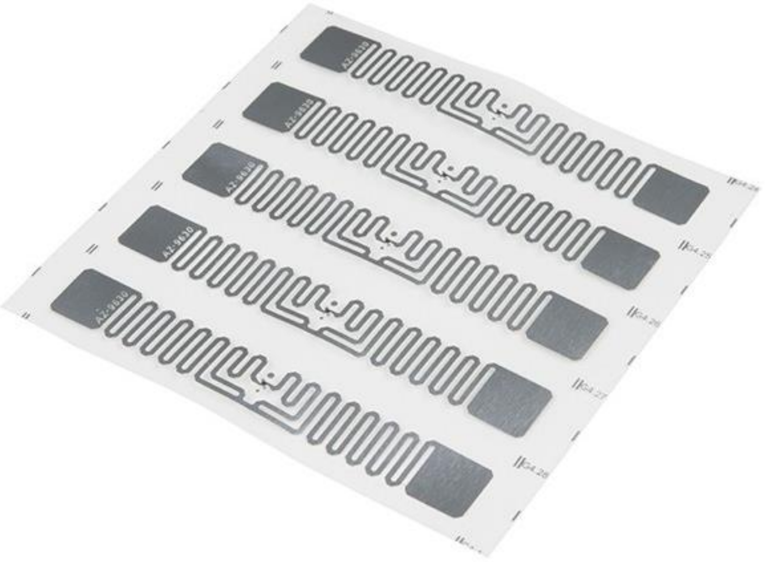
- Ultra-Violet lights

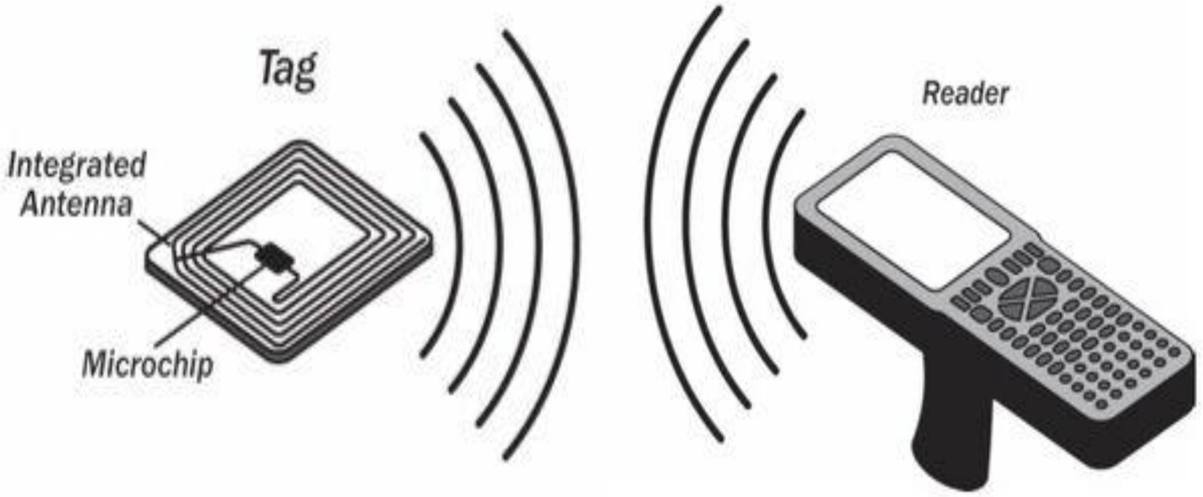




- RFID object location







Cafe Cleaner

Future Plans

Now-17 Jan reviewing results

18-31 January	01-11 February	12-21 February
Topology optimisation	Decide materials and processes	Working drawings
Dealing with safety precautions	Complete coding	Make specification
Disposal of waste		Send off to manufacturer

Script for Presentation

Good morning and welcome to my presentation about the progress of my cafe cleaning product. To remind you, last we had a proper discussion we decided upon the direction for the product being to automate the cleaning process. We both employed the idea of trying to reduce the stress of employees by reducing the cleaning work necessary whilst also limiting close contact between separately housed parties in a time like this pandemic. Since then, I have done an array of workshop testing and iterative design to create a product that would fulfil the functions we had discussed. I hope you agree with the technical decisions made and agree with the direction taken.

If you have any comments about any of the information I say, feel free to write it down on the notepads given until a convenient time to mention it. For example, if you have any disagreements with the reasons for design decisions made, note it down and we can discuss it at any of the time dedicated for notes and questions.

What is in this presentation

- Once I have recapped the requirements that were laid out for this product…
- I will walk you through the progress so far as well as briefing you on the justifications for the large design choices I have made
- Then I will show you the final design model reached, as well as taking questions about the progress so far
- After detailing the work done so far to reach the current design model, I hope to discuss other ideas I have had for features of the product with you as well as any other ideas you might have to offer.

Details on the product's use and the purpose I wish it to fulfil

Based on our previous discussions, as well as meticulous technical research, I reached some certain requirements for the product to have.
My design brief reads "I will design a product that quickly clears a floor space so that it is ready for sterilisation. The product should maintain a clean working place and thus reduce the spread of diseases in social spaces such as cafes".

For the product to clean the cafe floor sufficiently, it had to:

- Manage mess that came in both small and large sizes (from dust to dropped and broken plates, even abnormal debris like food squashed on the floor)
- Be able to cover all areas on the floor (whether it be in open space on under tables and chairs)
- Have the facilities to store the debris (in a user friendly way - ready for disposal)

For the product to increase efficiency of the work place, it needed:

- Have a method of covering the floor efficiently (whether that be a pathing algorithm or if it found mess itself)
- Not negatively impact the work done by employees
- (Somewhat) reduce the work required to be done by other employees

For the product to hold a place in a social space without disruption to it, or the people around it, there was a requirement for:

- Not disturbing customers (such as making noise or getting in the way)
- Having no ability to harm those around it (such as children nearby for example, or alternatively the cafe furniture or floor itself)

These points allowed for iteration that led to a model I am quite pleased with.

The developments so far

After our discussion I got to work pondering what features would be required to meet the product's task. This began with the decision to pursue a system that replicated the use of a pan and brush. Vacuums were incredibly loud and lacked versatility, and attempting to make a robot hand seemed an unreasonable goal.
Rather than look to create an entirely new cleaning product or reinvent the wheel, it seemed smart to make use of the resources available to me and use a pan-and-brush system. To back up this decision, it was clear from previous discussions that a pan and brush has the capability to clean every form of mess that you might see on a cafe floor.

The question then became, how does one automate the process of the pan and brush. First came the method of brushing. After some physical testing and iterative modelling, I decided upon **this** design. Having a brush either side that pushes rubbish toward the centre of the pan allows for a larger area of sweeping (thus making it faster and more efficient), but also it has the versatility to brush things of a very large range of sizes and even weights.

———

This led smoothly on to the design of the collector scoop, that would emulate the best parts of pans as well as shovels. **This** was the model reached, which would be optimally formed to easily pick up the smallest of dust and dirt while no larger than the right size to serve its purpose for larger objects. After running through a few ideas on how to store that which was picked up, I decided upon having the pan scoop the mess into a container behind it - a safe storage place for easy extraction by a cafe worker. This would work with a servo motor tipping motion **as shown**.

It should be noted that there was another solid option for this, shown **here**, that would to simply store the debris inside the scooper by tilting it back to stop it pouring out. This could save a lot of space on the product and potentially remove unnecessary functions, however I ran into problems in extraction of the scoop to dispose of waste, especially with the limited time and resources I had to solve this problem. If you have any ideas or want to discuss this prospect, just note it down and we can bring it up once I have reached the end of this section.

———

After deciding upon how the cleaning would be done, I explored how I could fit the parts together and how the robot should move. The verdict seemed to wholly point toward **this** chassis being able to move via dc motor wheels. This chassis compacted the parts into a simple linear layout, **[describe the layout visually]**.

—show chassis slide + with s&s—

The dc motors would be controlled by an Arduino system code, which can make decisions about the cleaner's movement.

If you are not aware, an Arduino system is a specialised circuit board that can have code embedded into it that it can execute. This includes taking inputs about environmental information, processing them, and outputting a decision in the form of the wheels moving, for example, noticing an obstacle ahead, and correctly navigating an avoidance path.

For this system I looked over a few different options and decided upon using ultrasonic sensors for this situational input. They should be able to correctly see things ahead of the robot in a way that allows efficient decisions to be made. **[in relation to diagram]** I can discuss this in further detail later if you want, but to keep it brief, two sensors can see if an object is directly ahead, slightly to the right, or slightly to the left in order to calculate whether a large or small avoiding turn is necessary. Additionally, of course, they tell how far away an object is.

Our most up to date model

From all the developments made and discussed over the previous slides, the final model reached was **this** one. **[point out features of the model]**.

Now that I have discussed all that and caught you up to date. Are there any questions about what I've said, or alternatively anything you wish to discuss any further at this stage?

Software requirements

This product is inevitably going to be a smart system. For this to happen, it needs a strong interaction interface with those in charge of using it. This will mean there needs to be a decided way that the robot knows when and where to clean. This begins with deciding upon what sort of pathing the bot will undergo.

There are three basic ways I can think of for this pathing to be chosen. It could:
- Be controlled by an employee at the cafe
- Path randomly (and meander, changing direction only to avoid obstacles similar to how home cleaning devices do
- Plan out its path using a map (avoiding obstacles of course, but generally maintaining an optimal route)

The final idea would undoubtably give the most efficient path. To generate the map needed to make the path, however, a worker from the company that sells this product may need to come to the cafe themselves. I am looking to get your opinions on whether that would be worth it, knowing an installation fee would be added to this already premium product.
Working off the average 2020 hourly earnings of an electrician, and discussions with the Wimbledon electricians company Netfixx, a figure of up to £100 installation fee was reached. This can be explained further if you would like more information.

[average £40 hourly according homeguide.com gives £60 for 90mins. Typically Service call-out can be up to an extra £100, however those working on this would be on contract most likely, which would likely change it. I was unsure about how exactly to price this when the electrician was employed by myself, as opposed paid for as a customer, so I decided to go to an actual company for help. After discussing with www.netfixx.co.uk in Wimbledon, we reached a number of an average of £80 an hour when the workers are employed to work regularly throughout the day. Another figure was mentioned - that being £250-300 per day depending on the task, where a day is a typical 8:00 until 16:00 time period. This gives a sensible figure of £100 per person for three per day per worker.]

There are further benefits to a mapped method. When there is mess on the floor, a product that knows the floor plan could be told where to go to clean by being told which table the mess is nearby. Therefore a map-path robot would have more efficient pathing for both cleaning the whole floor and for cleaning individual bits of mess.
The alternative to the bot not having a map to work off would, with idea 1 - being controlled and driven to the mess. With idea 2 it would be to either allow the bot to drive around the cafe floor on a constant cycle, or to let it out to do a full cycle of the floor when directed to do so.

Finally in terms of interaction, I wanted to enquire about the interfacing of the software. Products like this have a variety of methods of controlling them, the options I immediately thought of were:
- (Being controlled via) a screen on the rover (itself which has a full user interface)
- (Simply having) an array of buttons (on the product)
- A bluetooth connection (to an phone app or a local device owned by the cafe)

Any opinions you may have I will take heavy into consideration in this matter, including separate ideas, however I cannot guarantee that the interfacing will be done exactly as requested due to certain limitations based on having to code this myself.

Further feature ideas

There are a few more features I have considered the use of which I thought would be worth gathering your thoughts on. While for the most part, the functional designing phase is entirely done, there is opportunity for small additional features - whether that be for the first product or for updated products down the line. Obviously, depending on the extent of work needed to implement the function, I will be able to decide whether it is possible to get done before the first product deadline.

The ideas that I am currently looking at are:
- UV lights
  - The product currently has no method of sterilising the floor past cleaning dust and debris around the cafe. A possible method of doing this without adding too much extra design and manufacturing would be just adding ultraviolet lights to the back of the rover. The lights would shine over the newly cleaned floor and kill much of the micro-organisms that cover the floor.
  - UVC would be necessary and (via fda.gov) LEDs would simply not be effective for this application due to how weak they are - so they therefore do little for sterilising. Alternatively, pulsed Xenon lamps are used for hospitals but can cost upwards of £20 each so would increase cost a lot, or low pressure Mercury lamps which are up from £10 and just as effective - however I am looking into any harmful effects too as a precaution. The only downside I might see, other than cost, for something like this is the fact that UVC can be harmful when shone directly on to skin - posing a potential problem. The time factor for a feature such as this would not be adding it, more ensuring it complies with MHRA regulation, something very possible, however time consuming. Of course, using UV lights is not the only option for sterilisation, so I would be interested to hear any other ideas for methods of this function. Alternatively, if you have any thoughts in regard to the necessity of this product sterilising the floor I would employ you to discuss them too. [mum's mop idea]
- RFID object location
  - As mentioned earlier when discussing the software requirements for the system, the most efficient and accurate method of the rover moving around is to utilise a system where it paths itself around without the aid of a human controller. A perk of this method was that it could essentially 'look for' things to clean up. For it to find the mess to clear, it needs to be able to differentiate the things which it wants to avoid, such as table and chair legs etc., and the debris to clean up.
  - While there are methods that include 'seeing' things which are higher up as obstacles and those lower down are debris, I believe a far more reliable method might be by the use of radio transmission codes. By embedding RFID tags into the legs of your furniture, when the rover is close by to them, a receiver on the rover will learn that an RFID tag, and thus an obstacle, is nearby. This, in conjunction with the ultra-sound sensors, should allow the microcontroller to pinpoint the necessary information about the position of any objects as well as whether they are to be avoided or cleared up. The way this can be applied is arguably easier than any other additional features, or methods to carry out this same function, which is why it is my top pick. The solution to the software being able to decide if something is an obstacle or debris is a necessary one, however does not necessarily need to be done in this way. If you have problems with the implementation of a system that would introduce radio-wave-tags to all the furniture, or perhaps you simply have another idea for a way to solve this, I would love to hear your thoughts. If needs be I can always revert back to the basic idea I mentioned, simply differentiating the objects by height.
- If you have any other functional or otherwise requirements that should be met, please write them down and then we can discuss the possibility of their implementation.

Time scale and plan for the future

After summarising and concluding the findings from this presentation with you today, I will look at researching and potentially implementing the ideas we have discussed as well as think over your thoughts on the current model. Assuming all preliminary designing is done and all decisions are made about the contents of this presentation by the end of next week, I have a specific itinerary planned:
- Week 1 to 7 of February
  - Analyse the structural integrity of the product as well as redesign the full model to perform topology optimisation. This should make it safe and strong as to stop it being damaged easily
  - Look over all the parts and potential parts, searching for health hazards, to increase safety for the user and customers
  - Complete final designing upon the disposal of waste
- Week 8 to 14 of February
  - Decide upon the materials that need to be used for all the individual parts, as well as processes required to make the product
  - Complete the coding of the product
- Week 15 to 21 of February
  - Complete working drawings of the inside model and its casing
  - Analyse the findings so far to create a specification fit for a manufacturer

That is the end of the timings required to get the product moving, however I hope to also be constructing my own prototype down the line which I can review with you.

Conclusions

That concludes my presentation for you today. I hope you were happy with the development made so far and that you are as excited as I am for the future of this product. I thank you very much for your time and will gladly answer any questions you have remaining.

Stakeholder Comments

These are the comments made during the presentation by those who watched the presentation. I asked them at the start of the presentation to write down any notes about what I had to say so that they could ask me when a moment arose, therefore all the points on these sheets were discussed in the audio file (bottom right).

can it get all squished food - does it still require a mop?

Similar to a road sweeper.
└ would broken plates etc do any damage?

are the three modes combined? do all features show?
is it mechanical / robotic? how does it move and work.
└ similar control as a robotic hoover?

can sweeper lift all of the debris on the floor? can it reach?

Sharp edge to scrape, yet not too sharp to possibly damage / harm a customer or furniture

rubber? softer yet harder to scrape.
rigid material, not too thin to break, not too sharp to damage.

are brushes touching? if not middle part will not be easily collected.
size of the machine itself? too large, needs to be more movable.
↳ 20 x 50 cm is too large.

employee control is too complicated
- plan of own path is good, yet if is programmed (the space put onto robot) as cafe furniture is moved often.

what's in the installation fee?

turn on the spot. wheels can be moved itself, and a rounded system, can move in smaller angles and fit around easier.

UV lights, good idea yet with customers, i always think of skin cancer - 10% of population will get skin cancer, excess UV may not be good? LED works well.

why do you need a light? hoover cannot see, light wouldn't help. would only show more of the floor.
└ idea that it sterilises is good, but necessary for floor. it should be cleaned / sanitised but sterilisation is unnecessary for a floor.

└ if wet / or mop is used, shouldn't be as in customer time may cause accidents.

possible reduction of robot picking up customers items? a loose scarf on the floor / coins dropped etc.
└ especially babies? drop alot of food / toys.

RFID? would it need to be put onto the furniture ~~of the pot~~ necessary? if there is sensing of the robot already. an extra expense.

if no RFID notification is given, it may be a foreign object NOT to be picked up. a belonging of the customer.

- Automate
- Reduce close contact

Which ways do the sweepers go
Vertical or horizontal?

tip

manufacture guidance

Conclusions drawn overall as well as what I am going to do with the new discussions and information is on the following page. It should be noted that the audio is difficult to follow without visual aid of the presentation.

Reviewing the Presentation Questions and the New Information

There is lots to take out from this presentation in terms of changes to certain aspects of the product, as well as focus points for the last bits of development I will need to do. Before attacking the problems posed and creating solutions to the requests of the stakeholders (which will be in red), I need to have a full scope over what we had discussed, which I am presenting on this page in a pseudo-list form. They are discussed in a primarily chronological order (with time stamps in **bold**) but split between notes and ideas from the stakeholders about the information I presented them, and answers to the questions I had posed to them such as whether using RFID tags is a good plan.

Answers to my Questions

Q: What pathing method should the rover use? (slide 8)
A: It was discussed (**33-37**) that the clear only choice was to use a floorplan to create an efficient path that the rover should take. It became obvious that the other two options would be ineffective, especially if the product were to be compared to its target market competitors such as high-end Roombas. The added price for the installation seemed little object when considering the benefit that came with it. Pathing via use of a map will need to be coded.

Q: What sort of information input would be the best? (slide 8)
A: One of my stakeholders said (**38-39**) that they would prefer to be able to start and stop the rover exclusively from the robot itself, not via an external Bluetooth device, where I had to mention that buttons had the limitation of there only being so many. The other stakeholder said it mattered very little provided it was a simple system. What clearly mattered was that the software should be easy to use so most likely I will try a simple screen system with a very simple User Interface to aid user interaction.

Q: Is a Ultra-Violet light a good solution to sanitise the floor? (slide 10)
A: Rather than use harmful (**46**) UVC, a better method would be to use an attachment that can change the sweepers into having a mop like function (more info see **43-44**), however even these would have the problem of making the workplace dangerous (**48**). One stakeholder expressed how unnecessary sanitising or sterilising the floor would be anyway, unless it was done at the end of the work-day (**47-49**) as the floor would only get more dirty when people came in anyway. For future developments, such as an after-hours model, I might consider the mop attachment, however for this current model no sanitisation efforts will be needed.

Q: How should the microcontroller differentiate obstacles and debris? (slide 10)
A: The stakeholders and I decided that RFID tags, while noticing furniture obstacles, would not see the difference between debris and temporary obstacles like people (**56-57**). One person told me how the height discrepancy idea (first mentioned **51**) would be favourable for this reason. Since I have put little thought into ideas other than the RFID tag, I will need to explore the options for deciding if something is an obstacle or not further.

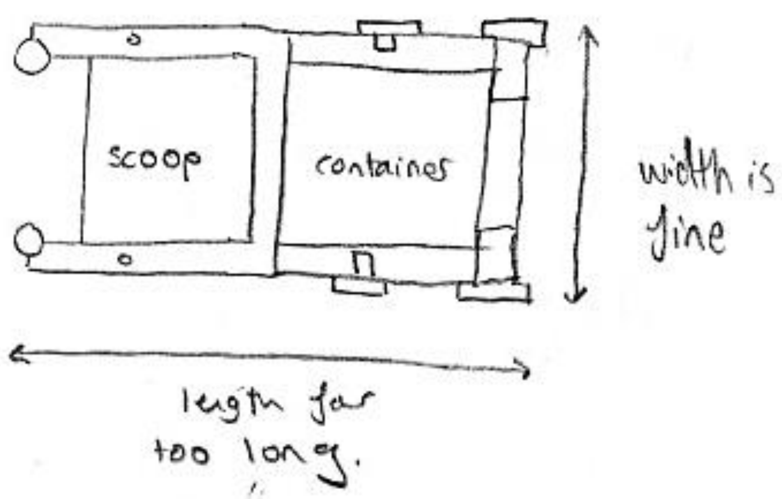
Additional Notes

Material choice of the scoop:
While describing the function of the current model's system, one of the stakeholders mentioned (**12-17**) that to be able to scrape up any of the mess that needs to be scraped up (such as squashed food), there will need to be a certain rigidity and sharpness to the tip of the scoop. Immediately after, the other stakeholder described the dangers of a sharp edge against the floor and how it could cause damage. She expressed how a rubber tip would be more appropriate. From these two completely separate points brought up, a balance needs to be made. Rather than compare on this page, I will need to pay very heavy attention to the material and shape of the tip of the scoop when I discuss the material choice for it later in this NEA.

Dimensions of the model overall:
Due to the current lockdown, I have not made a single physical model of the whole system at all except for the makeshift representation on [this](#) page that is quite different in size to the current model. While making 3D models can help give a visual showing, a lack of physical modelling makes it very difficult to recognise the overall size of the design. This led to it being brought to my attention that the current model is very oversized (**22-24**). While the width of the design is at a fair size, the length (of around half a metre) is far too much. Stakeholders said it would heavily lack the manoeuvrability that it requires, so I need to redesign to make the rover far smaller. There are a few methods I can think of to do this easily. The most obvious way would be to look back to the idea introduced on [this](#) page. By removing the container (**63-64**) and making the scoop store the debris, a lot of space would be saved so I should certainly have a look at ways I could make it so the scoop acts as temporary storage of mess. If the design ends up very small and with a very small turning circle (**58**), perhaps bump sensors might actually be an option.

New Chassis Design – Reducing the Length

As mentioned, there is a desperate need to reduce the length of the design to allow for greater manoeuvrability. There are a few ways I can do this…



① get rid of the container

↳ store above scoop

↳ make scoop store instead

② reduce size of scoop & container

↳ move them closer together

↳ reduce lengths

Before trying ① I should see if ② would work as a solution:

previously specified that I need

- around 2 Litres of space
- 180mm width of scoop & container

If the container length is moved from 170mm to 100mm which would take overall length to around 450mm, the container would need to be about 110mm tall.

A 40mm increase in height where the overall length has little change. 110mm tall is not too much, however 450mm length still is. Reducing the container length more would exponentially increase height

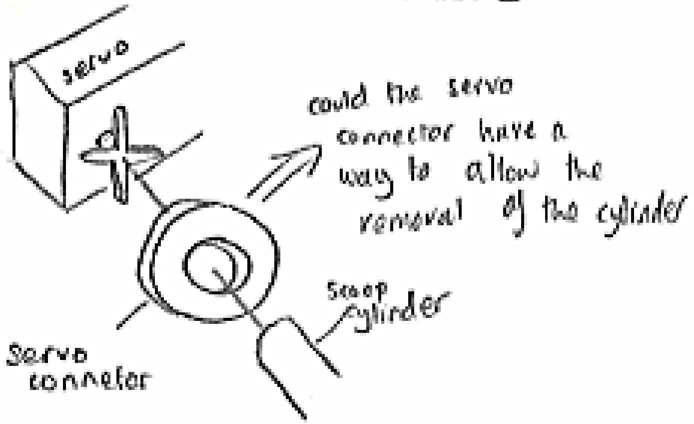
---

② Previously mentioned I could make it so the scoop could double as a container. This could be done by tilting the scoop upward as to not allow debris to fall out.

ie.

the servo motor rotates to tip the scoop-container

the problem I had had was being able to remove the scoop-container to get rid of waste.



question: how can the hole be plugged up to stop the scoop falling out when in use?

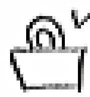
Method 1: Interference fit

Similar to fitting motors into chassis - plug with rubber-like

pro: stop any vibrations of the scoop

con: difficult to get in & out

handle?



↳ interference fit still very hard to move

if it is not interference it will not stay

Method 2: latch to hold in place

Rather than being tight with connector, a piece can fit tightly with the cylinder

Due to it being ill-fitting I need to find a way to secure this insert piece. This designing continues to the next page.

Simple to make it easy for uses

↳ velcro, ↳ button ↳ jubilee clip ↳ toggle latch

Velcro:
- quick to use
- easy to use
↳ + little effort
- can be tightened
- v. small system

Button:
- quick to use
- easy to use
- no tightening
- small system

Jubilee clip:
- time consuming to put in.
- very secure
- can be tightened
- may require screw-driver

Toggle latch:
- quick to use
- very secure
- one tightness
- requires large metal parts




From the short list of pros and cons of the four latch types it would be clear that Velcro would be the obvious choice. However, professional Engineers at school shared with me that Velcro has a tendency to degrade its usefulness when filled with dust – as a cleaning device would. Instead they suggested using the buttons suggested and have multiple holes for it as with an apple watch strap as shown. Straps like this are used in so many products so are easy to use and well known to many.

For this application, this would be quite an easy feature to add. The arrangement that is shown below can be used: the insert is attached to one strap and there is a second strap on the bottom (Fig. 1). When the insert is put in place (Fig. 2) the bottom strap can connect via the use of a small pin just as a watch strap does. This gives the final piece shown in Fig. 3.

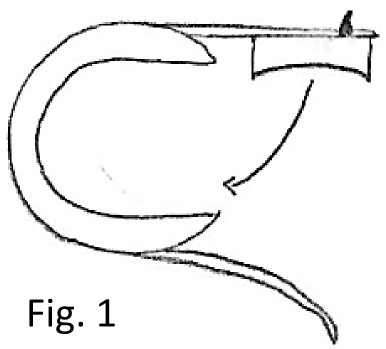


Fig. 1

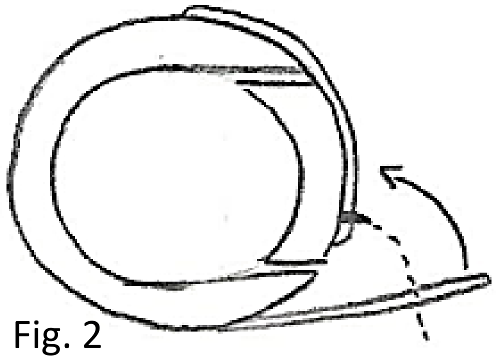


Fig. 2

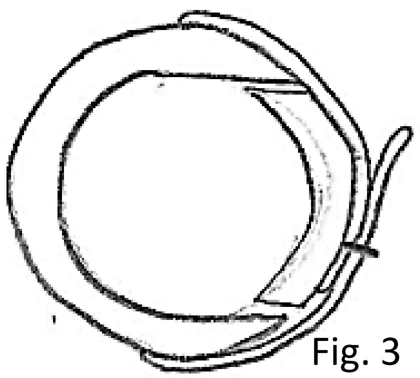
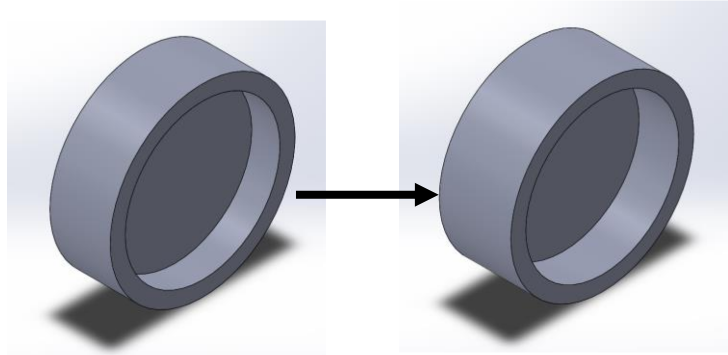
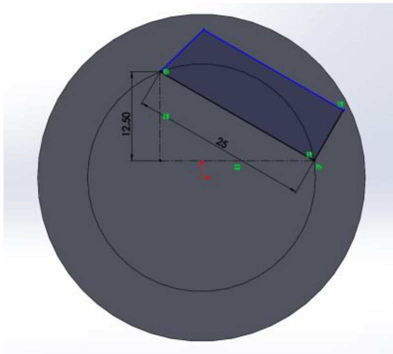


Fig. 3

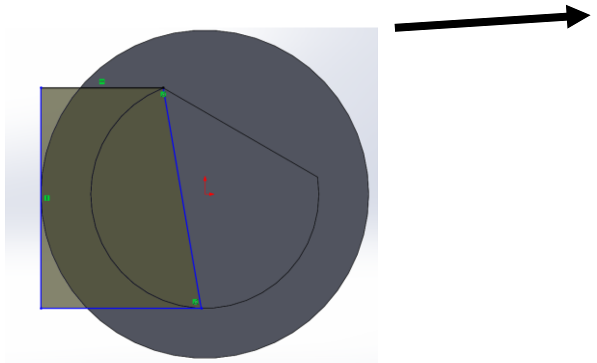
First I had to adjust the size of the connector to fit the 32mm cylinder. I decided to increase the clearance from 7mm to 10mm not 25mm as no screw is necessary and too large a clearance will either make the rover too wide or reduce the width of the scoop (the scoop could be designed to fit around the connector however then it would be unnecessarily more complicated to manufacture.

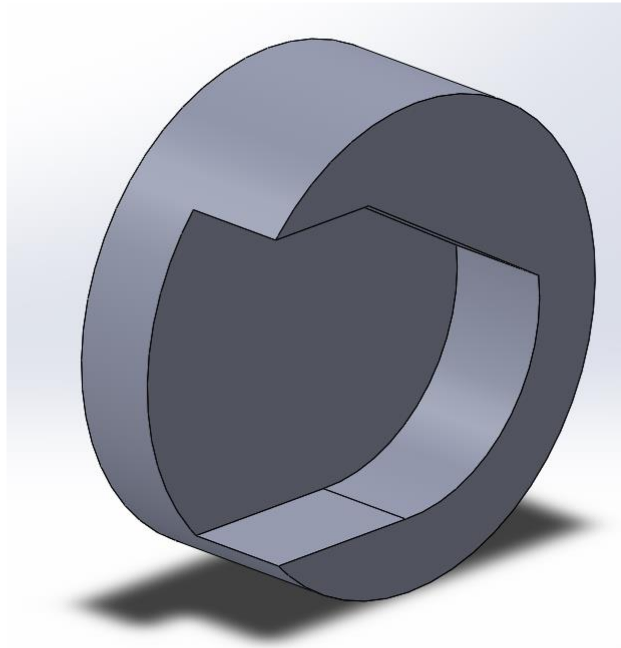




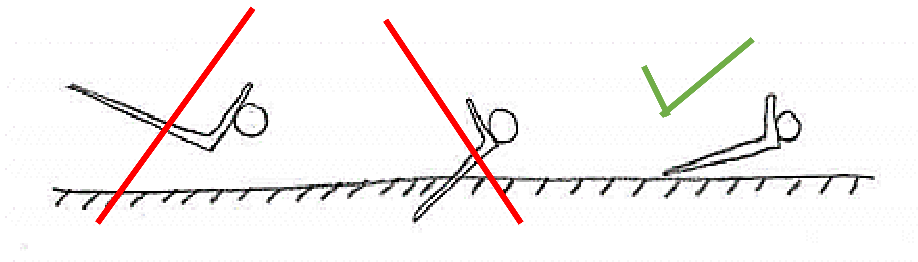
Next I needed to work out where the flat face would be. If the cylinder were inserted through the left side, the face would be on the top right. For the scoop to be flat to the floor, the flat face must be at 30 degrees to the vertical, so a substantial turn of 30 degrees to aid storage would leave the flat face at 30 degrees to the horizontal. Therefore I added a piece accordingly.

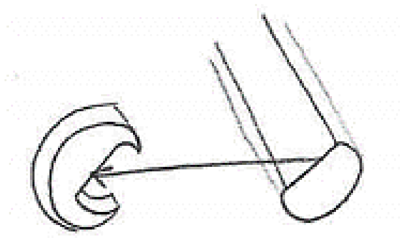
I then had to make space for the cylinder to enter through:





When the Scoop (and cylinder) is in use, its angular position needs to be perfect so that it can rest perfectly in the right place for scooping up debris. This requires it to be put in in the right orientation. This can be done by making the cylinder shape irregular – such as having a flat face on it which must match up with a flat face in the servo connector as shown:

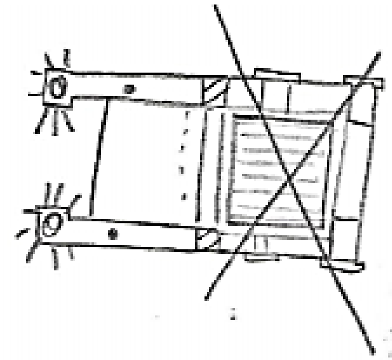




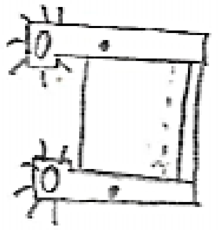
With these design choices complete, I could make a 3D model shown at the top right of the page.

New Chassis Design - Sketching

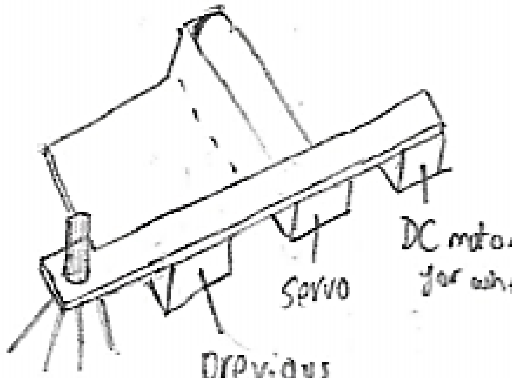
Having got rid of the container from before, there are some quite drastic changes to the form of the chassis. I hope that I can put the chassis together that does not miss out on any important features and drastically reduces the design from its previous 580mm.



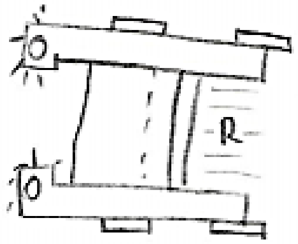
⇒ eliminate back half



← this is currently standing on caster wheels with no motor to move it
↳ add motors behind



Other than the container, the back half had a motored-wheel and a free-wheel. By compressing them to the front, we reach a design with all the previous parts



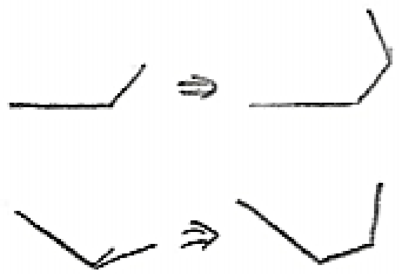
this design, when viewed from birds-eye, looks very front heavy. However gap ⇒ add weight ↓ random weighted piece at side

circuit board and batteries closer to back

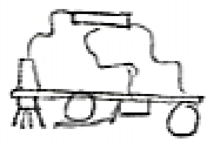
R needs to be free to let scoop out

⇓ nb: circuit & battery closer to servo & motor too.

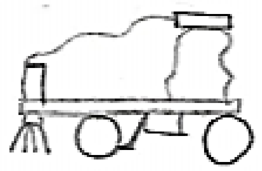
Since scoop is a container, the back needs to be tall enough as to not spill debris out. [Side match height of back] (and sides)



Rather than:



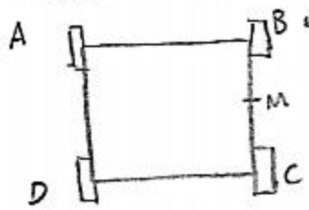
use:



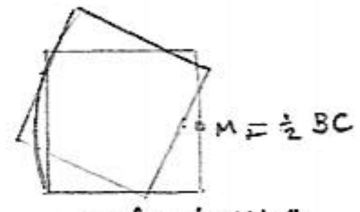
← This will also ensure the volume of the container is large enough to hold as much as possible.

Stakeholders mentioned that a smaller rover means more manoeuvrability. To increase it further we can reduce the turning circle.

Current wheel assembly

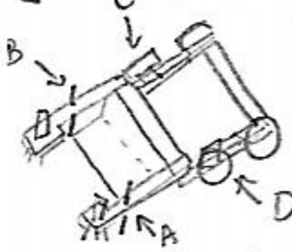


if it turns right fully ie. wheel C is off [and B but it is unpowered] ⇒

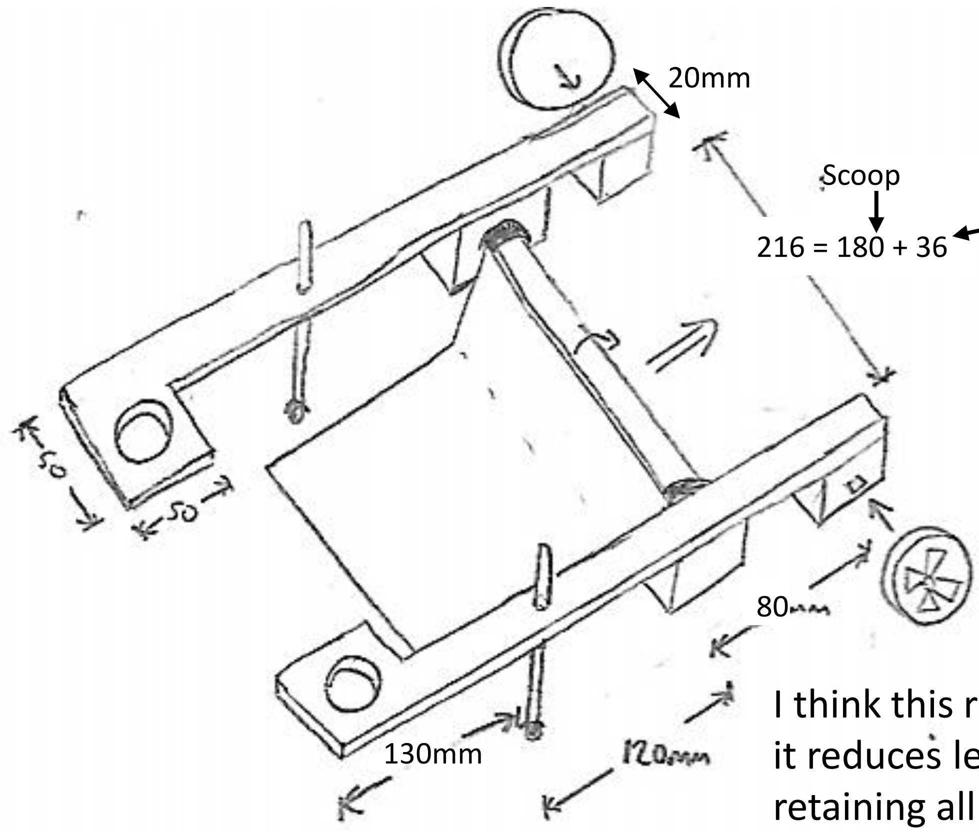


wide turning about centre M radius MA = MD

if we say the rectangle on the previous (too large) chassis between the free-wheel and caster wheel were to be used, the radius would be ⇒ BC = 150mm ∴ MC = 75mm, CD = 240mm ⇓ r = 255mm



⇐ This value of r = 250mm is also very reliant on the free-wheels being able to follow the turn without resistance
↓
much smoother turning can be done on a multi-directional wheel such as the caster wheel. Also the rover could turn on the spot ⇒ r = 240

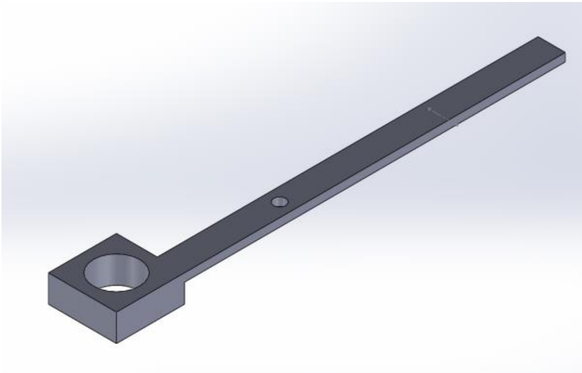


I think this redesign is successful as it reduces length to 330mm while retaining all the parts except for an unnecessary set of wheels.

New Chassis Design – 3D model

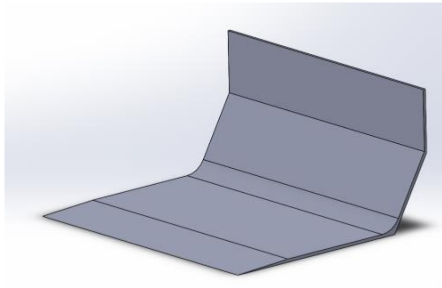
With a solid design made, I need to update my 3D model to meet the new scales. This included removing the container space, imposing the new servo connectors, and changing the scoop to be equipped to fill in as a container.

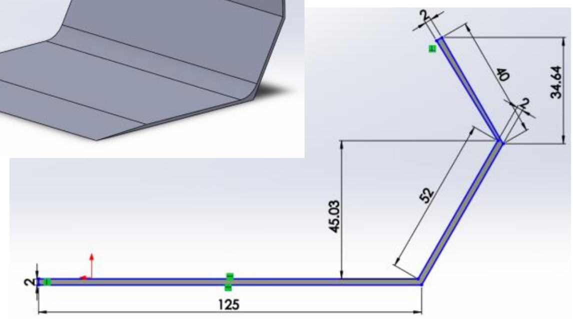
First I had to alter the chassis to fit correctly. This meant scaling up the front chassis piece from 250mm to 330mm to make space for the wheels at the back. Other than that, the other parts can stay in the same place.



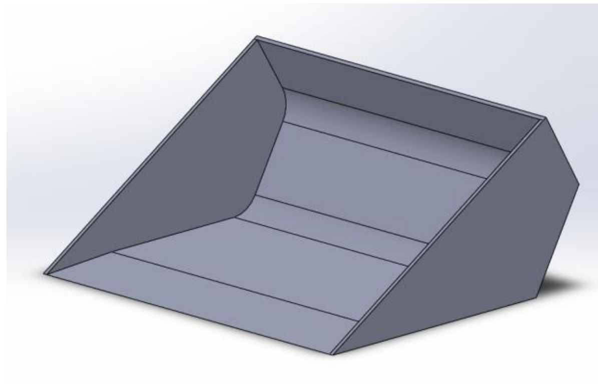
Next, I have actually found the chance to determine what size wheels I would like. I had realised that the scoop's dimensions dictate that the bottom of the chassis piece must be 44mm above the floor. This meant the wheel had to fit such that it allowed this distance to be fulfilled. In order to use a wheel size that is in high quantity, I looked for round-numbers and decided upon using a 30mm radius wheel, which would mean a 14mm gap between the centre of the wheel and the chassis piece (i.e. the wheel mount). When looking at the final model later, I can finalise the wheel size decision with the only requirement being that the mount and wheel are 44mm high as mentioned.

Following this I had to make the described changes to the scoop mechanism as a whole. This began with altering the scoop as described to fit its function. When tipped at 30 degrees, the scoop needs to ensure debris does not fall out the back so the back was made taller as described on the previous page. At the 30 degree tilt, the back needs to be at least 36.5mm tall to meet the height of the front of the slope (via 125sin(30) – 52sin(30)) and so I left it at a slightly taller height of 40mm to allow for some leeway.

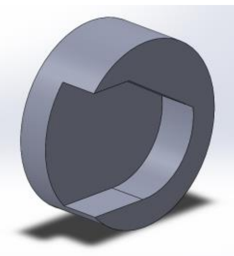


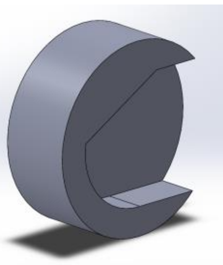


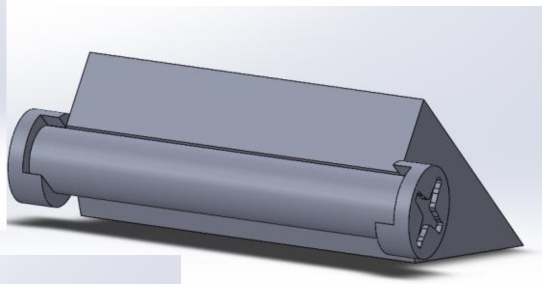
Also mentioned while redesigning the model was the addition of sides to the scoop to stop debris from falling out there either. A simple shape was formed to do this quite simply.

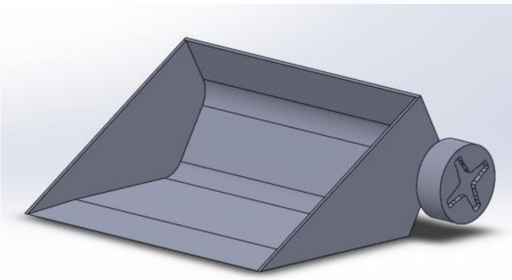


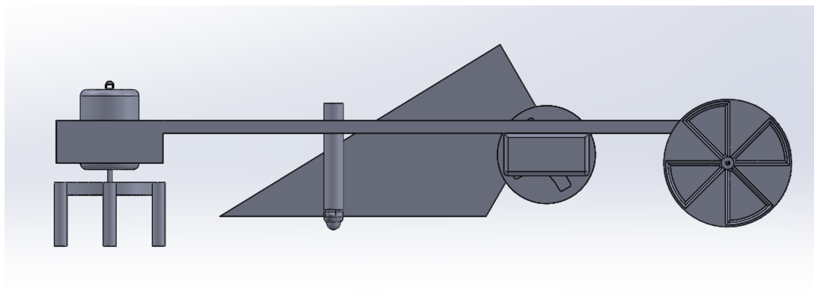
Finally, I realised the servo connectors had to be mirrored on either side and could not actually be the exact same piece so I constructed those before putting together the new scoop.

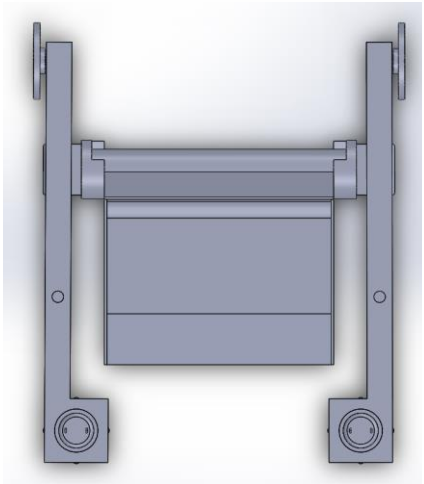


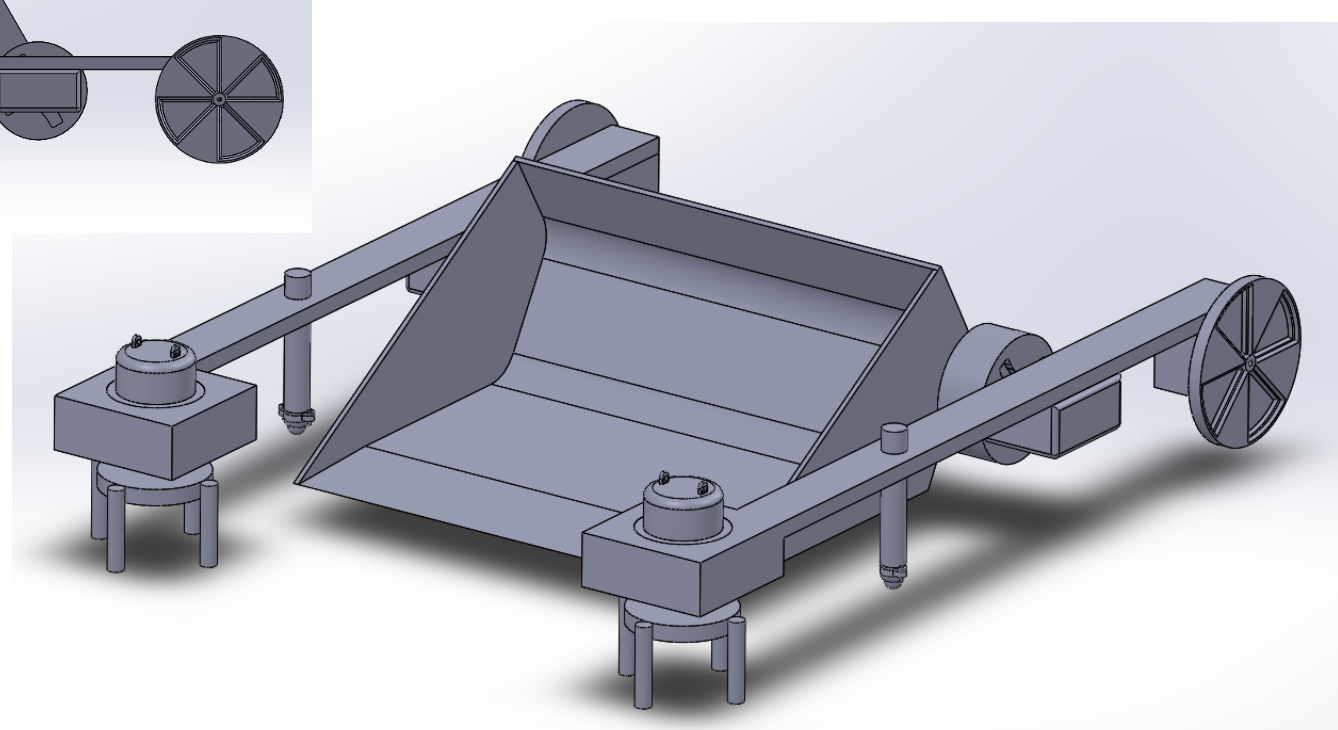












New Chassis Design – Strength and Safety

Before the model is complete, a consideration needs to be made about the safety of the user while interacting with the product, as well as the structural rigidity of the rover to prevent it from being damaged. For this I first need to organise a list of things that I should consider:

Threats toward damaging the rover:

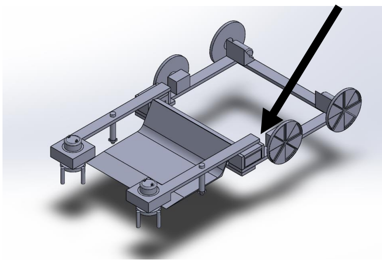
- Being stepped on from above
- Being knocked over or hit from the side
- It driving into a hard surface without realising
- Too much weight being put in the scoop

Threats toward the user:

- Tripping over the rover
- Sharp edges
- Potentially exposed wires
- Are Ultra-Sonic waves safe
- Safety when removing the scoop from inside the rover

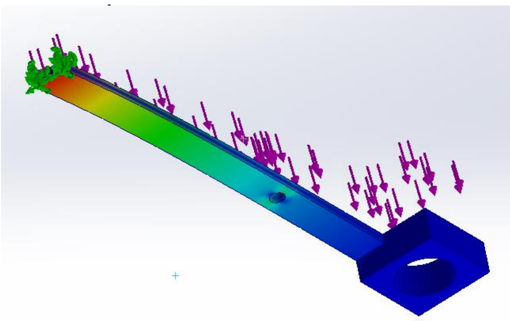
Threats to the Rover

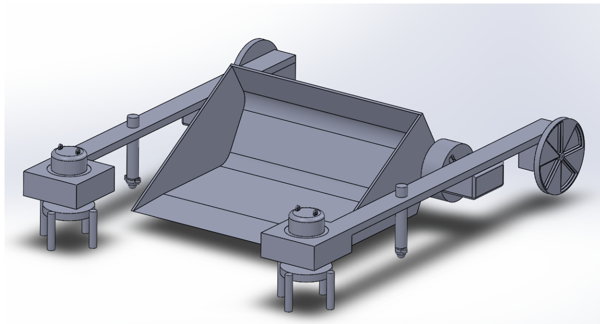
The rover needs to be prepared to deal with someone stepping on it, or alternatively a weighted object being dropped on top of it.



When I had professional engineers who work at my school look at my previous model they pointed out there are weaknesses in the structure where there are joins as shown by the arrow, this was one of the reasons the new model is held with only one chassis piece on each side, not two joined by the servo between.

Taking the value of force exerted by a heavier 98kg person at 54%, the design needs to be safe from a [53kg =] 520N force being pushed on it. Using the assumption that the chassis of PMMA (Acrylic for testing purposes, since the true material can be decided later), the piece can withstand 520N with only around 1.2mm deformation and a maximum of 1.49GPa of stress. This means the piece individually can manage with the force. Additional simulation testing was done to reach a value of around 1800N being needed to bend 9mm and fully snap the PMMA, which is equivalent to about 183kg, well above even the full weight of the 95th percentile. Instead of testing the pieces, however, Engineering professionals at school said the vulnerabilities would be where the joints are. Rather than attempt to make joints which can withstand over 500N without damage, especially parts like link between servo and scoop cylinder. Most joints which are not held by strong adhesive or other permanent bonds will never be strong enough for things like this, so it is a more reasonable solution to stop these parts from ever being hit in the first place. During the stakeholder presentation, a case was mentioned, which would wrap over and around all the parts. Additionally, this would stop anything or anyone from interfering with the moving parts such as tilting scoop – which could be dangerous. With a case, heavy items dropped will only put stress on the casing not the more vulnerable inner parts. However, the case must be attached to something so both the case AND the part it is joined too must be able to strongly hold the weight.





However, the smaller size of the model now means that there is only two wheels and two caster wheels holding it up, reducing its ability to hold weight above it. The 5th percentile of women is 50kg and the 95th percentile for men is 98kg according to hermanmiller.com. However, home testing I have done has revealed when accidentally stepping on an object of 200mm tall tended to be 54% of the persons true weight on average (table of values below).

I tested the comparison between a person's normal weight and the weight which they might exert if they accidentally walked over a box. Of course this action is acted so it will not be precise but a reasonable estimate at least.

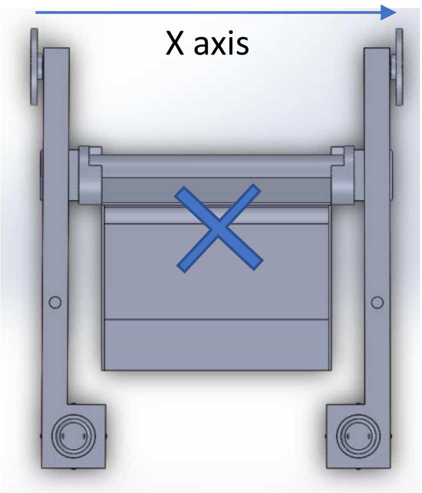
Person's Weight (kg)	Weight Over Box (kg)	Ratio weight to force
82	1/3(42+38+46) = 42.0	0.51
74	1/3(31+41+37) = 36.3	0.56
66	1/3(39+34+32) = 35.0	0.53
73	1/3(41+36+40) = 39.0	0.54

It is by far most likely that the chassis pieces are what the case will be attached to on either side. Therefore all the joints which are directly connected to the chassis piece must also be prepared to take that force. This means minimising the number of joints on the chassis and making the few joints left as strong as possible. By doing this, other joints such as servo to scoop, can afford to be weak as they are protected by the casing. Obviously the chassis still has its limit of 1800N. The casing will certainly be designed in the interest of having a far higher breaking point than this in order to ensure the chassis pieces do not break if a larger force than this is put on it, the joint between casing and chassis must be sacrificially designed to break at 1800N, then the case will break off and take the force– the joint can be easily fixed - instead of the chassis and inner mechanisms taking the force and being rendered unfixable.

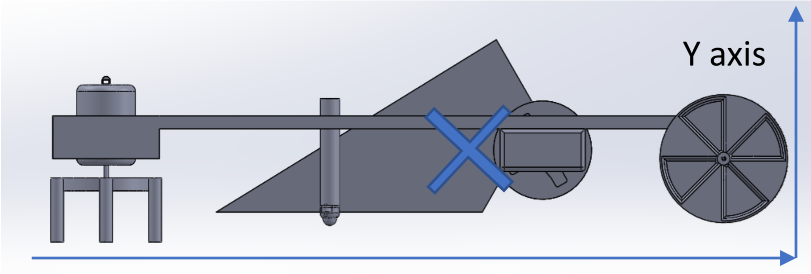
New Chassis Design – Strength and Safety

Threats to the Rover

Next the product needs to be unflinching when it is given a force from the side. Luckily, the current chassis is very low so likely has a very low centre of gravity



Being totally symmetric along the X axis centres the cross in picture one, but in the Z axis is moved backward by the heavier servo and DC motors. The Y axis centre is also moved down by these motors.



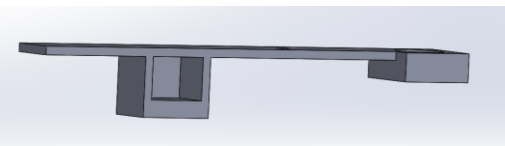
Where the Origin is the bottom left of both screenshots, the centre of gravity is approximately (x, y, z) = (110, 40, 110) in mm. Using Pythagoras' Theorem I can find what angle would be necessary to make the weight cross over the edge of the rover and thus tip it. This means a tilt of 70 degrees would be required in the X axis or 66 degrees in the Z axis, both very high angles. Therefore it would be incredibly unlikely for the rover to tip over. The measurements made for this are based on the assumption the casing will be rough symmetric and low weight.

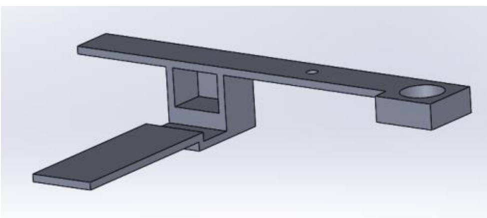
Additionally, the product could have force come at it from the side via someone kicking it potentially. The stress it might be able to take can be estimated using the Young's Modulus equation, but to take away the uncertainty of the estimated lengths and area I will use an extreme force. According to mathmaticshed.com, a professional footballer might kick a ball with around 1200N. The side of the rover has an Area of $0.00268m^2$. The width of the chassis piece is 0.02m. The YM of Acrylic (again the material for testing) ranges from 2.76-3.30GPa [via matweb]. Even using the minimum Modulus and extreme force, there is only a deformation of 0.0033mm, a very small movement that is still under elastic deformation.

Since the pieces themselves are under very little threat to being broken the main stress when hit from the side would be the joint between the chassis piece and the servo. Previously this join was simply making a case for the servo to be stuck in and using an adhesive to attach it to the chassis. That solution is not in any way viable, especially in this case where the servo hangs beneath the chassis.

I believe to keep the model resistant to being compressed in the X direction, it should tick a few boxes. Firstly there should be something between the two servos to keep them at distance as well as something to keep the chassis pieces at their distance. Next there should be an effort to minimise the number of pieces as joints create vulnerabilities. Finally, edges should be soft as to spread out stress evenly and reduce chance of breakages.

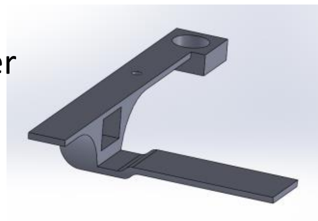
Previously mentioned in an earlier model was the bar between the two servos in order to hold up the servo cylinder that is attached to the scoop. If I were to use a part like this again, it could further its use by also connecting the two sides of the chassis (as the previous parts that did this are gone with the smaller design), when the scoop is not there in between. For this to be optimised, it could be part of the chassis itself and therefore reduce joints, however this would require the chassis to go below the servo motor. I actually have an idea for how this can feed into the securing of the servo motor.



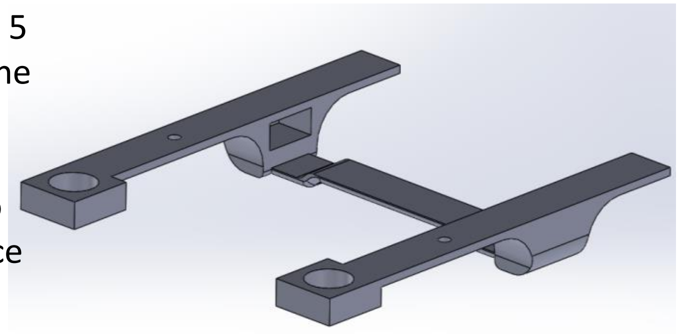


The idea I had was to have a small space for the servo to sit in which can allow the chassis to branch down to a piece that can run under the scoop cylinder. With a proper process this can be made as one part too. First I had to make the chassis arm 36mm wide instead of 20mm as the servo is 30mm and a 5 walled container for it (shown in the second picture) would keep it secure. The under part went a further 19mm as to make space to go under the servo connector. Once clearly past the servo connector, however, it moves up 7mm to sit under the cylinder snuggly.

As mentioned earlier, I softened the sides to ensure stress is spread out.



Then I mirrored the modelling to the other side to finish the complete chassis piece.



The creation of this new chassis piece solves two of the problems previously posed:

- it provides a branch between either side of the chassis while reducing the number of joints required and also giving a secure holding place for the servo motor
- It branches underneath the cylinder to hold it up as to reduce radial strain on the servo motors. Providing the scoop to cylinder join is secure, the scoop should not be able to be easily overloaded with weight.

I will implement this new piece into the design once safety toward the user is considered and any other changes are made.

The final thing that might have damaged the rover was it moving into an object that it has failed to notice. This could and would result in forcing the motors to work against themselves which can cause them damage. It is likely that the overloading of the movement DC motors should be considered when producing the code for the system. Therefore contingency for this problem will be covered once I move on to the requirements of the code on this page.

New Chassis Design – Strength and Safety

Threats to the User

Reducing Tripping Hazard

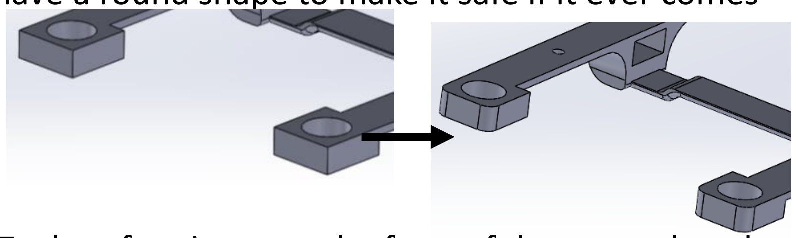
Since the rover will be used while café customers are around, it needs to make sure it can be noticed in order so it will not be tripped over, but not too noticeable as to be in the way of customers. Other products solve this problem in various ways. Roomba's for example, make noise as they have a vacuum, so they are noticed no matter how small they are. However, noise is not really an option for this device due to the context of being used in a café, so a visual cue is more appropriate.
For something to be a trip hazard, it needs to be roughly around the height that someone would step. For example, people trip over stairs as they need to step up about 25cm to get over the 20cm step but might not step high enough and tap the edge of their foot on to the edge of the stair – tripping. In contrast, someone who walked in to a half metre high ledge would never trip over it as their foot would be so much lower than it. The difference is that the stair is at a close height to the elevation of a person's foot as they walk. I need to make the rover too large or too small to trip over. Excluding the circuit board, the max. height reached of the rover currently (scoop tipped back) is around 9cm, so it is already too large to go under anyone's feet. The casing needs to be far taller than the height of a person walking but still short enough to easily get under any chair or table that may be in the café.

Is the Ultra Sonic Sensor Safe?

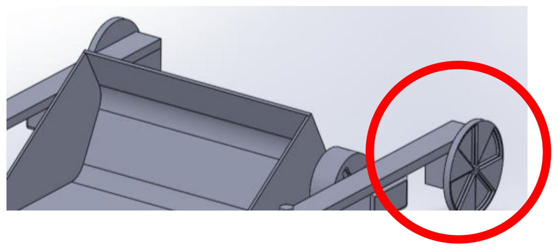
An ultrasonic sound is defined as a sound wave with a frequency above 20kHz, the top of the human range. The sensor I used for my tests (and would like to use for the final product) use frequencies around 40kHz, well below the 300MHz required to harm us. While we cannot hear the ultrasound, dogs and cats can (with 60 and 80kHz ceilings respectively). While pets may be able to hear the sound, it will likely be too quiet. The power usage of the sensor is about 0.1W while iPhones are typically around 5W [according to forbes.com]. These phones have a maximum volume of up to 100dB, which led me to estimate the volume of the sensor as a maximum of 10-20dB. For comparison, most restaurants are typically between 70 and 100dB [according to restaurantengine.com
This means the sound is too low pitch to cause harm, and also too low volume to be noticed (or harmful according to exponent.com saying harm comes above 90dB). The Ultrasonic Sensor I wanted to use is perfectly safe and unintrusive to café life.

Sharp Corners

Being a device that will be nearby people of all ages all the time means that there must be precautions to stop the device from hurting people. One way this can happen is sharp corners. An easy solve is adding chamfers to the outside edges of the rover as shown. Additionally the casing will need to have a round shape to make it safe if it ever comes into contact with anyone.

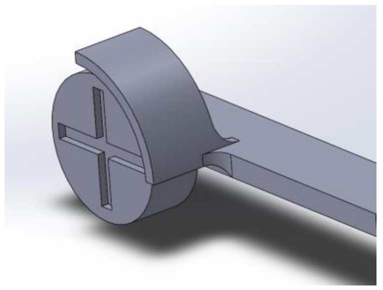


One problem that has arisen from this is it would be difficult to have soft edges at the back where the wheels are as the motor and wheels would be in the way.



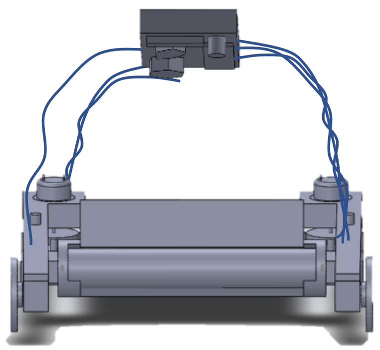
To therefore improve the form of the rover, the wheels chassis could be extended past the wheels – however this leads to vulnerability at the back and re-increases the length – or have the wheels instead be on the inside. This would decrease tipping angle marginally but also make the turning circle even smaller which is always helpful.

Obviously the wheels will then be in the way of the user pulling out the scoop. A simple easy solution is to give the scoop enough space to be pulled out above the wheels, and have a sort of dirt guard over the wheel to stop the user from hitting the wheel with their hands as shown.

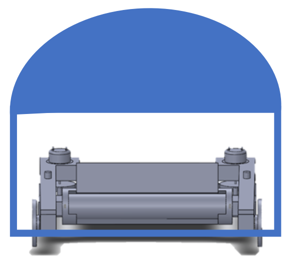


Safety Removing the Scoop

If the casing fully wraps around the chassis, there will need to be an opening at the back through which the scoop can be taken out through (to dispose of waste). In order to make this as safe as possible, there must be an open space through which there is space for the scoop and user's hands, as well getting rid of sharp edges and keeping wires out the way. It goes without saying wires should be insulated, but also they should be fixed upon the inside face of the casing to keep them out the way. An ideal place for the circuit board to be also would be perhaps fixed inside the top of the casing as shown.



Additionally, inside parts would need to be covered such as the wheel guard mentioned in the 'Sharp Corners' section and a case for the circuit board. Additionally it would be convenient if there was a face blocking the user from sticking their hands past where the scoop cylinder is pulled out - as to stop them damaging any other parts or themselves.
The fact that there needs to be space for the scoop to be taken out even above the wheel guards means the case must go directly up until it has gone past the height of the entrance as demonstrated →. Finally, the scoop-container should only be extracted when the rover has stopped, so there must be a way to close and lock the casing and stop the user from interfering with the rover while it is in use.



New Chassis Design – Casing

Now having ironed out a set of requirements for the casing, it is time to begin designing it. The requirements that have been set are:

1. Must wrap around all parts of current system
2. Fixed on via a joint with the chassis
3. Joint designed to break at 1800N
4. Far taller than the elevation of walking feet
5. Shorter than the height of a chair base
6. Wires and circuit fixed on the inside
7. Must be an entrance at the back, suitably sized for removing the scoop
8. That entrance should be able to be shut/locked during use

Additionally, the case should be relatively aesthetically pleasing such as using a simple shape, as well as potentially being coloured to literally highlight it as a (low) potential trip hazard (just in case). Before beginning the design process I need to analyse more technically points 3, 4, 5, 7 and 8

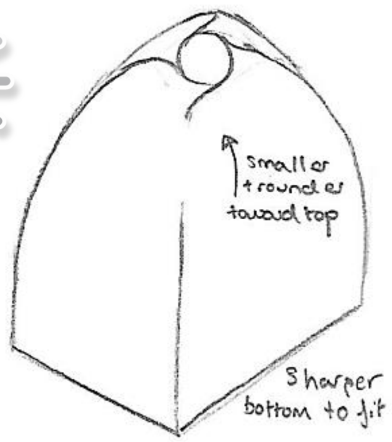
Aesthetics

As mentioned, aesthetics will also be an important factor toward ensuring the rover is noticed. I discussed previously a simple rounded box shape would be an ideal aesthetically pleasing form and while other shapes like stars might be more visibly bold, a rounded shape ensures the safety of those around it if they do manage to fall on to it somehow. Therefore I need to find ways that a simple rounded box could be seen more easily.

My mind immediately went to how road ornaments and signs make themselves easy to see. Cones like those shown right are always clearly visible due to bright orange colour. Even if it is dark the cones are visible due to their reflective strips.

My rover would benefit from a bright colour greatly – however making it too bright a colour might draw too much attention to it. This is something I should ask my stakeholder. Additionally, while reflective strips could work, a potential alternative could be lights – I will ask about that too.

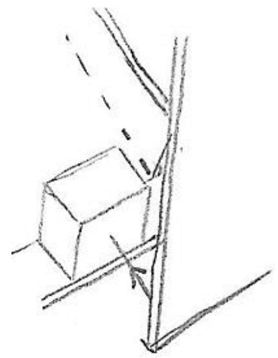
When I asked my stakeholder she said that it is certainly a good plan to make it coloured. She then went to mention that lots of cafés have different themes so different buyers may want to have different colours, following this she expressed that yellow is renowned as the main 'hi-vis' colour so that should certainly be the main colour if there are to be options (if not the only option). Additionally, she did not think reflective surfaces or lights would ever truly be something that was particularly helpful – considering how cafés will not be open in late hours and if it is dark then they always have more than capable lights.



A simple web search of floor and road cleaners shows results that are clearly not aesthetically pleasing, nor do they make any attempt to do so. Therefore it is clear that a simple rounded shape is more than enough to make my rover more aesthetically pleasing than potential competitors. Due to the strict size restraints there is not really anything that can be added to the simple shape to make it stand out more (such as the jokingly mentioned flags).

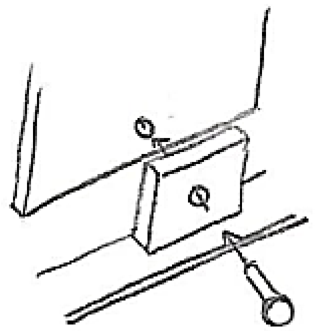
Point 3 – Joining the Case On

Next the case needs a way in which it will be joined on to the chassis. In order to allow the chassis to remain unbroken, the joint should be designed to give in once it reaches around 1800-2000N (since the case will distribute the force across the product, the actual force the rover will be able to take is much higher than this). Also, so that when the joint breaks, the case will simply hit the floor and remove all stress from the chassis, the joint should allow the case to be outside the chassis as shown. →



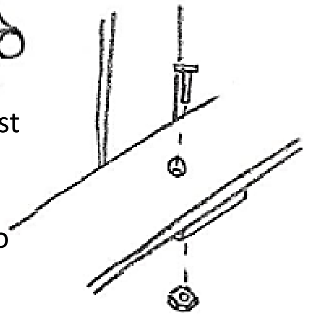
The two avenues I could go for joints can first be divided into are permanent and impermanent. In order to **Design for Disassembly**, impermanent jointing such as screws should be used. Designing for disassembly allows for far easier repair and replacement of parts – which is greatly favoured for the concept of sacrificial joints. This means I should exclude adhesives, any form of brazing or riveting,. This leaves methods like screws, interference fits, and nuts & bolts.

Unlike screws and interference fits, nuts & bolts can be used by anyone without any specialist equipment. This means that if the joint breaks, any new components can be bought and the repair can be done very easily by the user without professional help. Next I need to solidify the orientation of the joint.



Conceptually, my first idea was the obvious one, to have the casing directly attach to the chassis through the side. The problem with this is that the chassis is only 6mm (and 20mm where the sweeper is), so there needs to be a piece upwards that is big enough to have a nut through. Instead of having this extra piece (or making the chassis an even more complicated piece), the second idea solves the problem instead.

Note: this would be something to stress test properly nor does my version of SolidWorks have the capabilities to simulate. Thus I am working on educated theory only.



Strategically placed lips should let this design work, potentially a heavy chamfer would make it less prone to corner stress too.

Additionally, this shape means when force it placed on the top of the case, the stress will fall to the case lip instead of chassis as the casing is now below the chassis with this joint – meaning that the joint should theoretically break before the chassis piece.

New Chassis Design – Casing

Points 4 and 5 – Height Requirement

To work out how tall the case should be I need to first analyse what makes something a tripping hazard. Hud.gov defines a trip hazard as 'Hazard caused by abrupt change in vertical elevation'. Usually this means anything larger than about 20mm, but I found it difficult to find a solid definition of an upper limit. The 2003 Tomlinson vs. Congleton BC court case ruled that a hazard can only be considered liable for damages it causes if the person who the damages are done toward do not carry any responsibility for the situation. In simpler terms, something is only a hazard if any person around it could act normally and would still be in danger of it. This ruling was used in a thrown out 2005 housing case about someone who jumped over a 400mm fence. It was clear from this case that 400mm was only a hazard if the person was jumping, and since walking is a lot lower, that threshold can be reduced dramatically. The average vertical jump height is (according to topendsports.com) is around 35-45cm, roughly the same as that fence, thus I would conclude the height of a step to be the height of a walking-trip hazard. Tests in both stationary and video form led me to the value of feet being at a maximum 3-6cm off the floor while walking norm
legal requirement to be larger than at least 10cm. With the chas
that is not a problem.

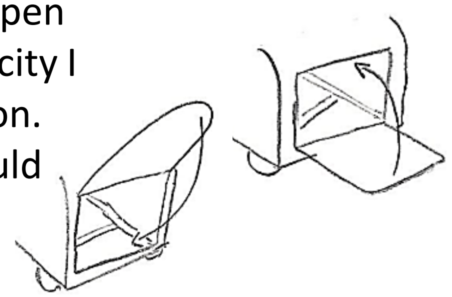
Now with an absolute m
absolute maximum heig
preferred. The max heig
must fit under chairs, so
closed) café to measure
was certainly a wide arra
28cm for the chairs used
When I asked my stakeh
compared to others, she said that this size was very common – thus I should use this as a strong reference. In order to meet the required size of this chair, the height should be no larger than 27cm tall. Additionally, something important to note was that while the chair was 34cm wide at the base, it was only 23cm wide at the top (current design is around 280mm); the case cannot be straight up and must contract.

For the preferred height, I tried to see what I would trip over. Walking into boxes led me to the conclusion that the more mobility my leg was allowed, the easier it was to trip over something. The maximum manoeuvrability I could get was when the box was approximately the height of my ankle while walking which (including the 3-6cm elevation) was about 220mm. Thus in order to stop one from tripping while allowing the rover to fit under a range of chairs, 250mm is a reasonable height to use. This means the case would need to be approximately 200mm tall.

Points 7 and 8 – Taking Out the Trash

In order to pull out the scoop, there needs to be a hole at the back of the rover. This hole needs to have enough space for the users hands too to make it easy and safe for them to do this. The scoop itself (currently) is 180mm wide while the cylinder is 200mm, also to be noted is the OCR Anthro booklet regards the width of fingers (5-95th percentile mm) is 18-24 for men and 15-21 for women. While the preference would be for the scoop to be carried out from the bottom, the space necessary to allow it to be removed while holding it on the sides should also make the exit spacious enough to make removal of the scoop easy. Thus the exit should have a width in the region 200-240.

imple decision of if the latch would open
wnwards. In order to maintain simplicity I
eways or sliding up out of the equation.
o final choices, opening upwards would
er to hold it up, an unnecessary
Thus the latch will open down.



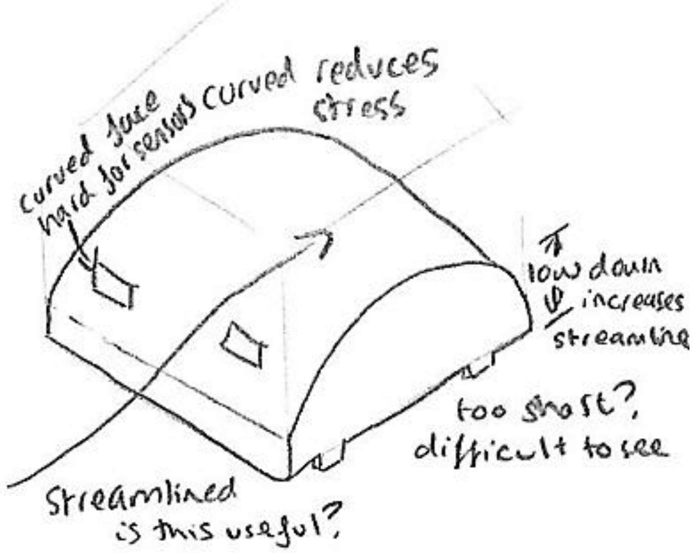
o decide the method in which the opening should be sealed.
discussed some latch types while looking at the servo-
n first look at Velcro, buttons, jubilee clips, or toggle latches. Velcro would be too unreliably weak to keep it shut while moving, similarly a button could easily be undone by the user while the rover moves. The slightly higher difficulty in using jubilee clips and toggle latches means that they would be difficult to undo while the rover moves.

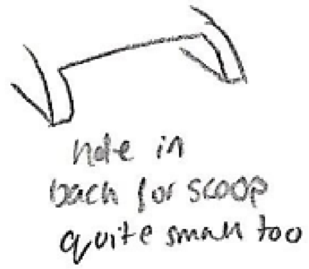
Additionally, I considered using an electromagnet to lock shut the hatch while moving. This would work in such a way that the hatch could not be opened at all without first making sure the rover had stopped. How this could work would be to have the hatch be made of a metal and have the electromagnet turn off when the rover stops to release the latch. The problem with this, However, is that the latch could not be closed when not moving (without using power idly), additionally lack the time required to add this feature of this complexity with current time restraints. I believe Jubilee clips are too time consuming to use so I think a simple toggle latch would be perfect for this.

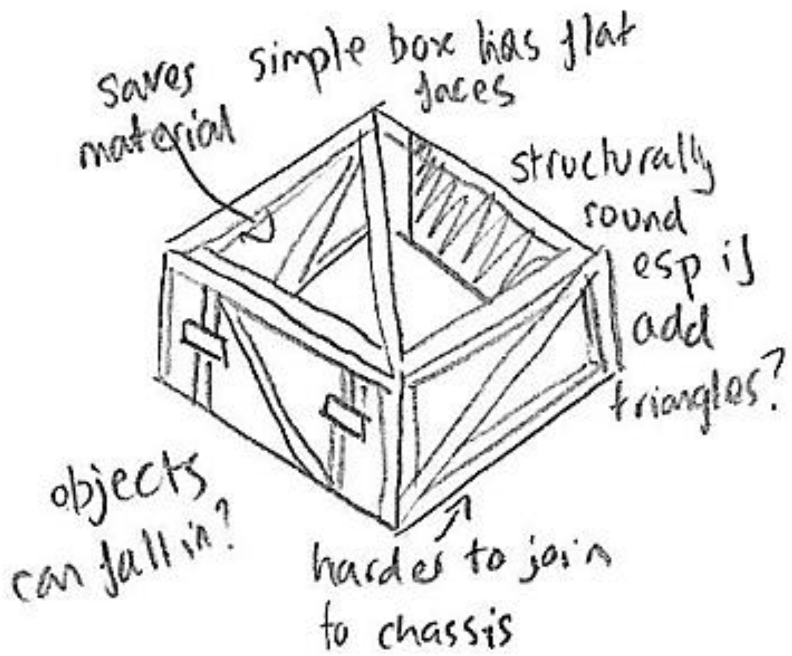
New Chassis Design – Casing

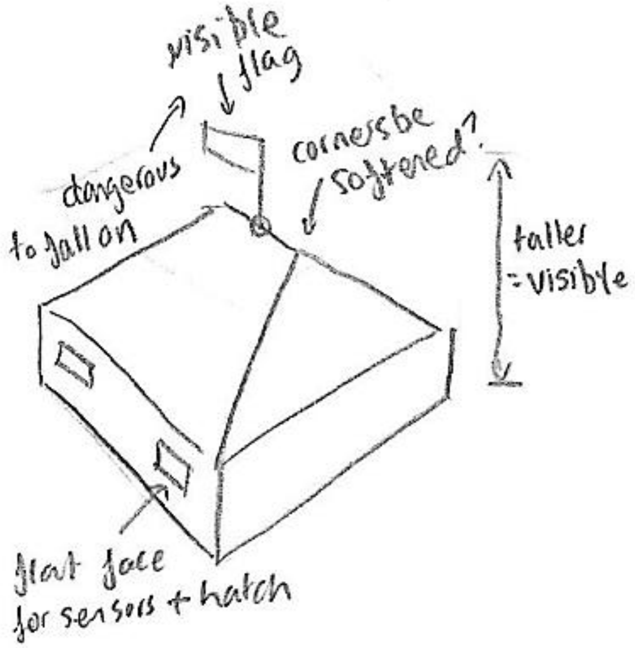
Casing Requirements:

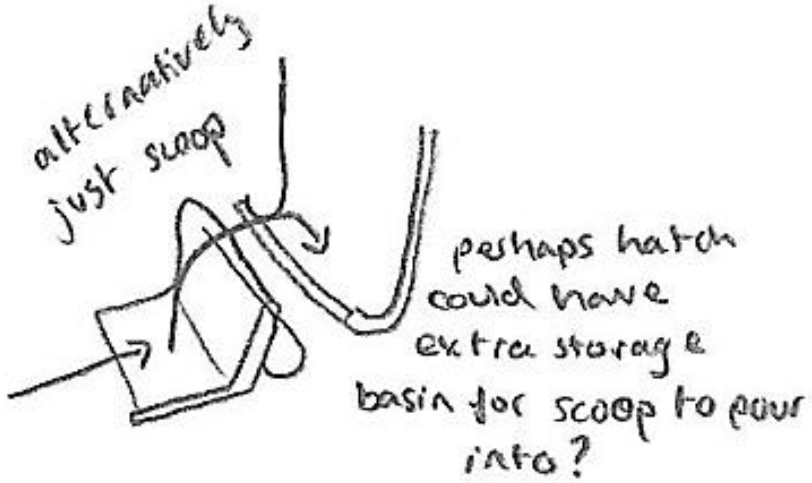
- House the Chassis + Scoop
- Built to withstand force
- Not too short or tall
- Minimise Sharp corners
- Hole in the back (for scoop)
- Spot to house sensors
- Efficient join to chassis

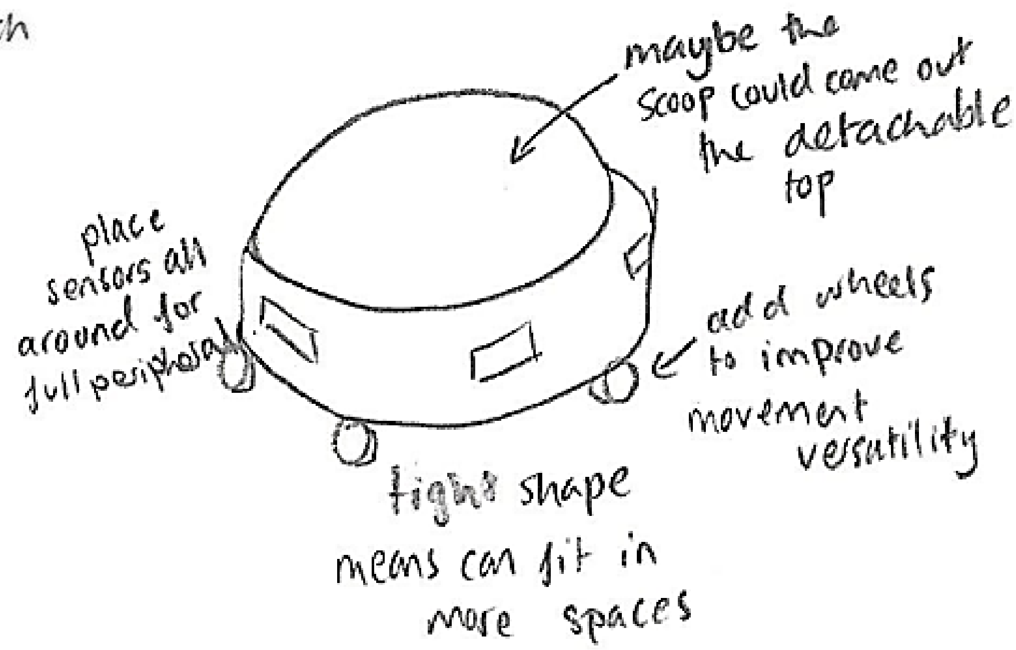






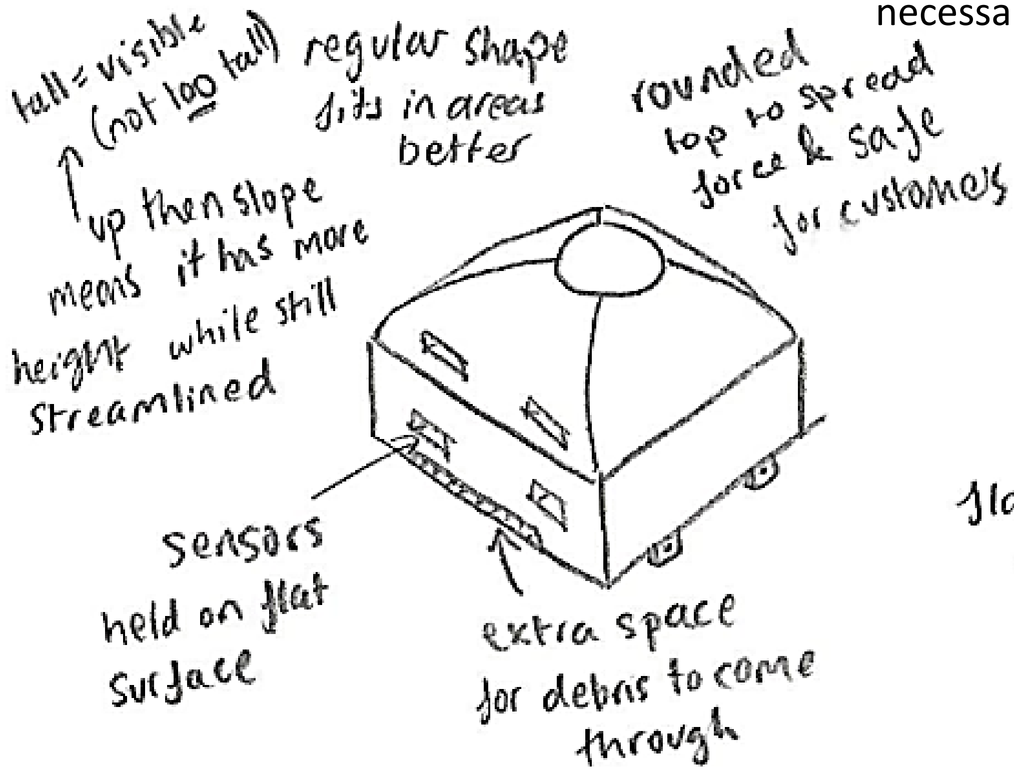


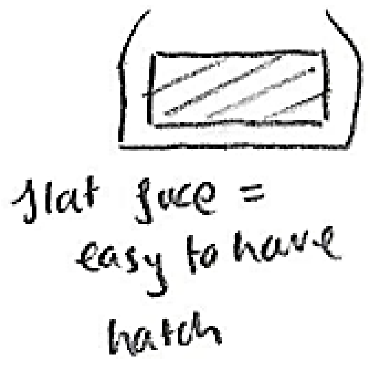




Combine as many positive features as possible – aesthetics can come later (and leaves room for further functional improvement).

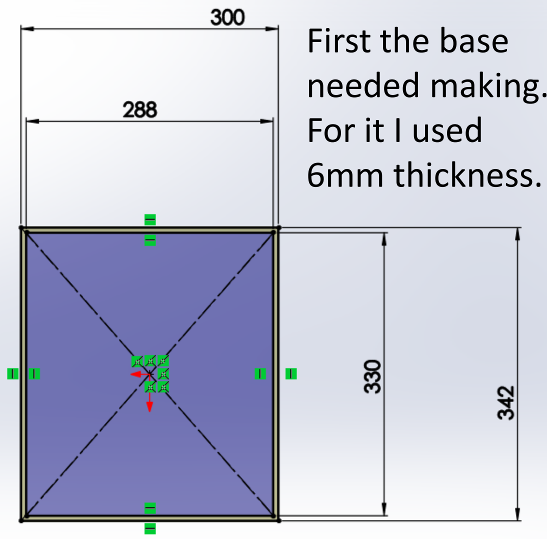
Due to it being the most versatile, I picked the design below. The benefit of a far more simple and un-specialised design is that it is far more easy to improve over time as necessary.



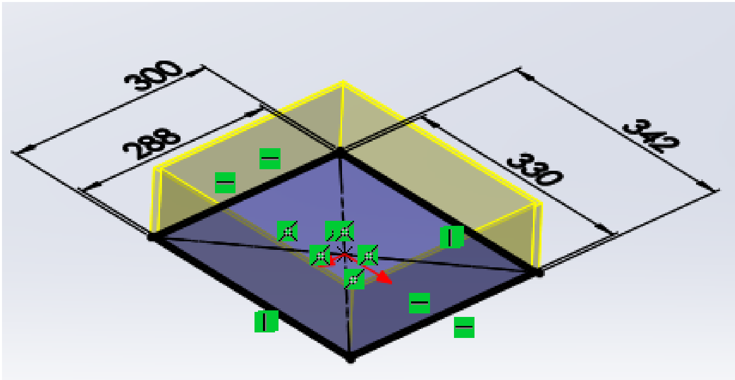


New Chassis Design – Casing

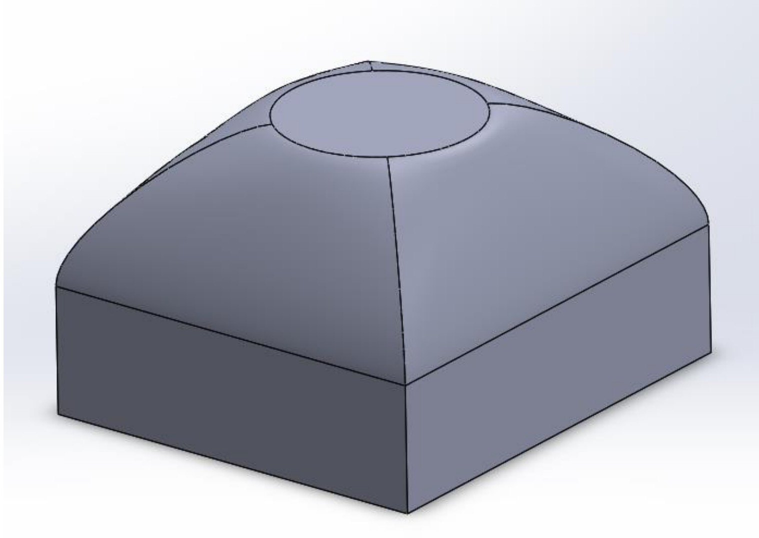
Since all the requirements have been discussed and solutions have been made, I need to make a scale 3D model of the casing to visualise what has been decided.



First the base needed making. For it I used 6mm thickness.

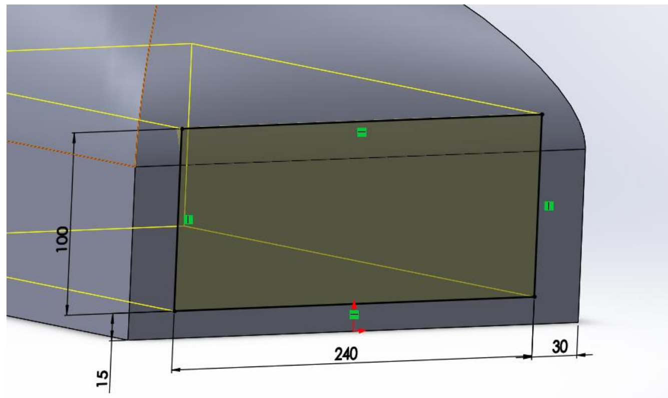


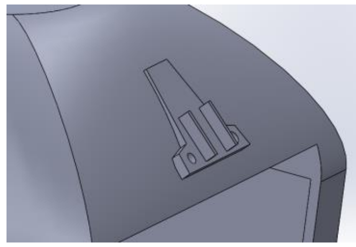
Next I made the case go straight up for the first 9cm – so if the joint broke and the case fell, it would hit the floor and not touch any of the inner components.



With the initial part moving straight up done, the rest of the shape could be completed. On the previous page I mentioned some of the chairs got more confined as they went up (34-23cm). Therefore the case has too. Also to spread stress more I rounded it – lofting toward an arbitrarily chosen 150mm diameter circle at the top. With this the base design was done.

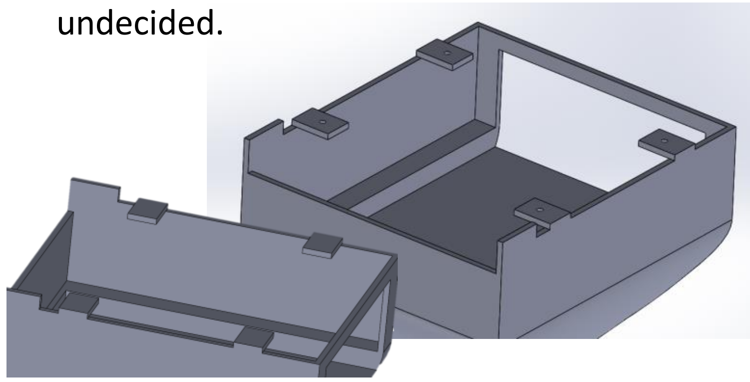
The decided hole at the back was formed – sized for its requirements previously laid out – dimensions shown

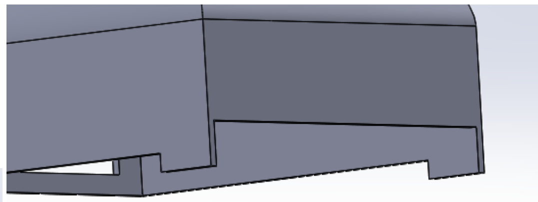




For modelling purposes only, I added the top of a toggle latch to show approximately where it might go.

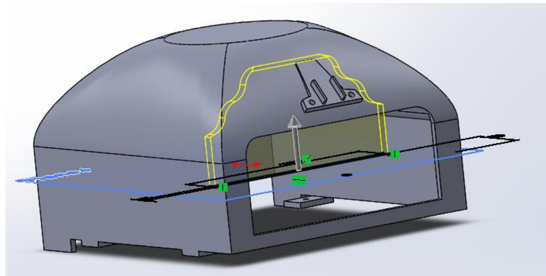
Joining place and holes for nuts were made to fit under the chassis, however the places for the joining points are undecided.

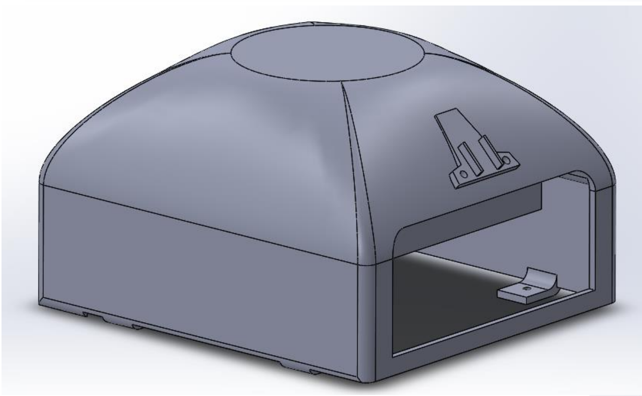




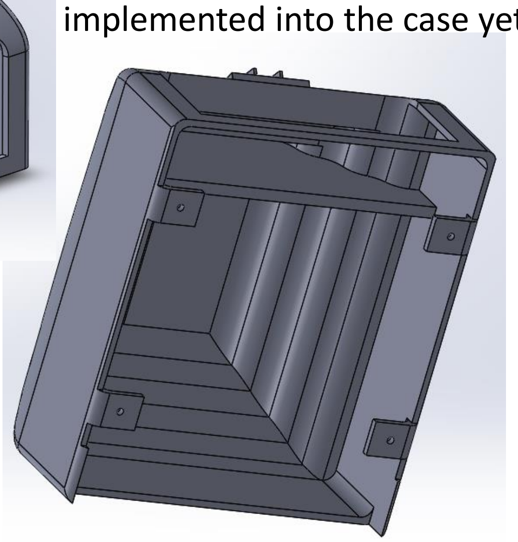
Due to the differing depth of the chassis piece where the motors are held, a dip in the case was accordingly made. Additionally, I added an extra 20mm of space for the front – in case swept objects happen to be very tall.

The required face that blocked the user from reaching past the scoop was added too , being 90mm from the end and stretching to 70mm from the bottom.



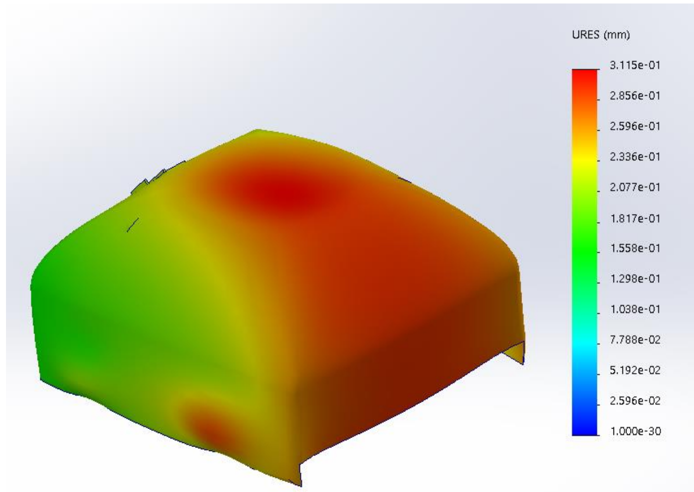


There is more sensor discussion on the next page so the sensor system is not implemented into the case yet.

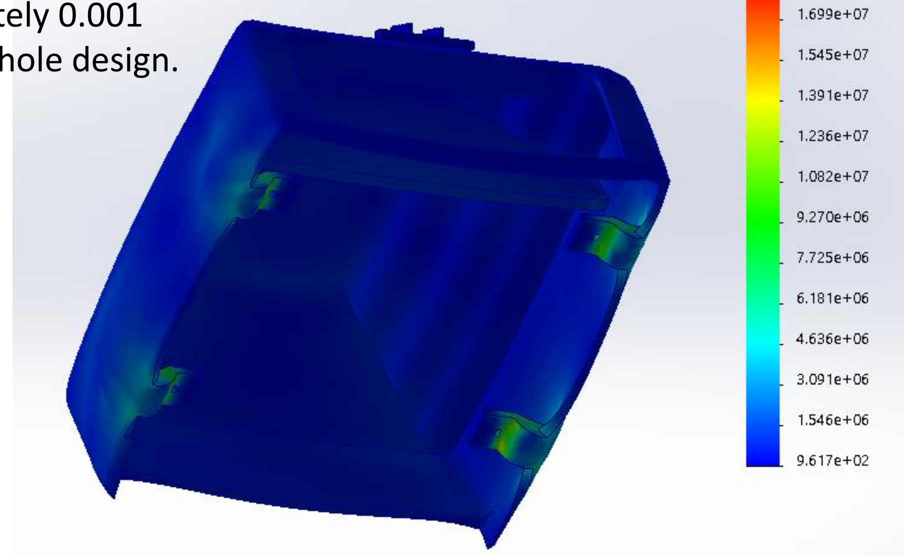


After finally chamfering a few edges to improve its stress reduction even more here is the finalised models. Obviously when properly made there will need to be a hinge on the bottom for the opening hatch.

Testing as Acrylic, the case was even more stress reducing than I had hoped. There is almost no deformation (max 0.3mm) and the amount of stress was approximately 0.001 times the max it can manage across almost the whole design.



Very blue!! ☺



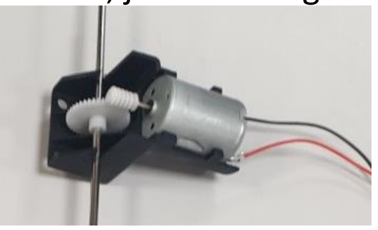
Coding Requirements

Before finalising the design process, I also need to consider what the requirements are of the code that is run by the circuit. These requirements will include a few hardware needs as well as planning algorithms toward the method of some of the required processes. The things I will explore are:

- How the wheels move
- Dealing with the motors over-clocking (mentioned this page)
- New method of recognising obstacles
- Screen system (from this page)
- How the code will input a map/chart of the café and output an efficient path to take

Use of Wheels

The primary function of the code is to control the movement of the rover, this includes proper use of the functions of the motor to move forward, backward, turn, and vary speed. The DC motor I previously tested my code with on this page had the capability to turn both clockwise or anticlockwise, and at a range of speeds (with the maximum being 9600rpm without gears). It therefore meets all the initial criteria, just it must go slower.



The addition of a Worm Drive dramatically slowed the speed of the output while also changing the orientation of the motion. I can utilise a similar protocol in order to make the perfect output speed for my rover. Previously on this page I concluded the rover needed a slow speed in order to ensure it had enough time to react to objects and turn accordingly, however the turning circle of it has been dramatically reduced so it does not need to be as slow.

Nevertheless, since it will be travelling around people all the time, it should still be in no way fast. Rather than compare many speeds, I can take a page from Roomba's book and replicate their normal speeds which, according to a range of sources on the internet, about a foot per second = 0.3m/s. On this page I decided upon using 60mm diameter wheels, with this in mind I used the following maths to produce a gear system that would get me the required speed:

$$V = \omega r$$

$$0.3\,ms^{-1} = \omega \times (30 \times 10^{-3})\,m$$

$$\therefore \omega = 10\,rad\,s^{-1}$$

$$\text{revolutions per sec} = \frac{10\,rad\,s^{-1}}{2\pi\,rad} = \frac{5}{\pi}\,rev\,s^{-1}$$

$$\approx 1.6\,rev\,s^{-1}$$

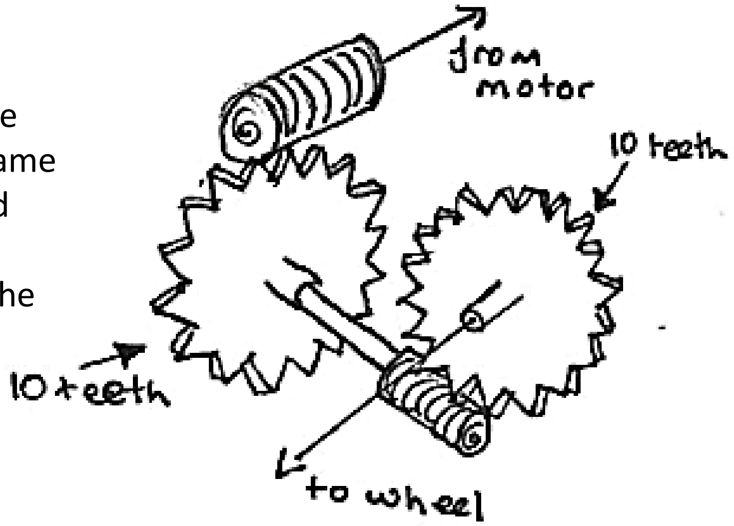
$$\Rightarrow 96\,rpm$$

The desired output for speed was 96rpm while this motor, the one I tested with, had a given input speed was 9600rpm.

$$\text{Mechanical Advantage} = \frac{\text{input rpm}}{\text{output rpm}} = \frac{9600}{96} = 100$$

$\therefore$ want overall gear ratio = 100

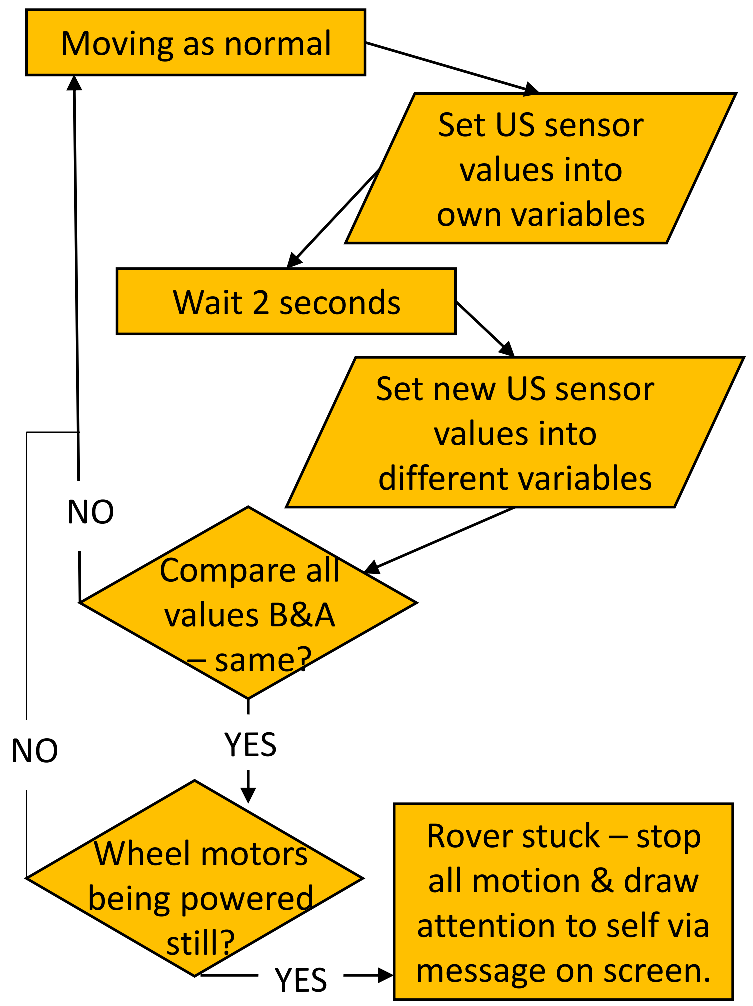
Knowing I wanted a gear ratio of 100:1, I needed to make a gear train to fit. To help, ratio 1 x ratio 2 = overall ratio. Additionally, I have a strong preference for keeping the output wheel at the same Y level as the input motor – this would maintain the distance of the centre of the wheel from the ground and thus the elevation of the chassis. From this the following gear system was made:



$$10:1 \times 10:1 = 100:1$$

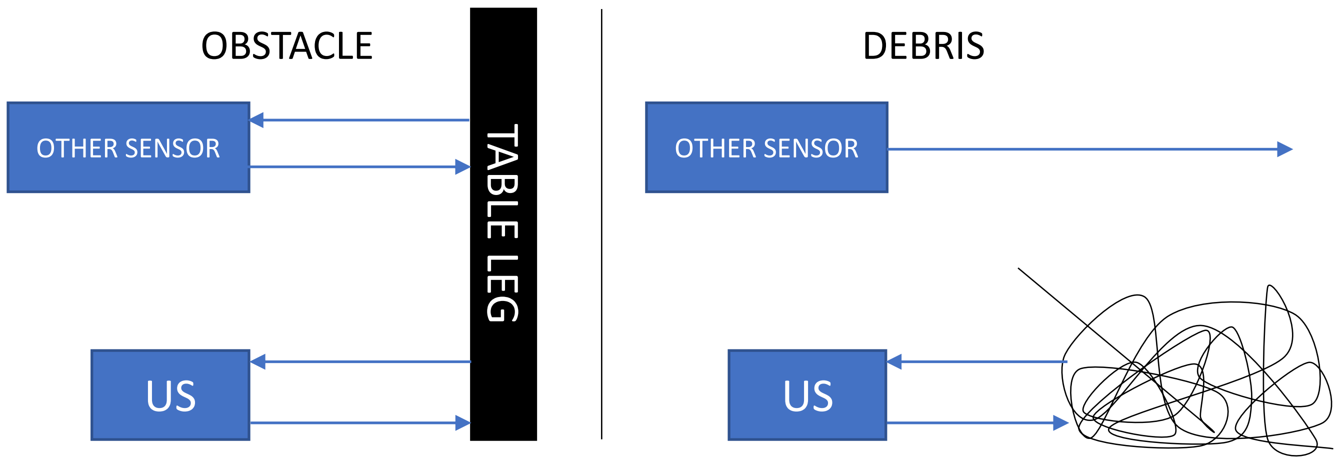
Maintaining the Motors

There may happen to be times where the rover gets stuck, whether it be a wheel stuck or accidentally driving into something without realising. The following flow chart is a solution to such. When the rover is stuck, it can inform the user by turning on the mentioned screen and displaying a message e.g. "stuck, please help".



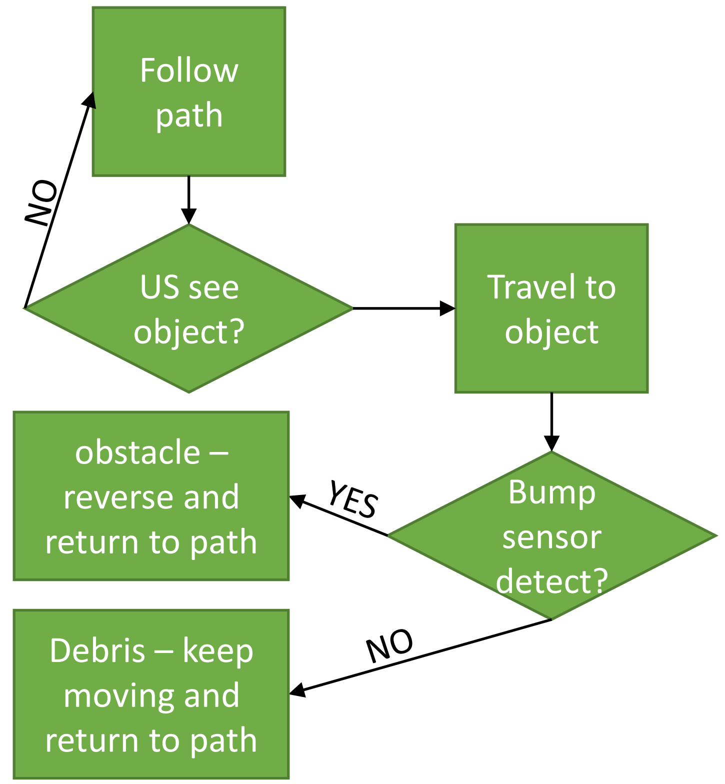
Coding Requirements – Differentiating Obstacles from Debris

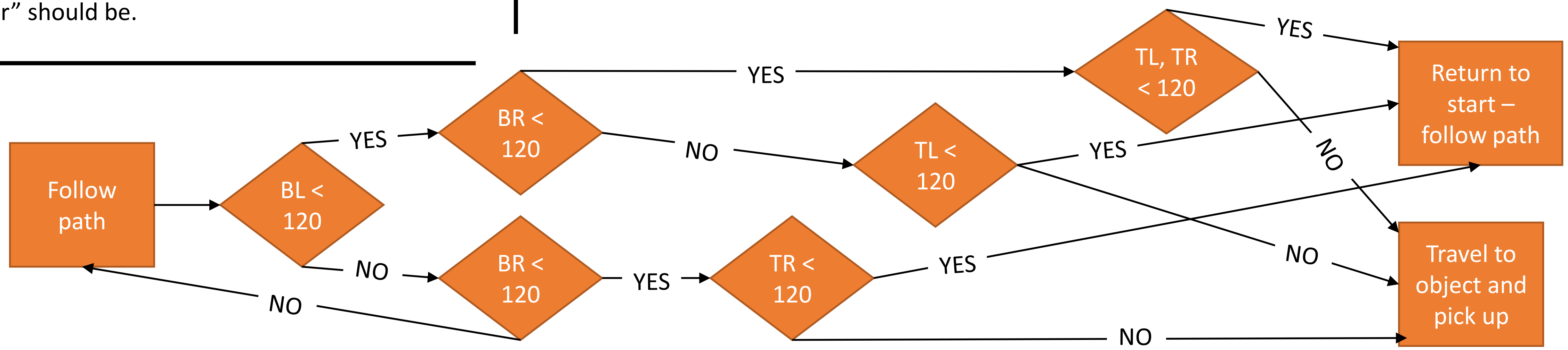
My stakeholders expressed their preference of differentiating obstacles and debris via their height, so that is what I should attempt to achieve. The Ultra Sonic sensors at the bottom should detect an object and its approximate position, but another sensor needs to see if that object is tall enough to be an obstacle or short enough to be something to pick up. The sensory system required can be visualised clearly like this:



All I need to do is pick what this "other sensor" should be.

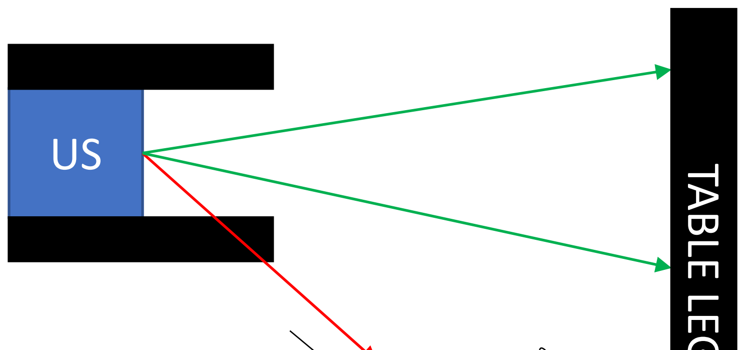
Idea 1
As I mentioned on [this](#) page, the new, far smaller, design should have the capabilities for a very small turning circle not that far from turning on the spot. As I discussed in my presentation, a small turning circle was the main outlying reason for having to use a ranged sensor instead of a bump sensor. Now with that being a possibility, one option would be to utilise bump sensors to tell, once the rover has reached the object, whether it is possible to pick it up or not. A simple flow chart to represent is as follows. →





Idea 2
While the bump sensor idea would work well, there is a primary problem with it being that it would require the rover to travel toward every single object it sees. In a place like a café, with so many chairs and tables and people, this means a lot of deviations from the path of the rover. For example, in this picture of my school café alone (not even the whole eating area) there are 36 leg-like obstacles.

Instead, I could maintain the theme and have another set of ultra sonic sensors on the top of the rover. If both sets of sensors decide there is an object in about the same place – it can be deduced it is one object that is taller and thus an obstacle. If it knows it is an obstacle, the rover can decide to never go toward it, therefore having no unnecessary deviations from its path. A flow chart for this method is shown above. B = bottom, T = top, L = left sensor, R = right sensor
The only potential problem is about whether US sensors detect directly across from themselves or if they can also detect up and down. If they can detect up and down then if there was debris ahead, the top sensor would not see nothing, but still see the debris below it – therefore misidentifying the debris as an obstacle. If I were allowed in a workshop, I would test to see whether the sensors can see below them, however I do not have that luxury – so just in case they can, blinders can be used to restrict the view of the sensors. A feature of the sensors I have picked is that they cannot see objects 2cm away, so I can use that and embed the sensors in a 2cm depth hole so the walls of the hole will not be detected by the sensors either.



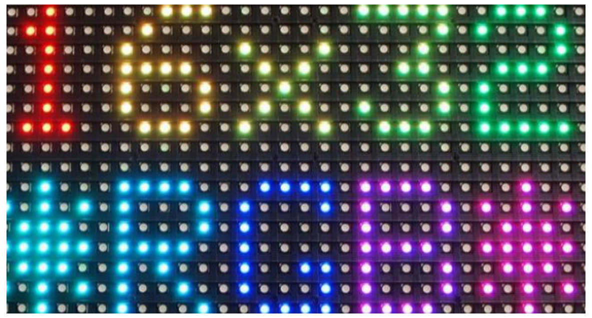
Blinders **only** top and bottom, not at sides to ensure full width of vision.

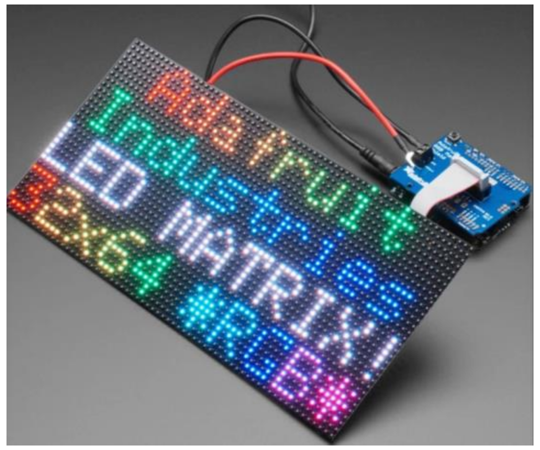
Coding Requirements – Screen System

In order to interact with the user, I decided on using a screen that would send commands to the code, this was discussed in the presentation and evaluated here. The options that should be on the screen in some form are on and off buttons, the option to travel around the whole café area, and the options to travel to specific tables.

An obvious product to look at for a first option would be one of the most common, easy to use, screens – a Raspberry Pi screen (more info on Raspberry Pi here). Raspberry Pi is well known for being very easy to code complex things so this screen would be relatively easy to implement. Its size is 100x76mm so would easily fit on the top circle of the casing if added. Videos of this screen in use, however, showed its functionality to be far beyond the needs I have laid out. This screen can show a desktop and even animations, whereas I would only need a list of options of commands for the rover to carry out. Additionally, this screen costs £70-80 so would greatly contribute to a higher cost of parts. While my rover will likely be a more premium product, a £70 screen which does way more than I need it to would be an unwise addition.

What I would be more looking for then is something similar to an LED matrix. The more pixels something has, the more detailed it gets, however writing words does not need nearly as many pixels as a detailed picture. Thus, rather than having a screen with thousands of pixels, all the information necessary can be shown on a simple – far simpler and cheaper screen as shown →.





While an LED matrix like this can be constructed by assembling mass bought LEDs and piecing them together, a company called AdaFruit makes LED matrices like the one shown left for only £6. This model in particular is a 68.5x53.2mm Arduino Shield so would fit quite nicely on the 150mm diameter circle on the top of the casing. Additionally, by putting it here, the shield is very close to the circuit it would interact with (as I am planning to have the circuit fixed to the inside of the casing at the top. To use this product (or any similar model) a partnership with AdaFruit would yield a supply of these matrices at a reduced price when bought in bulk, reducing the already low price even further.

As shown, this matrix works best when displaying 4 lines, so the User Interface would look a bit like this:

- RESET
- CLEAN ALL CAFE
- PICK TABLE
- OFF

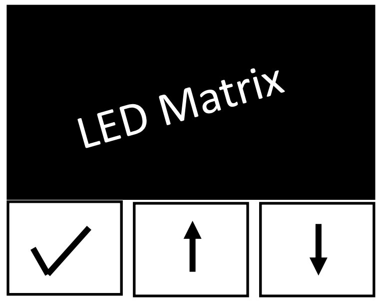
- ← BACK
- TABLE 1
- TABLE 2
- TABLE 3

MORE ↓

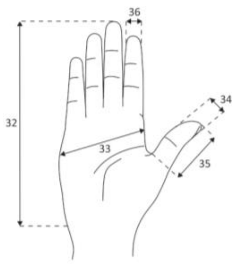
In this representation, reset would put the scoop into container position again. Also, 'pick table' command is what changes screen 1 to screen 2, where more table options can be found by scrolling down, the large number of table options is a large reason why a screen would be more useful than buttons alone.

Buttons

The AdaFruit LED matrix is in no way touch screen and requires buttons to control it, however a simple UI such as the one shown bottom left needs very few buttons. For a list UI, the only necessary buttons would be an arrow button that allows the user to scroll between the options, and a tick button that allows them to choose the command. Added functionality can be added with a third button that allows the user to scroll back upwards again – while this is not necessary, it is a very simple addition and yet one that greatly improves accessibility of the list. Since the top of the casing is a 150mm diameter circle, there should be more than enough space to have the buttons sit beneath the screen as shown in the diagram below.



OCR Anthro data labels a finger width (5-95th percentile, mm) as 18-24 for men and 15-21 for women. Therefore the buttons should be squares of approximate side length 20mm and have a small gap in between to fit the width of the screen.

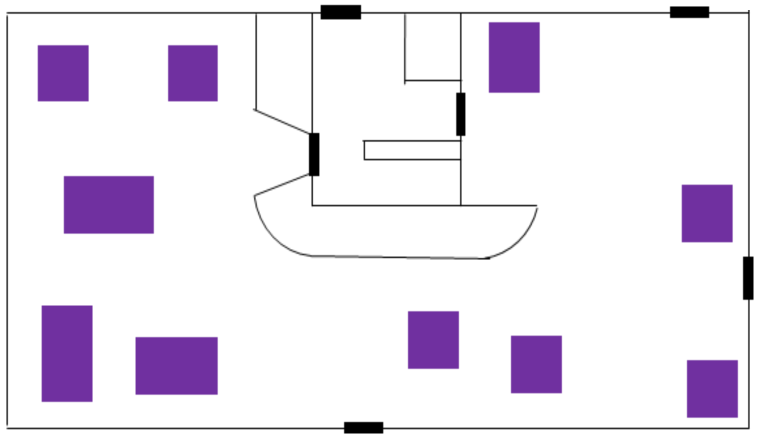


As this is a moving rover with circuitry inside it, there will always be possibility that something or someone could be in danger of it via being caught in it somehow or the rover going somewhere it should not. However unlikely, a contingency is absolutely necessary and can be solved by having a large red button at an easily accessible point, such as at the front between the top US sensors.

Coding Requirements – Pathing

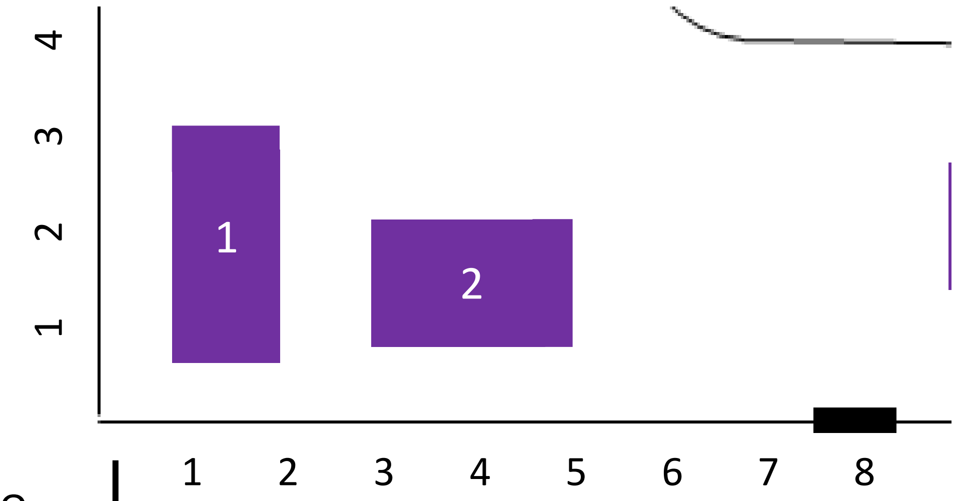
In the stakeholder presentation it was decided that the product would be given a map of the café and with it produce a path for the rover to follow. In this slide I will decide how that pathing will be done.

Here is the map of my main stakeholder's cafe I made on this page. I need to make a way to digitise this picture, and I believe the simplest way would be to code the room as co-ordinates. This would mean the dimensions of the room and all the tables would need to be found as well as their distances from the 'origin'.



For example if we set the rover's "start point" as the origin (0,0), other points can be found in relation.
e.g. corner is origin, then table 1 is made up of 4 vectors:

- (1,1) to (2,1)
- (2,1) to (2,3)
- (2,3) to (1,3)
- (1,3) to (1,1)

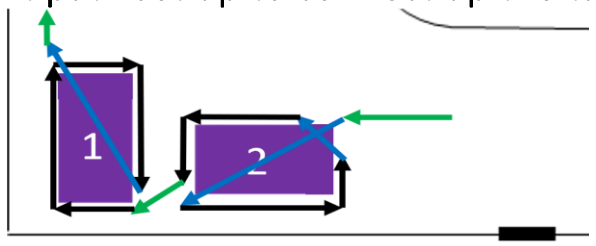


A mentioned necessary part of this co-ordinate plotting is that the start position needs to be fixed. Therefore there needs to be a start place for the rover which fixes its orientation and position exactly.

My first thought was to use a compass as these are what planes and boats use to find their way. For this to work, however, I need a digital compass as the user cannot be trusted to get the orientation perfect. If the computer knows the compass values, it can compensate. Additionally the position is not known, only the orientation.

A separate method might be to have some kind of mount. This would mean the rover would have to start in a precise position and therefore will know its precise position. The mount could be a small box that it should fit into, or a line to start on, but I think the best way to do it would be to have a small insert on the wall below the socket it is plugged into while it Charges. It would need a set height so must be low as skirting will get in the way otherwise. Thus the connec -tor on the rover would be on the outside of the hatch.

With a map and starting position set, the route needs to be made. On this page I discussed how I spent a few hours watching the workings of the café. During this time it was clear that when mess had to be cleared, it was mostly around tables, and for obvious reason. I checked with my stakeholder that she agreed with this statement and she did, saying (see audio above) food and other mess was nearly always found around tables or under tables. Other mess could be found further from tables, but it was less often and had less urgency to be cleared up.
I believe, therefore, that the most efficient pathing would be for the rover to travel around and under the tables individually and then have a short path set up to connect up the tables as shown.



In this diagram, green arrows connect tables, black arrows go around the tables, and blue arrows go under, also this is an example path. If there are customers at the table, I think that they would not want the rover under their table – there must be an option for the user to disallow the rover from going under tables.
The rover should use this path by travelling at a constant, known, speed, that way it can work out its position and ensure it does not lose track of where it is – the exact numbers for this would have to be worked out after layers of physical testing, which I cannot do right now (pandemic). No matter how perfect the maths is, the rover will inevitably begin to lose track of where it is if it travels for too long, but this is easily solved by resetting its position after every clean back to the mount.

Obstacle Avoidance

In the case that an obstacle such as a chair leg makes its way into the planned path of the rover, there needs to be an avoidance plan. I have mentioned it before in parts but I am solidifying exactly what the protocol is here. If an obstacle ends up within 0.3m away (1 sec), and is directly ahead (i.e. in all sensors), then the rover should turn itself 30 degrees away from the table and travel for 0.335m, before turning 60 degrees back for 0.335m in order to re-join the path. This method gives just over 0.15m of clearance from the obstacle. There is a fair chance that obstacles will get in the way of that new path, so overall the necessary requirement is that obstacles stay outside of the 'directly ahead' area of the sensor vision, that will keep the rover safe enough anyway.

Pathing for Pickup

In the exact same way that objects can be avoided, the path of the rover can be altered to pick up mess. When an object is seen, and it is decided that it is debris not an obstacle, the rover can slowly turn until the object is in the 'direct ahead' area of the sensor vision. From there it can travel forward, adjusting its direction if necessary until it goes through the object – picking it up. After that it can turn around 180 degrees and return to the point on its path it left from (to ensure no part of the path is missed during the trip).

Completing the Model – Implementing Changes

To finish off the design, I need to add the design elements discussed over the past few pages as well as a few parts which have been shelved due to the lack of urgency of their completion.

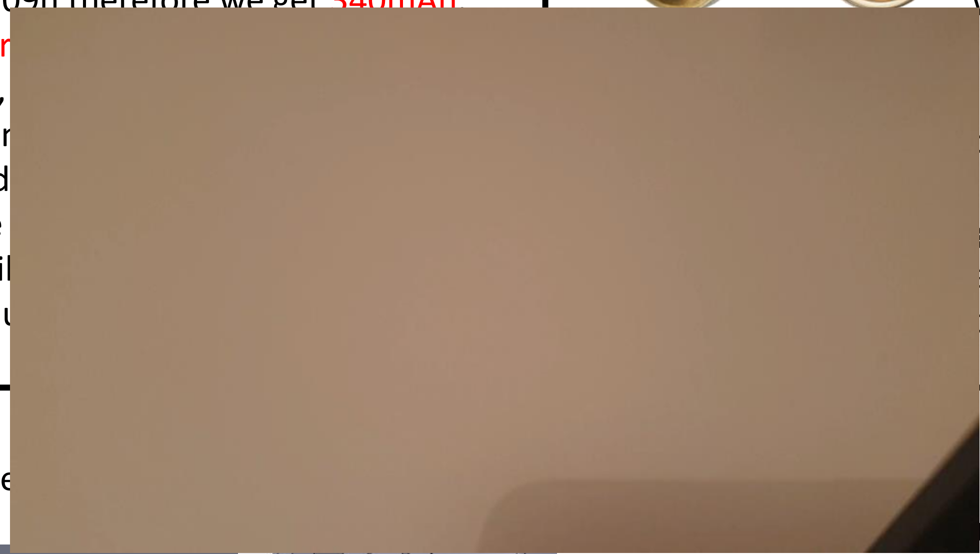
Final Power Requirement

Now with the entire set of circuitry required having been explored, I can finalise the power requirements of the rover and from that, decide what battery pack to use. The list of requirements on this page dictated a need for 9V battery (and 2.64A) that would provide power in parallel to 4 DC motors, 2 servo motors and 2 ultra sonic sensors. This has now increased to 4 ultrasonic sensors as well as an added screen. The two sensors need another 20mA each (and are 5V) and the screen is around 1A (depends on how many lights used) and 5V. This increases current required by 1.04A to 3.68A, additionally the voltage can be left at 9V, and stepped down as required in the circuitry. To convert this to Amp-hours, a unit usually used for batteries, I can drastically overestimate the distance travelled in one round trip of the café as 100m. At 0.3m/s this would take around 5.5mins = 0.09h therefore we get 340mAh. The best batteries I found for this application was the LP 9V r
battery pack. It can reach up to 600mAh, more than enough,
does not need to be removed in order to charge it. This mear
it stay inside and let the battery still be charged. I mentioned
that the battery should be removable if necessary, therefore
best placed as close to the hatch at the back as possible – stil
out of harms way however. Finally, this battery is £14 individu
company respond to inquiries of mass buy.

Caster Wheel Mount

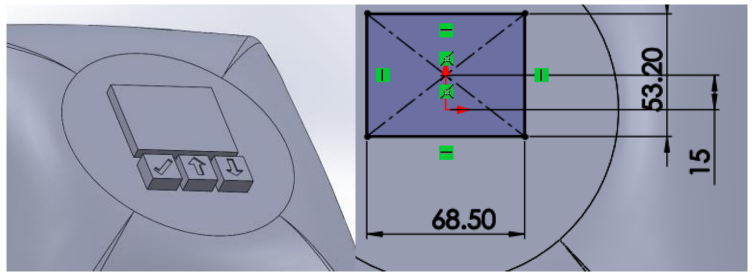
Previously, for testing, I made a very simple mount for the caster wheel, on this page. This mount, however, was not particularly secure, nor did I have a specified way of fixing it to the chassis. Rather than use such a small caster wheel (which likely cannot

deal with much weight) I looked at slightly larger caster wheels that would fit more snuggly into the 44mm gap between the chassis and the floor. For this I picked out two quite similar wheels shown left, costing £3.67 and £3.47 respectively individually from rosscasters. Their heights are 35mm and 40mm (resp.) so they would both fit under the chassis comfortably. In fact, since there is
ll it would be to have the caster wheel screw actually be the joining
and the case. While the initially planned nut (see this page) was
chassis did, the caster wheel would do the same: first caster wheel
and the second supports 60kg (each). When I inspected both
ght them), I saw they were almost identical in height – rubber one at
e main point, however, is that the all brass one makes a large noise
bber 'tyre' makes the other almost silent a shown in this video.

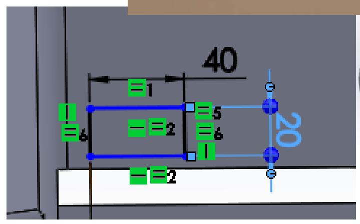


3D Designing the Features

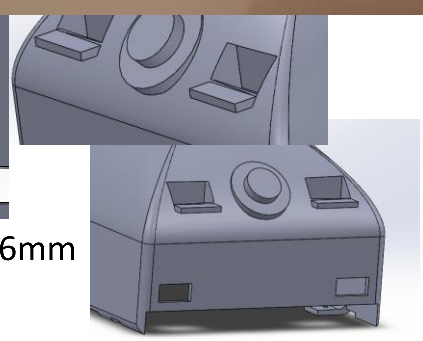
Having done those final few parts, I can add all the new conte



First, I made a mock screen and buttons, correctly sized, to go on the top. The 'big red button' was also placed at the front and made at 40mm diameter.

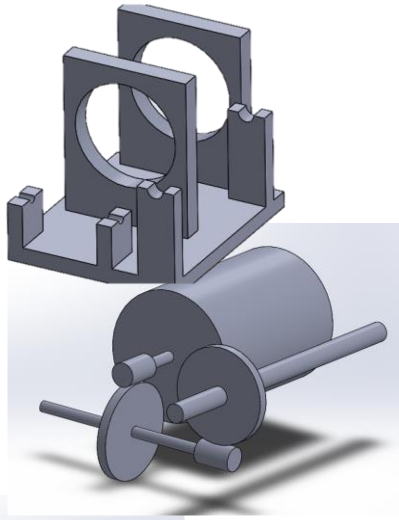


US sensors are 46x22x16mm

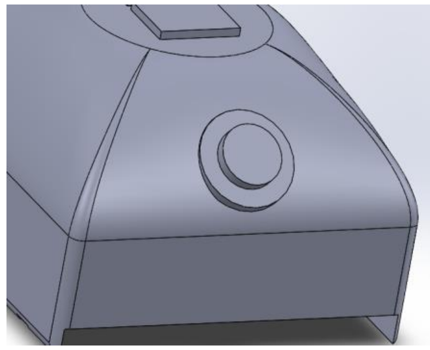


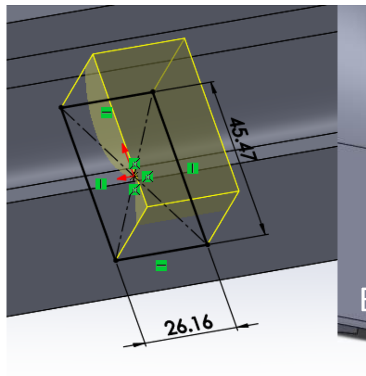
A small, aptly sized mount was added just above the back hole so the charging cable could run through it.

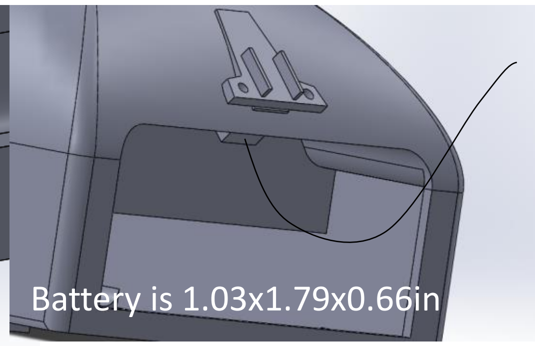
r the
sensors. The bottom sensors would be stuck to the inside wall of the case, while the top sensors would be slotted upwards into place where a 2cm lip would block them from seeing down.



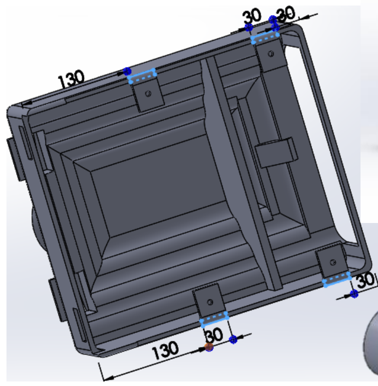
Making the module 2 (20mm diameter for 10 teeth) I 3D modelled the gear system. The rod that connects to the wheel is 4mm diam. With that I made a case that could be easily joined by adhesive to the bottom of the chassis. The face is sized 57x46mm so is slightly over the edge of the chassis, but it would not be in the way so the chassis can be adjusted slightly.

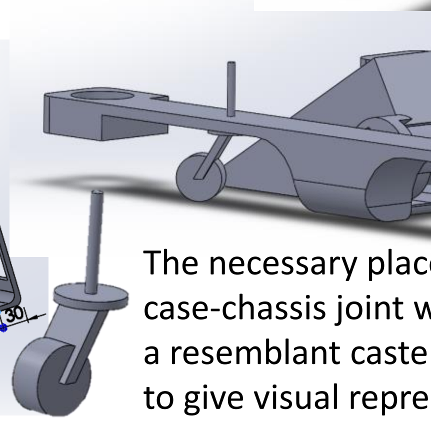






Battery is 1.03x1.79x0.66in





The necessary places for the case-chassis joint was made and a resemblant caster was made to give visual representation of the new wheel.

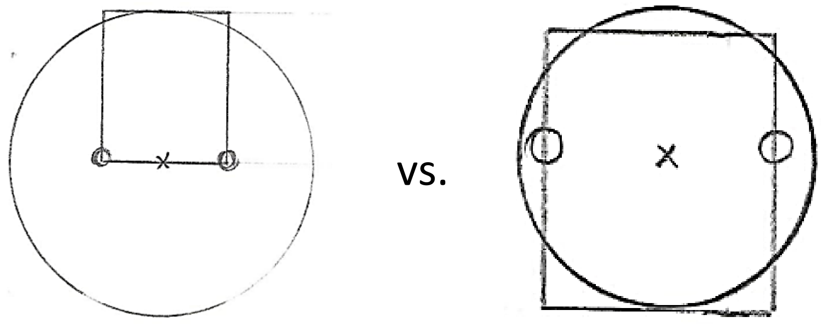
There are a few sizes of things which may not be perfectly accurate, this is because lockdown has restricted my access to physically having most parts. Specifically, I only know box dimensions of the servo motor, not things like the shaft length.

Completing the Model – Shelved Additions

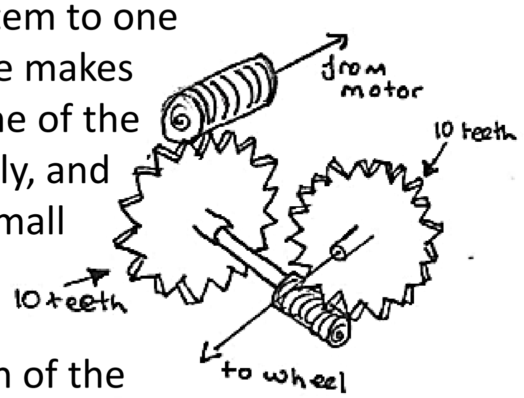
Finally, there were a few changes that I wanted to trial and test which I could not do due to lockdown restrictions. While I was hoping to test them once lockdown eased, it seems that is not yet happening so instead I am going to look over them and see if I can use them at all, even without the benefit of physical testing. Heavy time restrictions at this point in the process means that a very simple solution would have to be found if I want to implement it now. Nevertheless, it is worth having a look at them.

Rearranging the Wheels

When I shortened the design on this page, I very quickly dismissed having a wheel at the front as by having a caster wheel there I could reduce the turning circle a lot. However, I never considered having the motored wheel at the front, which would in fact lower the turning circle even further as the wheels would be far closer to the middle of the rover. A comparison of the turning circles is shown, so clearly there is a great difference in manoeuvrability. Front wheels actually half the radius of the circle the total turn takes.



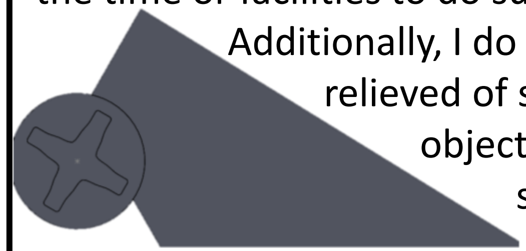
There are some difficulties, however. The gear system, as discussed, takes up an area of 57x46mm, which means if the wheel was at the front, the gear system would either protrude outwards of the chassis – widening the rover – or protrude inwards and be entirely in the way of the scoop when tipped up. Instead at the back, the gear system is free to be as large as it would like as its only requirement is give the scoop enough space to be extracted safely. Widening the rover any more than it already is quite simply is not an option as it is already on the cusp. There is of course the option to change the gear system to one that might fit better. The gear system currently in use makes use of worm drives, which to my knowledge are some of the most compact ways to increase gear ratio very quickly, and only with two could I reach a ratio of 100 in such a small space. It is worth noting that while the 57mm side would not fit nicely, the 46mm side may just about, however this means I need to change the orientation of the gear system, which would inevitably increase the size of it again. If I had more time, and potentially a workshop, I would like to trial and test many different gear systems to get one that could make this happen, however I do not have that luxury at this point. I will perhaps look to try it on a following model if one is made.



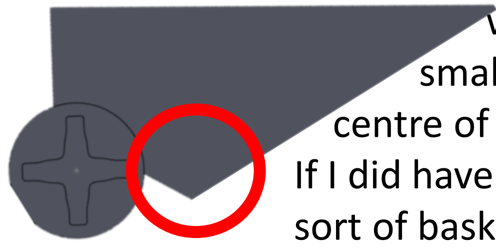
Moving the Servo Motor

At the current point, the servo motor is on the very edge of the scoop picking debris up, instead a method could be made to have the servo closer to the middle of the scoop. Moment = Force x Perpendicular Distance from Pivot, so a larger moment is made by the scoop when the servo is at the edge. What this means is if the scoop was altered to have the servo in the middle of it, then the force required to be carried by the servo would be reduced.

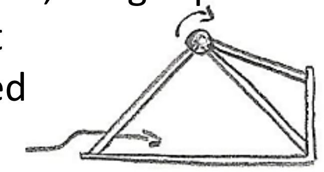
Redesigning the scoop would take a relatively long time, the scoop is the primary functional feature of the rover so changing it in such a dramatic way would likely affect much of the rest of how the system works, such as extraction or interaction with the sweeper. Unfortunately, as with remaking the gear system, I do not have the time or facilities to do such a thing.



Additionally, I do not believe there is an urgent need for the servo to be relieved of some force, as the scoop is not that material heavy, objects picked up will almost always be very light, and the servos are still strong (especially with supportive beams). In fact, while the scoop stretches away from the servo while scooping, when used as a container, the servo is very close to where all the debris will slide to so will have a far smaller moment. The red circle is approximately where the centre of gravity might be when the scoop-container is tipped.



If I did have the time and facilities to explore this, I might pursue a sort of basket like scoop, however there is just as much chance that the fact the scoop is not directly connected to the servo would mean the servo would need to carry just as much force – this goes to show how much extra time and thought would have to go into this large redesign.

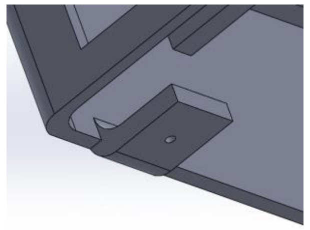


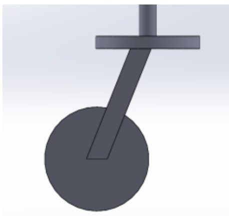
Now I can piece together the final model and prepare a compilation of materials and processes to ready the product for a manufacturer.

Completing the Model – Final Piece

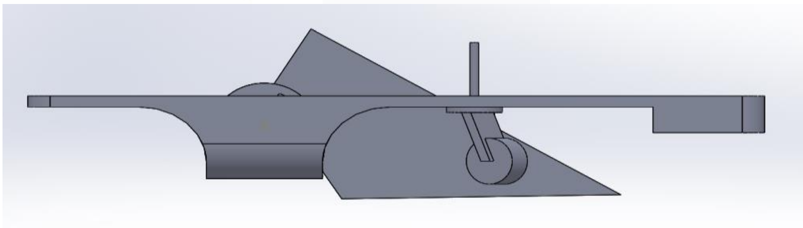
n.b. This design is subject to very minor changes over the next few pages in order to make it easier to manufacture if necessary.

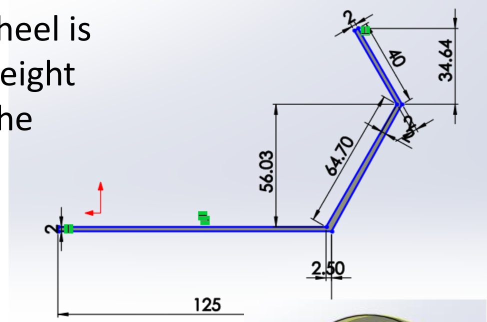
Quickly, before finishing, I realised that the scoop was at the same level as the piece of the chassis that goes under the scoop cylinder, and so that chassis piece would be touching the floor. Of course it is not ideal for it to be touching the floor so I have to make the scoop slightly larger, I fit it to the size of the rubber-tyre caster wheel by making the case joint thicker too – meaning the gap between chassis and ground would be 50mm not 44mm.

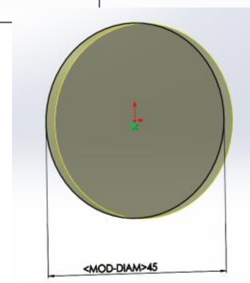




n.b. the caster wheel is not at the right height in this photo as the case is not on

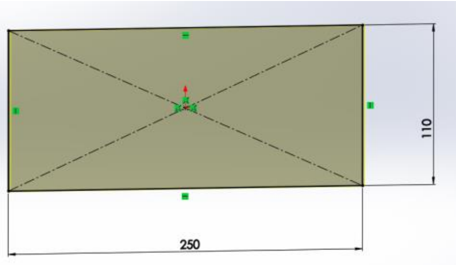






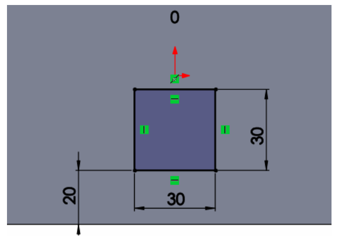
I also need to size the wheel to fit this gap accordingly, the wheel would be diameter 45mm due to the gear mount leaving the centre of the wheel 27.5mm from the chassis.

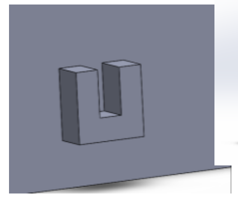
Additionally, I needed to make the hatch at the back following the brief sketches of it earlier.

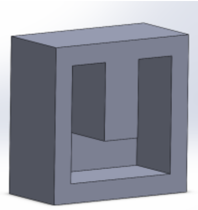


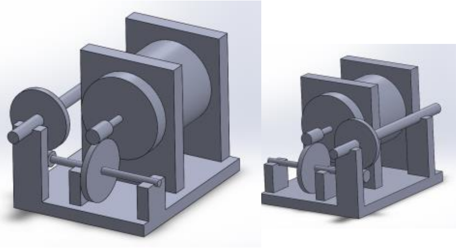
I made it slightly larger than the hole at the back of the chassis

Also the mount had to be added

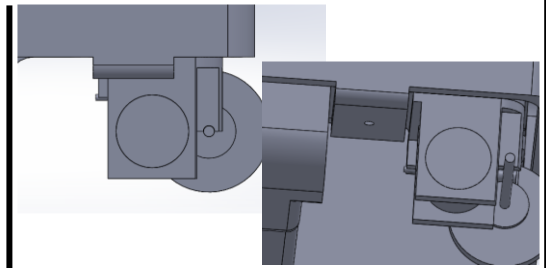






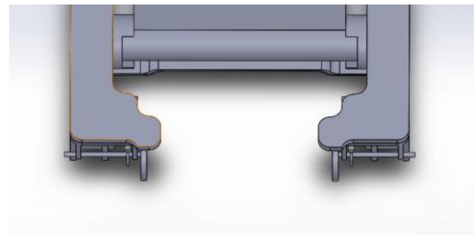


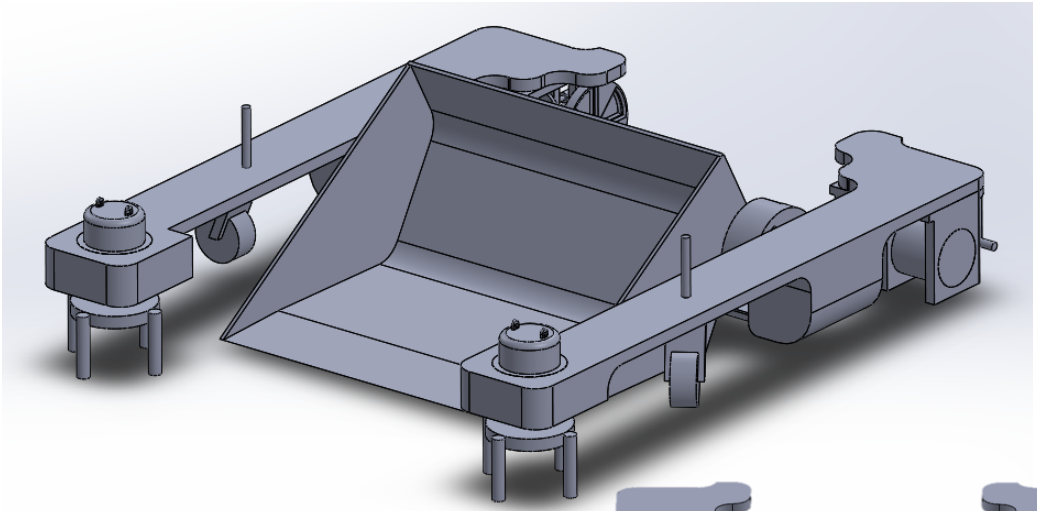
I realised there had to be a mirrored version of the gear system and hold so I reflected the piece for the other side

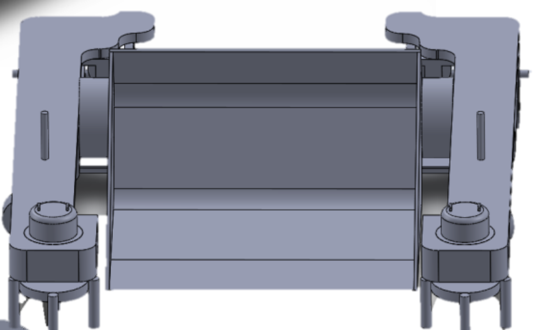


When I put the case and chassis together, I noticed the join did not fit with the new gear system so I altered accordingly.

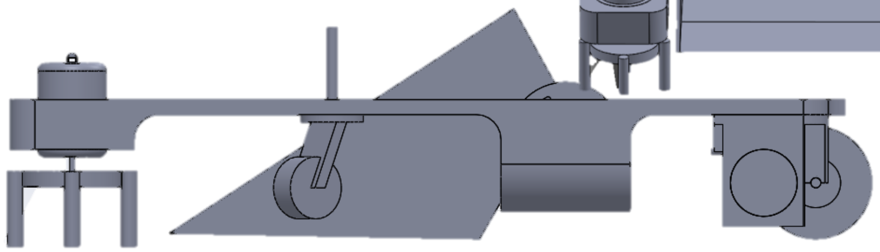
The back of the chassis needed to be slightly larger to account for the gear system size, and also make a small wheel guard

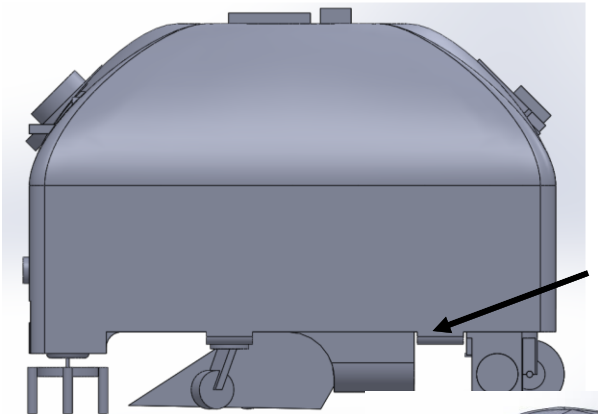






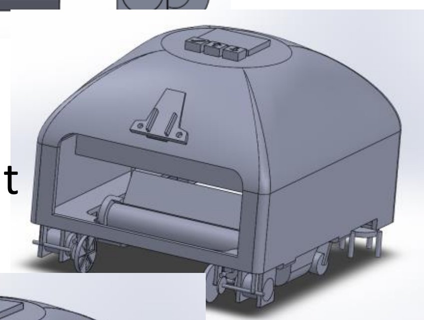
Chassis without the casing

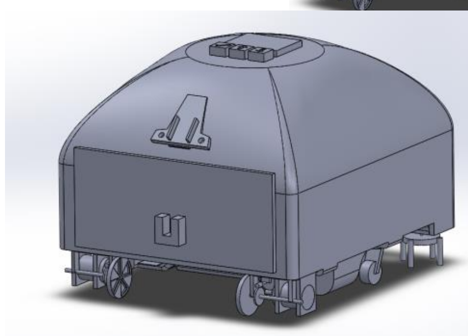


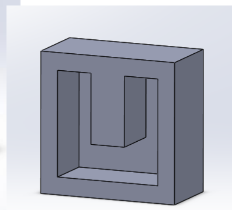


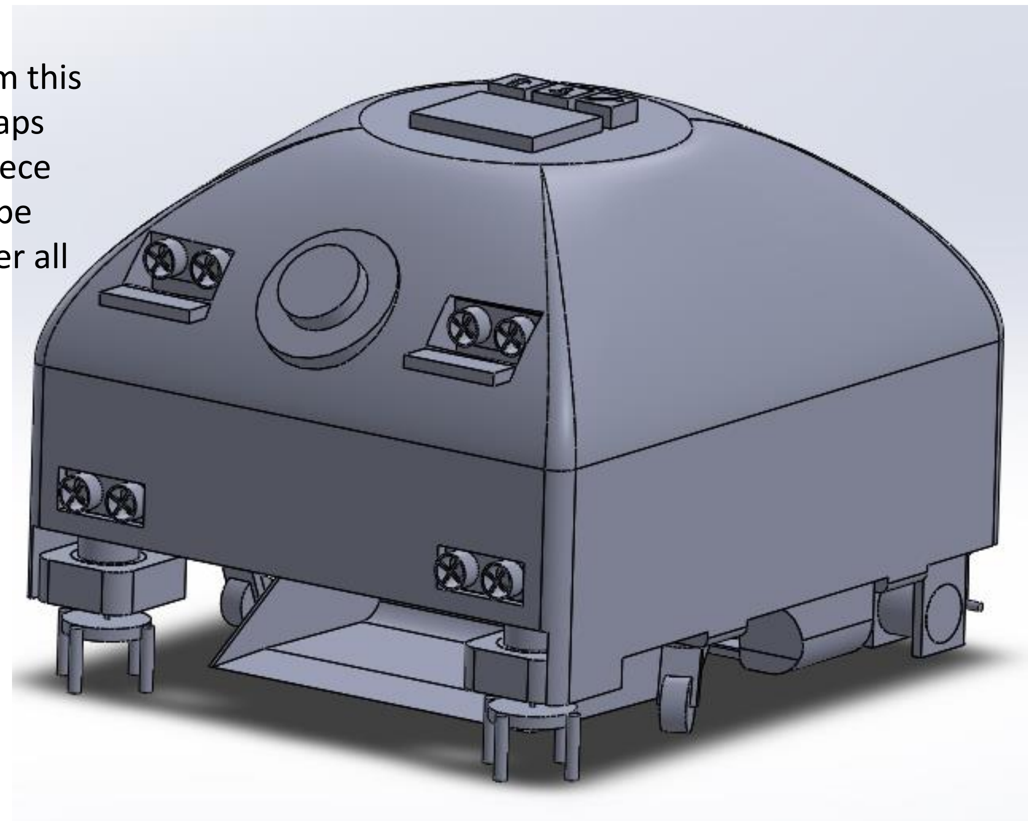
To have the join fit, I had to remove the chamfer from this edge – perhaps the under piece will have to be separate after all

With vs. without the hatch









Materials and Processes

With a completed design, I need to begin making the product suitable for manufacture. This means looking through all the parts and deciding how they should be made and with what materials. All information about how to assemble/join the pieces is also useful to a manufacturer so will be provided in brief when discussing the product but expanded on in full on this page. While some information is already given on previous slides, such as the servo connector being 3D printed, it is helpful to briefly review them as well as having all the information over the next few slides. The pieces that exist and need decisions on are:

- Servo/scoop cylinder
- Wheels
- Container
- Mount for wall
- Sweeper grip
- Main chassis frame
- Scoop-container
- Sweepers
- Servo connector

Additionally, some parts are fully decided such as:

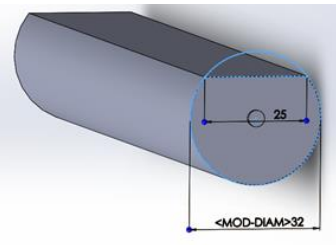
- Bought caster wheels
- Bought components to circuitry

However, as mentioned, these too will be reiterated briefly

Additionally, ecological information is collected and discussed on this page.

n.b. I am inexperienced making moulds for any moulding processes. I have made moulds for all the occasions requiring them, however it is more likely a professional would make one properly.

Servo/Scoop Cylinder

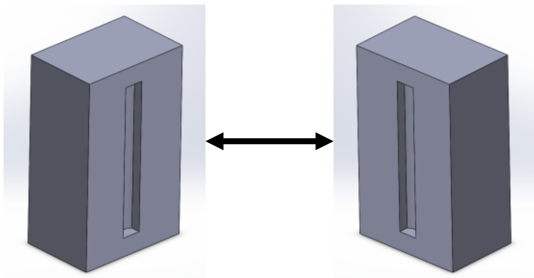


The cylinder that lies between the two servos and holds up the scoop-container. The shape of it is incredibly simple, being just a cylinder with a slice cut out of it.

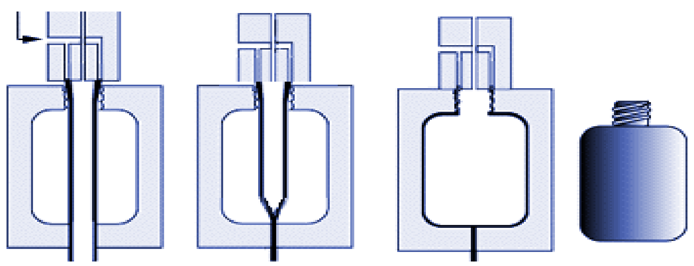
The requirements for this part are very limited, all that matters is that the piece is as light as possible to reduce strain from the servo as much as possible. On one hand, I could make an effort to make the part out of an incredibly lightweight material, however most of the weight can be bypassed via making the part empty. A very quick and easy way to do this is via the use of blow moulding or rotational moulding. According to page 330/1 OCR D&T text book, rotational moulding is very cheap however tends to take longer while blow moulding fast and efficient (and thus also cheap). Blow moulding is said to be for simpler, easily reproducible parts such as this so blow moulding would be my choice. Within this, extrusion blow moulding is the method most suitable for such simple low requirement pieces like this.

Blow moulding is said to be done with LDPE, HDPE, PET, PP, and PVC the most. Due to their higher use for stiff objects, I would be choosing between HDPE and PVC. Currently both are about the same price, and their properties are incredibly similar according to focuselearning, especially for such low stress products like this, so its really an arbitrary decision. PVC has a price that fluctuates less and is more impact resistant so I will use it. Using $V = \pi r^2 h$, and thickness 5mm approximate volume of each piece is $8.5 \times 10^{-5} m^3$ which gives a mass of 0.124kg

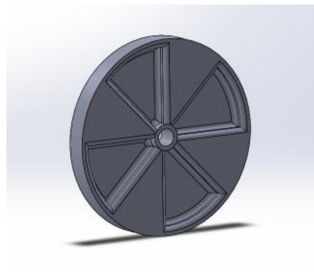
And a cost of 12.0p each + process costs.



Extrusion blow moulding first requires a split mould to be made shown right. A tube of PVC (parison), made via injection or extrusion moulding, is put into the blow mould while still hot. Once the parison is fully in, the mould can be closed and high pressure air blown into the PVC, spreading it to the edges. The walls are cooled so the PVC cools too and can be removed and ready when the mould is opened. Excess material cut off.



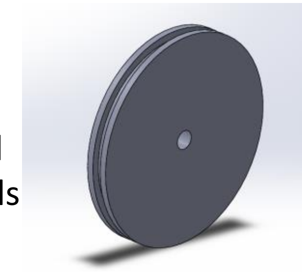
Wheels



Similar to the cylinder, there are some very limited requirements for the wheels. I want them to be 45mm diameter with a 4mm diameter hole in the middle. Their weight capacity will not matter as the part that needs to be strong would be the gear system and caster wheels, nor do they have any aesthetic requirement as they are on the inside.

Their main requirement is to be made of something that is forgiving to the floor and will not damage it, similar to how the caster wheels have their own tyres. Therefore by constructing the tyres to fit around wheels, the floor will be safe and very minimal noise would be made. Additionally, the rover would be more prepared to drive over uneven surfaces.

Therefore I can make 60mm diameter wheels with a 1.5mm tread depth in order to fit inside it 2mm diameter rubber tubing. Being the most common and cheap forming process, I can injection form the wheels that are shown right and rubber tubing can be found abundantly online or in stores anywhere really costing as little as £3 for 5m such as this one.



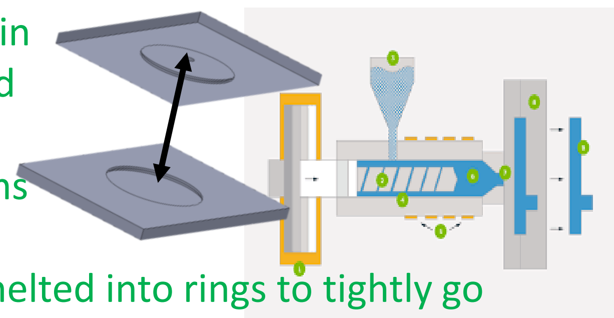
PVC: 4.5p

0.0124m each

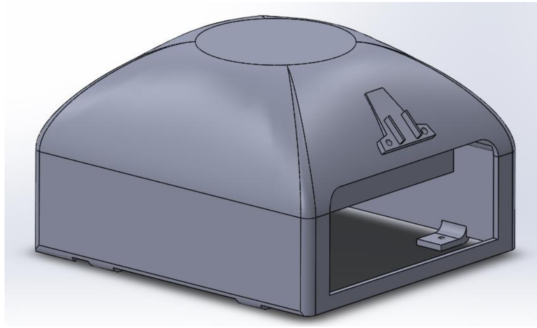
Tubing: 0.74p

Injection moulding can really a very broad range of materials. Most commonly HIPS is used and would work to be very rigid, however PVC is also very suitable and since is it is already being used for the cylinder, might be more suitable – this could be up to the manufacturer however I would choose PVC for ease of access to materials.

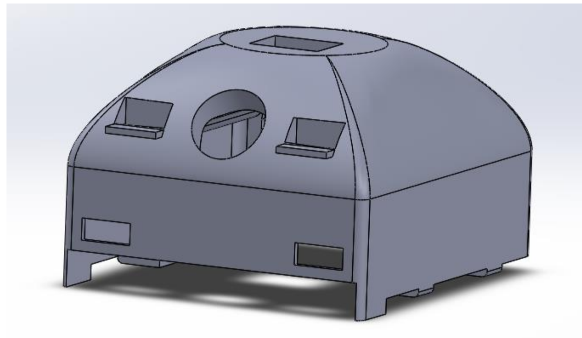
To injection mould, PVC granules are placed in through a hopper where they are heated and pushed in to the shown mould by an Archimedean screw. It is injected in and forms the shape before water around the moulder cools it for removal. Tubing can be cut and melted into rings to tightly go around the thread (and be adhered on with one component acrylic cement).



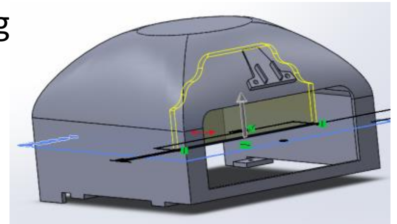
Materials and Processes – Container



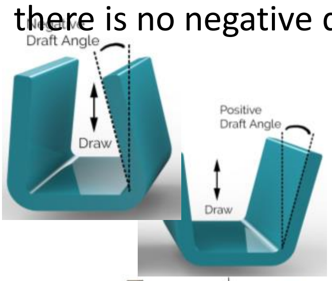
The model I have of the container at the moment is not how I would actually want it as I made it for demonstration purposes. In reality, where the screen and buttons etc. are I would want holes the real components can be placed in. This also means they would need ways of holding those components up.

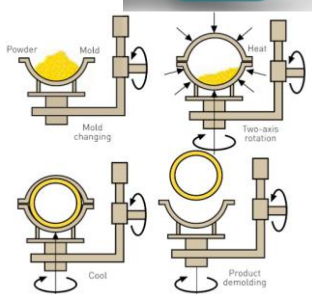


Even without all the extra features, this is quite a complex piece and will have to have a process to make it that fits this intricacy. Therefore originally I had thought to use 3D printing as this would precisely make the model I wanted, however there are still some drawbacks for 3D printing. This choice of process would struggle to make the horizontal parts like the roof and also this process takes a very long time especially for such a large part.



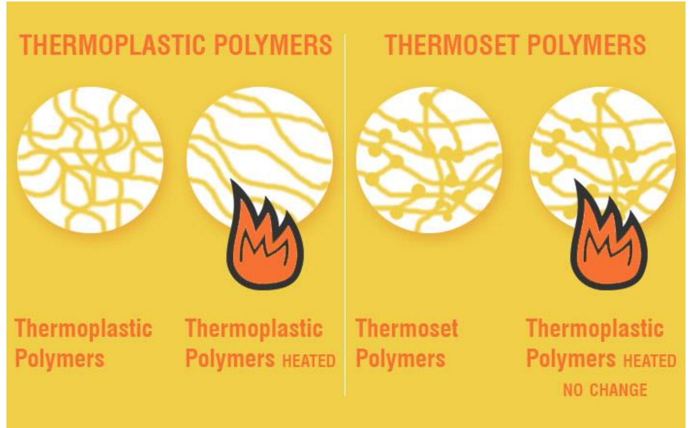
If the blocking face is removed, the casing is a hollow shell, which once again points directly to blow moulding and rotational moulding. On the previous page I also mentioned how rotational moulding was the one that was typically used for more complicated parts. Therefore, rotational moulding is certainly an option for this manufacture. The only thing holding this process back is that it is usually used for larger objects and is quite slow a process. Despite this, with the current casing design, rotational moulding is in my opinion the only process that could reach this level of complexity. There is certainly room and time to make any changes to this but I should work under the pretence of using rotation. The main shape of the mould is not too hard to make, simply following the general shape of the case. The difficult bit is creating blind holes in the case. Of course, one simple option would be to drill the holes, such as using a Hole Saw Drill bit, but it would be quicker and easier to have the holes made during the rotational process already. According to MachineDesign's information database on rotational moulding dictates that 1-5 degree negative draft angles stop parts of the mould from being filled in. while some material will still go through the hole even if it will not be connected – this wastes a small amount of material. Additionally, to ensure they do not split off, I need to ensure there is no negative draft angle on anything else.





The material, as a polymer powder in a pre-decided amount, is poured into a mould similar to that shown right. The mould is then closed and locked and put inside some sort of oven. While being heated by the oven, the mould is rotated so that the powder melts and sticks to the inner surface of the mould. When finished, the entire system has to be cooled (usually by water) and then removed. Split off parts due to negative draft angles can also be removed and remelted for reuse.

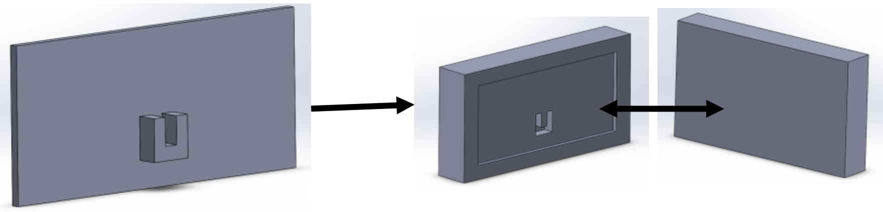
Rotational moulding is most often done using polymers of the polyethene group, but also can be used on PVC, ABS and even aluminium (as well as other materials).



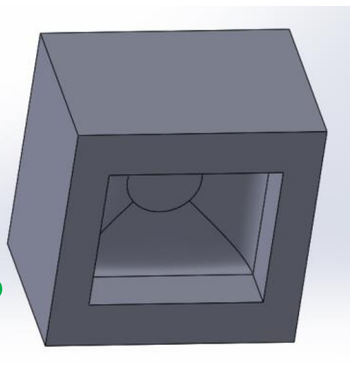
The primary difference between thermopolymers and thermosets is the fact that thermosets will strengthen when heated, while thermopolymers will lose their structure and become flimsy and mouldable. Thermosets would therefore be more suitable for parts that might be put in hot environments to ensure they do not lose rigidity, however thermopolymers would be better here as they can be recycled. Products are easier to recycle when they are made of few materials and are easy to disassemble so I can therefore use PVC for the casing too.

PVC has a good chemical resistance, making it strong against food and liquid in and around the café. This bodes well for both the casing and wheels on previous page (and potentially the scoop). Additionally it is available in opaque colours meaning yellow PVC powder can be used for the casing and it does not need painting. Also as previously discussed it is cheap, currently standing at 44p per lb. SolidWorks says the case is roughly 3500 cubic cm, this is 4.55kg which is £4.40. it should be noted, however, that model was a representation and so far thicker than the real one.

The components of circuitry that are supposed to be on the holes would be fit via an interference fit along with the use of an adhesive for the sake of ease, unless they already had a method e.g. US sensors have holes for screws. A preference would be for one component acrylic cement to be used, as this is a thermoplastic adhesive so would melt off during disassembly for recycling. The latch for the hatch would be screwed in through a newly made hole, and a hinge for the hatch would also be screwed on at the bottom (hinge discussed here)

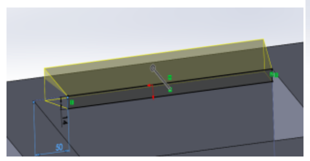


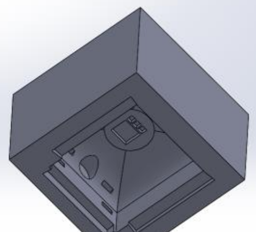
The hatch can be made quite easily, also using yellow PVC, through injection moulding with this above mould. The description for such a process is on this page. The material cost of this piece is 25.7p



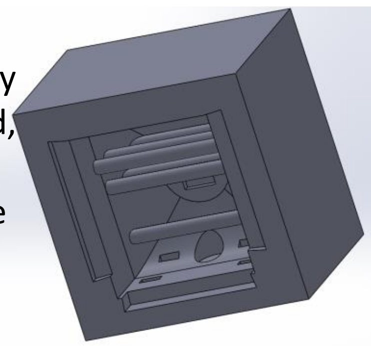
First the overall shape had to be loft cut before adding all the holes necessary

In order to ensure the holes stayed, I settled on 7 degrees





Support beams are good for any large mould, so I used them as the face that blocks off the front.

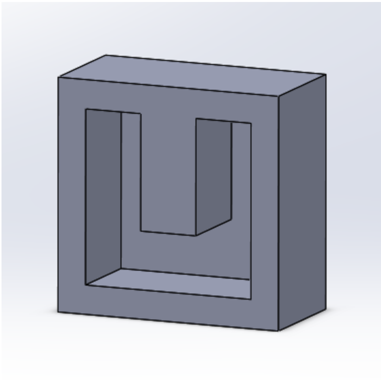


Retrospective note: I did end up changing the casing and its process here.

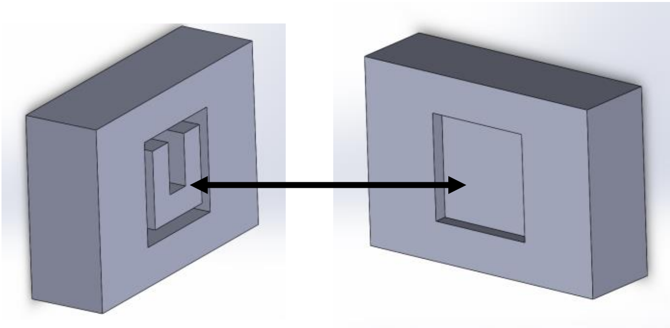
Materials and Processes

Wall Mounting

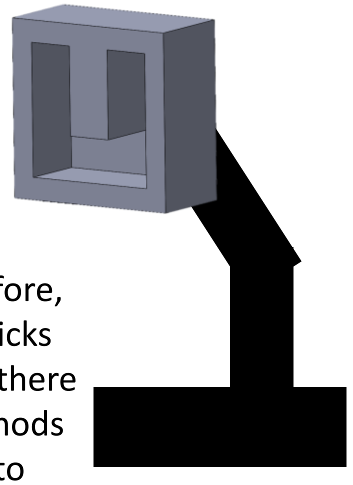
Cost of parts on this page: 10.2p



The part that the rover mounts on to at the wall is a very small, simple piece. For the sake of continuity, it would be best if the piece was made of PVC and injection moulded using the moulds shown below. The description for injection moulding is on this page. The mould is shown below



The question, therefore, is how the mount sticks to the wall. For this there are permanent methods such as drilling it in to the wall, and impermanent methods such as a sticky surface



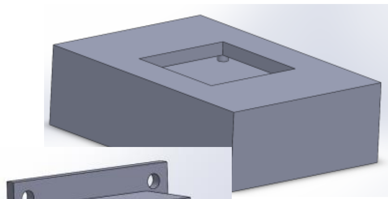
Rather than have the mount attached to the wall, it could stand alone. This would allow the starting point to be moved while also setting the height of the mount.

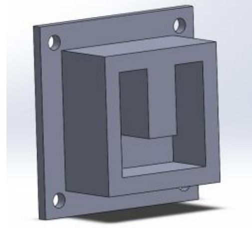
Here is a quickly made simple representation of the kind of thing I mean ←

The problem that I quickly realised, however, was that the rover will not know there is a new starting position, never mind the exact spot of it. Perhaps in later products when I can code the device to understand its surrounding, might this idea be more useful.

This returns me to looking at ways to stick the mount to the wall and **keep it fixed.** The person who measures the room can put the mount in too at the correct measured height.

After speaking briefly with my stakeholder, she suggested it would be best for the fixture to be as immovable as possible and so should adopt a method of being screwed into the wall. It would effectively be the same as the type of door stop shown on the right. This can be done by the fitter. The mould was also changed accordingly for a place to screw through. Holes were for 4mm diam.

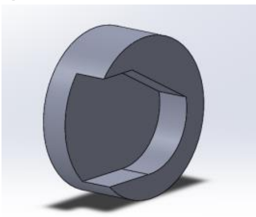


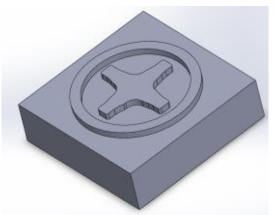


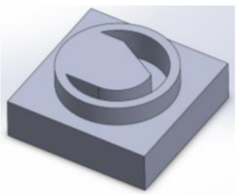
Servo Connector

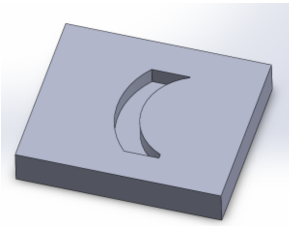
When the original piece was made, I used a 3D printer to get the shape I wanted. I now realise how much faster and easier a piece like this would be to injection mould. It is not too complicated a design and has no inner mechanisms, for which 3D printing would be a better choice. Continuing to reduce the number of materials I use, this too can be made of PVC.

n.b. SC has different models for L&R





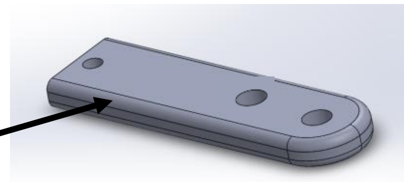


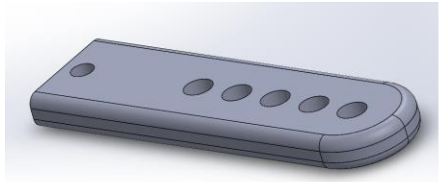


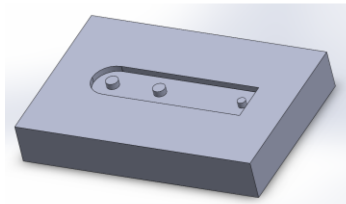
Additionally, the insert would be made the exact same way so I have made moulds for both which you can see left. The insert would be attached to an elastic material which, as well as a second one, is attached to the servo-connector itself. Objects such as rubber valves show how injection moulding can be used to make rubber parts. I can use this to make the straps which can therefore be constructed with this information.

The radius of the servo connector is 23mm and therefore the circumference would be about 144mm. Discussion on this page had the straps go from the top and bottom of the connector so straps are 45mm so they cross over. The small holes on the left are 2mm for screws to fix to the servo connector, other holes are for 3mm button fix/insert.

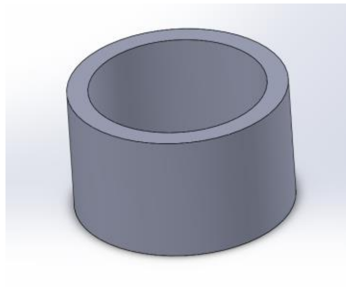
n.b. the buttons in this strap can be screwed through the insert to fix them together.





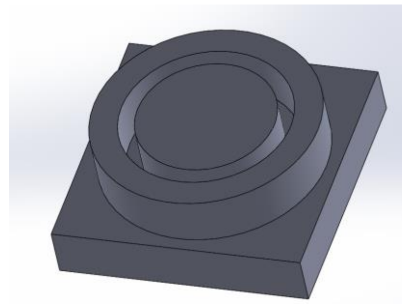


Sweeper Grip



Similar to the Servo connector, the sweeper grip does not actually need to be made using the 3D printing I had initially discussed. In the exact same way as described for the servo connector, rubber injection moulding can be done.

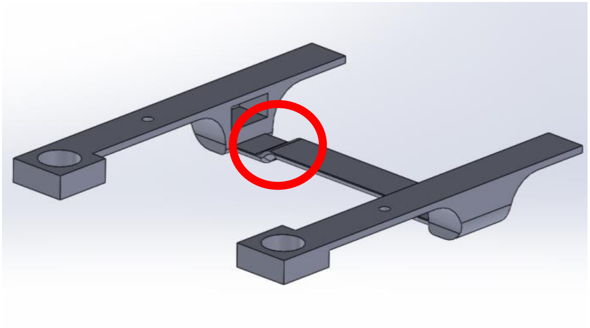
This website details the use of rubber injection moulding and also leads to a list of rubber materials that can be used. The previously mentioned TPE (thermoplastic elastomers) is one such material and its usefulness in sealing would make it perfect for this interference fit piece.



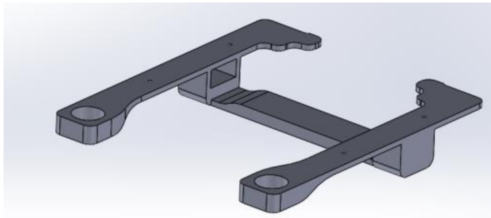
Another option would have been Sponge Rubber for its sealing & cushioning properties, however this rubber would likely lack the support to hold the motor by itself. For the straps for the servo connector on the left, I would use Natural Rubber for its resistance to tear and limited willingness to stretch when in a thick amount

Materials and Processes

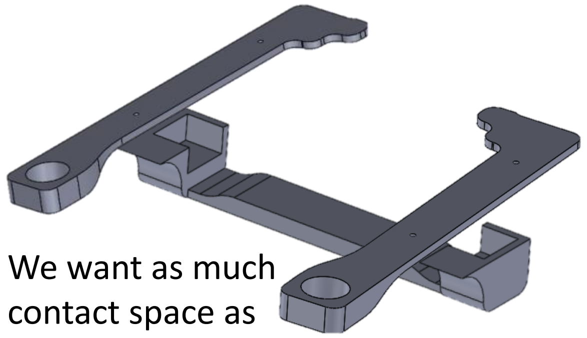
Chassis Frame



The chassis frame, like the container, is one of the more complicated looking parts. The changes to make it more structurally sound have improved it so but in turn it will be a more complicated piece to make and likely need amendment again. The preference, of course, would be for the frame to remain as one piece, however if it is split up in to multiple parts, it has to be done in such a way that once the processing is complete, the frame needs to be as if it was always one.



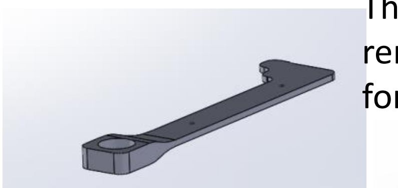
First, the piece needs to be rounded off and slight changes need to be made to make it so that can be a more mouldable piece, this includes more heavy chamfering, and an effort to keep as many pieces at similar thicknesses. Additionally, stepping (circled in the picture above) should be avoided too.



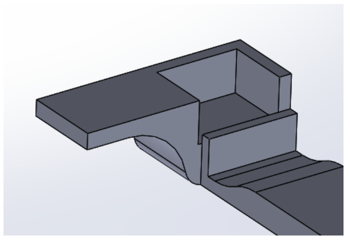
We want as much contact space as possible for an adhesive

It would be very simple to 3D print this piece and keep it all together. There is certainly potential that if one prototype model were made, then this frame could be 3D printed. However, 3D printing is very slow and not ideal for mass or batch manufacture, so realistically a moulding process needs to be used. While moulding that whole piece may be possible, it would not be ideal as a mould would be unnecessarily difficult to make, similar to trying to injection mould the casing, and additionally more intricate and thin pieces make for less reliable moulding. It is quite clear that the piece should be split up.

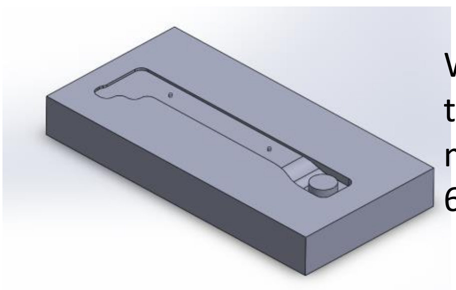
In order to keep the piece as strong as possible, therefore, the three separate parts need to be joined in the strongest way possible. Single component acrylic cement mentioned for other parts, while a thermoplastic, is not nearly as strong as most two component cements. While most two component cements are thermosets, there is certainly a higher need for functional working than environmental excellence (expanded upon here). If bonded properly, this will make the three pieces as strong as it might be as one piece. The splitting of the parts means they can be moulded.



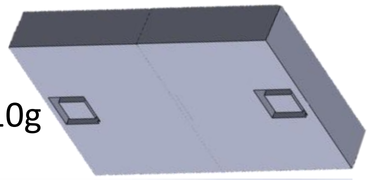
The side pieces can be remade to be the same for both sides.

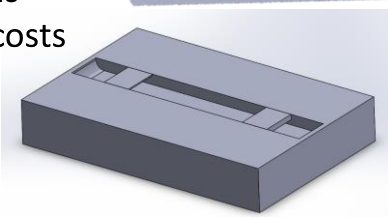


Lip can be added so the servo can be put in before joining.



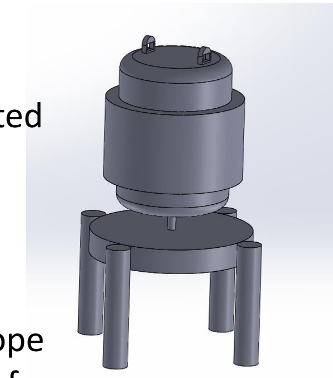
Weighing 610g the chassis material costs 60.4p





The shape of the side pieces lend themselves to either vacuum moulding or CNC milling, however the middle piece (due to the servo motor hole), is not. It would therefore be quicker to keep with the theme running and use injection moulded (see this page) PVC, its strength is of great importance here.

Sweepers



Since their conception on this page, there has been a limited need to develop the sweepers past what they began as, nevertheless there have been a few points which I should reiterate here. It was decided that fewer pieces of a rigid rope-like material would be used instead of bristles and bristles specifically become too flimsy when long. Some rope can be regarded as effectively being a winding collection of bristles so it makes sense that a rope-like substance would be more suitable than singular bristles. A more rigid material would be necessary because the sweeper needs a radius of 100mm to have the reach required.

This website has comparison tables I can use to decide of the type of rope that can meet the demands of medium rigidity while also holding itself reliably, and being safe for the customers around it

I used their resources to compare ropes based upon their strength, change in strength by wetness, if it shrinks or rots, its response to acids and alkali and a small elasticity

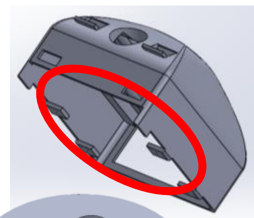
Orange Polyethylene Rope

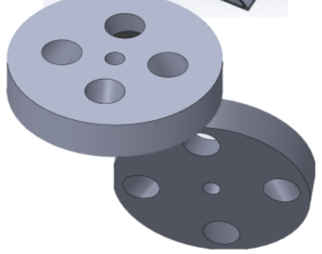
White Staple Spun Rope

From this I reached three ropes that were also about the same density(kg/m^3), staple spun (0.95), synthetic hemp (0.91) and polyethylene (0.91). While all would be perfectly suitable for this, I chose polyethylene rope as it tends to be the far cheaper option of the three.

Synthetic Hemp Rope

Additionally, this, and most other ropes, are most often sold as 220m rolls at 6mm diameter. This is a very acceptable size for this application and this length sits between £20 and £40. Average £30 for 210m means each piece of rope on the rover costs 1.43p. Four pieces each side would thus make 11.4p



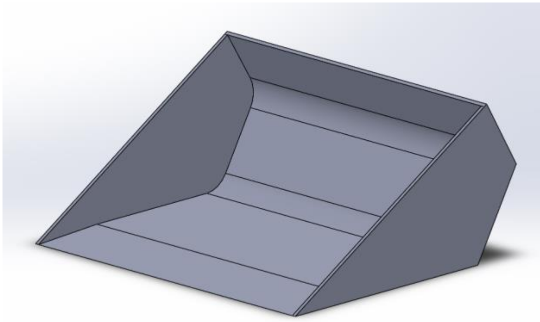


The rope cannot attach itself to the spinning motor, it needs a wheel to be attached to like in the model shown at the top. Instead of using wooden wheels like I did in the testing process, I can make use of the large amount of scrap material from the moulding of the casing (thus 6mm thick). There will be large flat pieces from it which can be machine cut into small circles 32mm diameter and 6mm holes can be cut at 30 degrees from the horizontal to look like the model on the left. The rope can be secured using a liquid adhesive, being careful not to fray the rope in the process.

The simple way of attaching that mount to the motor shaft can be done exactly as before with the small plug shown called a shaft coupling. This can be made stronger with a small addition of a multi surface glue.

Materials and Processes

Scoop-Container



The Scoop-Container will be one of the few parts of this system to not be made using an automated moulding process. Despite this it has quite a few necessities. The material it is made from **must** be low friction to allow easy picking up and disposal of dust and other debris, but also there must not be any cracks, crevices, or visible joints for dust to be trapped in.

The best way to have no sharp corners or joint marks is to first make the whole centre part (i.e. not the walls) made from one piece of material bent at multiple points. For a single prototype I would look straight to a line bender (plastic) or a sheet metal folder. These processes are very quick, yet an automated process similar to this would be far more convenient. In fact, metal line bending is a very common automated process such as these factory's ones. In fact, the hole piece can be made with line bending – where the sides can be folded up and cemented to the rest of it – like a shape net.

Method: put sheet through, wait for it to heat and then bend it as necessary.

While slightly less common, automated plastic line benders do also exist such as this one by a UK company (Norfolk) so there are likely local factories with this, or similar machines. They say it is made to operate on Acrylic, ABS, HIPS, PC or PETG. All the plastics on this list share the trait of a low melting point – if another plastic has that trait then that could be used too, e.g. the melting points are 160-300 degrees Celsius but tending to be around 240

The entire pan and brush handle of the product discussed on this page was nylon, which manufactures used injection moulding to process. The melting point of Nylon is 220 degrees so fits comfortably in the range given above.

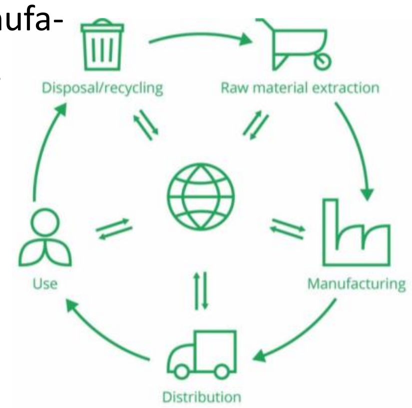
Other products I have found have been made of Polypropylene (160), aluminium (metal line bender) or unspecified. Polypropylene would be good for strength, I think Nylon would be best due to its rarer trait of self-lubrication. This would mean dust and debris would be free to move in the scoop and would not be trapped at all. Material Cost 27.3p

A key point discussed in the stakeholder presentation was for the tip of the scoop to be rigid enough to be ok picking up any of the debris my rover should, while also ensuring the floor is not damaged. While some of the products I looked at where just their material, rubber such as that used in the blue pan shown can be made rigid enough to keep solid contact on the floor without being sharp enough to harm it. From this website previous mentioned, I have deduced an injection moulded piece (see this page) of TPE as it is cheap, solvent resistant and flexible enough. It can be easily joined with a polymer glue like single component acrylic cement. Finally, the method in which the scoop should be bonded with the servo cylinder so that smooth scoop face is not affected. This requirement lends itself to adhesives, of which it can really be any polymer glue, preferably a thermoplastic like single component acrylic cement.

Ecological Thoughts

Over all the past pages of discussing materials to use and ways to process them to make parts, there has been an extra need to ensure they all have the lowest carbon footprint possible. Processes should be chosen to minimise energy usage, which would mean plastic moulding might be preferred over metal moulding as metal's higher melting point means it takes more energy to make it mouldable – hence the abundance of plastic parts. Of course plastic is also fat lighter than metal or wood too. Choices as to which plastic should be used should consider whether it is a thermopolymer or a thermoset as thermosets are not recyclable (discussed on this page).

There should be attention on the sources of the materials as part of a Life Cycle Assessment on the parts of this product. Often this might mean taking a wood from a sustainable source rather than a rare wood taken immorally like some companies do, for this product it means choosing common plastics instead of rare ones as they are more likely to be produced locally. Local sourcing reduces energy used for transport and also lets a manufacturers be certain that ethical extraction of materials has been done. Finally, the product, as has been mentioned many times (such as here) needs designing for disassembly (DFD). DFD ensures a product can be taken apart easily, e.g. unscrewing nuts & bolts to replace a case that was broken – this means an entirely new model does not need to replace it which saves materials. Alternatively, it also means using temporary joints which can be taken apart in the disposal phase so re-mouldable thermopolymers can be repurposed.



Other Parts

Outside of the parts whose materials and processes have been chosen over the past few pages, some bought parts should be reiterated. The changes are shown in the working drawings.

Already decided parts:

- LED display here
- Ultra Sonic Sensor here
- DC motor here
- Servo Motor here
- Caster wheels here
- Battery here
- Gears here

Quite a few screws and nuts & bolts are needed:

- Any screws necessary for a toggle latch
- 6mm diam. nut & bolt for chassis-case joint ~20mm long
- 2mm screws for the ultrasonic sensor fix <10mm long
- 6mm diam. screws for gear system-chassis join ~20mm long

The gear system can be easily joined to the chassis by screws placed in its corners, also this means if anything breaks it can be easily disassembled and replaced.

Latches can be found in many places, and it a lack of requirements for a latch means it does not matter what one should be used, however for reference, this toggle latch is a good example of an option.

All the buttons can be simple component buttons which just have cases around them to portray their meaning (see this page).

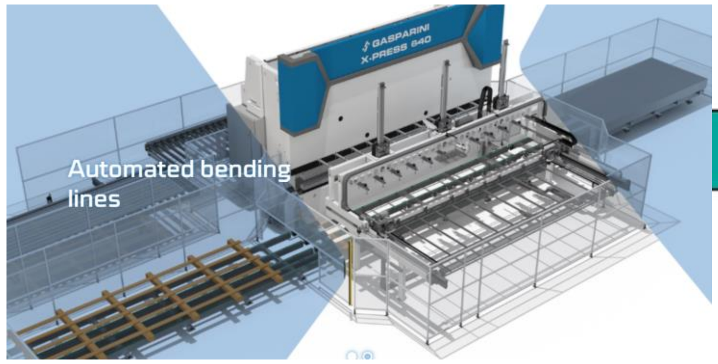
The hinges need to fit an approximate 2cm that the casing has to connect to the hatch. Due to the latch as well as the lightness of the hatch, it does not need to bear much weight at all. I found these hinges at 2.1cm (I have adjusted pieces accordingly) which come as a pair for £2.77, they would be used as such, with one on each edge of the hatch.

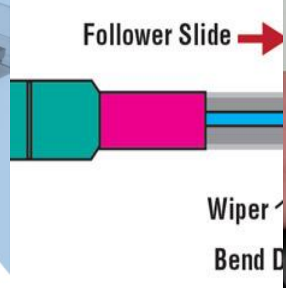
Materials and Processes – Showcasing Manufacture Methods

While the short descriptions of method of manufacture are helpful, a full overview and knowledge of them is important to have. Where possible, I have looked at similar processes in my school workshop to get a feel for it. As mentioned on [this](#) page, short descriptions of methods are on previous pages, but full exploration of the machines and how they work can be found here.

Line Bending

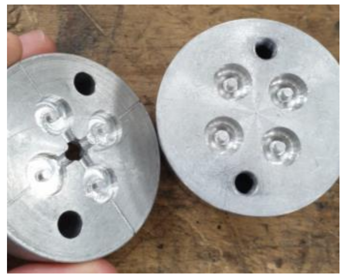
As discussed, the scoop will be made using Industrial line
such as the one discussed [here](#) are able to bend massive
[Gaspirini](#) work-line specifically can bend one large sheet
pieces. With a line like this, 24-7 bending can happen wh
inputted and completed parts are outputted. Even on a s
works the same – so I got to understand the basics using
A strip heater heats the corner, in the school machine th
over the heater for a few minutes whereas at industrial l
hence mass production. Industrial machines will then au
into a shaped area and rapidly cool it to maintain the sha
works for the school except shaping is done manually.

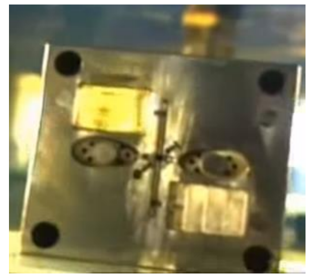




Injection Moulding

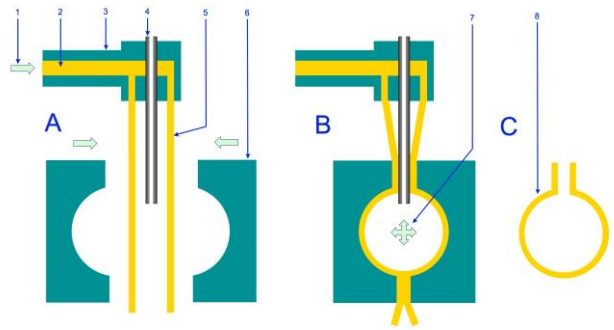
ulding is the method that will make the majority of the parts of this
e again, we have a small moulder that I could use to learn the steps of the
cately. First a mould has to be
s those shown right (metal mould
ugs and made with the centre
trial moulds are usually made
mium iron which is Milled to shape.
uld is inserted, polymer beads can
to be heated in the tubing. After
wo parts of the mould, the heated
be injected into the mould under
e to force it into the entire mould. In
achine, the first one would often be
here was no way to know if the
melted, but at an industrial level,
rts would be more successful, and
r controlled process would be more
d therefore quicker too. The result is
as that shown on the far right.





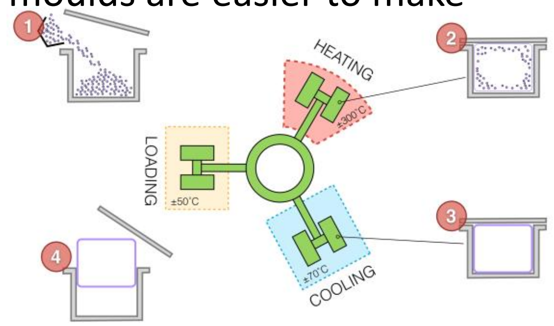
Blow Moulding

The Scoop Cylinder, as mentioned, should be made using
unfortunately I did not have any school equipment to lea
said the process is very simple so the description previo
what is more important is the benefits. Blow moulded pieces are very fast to make while still being very accurate. Such a process would be ideal for the Scoop Cylinder as it is a simple piece that can be made very cheaply, and will be very lightweight due to its small thickness.



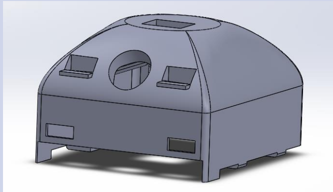
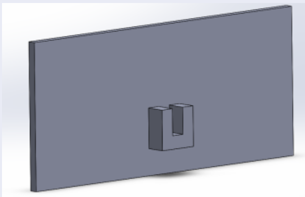
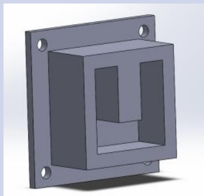
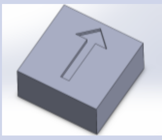
Moulding

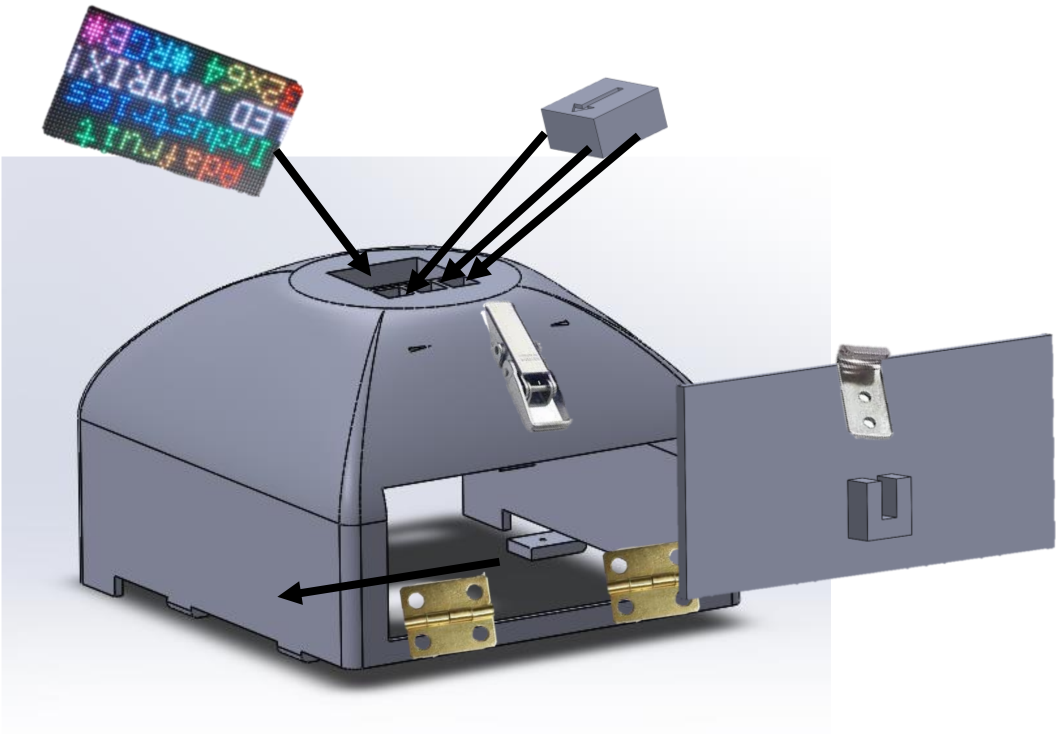
onal moulding would be suitable for making the casing. Once again, the
es similarities with the others where a polymer is heated and placed in a
e for this process it is spun until it sticks to all the sides of the mould.
Rotational moulding would be more suitable than something like blow moulding for this piece is because, despite the much longer time per piece (up to 30mins even against blow moulding sub 1min), rotational moulding yields thicker and therefore stronger parts – important for the casing. Additionally, moulds are easier to make therefore favouring the complex design of the casing.

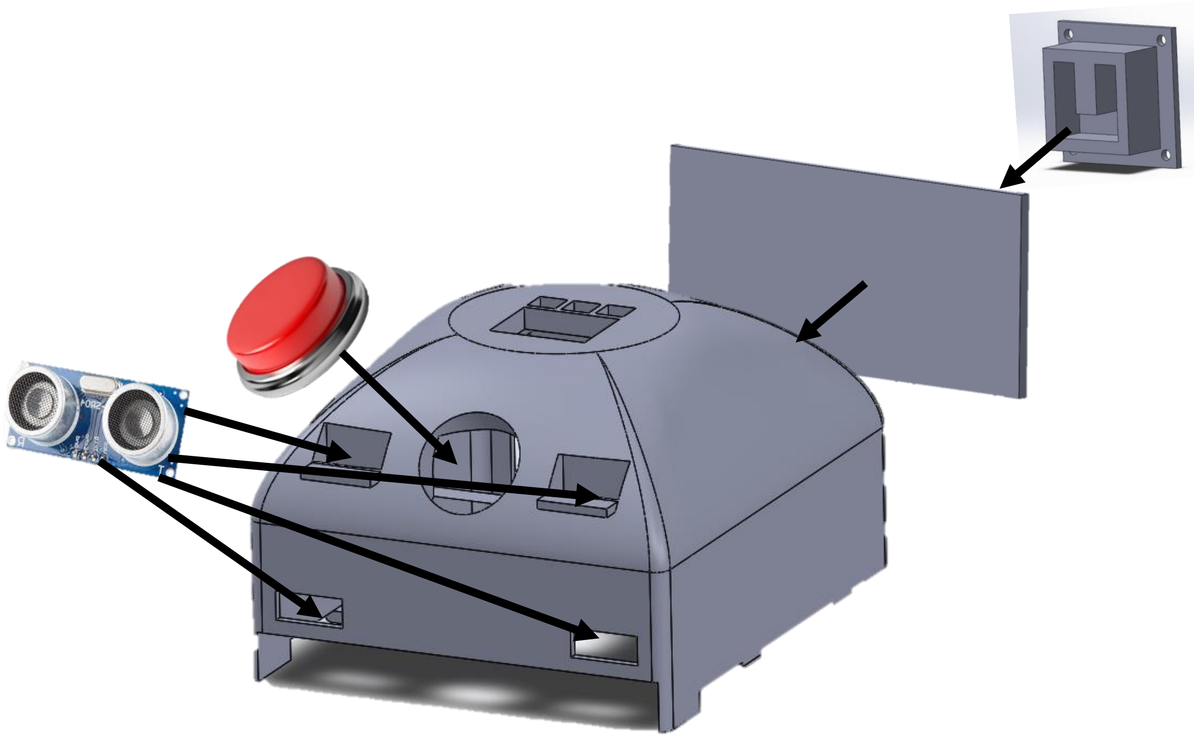


Manufacturers Content: List of Parts

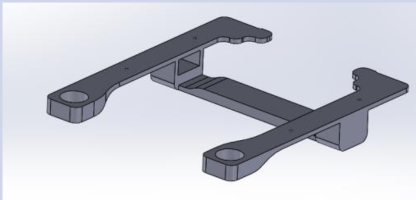
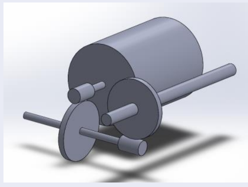
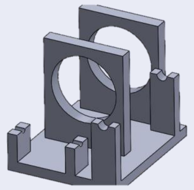
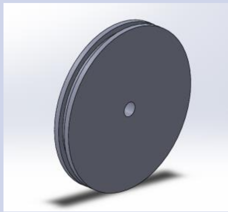
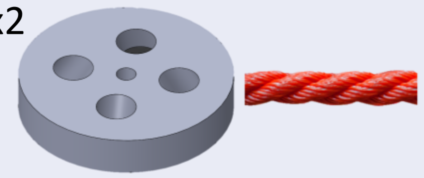
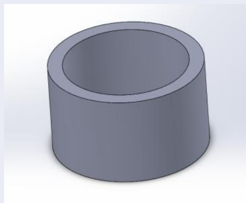
Information for the manufacturer now can be collected and abbreviated. This includes summary of parts, a flowchart of the coded algorithm and the final specification. (n.b. once I got to go back into the workshop, some changes were made. Because of this, I moved working drawings to here as updated after those changes, where those working drawings are final).

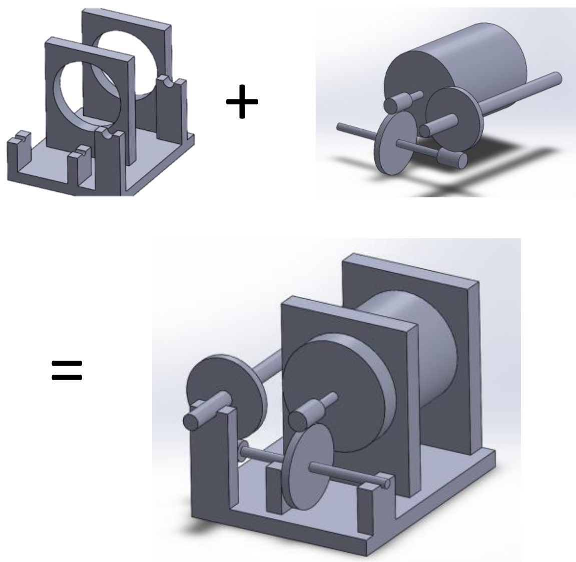
Section	Part	Material	Manufacturing Process
Casing	Casing Shell 	Yellow Poly-Vinyl Chloride	Rotation moulding of 8mm thickness is done to make the shown shape. Any holes that should have been made that were not should be poked out.
	Hatch 	Yellow Poly-Vinyl Chloride	PVC injection moulded to make the hatch. Attached via a hinge and toggle latch to the case
	Mount 	Any colour Poly-Vinyl Chloride	Injection moulded pieces made to look like the shown picture, it has space for screws to go into the wall
	Electronic Components	LED display, Buttons, Ultra sonic sensors x4, circuit board, wires as necessary	
	Other   	Toggle latch, hinges x2,	Also, button covers injection moulded to the three shapes shown (with circuit component buttons beneath them)

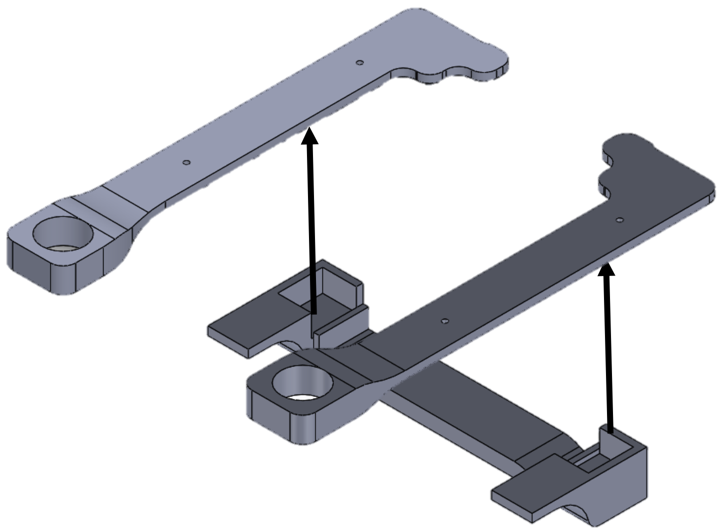


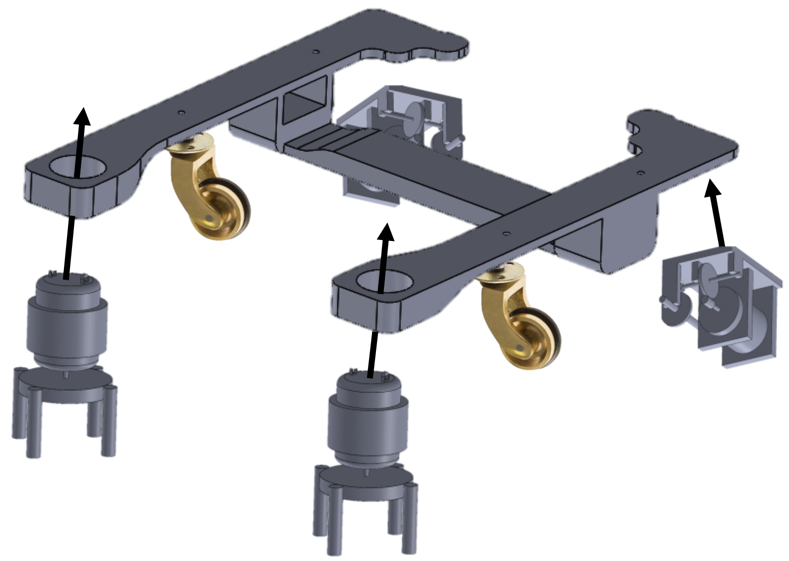


Manufacturers Content: List of Parts

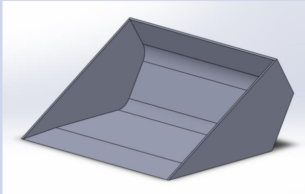
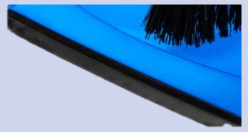
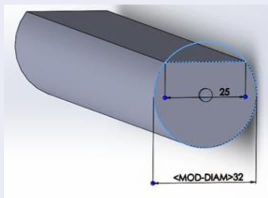
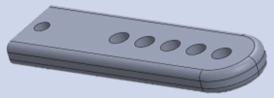
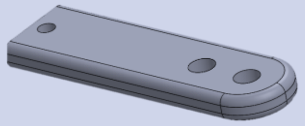
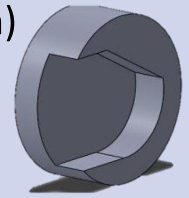
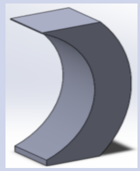
Section	Part	Material	Manufacturing Process
Main Chassis and movement related parts	Chassis Frame 	Any colour Poly-Vinyl Chloride	Two of the top piece part and one of the bottom part (all shown left) are injection moulded. After this, the pieces are glued together using a two component polymer adhesive in the dimensions depicted in the shown model.
	Gear System (one left one right)  	Any colour Poly-Vinyl Chloride	Scrap PVC can be repurposed to make the previously described gear system hold. There is a preference for sides to be added to protect the gears. The motor, two 10mm radius 10 tooth gears, and a 3mm and 4mm diam. Shaft should be slotted in to make the functioning system
	Wheels x2  	Any colour Poly-Vinyl Chloride 3mm Rubber Tubing	PVC wheels are injection moulded to shape, after which tubing is cut to fit into the crevice tightly as a tyre, bonded with single component polymer glue.
	Sweeper Parts x2  	Any colour Poly-Vinyl Chloride 6mm Polyethylene Rope Thermoplastic Elastomer	Scrap PVC can be repurposed to make the sweeper mount by using remaining pellets to injection mould. Rope is carefully glued in holes with single component adhesive. TPE injection moulded can be used as a grip to hold the motor in the chassis
	Other Components	Motor x4, Motor Plug x2, Caster wheels x2, 6mm screws (L = 20mm) x4	

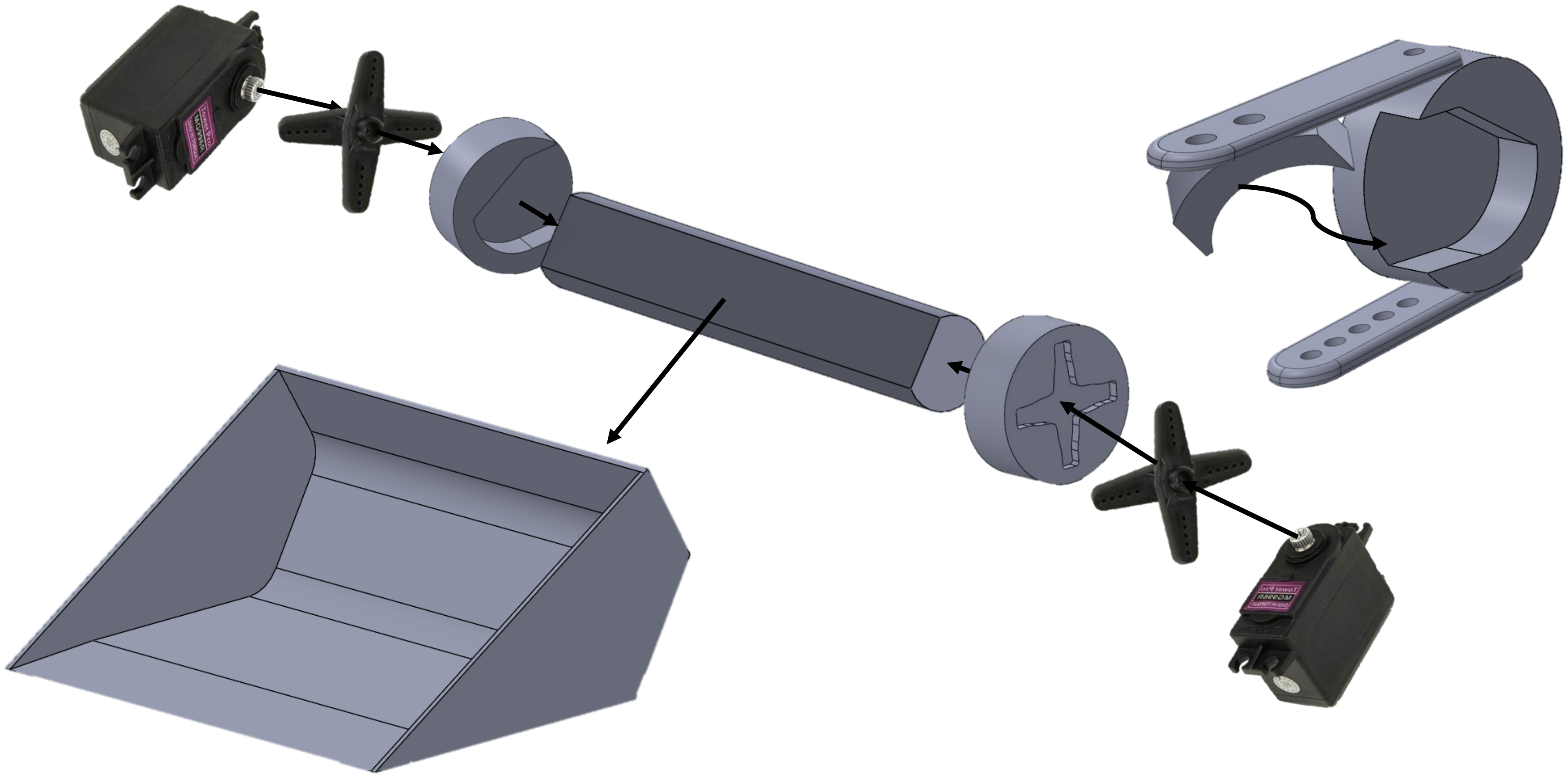


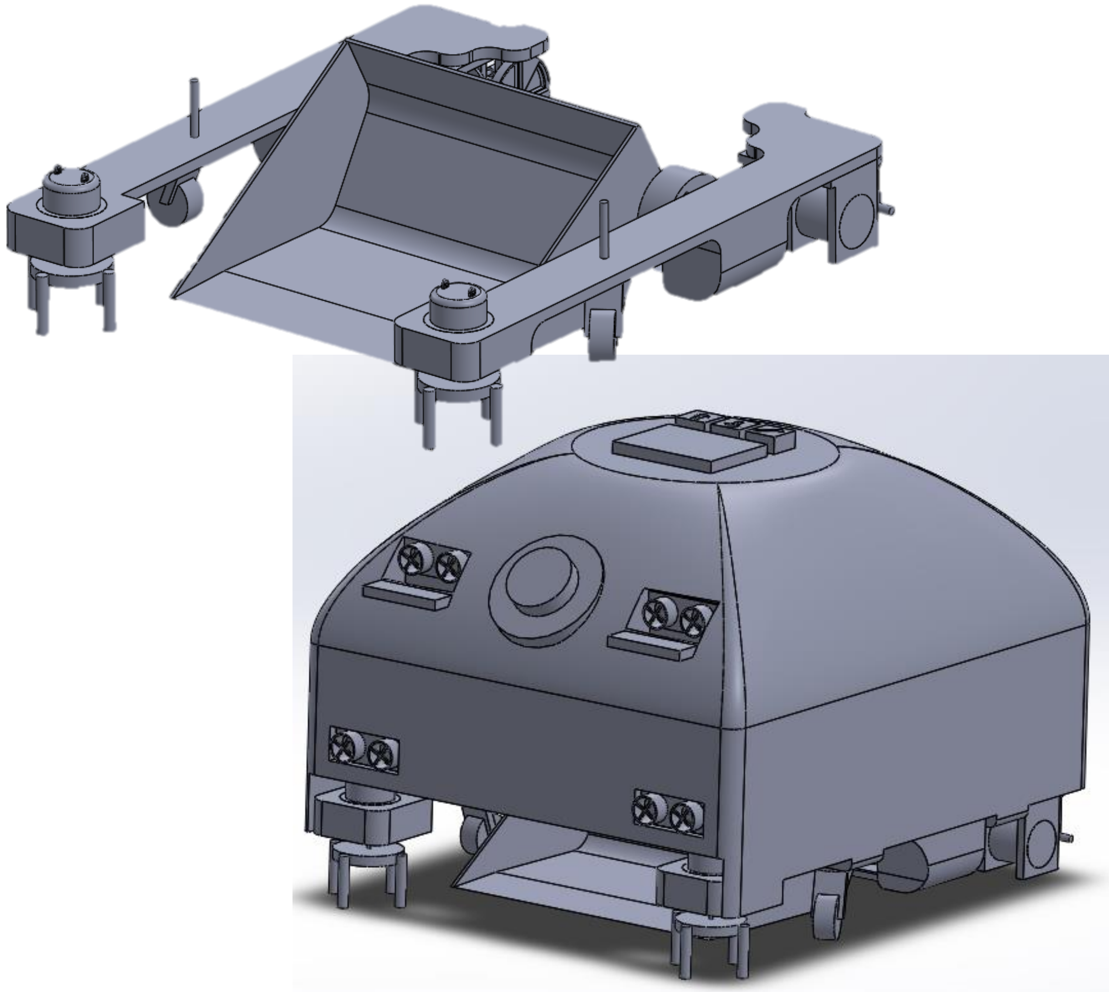




Manufacturers Content: List of Parts

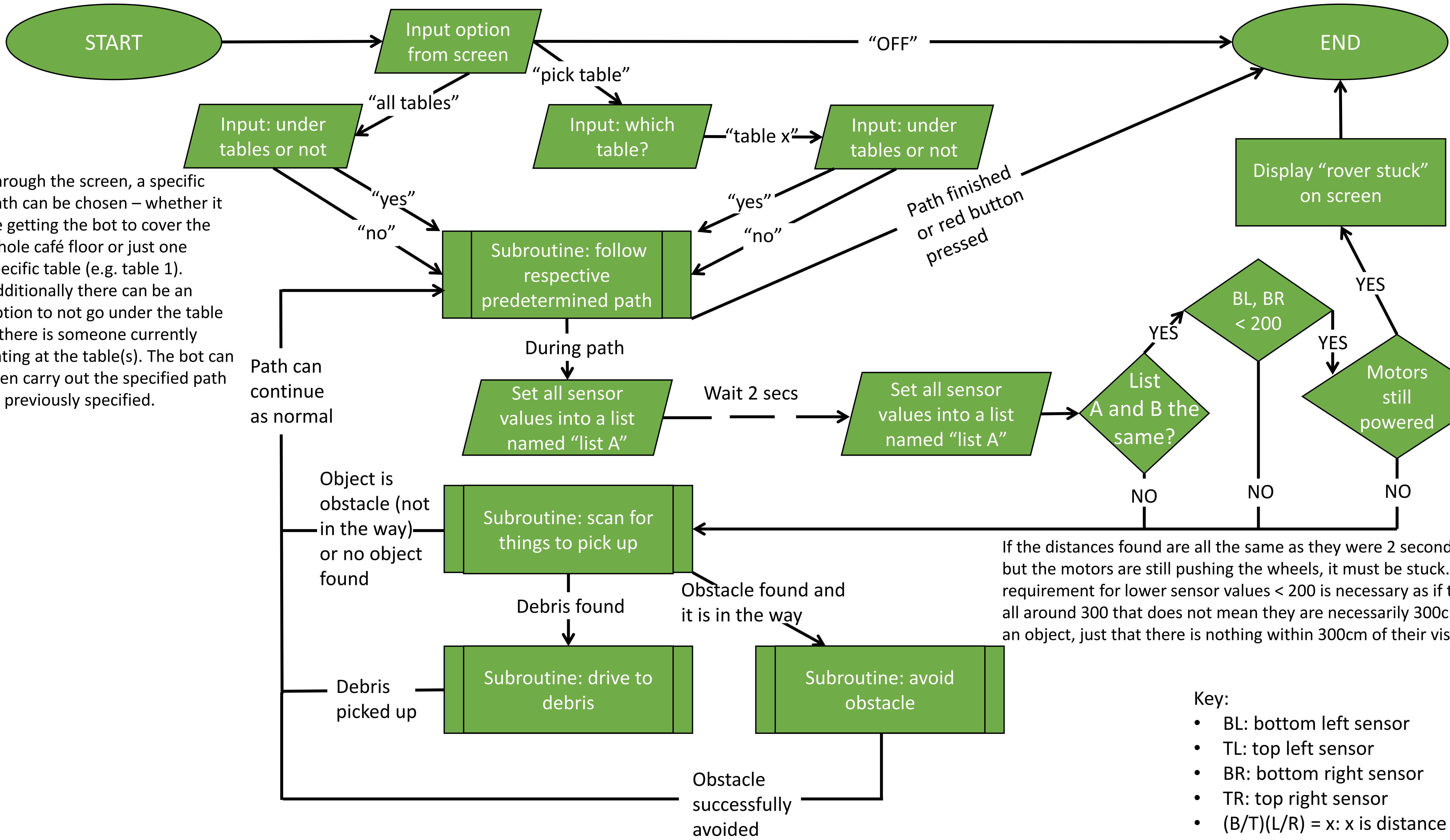
Section	Part	Material	Manufacturing Process
Scoop Mechanism	Scoop-Container  	Nylon Thermoplastic Elastomer	Frame of Nylon line bent to make the Scoop, ensuring soft bends to have no cracks or hard corners with gaps in them. Injection moulded TPE can go on the leading edge to touch the floor
	Cylinder Bar 	Poly-Vinyl Chloride	Blow moulded into a cylindrical shape, having 6mm thickness. Attached to scoop with thermopolymer polymer adhesive
	Servo Connector (one of each orientation)    	Poly-Vinyl Chloride Natural Rubber	Injection mould PVC to make the main servo connector part, as well as the same method for the insert. They attach via rubber injection moulds of the two straps shown
	Other Components	Servo Motor x2 (and shaft connection with it), Pin for strap x6	





Manufacturers Content: Algorithm Flowchart

Previous testing has allowed me to work out what components of the circuitry I am using can do, so to make best use of them I should write an algorithm for a professional programmer to write in code. This allows the electronic functions to be carried out as best as they could be. I have decided to write the algorithm as a flowchart. Key for both pages is in the bottom left.



Through the screen, a specific path can be chosen – whether it be getting the bot to cover the whole café floor or just one specific table (e.g. table 1). Additionally there can be an option to not go under the table if there is someone currently eating at the table(s). The bot can then carry out the specified path as previously specified.

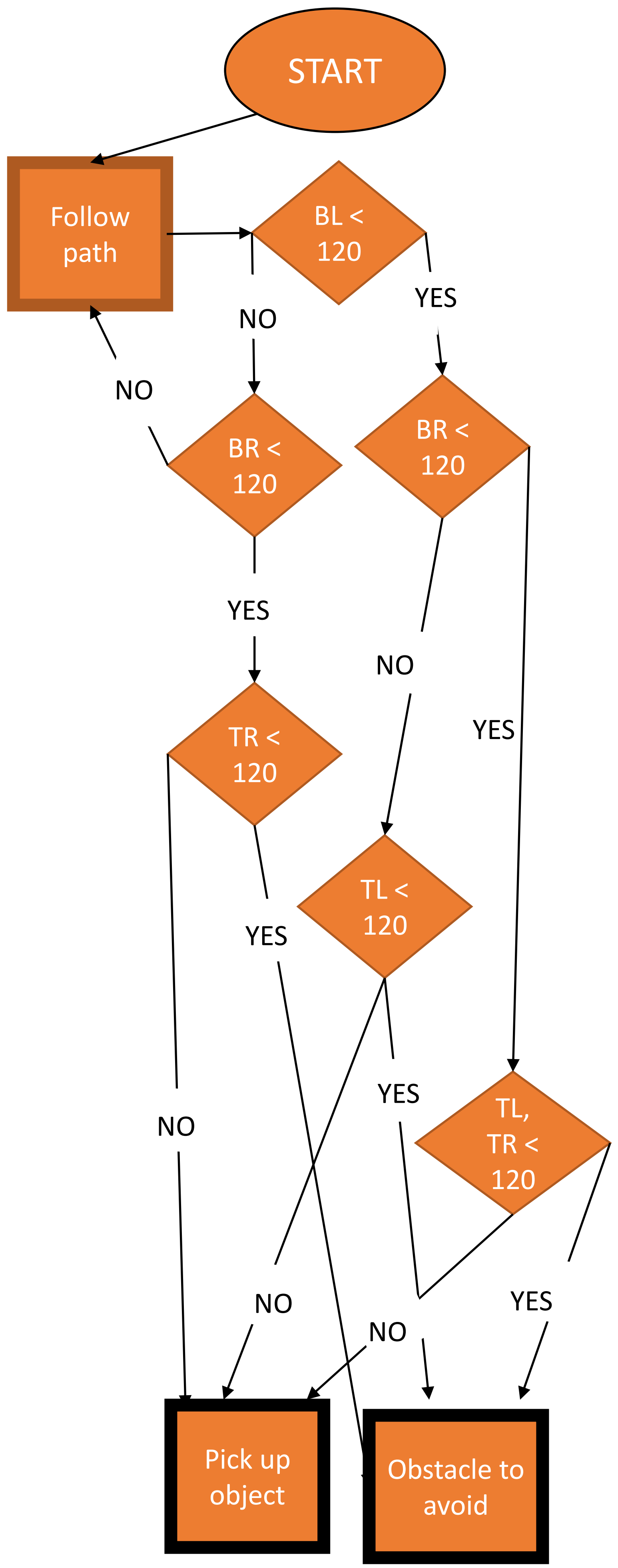
If the distances found are all the same as they were 2 seconds ago, but the motors are still pushing the wheels, it must be stuck. The requirement for lower sensor values < 200 is necessary as if they are all around 300 that does not mean they are necessarily 300cm from an object, just that there is nothing within 300cm of their vision.

Key:

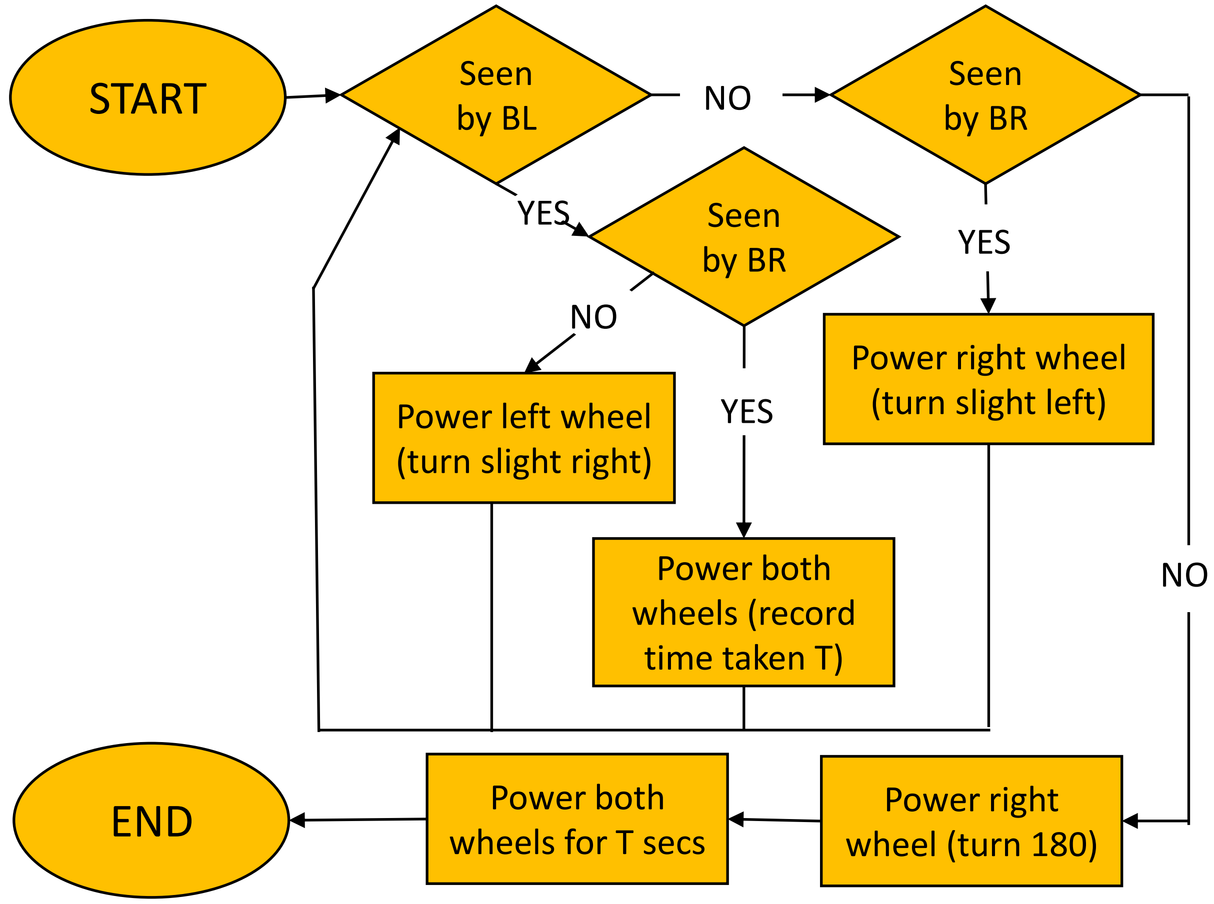
- BL: bottom left sensor
- TL: top left sensor
- BR: bottom right sensor
- TR: top right sensor
- (B/T)(L/R) = x: x is distance detected by sensor
- "…": worded input from screen

Manufacturers Content: Algorithm Flowchart

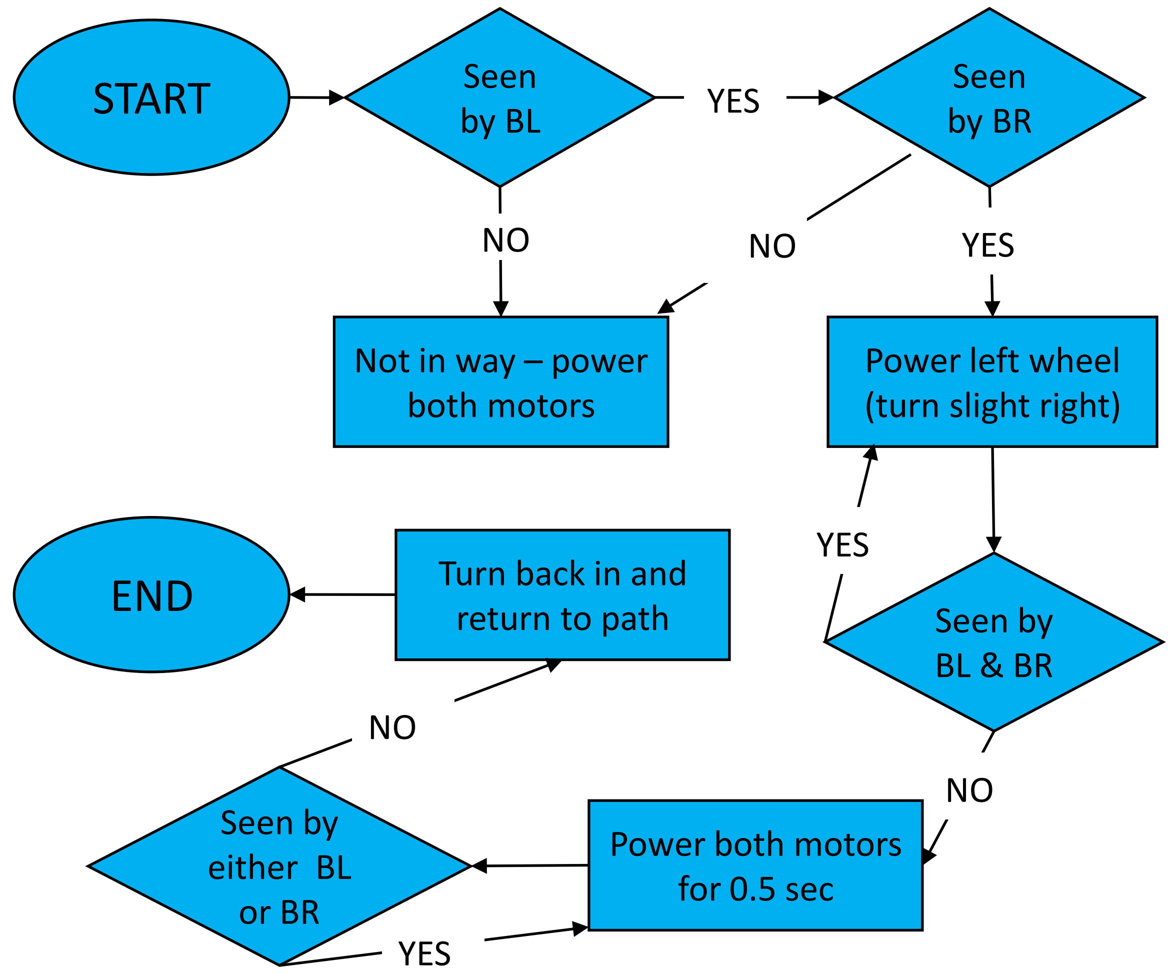
Subroutine: scan for things to pick up



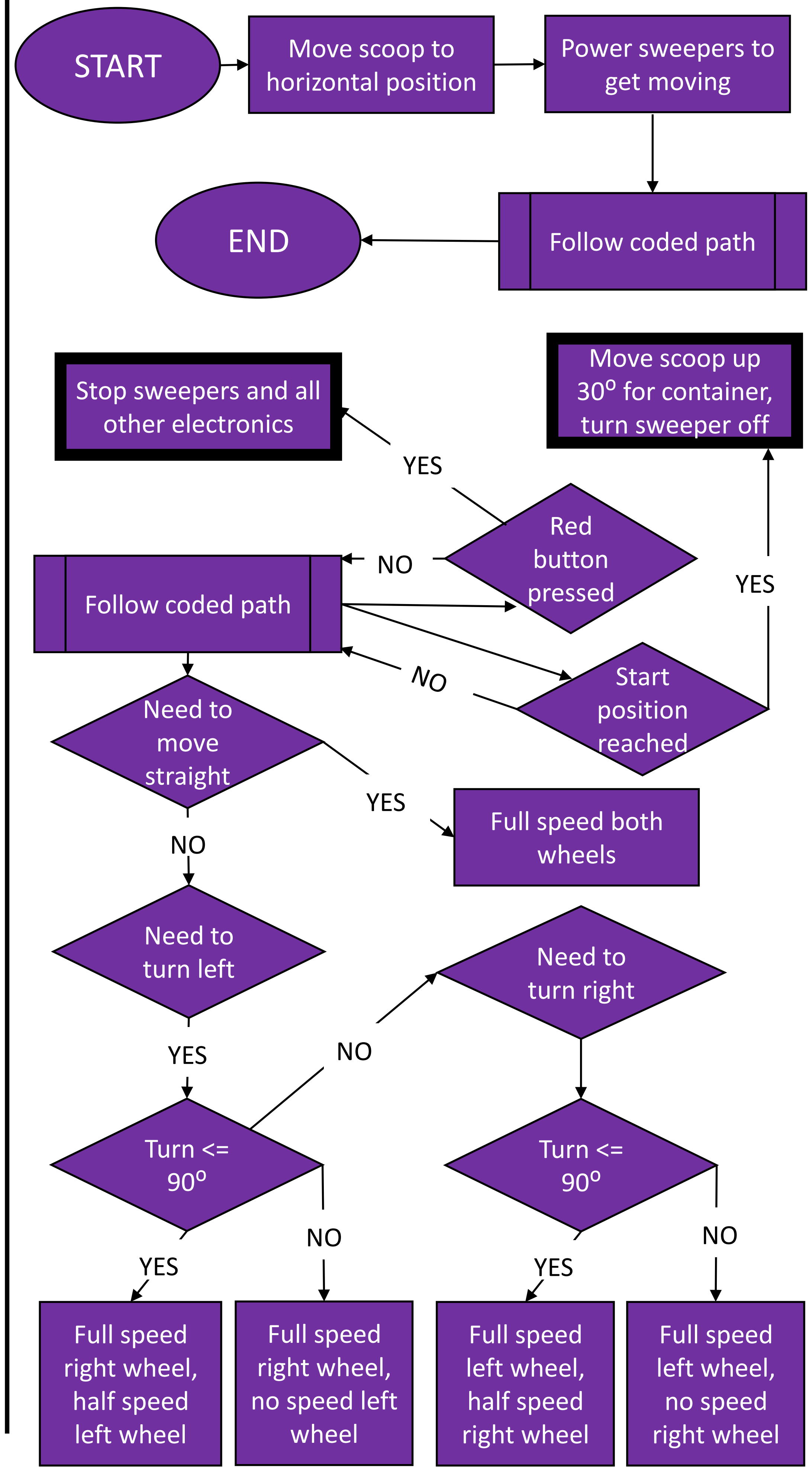
Subroutine: drive to debris



Subroutine: avoid obstacle



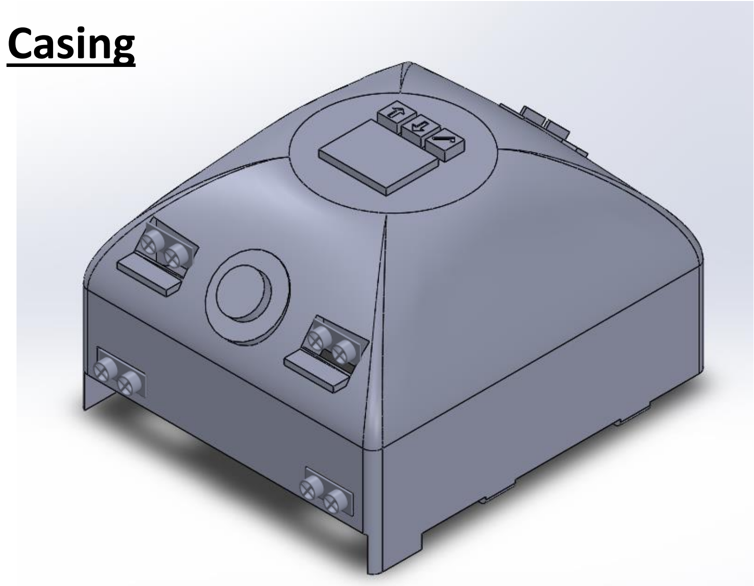
Subroutine: follow path



Manufacturers Content: Specification Points

also costs given, however it is very primarily electronics which could be bartered lower if bought in mass, the prices I have used assume I buy them one by one

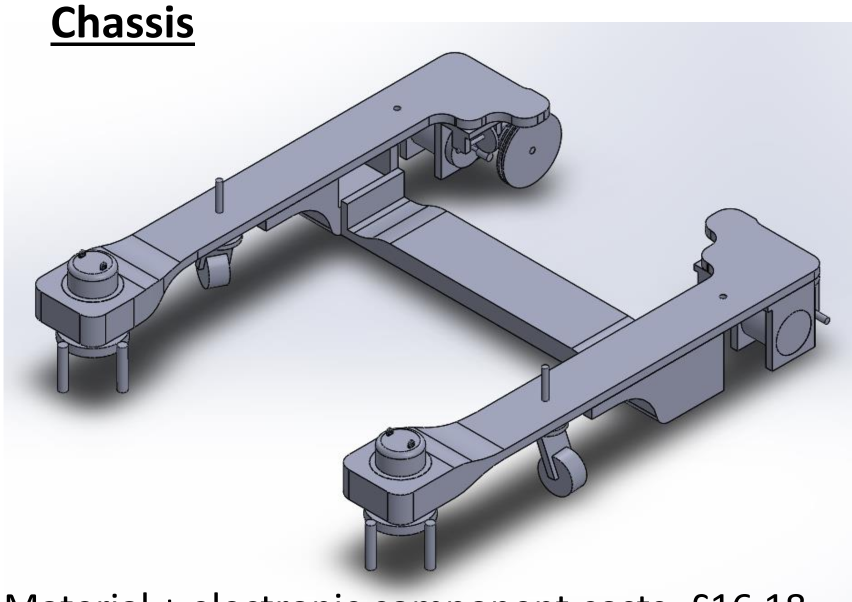
Casing



Material + electronic component costs: £37.88

1. The screen interface should be very simple and easy to interact with as it means any one can use it, no matter who is working at that time.
2. The rover must be easy to slide on to the mount to ensure it will always be the exact right place to start its cleaning route
3. A solid yellow colour should dominate the casing overall as to ensure it is very easily seen and to add extra prevention of potential tripping.
4. Making the overall system around 25cm tall reduces the threat it poses to those walking around and ensures it is not a hazard
5. The casing must be able to withstand great forces up to at least 1000N (due to 95th percentile of men being 98kg) without harm
6. The casing generally should not be so light, nor should the screen be so bright, as to distract customers constantly
7. If someone does fall on the casing, there should be no sharp edges or other features that might injure the person
8. If the joint between case and chassis breaks, the case should hit the floor and not hit or damage any of the inner parts so they will be very difficult to damage ever in normal use
9. Sensors must not be obstructed from seeing their full 30 degrees so the debris finding system works
10. Top sensors must never pick up the blinders below them instead of what is ahead of them so obstacles are not misinterpreted
11. PVC must be extracted in such a way that limits its contribution to global warming
12. PVC must not be contaminated to ensure it is still recyclable

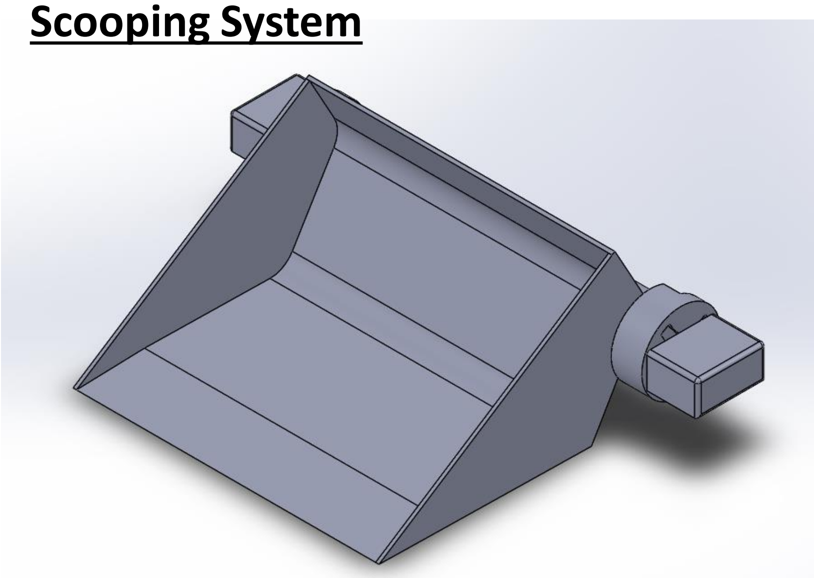
Chassis



Material + electronic component costs: £16.18

13. The parts of the chassis frame must be glued together with such strength that they could be considered one piece as this is one of the primary parts holding the whole device in its exact position
14. Peoples hands should be suitably shielded from the wheels while taking the scoop out so sharper parts of the gear do not hit their hands nor is any of the gear system damaged by the user
15. Neither the wheels nor caster wheels should make any significant noise nor make any marks on the floor as this would distract customers and require cleaning respectively
16. The rover should not move any faster than 0.4m/s so it is not a sudden danger to anything or anyone around it and so it can sense properly
17. The servo motor must be securely held enough to ensure the scoop cannot vibrate nor can the servo be easily removed by the user
18. The sweepers must be able to aid any debris in its movement on to the scoop so that the rover is useful for all forms of mess
19. The overall chassis can be no more than 29cm wide nor 34cm long to give it enough manoeuvrability and to allow it to fit anywhere it might need to go
20. Joints (with the 3 piece chassis as a potential exception) should be able to be disassembled as parts can be more easily fixed or recycled at the end of the products life
21. Scrap PVC such as from the making of the casing should be a priority to reuse to make parts like the gear system or sweeper base as to not waste material

Scooping System



Material + electronic component costs: £6.48

22. Any object of any size or weight should be able to be picked up by the scoop so that it can be used for any form of mess
23. The nylon must be smooth enough any mess to freely move on it, this is to ensure it can all be collected and disposed of without requiring any significant force – reduced need to clean scoop + sweepers do not have to do as much work.
24. the servo motor must not turn the scoop any further than horizontal to stop it from pressing itself into stuck hands or alternatively damaging the floor
25. The scoop must be solidly 18cm wide and therefore have the full size and volume to pick up everything it needs to without having to be emptied more than once a day
26. There should be great ease in undoing the servo connector so the scoop can be easily removed for waste disposal
27. The scoop should not have crevices in it that can trap any form of mess for example dust, so that it can all be easily disposed and will not subtly build up
28. The 30 degree tip should appropriately balance the collected debris so that the user finds it easy to carry without spillage
29. The servo connector holds the cylinder (and scoop) very tightly to reduce any vibrations or movement that could decrease effectiveness or efficiency
30. The button joint of the servo connector should not be affected by dust so that it does not lose its security while the rover is being used
31. The cylinder and scoop should be comfortable to hold for the user when disposing of waste to make it easy to remove the scoop and to improve user satisfaction
32. Adhesive joint should be meltable to aid recycling of materials

Workshop Additions

I have spent the past few months without access to a workshop, as well as being quite pressed for time. We were recently allowed to come back to school, however, and the deadlines were slightly pushed back too. This means some physical testing can be done, there is time for low level redesigning of some of the systems, and I will get the resources to construct a prototype model. Therefore the following aspects are things to revisit at this time:

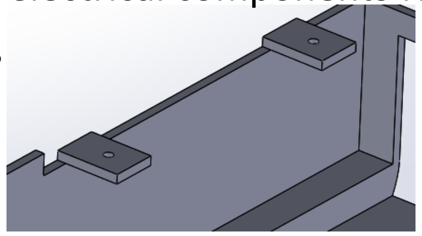
- Joining the case to the chassis in a way that is easier to disassemble
- Improving security of electrical components by analysing their joints closer
- Testing function of the scoop in its current form in relation to weight limits (again see this page)
- Rearranging which wheels go where as discussed on this page
- Revaluating the necessity of all the different paths against the difficulty of coding at my level
- Limiting cost of parts, components and manufacture

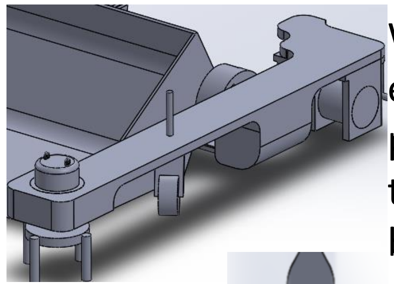
n.b. many models (physical and 3D design) over the next few pages are demonstrations of form for the sake of problem solving and finalised scale models will be found afterwards on this page.

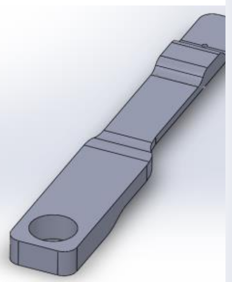
Container Joints

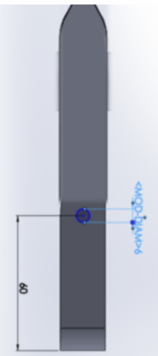
With time to evaluate some of the decisions I made previously, it was noticeable that the join I decided upon between the casing and chassis was, while secure, difficult to take apart. The way that the join was arranged would make it very hard to both assemble and disassemble – which was contrary to my attempt of designing for disassembly. Additionally, there are some weaknesses with other joints with electrical components for example such as the Ultra Sonic sensors.

Here are the previous joins. They are a bar that would slot under the chassis and be fixed by screws. The problem is slotting them in, however there is also the problem of making them too as they are at right angles to the container side and cannot be filleted as they have to fit around the chassis.

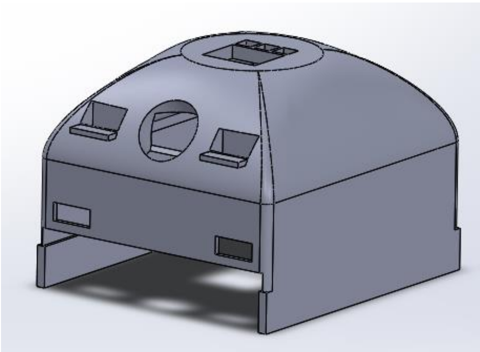




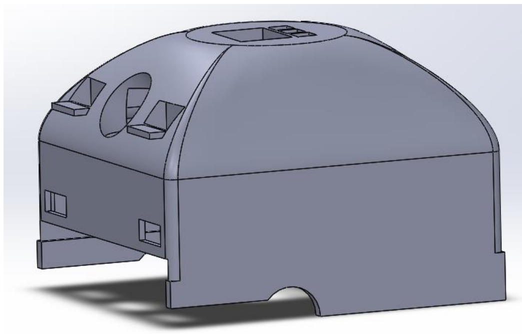




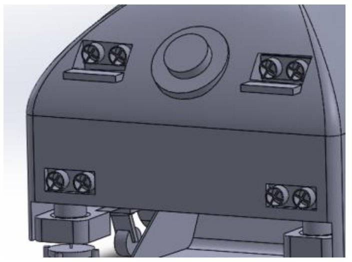
When originally designing the joint, I cited that the side piece was not thick enough for screws in the side. However, with hindsight analysis, it is clear the piece is thick enough where the sweep motor is. Obviously a screw cannot go through the motor, but if this thicker part were extended slightly, there would be sufficient space for a hole for such a join. Also, the extra thickness should provide the strength required to stop any parts breaking when under the stress it could endure (see this page for discussion of this problem). Another problem (initially brought up here) can be solved more easily: that being stopping inner components being damaged if the casing joint is broken. My initial solution to ensure the container hits the ground first makes sense, but can be greatly simplified (see here for its details) by simply making it so the container side simply reaches very close to the ground as shown below.



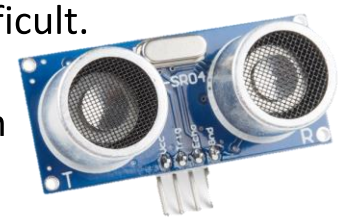
There does, however, need to be gaps to allow the caster wheels to have full movement and the sweeper its full rotation. Additionally, screw holes have been added to this. Premade holes for a bolt reduce number of processes required and also stops the chance of fracture that comes with screwing into the thinner chassis piece.



There are many electrical parts on the outside of the casing that greatly lack the protection they require on a device that would be used in a public place.



The Ultra Sonic sensor in both top and bottom positions is quite exposed whereas the only part that should be visible is the signal sender and receiver. The current problem with that, however, is making such small holes in the container that need to be so precise will likely prove to be too difficult. The container's mould is already incredibly complex this new problem makes it too much to ignore and the container requires a much needed change in form and construction.



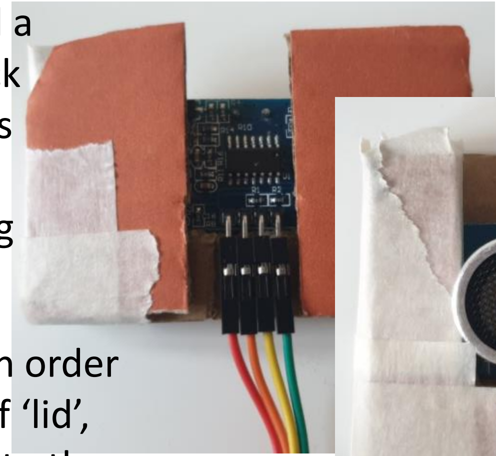
It may become easier to split the container into more parts, for example a front flat face to hold two sensors at the bottom and a second one just above it. As the casing has been extended to end just above the floor, it does not necessarily need to go straight up for 90mm (see this page for more details), and has more flexibility. I can explore how I might do this redesign on this page.

Workshop Additions – Container Changes

Continuing what I started looking at on the previous page, the container is in need of some redesigning to best secure all the parts on it as well as improve the ease of manufacturing by splitting it into multiple parts.

The Ultra Sonic Sensor would be safest if snuggly contained within the casing, but there is a necessity for the wires at the back to be accessibly from the inside too. I took to cardboard modelling to figure out a solution.

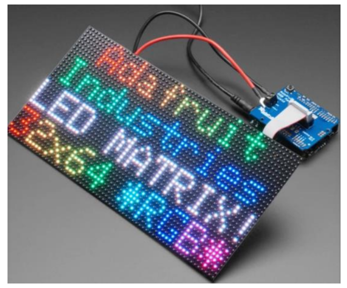
I therefore added a not-filled-out back to reach the wires but also stop the sensor from being too loose.



From there I added a base part that could fix to the rest of the casing. I also thought, in order to prevent the sensor from being pulled out, another piece could be added as a sort of 'lid', fixed to the base by screws which also (along with the ones at the bottom corners) fix to the casing. In the case of the top sensors needing a small blocker, this lid is in such a position that it carries this function too. Of course the real one would angle inwards, but that is quite hard to do with card models – this will be represented when I make its 3D model.

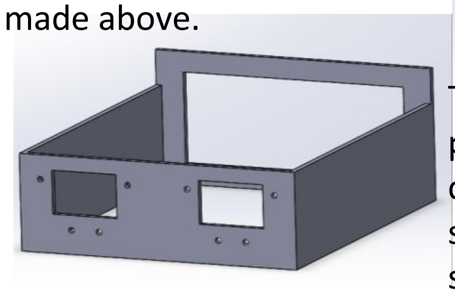
In reality this would of course be injection moulded, likely from PVC again.

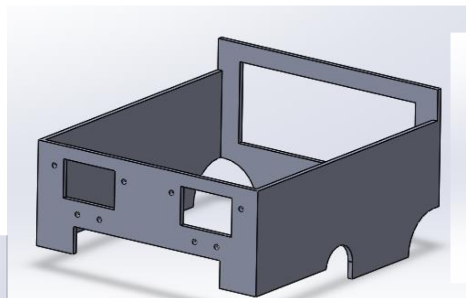
The Screen, introduced here, was a feature that could allow a very large set of choices of paths that the rover could take and is therefore not a necessary addition to fulfil the functional or user requirements. What is required is for the rover to path around the whole café. Therefore, to reduce on costs of parts, the screen and its components can be taken away (but potentially used for a higher market model). This would also greatly reduce the amount of work required to code the pathing of the rover – which also reduces costs of paying for coders significantly. Before going ahead and taking it away, however, I ran it through my stakeholder to check if she agreed which she did especially if it reduced the price of the rover. As I mentioned, the extra paths function is not necessary but certainly useful so perhaps if I developed ideas down the line it would return in some form.



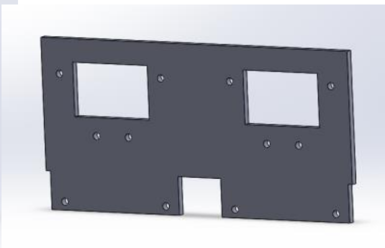
While I was altering the casing to fit this change (shown left with the red button now on the top), I realised a change clearly had to be made to ensure the fit of the Sensor case (shown above). Furthermore, there are clear disadvantages with rotation moulding as a method – including very long run time, and is very expensive especially since only the casing would use this method – therefore a change of process, and by extension a redesign of the part, is needed at this stage. The new casing must be essentially the same part, except there must be a flat face suitable for the sensor cases, should be no screen, and must match a method that is already in use (to reduce processes) (i.e. blow moulding, line bending, or injection moulding).

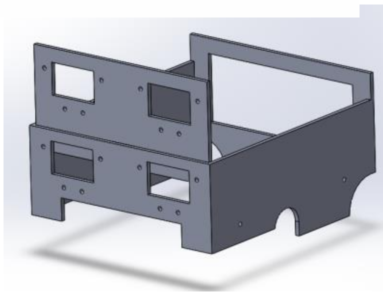
I started with the main casing part that joins to the chassis, modelling its form around the sensor holder I made above.



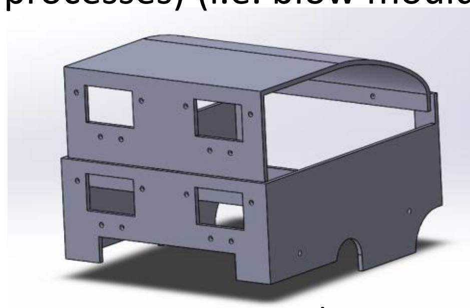


Then the addition from the last page was added, reaching closer to the floor but making sure to not be in the way of sweeper or wheel movement.





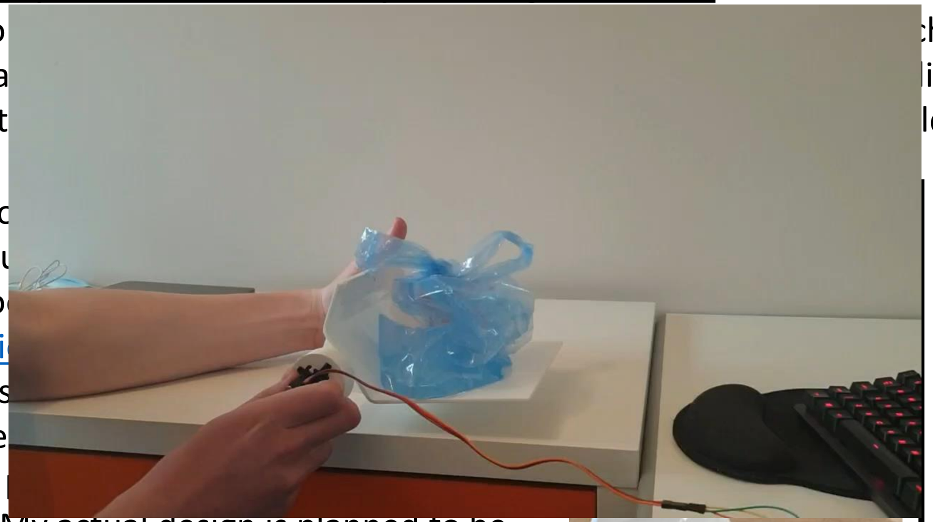
To have the top US sensors fit well, a top piece can be made that can use the screws that hold on the bottom sensors (to save on screw holes).



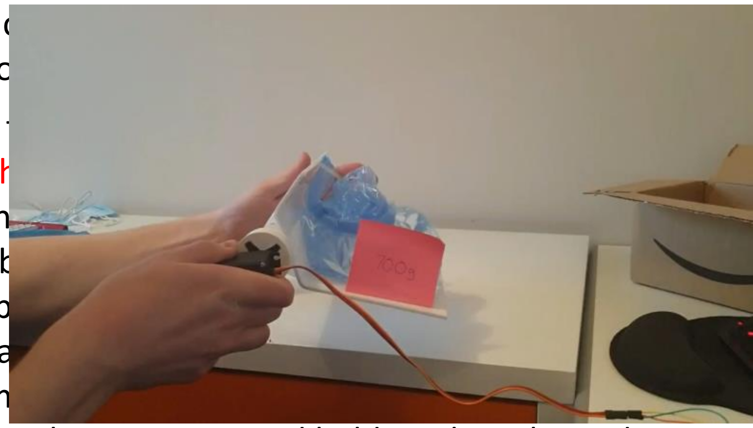
An extension on the top piece joins it to the back along with a flat piece on top. Now with the frame done, I develop the full final casing model on this page

My thought process is that simple flat pieces like this can be industrially laser-cut. They can then be line-bent to form full shapes. The bottom piece can have acrylic cement applied to join up the first and last side, and top-side pieces can be permanently joined to the top-front piece so it is one part, impermanently screwed to the bottom. This arrangement should allow the top to be removable to access potentially broken parts, or during disposal.

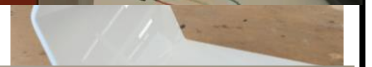
Workshop Additions: Scoop's Weight Limits

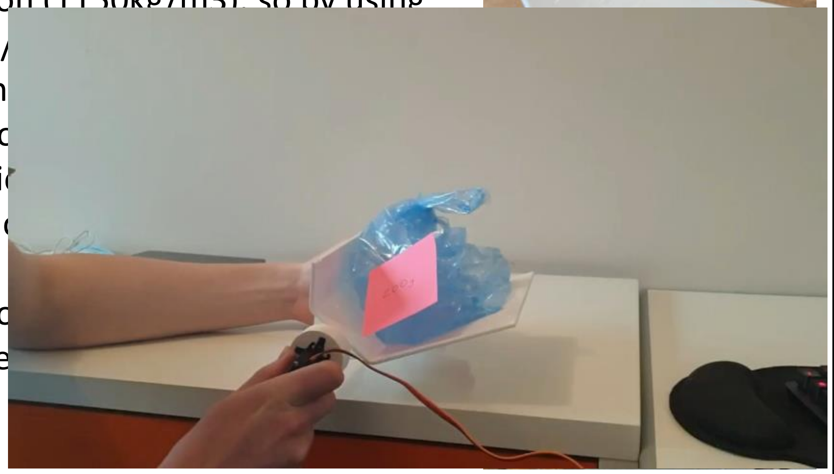


The Servo ... heapness was the Tower Pro MG 996R (here on amazon), it is clear they go down in price dramatically in bulk. My initial design ma ... ift the scoop together, however I c ... motor is enough. If neither one nor two servo mot ... ld look to use a different servo mc ... ssed on this page.



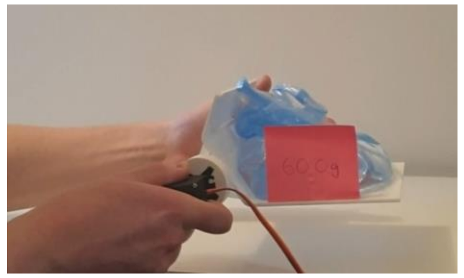
In order to ... need to bu ... actual sco ... constructi ... and forces ... add a laye ... make the ... material. My actual design is planned to be made from Nylon (1150kg/m3), so by using Acrylic (1200kg/ ... be made. Mean ... as it was the mc ... used a 6mm thic ... I began construc ... acrylic sheet to ... market out scoc ... make the desire ... bending will be ... manufacture).

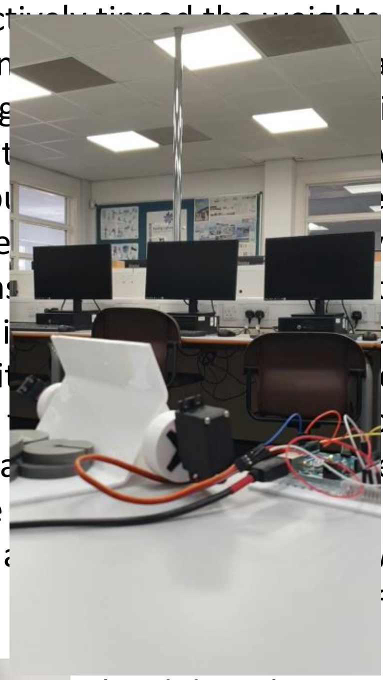




With my new model I could test ... empty, the scoop easily and smoothly moved just as intended (shown h ... ned with weight. When deciding size requirements of the scoop I men ... object, so I could model the weight requirements around this too – b ... , however, that are also quite heavy – such as (possibly broken) mugs b ... should have the ability to hold multiple objects of this weight ra ... be able to hold (and tilt backward) at least. Weight data for these item ... cending weights to find the limits. As planned, I began by testing with only one servo, and held up the other side to grant some stability. I tested 100g, 200g, 500g, 600g and 700g to see how it faired (videos linked on respective numbers).

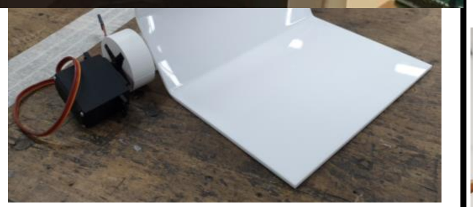
... e 100g and 200g bags with ease as I had ... as a slight lag on the down stroke (which as ... ary function) but it worked with good ... esistance to motion, which meant that the ... lowly and could not quite reach the full 40 ... at 700g. Initially I had thought that by simply adding a second servo on the other si ... this was not the case. Another servo likely did not increase force only improved stability to allow it to fail at 800g instead. Despite failure to reach 1000g, this test was a very solid proof of concept: the design that I used effectively tipped the weights back to hold them in place and had the ability to carry significan ... a successful design. What this means is rather than redesigning ... in slightly more powerful servo motors the 1000g requirement ... limit of 800g is still sufficient in almost every occasion bu ... current servos can act as a lower-end model easily, but a higher end model (with the 1000g re ... reached by swapping out the servo for one like this which is the same size, slightly more expens ... the force output. Nevertheless, no matter what the weight limit, there should be a protocol for i ... d – per ... If either servo motor breaks, it is quit ... ce to r ... overloading of the servos, then that ... ble. Aft ... that while servo motors do collect da ... e servo ... the position information back to the ... to do ... analyse the voltage usage, however ... with a ... f the sc ... be pre ... r if this did not happen as pla ... make an alert (e.g. LED or buzzer sound) and stop the servo motion. The buttons placement is a case of simply adding to the design of the chassis under piece (which is easy to manufacture since this piece is already injection moulded). Additionally discussions led to the conclusion that this, like the more powerful motor, could be additions for higher priced commercial models as opposed to for local café owners.

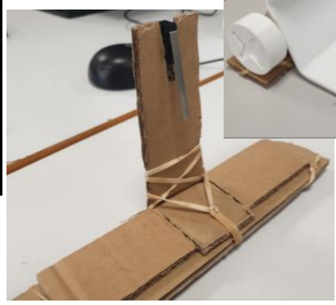


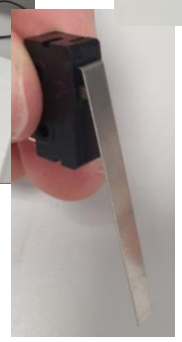


I ran the 3D printer to make one servo connector for each side between lessons, having modified the design to account for the fact that I did not need to remove the scoop from it (i.e. no insert). The next lesson I t ... flat face, this ... testing), whic ... scoop to crea ... component a ... the cylinder t ... model. I also

```
#include <Servo.h>
Servo tower_pro;

void setup()
{
  tower_pro.attach(9);  //  Arduino pin 9 = servo motor
}

void loop()
{
  tower_pro.write(0);   //  reset position
  delay(5);
  tower_pro.write(40);  //  extra turning to add confidence
  delay(5); }
```



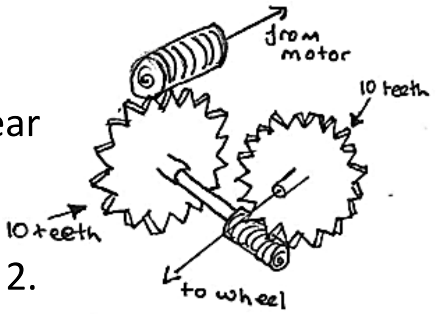




Workshop Additions - New Gear Set

Previously, on this page, it was decided that it would be possible to move the wheels to the middle of the chassis if the motor and gear box were small enough to not obstruct the scoop or protrude too far out of the chassis side. The benefit of doing this, of course, would be halving the turning circle – a very helpful inclusion to the manoeuvrability of the rover.

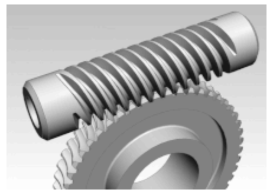
It was discovered on this page that the necessary gear ratio is 100:1 and for the gear system I chose (→) I decided upon a module of 2.



For it I used 20mm, 10 tooth gears that utilised worm drives to function.

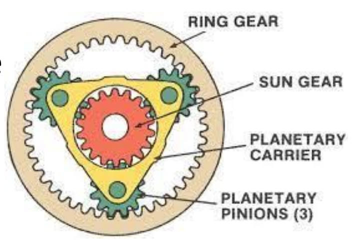
In order to make optimum gear train, I need to first have a scope of what options of gears I can use. For this I only need to consider gears that add to gear ratios.

Bevel Gears have a 1:1 gear ratio but can be a simple and compact way to change the axis of rotation.



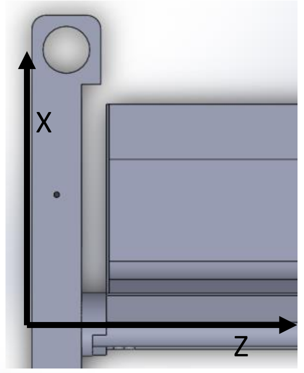
Worm Drives (used in previous gear) connects worm gear and normal gear to create a very large gear ratio as the worm gear is considered as having 1 tooth. It also changes axis of rotation.

Epicyclic or Planetary Gears have multiple parts which are used to make a range of gear ratios depending on which part is stationary. What is even more special is that it does this while being co-linear.

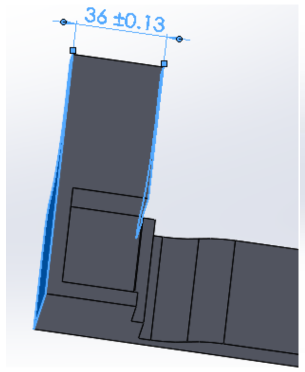


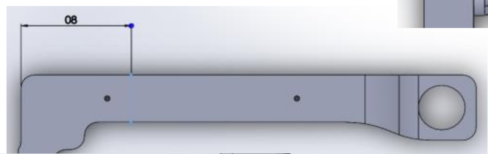
Despite Epicyclic Gears being very useful, I cannot imaging any simple way to make them and believe they might add more work than necessary. Buying is an option however they are usually far too expensive as with most gear boxes. There are a few cheaper results (e.g. this), however it is even harder to find anything to fit to my very specific size requirements. It is safer to look at Worm Drives and Bevels.

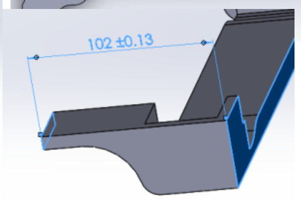
The problem previously was that the designed gear was too large to fit between the edge of the chassis and the edge of the scoop. I knew it was far larger than the gap and never worked it out precisely, so I should do that now (before I design a new gear).



It is clear from a first look that in the Z axis there is the width of the chassis piece + servo connector. In X axis it is the of the spinning brush and the servo motor

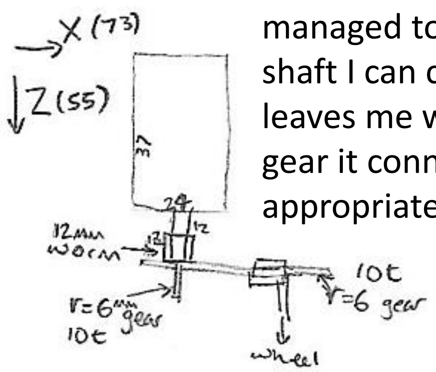






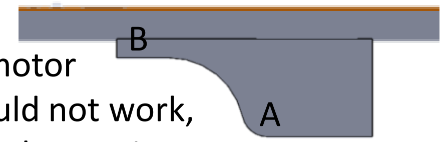
From calculation I have deduced the room is 55x73mm and has a previously show max height of 45mm

Additionally, I want the gear box to have around 5mm or more clearance from the floor plus a casing of 4mm thick. It is worth considering that the DC motor I am using is 37mm long and 12mm radius with a 12mm shaft.

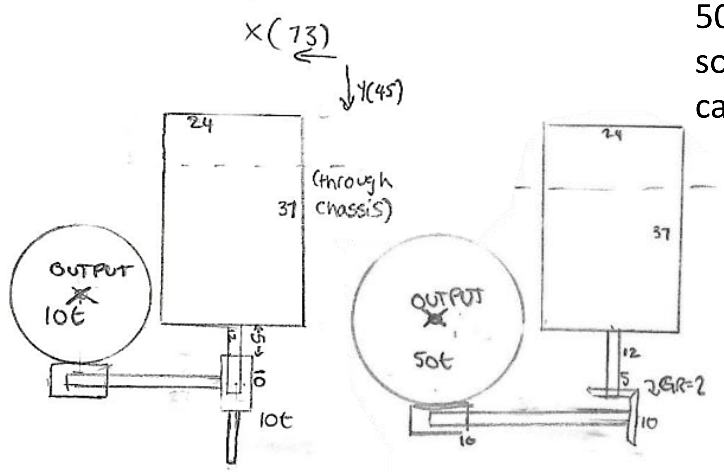


First I tried simply down sizing the gears I used. If I managed to fit the worm gear over the whole motor shaft I can conserve the most space, but even this only leaves me with 6mm without having considered the gear it connects to or the box casing. I think it is more appropriate for the motor to be on a different axis.

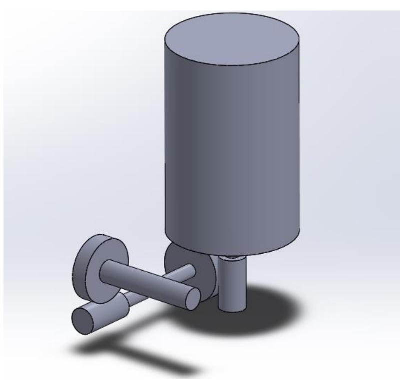
The previously named 73mm X axis is the distance between point A and the spinning brush, but if you measure with point B instead it is only 23mm. As this Is less than the diameter of the motor, fitting the motor facing the X direction would not work, the only solution is facing down – i.e. through the chassis. Then I can use the gap between A and B easily for non motor parts as shown below.

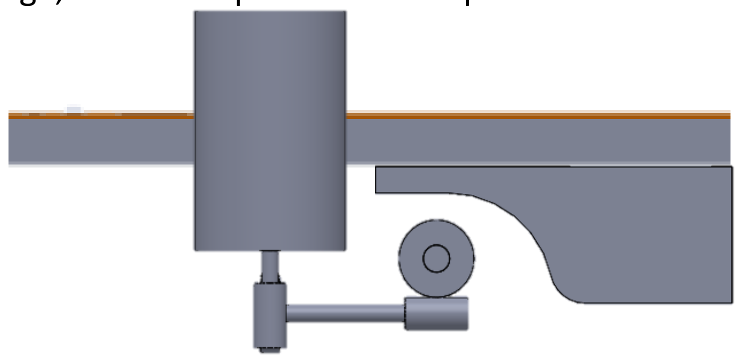


I tried using the motor pointing downward in two models, one using Bevel Gears and one with only Worm Drives.



As the wheel is 45mm, I need the output to be 22.5mm from the floor. With the previously mentioned 5+4 clearances, this means gear 1 would use two r=6mm 10 tooth gears, while gear train 2 would use one r=5mm bevel gear and one r=6mm 50 tooth gear. 50 teeth on that wheel would make it difficult to maintain precision so the simpler choice is gear train 1. I sized it and modelled it as shown below. The casing for it, made on the next page, can be bespoke to this required form.





Workshop Additions - New Gear Set

Now that I have a gear train, the delicate parts need to be kept safe by making a gear box. Once again, I can make the gear box a bespoke shape to perfectly fit the area it is meant to be in. Additionally, with the extra time I have, I can work out the right materials and manufacture methods from the job as well as check-test the mechanism.

Now having designed the new gear system I wanted to use, I had to adjust the chassis pieces to accommodate for the change. Now with motors going through the chassis, there obviously had to be a hole in it similar to that for the sweepers at the front. The presence of a motor also meant that the chassis piece needed to be thicker at this point (as shown in Fig.1) in order to have a more secure interference fit with the rubber grip, then I also had to move the hole for the caster wheel to the back as shown in Fig. 2.

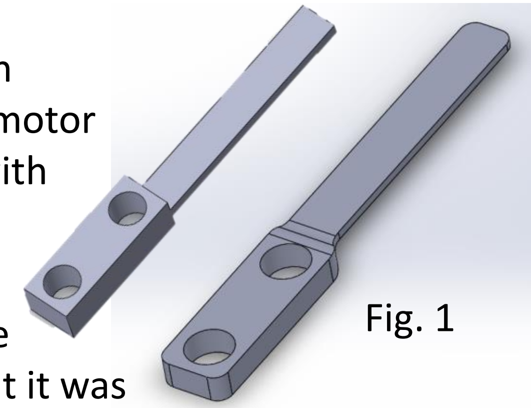


Fig. 1

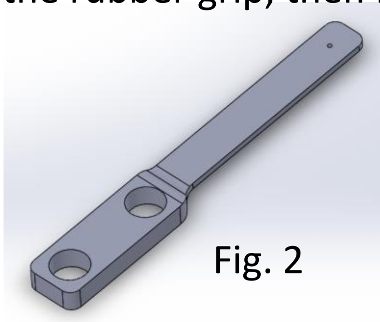


Fig. 2

While initially I had simply made the thickness at the point of the second hole the same 20mm thickness as the very front, a few calculations revealed that with the current gear sizing this would make the gears lower than the wheels. Rather than a complicated process of redoing certain parts, I decided to make the chassis piece such that it was still 20mm thick at the front, but only 13mm thick for the gear motor. This meant I could raise the gear system slightly so it was not too close to the floor, while also keeping a large enough space such that the TPE ring can keep grip on the motor sufficiently. The final chassis piece I decided on is in Fig. 3, the gear in this chassis Fig. 4 and the overall chassis assembly in Fig. 5.

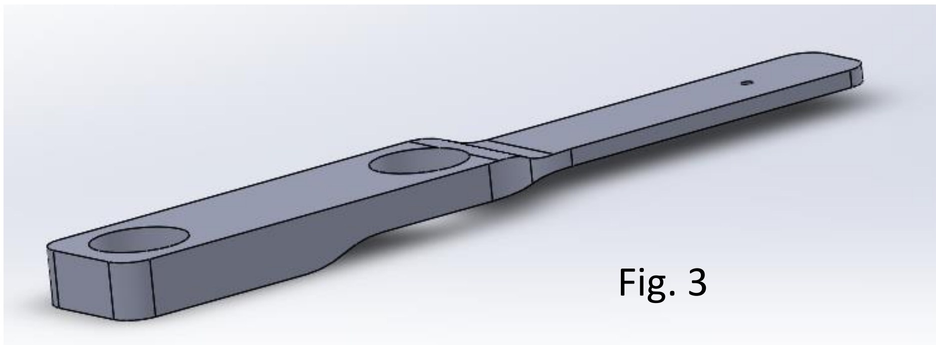


Fig. 3

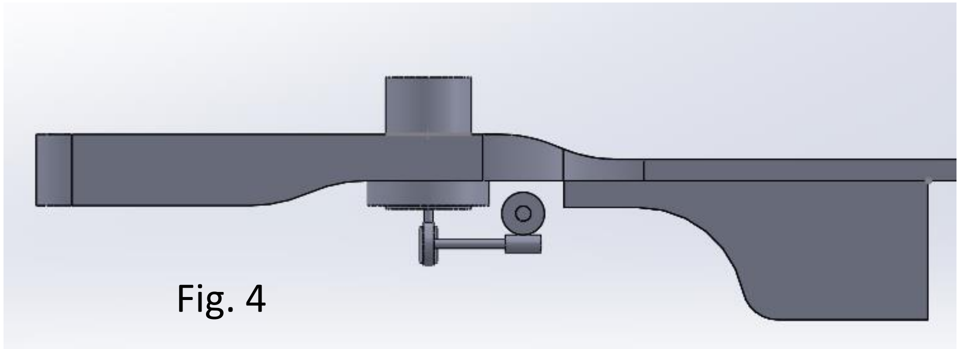


Fig. 4

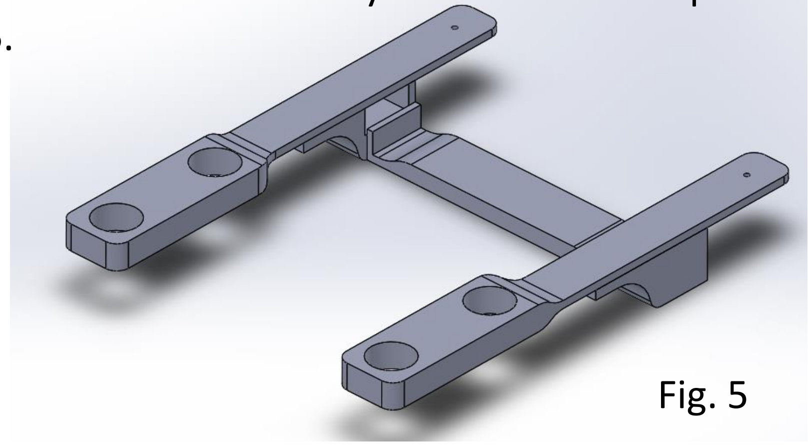


Fig. 5

Finally, I had to make the Gear Box such that it would appropriately fit to this space. First I had to make small mounts on which the axles could rest at the appropriate heights as shown in the demonstration on Fig. 6. If I were to make these pieces for a physical demonstration of the working of this piece (which I cannot do because of lockdown restrictions preventing me from using a workshop), I would 3D print these holding parts to ensure accuracy. The box would then likely be made from an assortment of held together laser cut plastic pieces made into the shape shown.

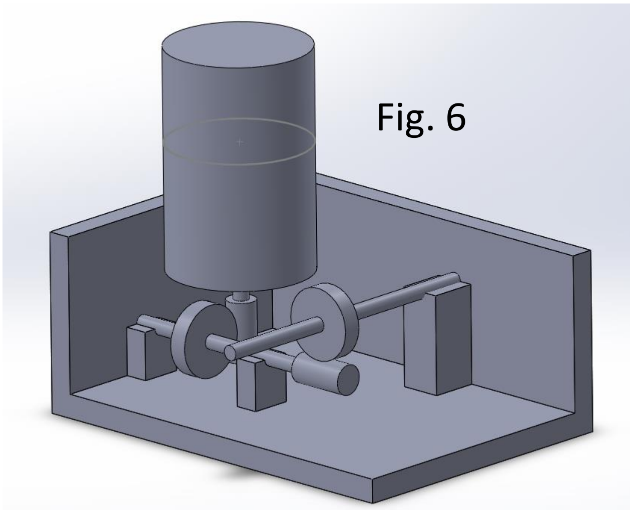
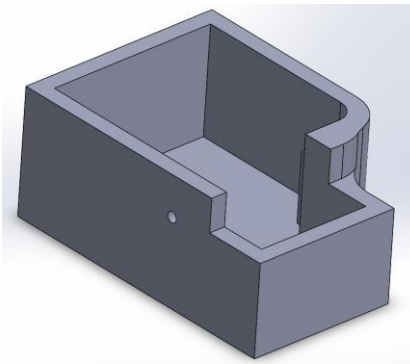
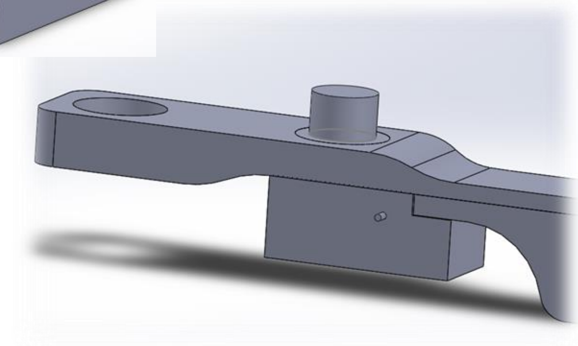


Fig. 6

Now having put that together, I had to create the outside casing part. To ensure some discretion of parts, I made sure that the casing would accurately follow the edge of the chassis. Additionally, there had to be a small drop so that the case could fit snuggly under the chassis under-piece.



Finally, by adding a lid to the gear box as shown in Fig. 7, a contact adhesive join could be made between gear box and chassis that can reinforce the interference fit with the TPE grip. This left me with this final gear box design.



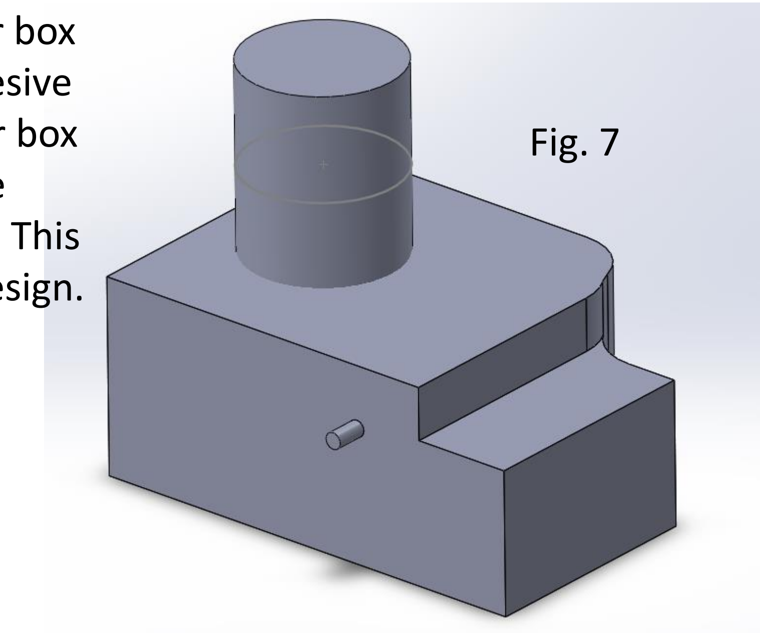
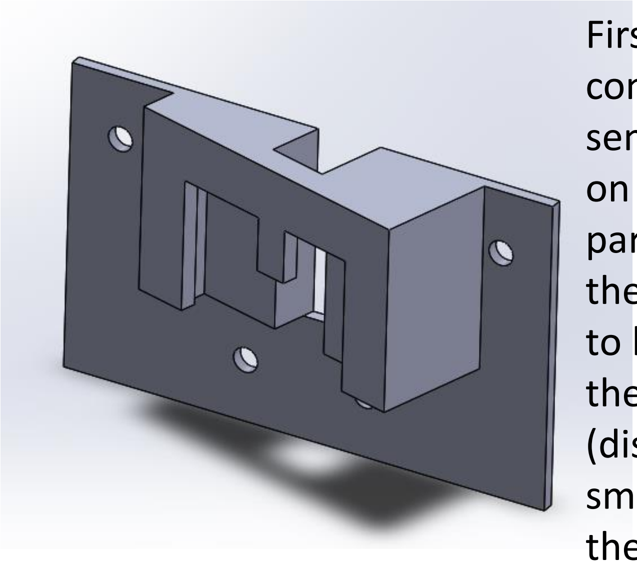


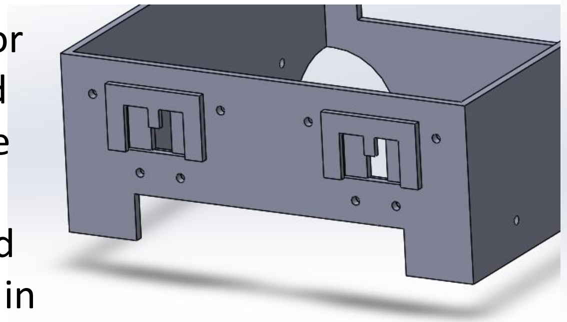
Fig. 7

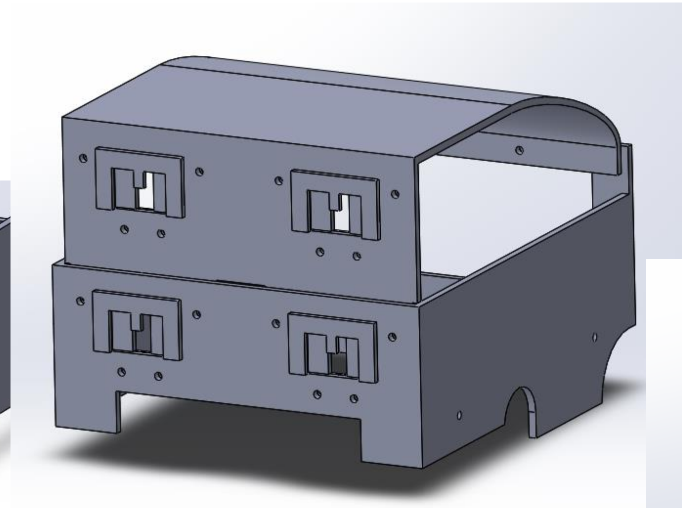
Modelling Final Design

Now having used my time and access to a workshop as much as is possible, I have a complete model which better serves my design brief and specification while also being easier to manufacture and cheaper. It is at this point which I can say the design is complete as I have used all the extra time I have and with what I have left to make a working prototype. So before I do that, the 3D model representation must be made.

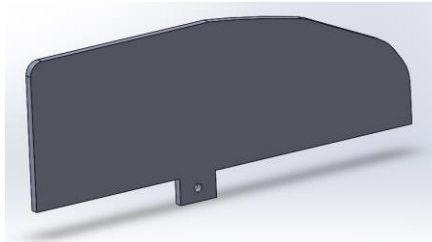


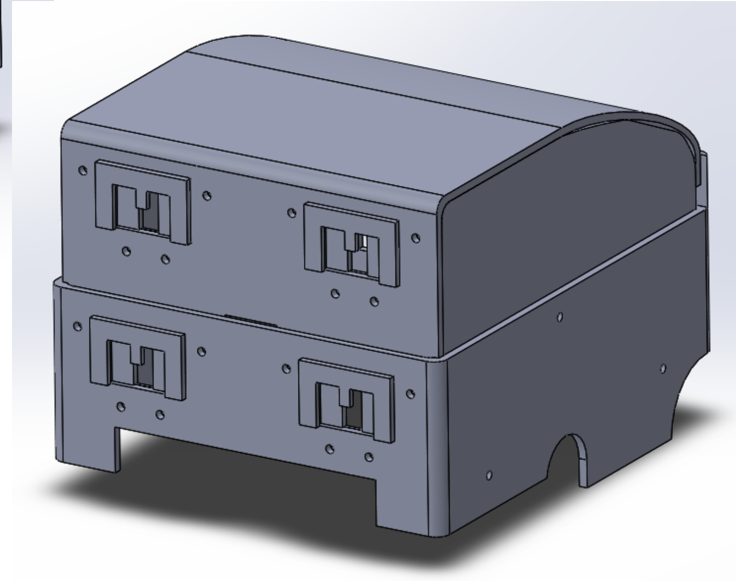
First I had to make the computer model of the sensor holder I designed on this page. It was particularly important for the holders to be angled to help the device locate the position of objects (discussed here). It fitted smoothly into the holes in the casing as required.

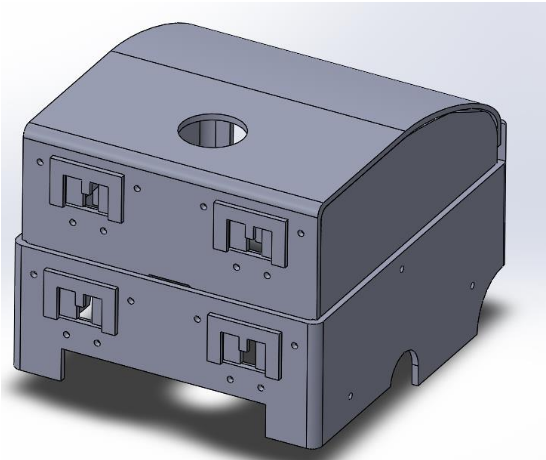




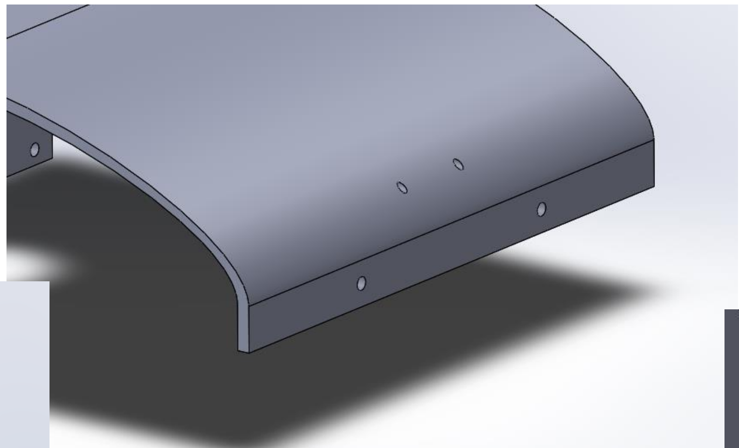
I then assembled the two main casing pieces and constructed the side pieces that would joined via acrylic cement to the top piece as mentioned.





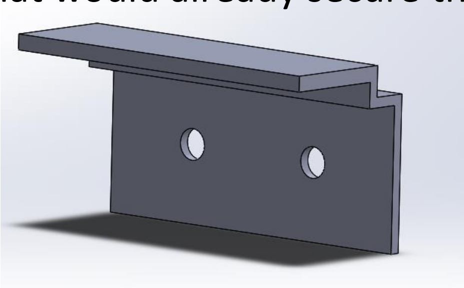


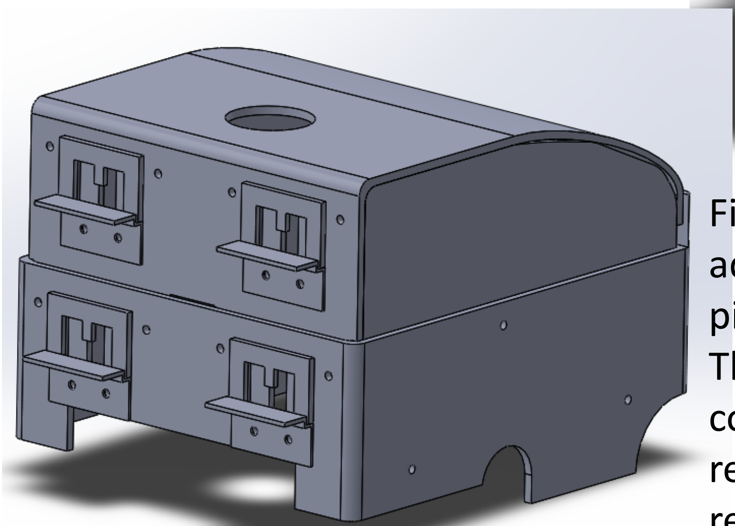
Also as mentioned, I implemented the hole in the top for the button that would get put in. The circuit inside the casing can be placed directly under this, but there is also enough space to place it at the side if need be.



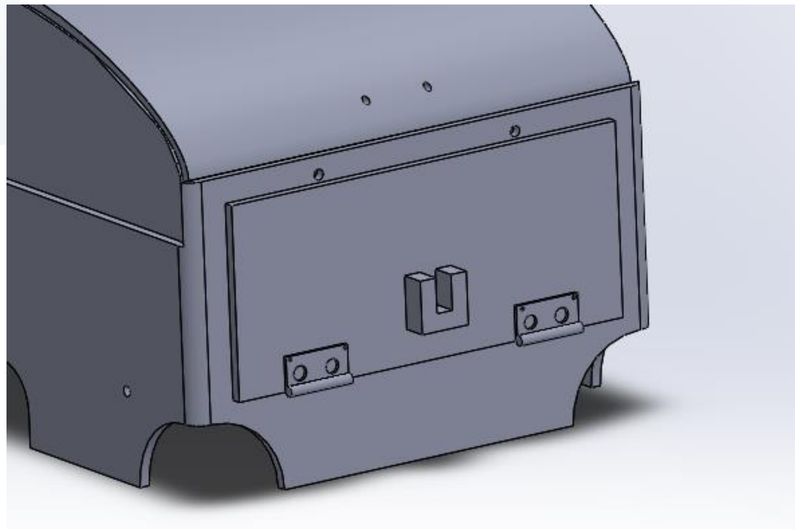
Small holes in the top casing part were added which would be the place in which the latch for the hatch could be screwed on.

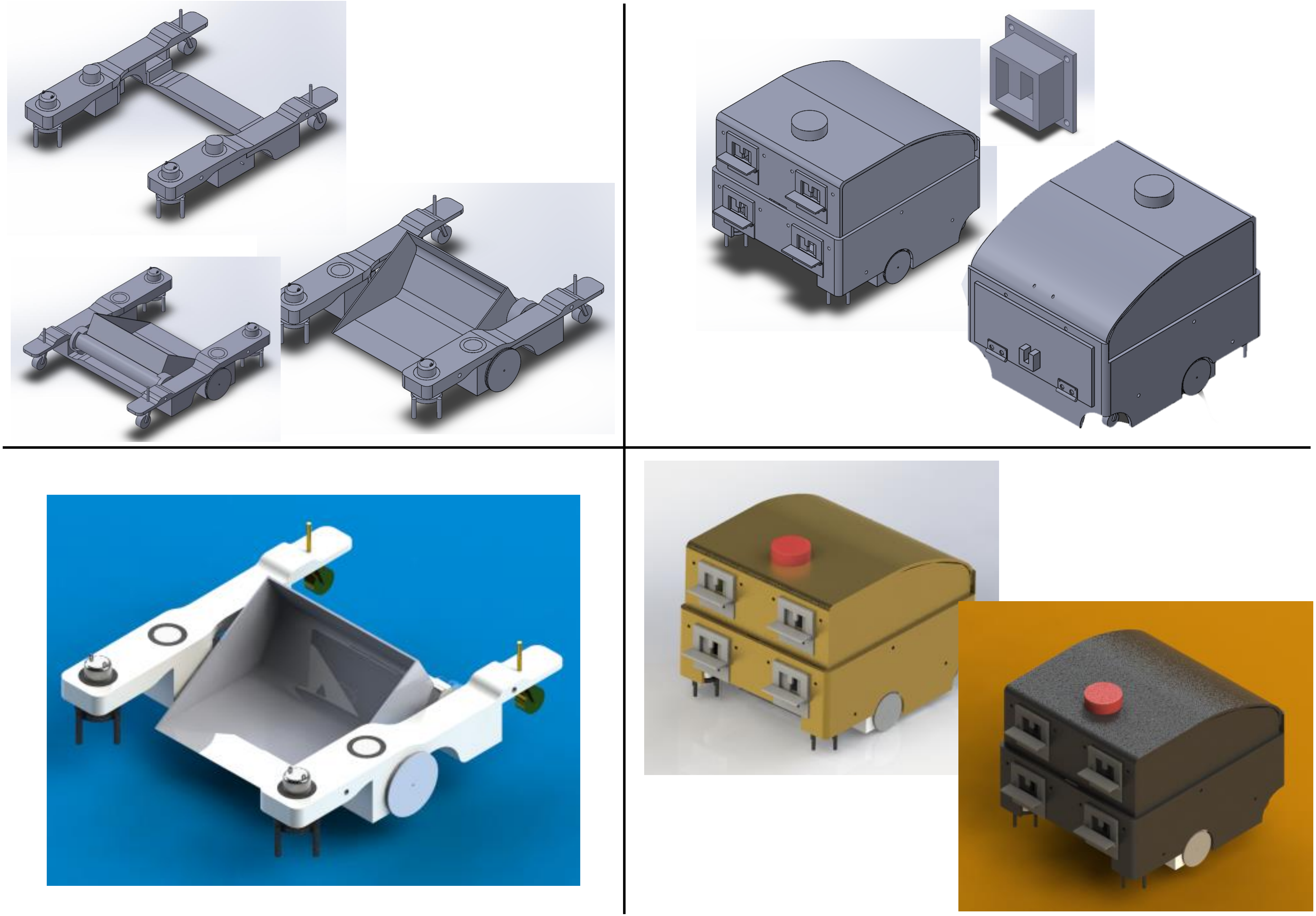
A blinker for the sensors also had to be made to stop top sensors looking down. They had to be large enough to extend past the angled holder fully as shown. Additionally, they can be held on using the nuts that would already secure the holder



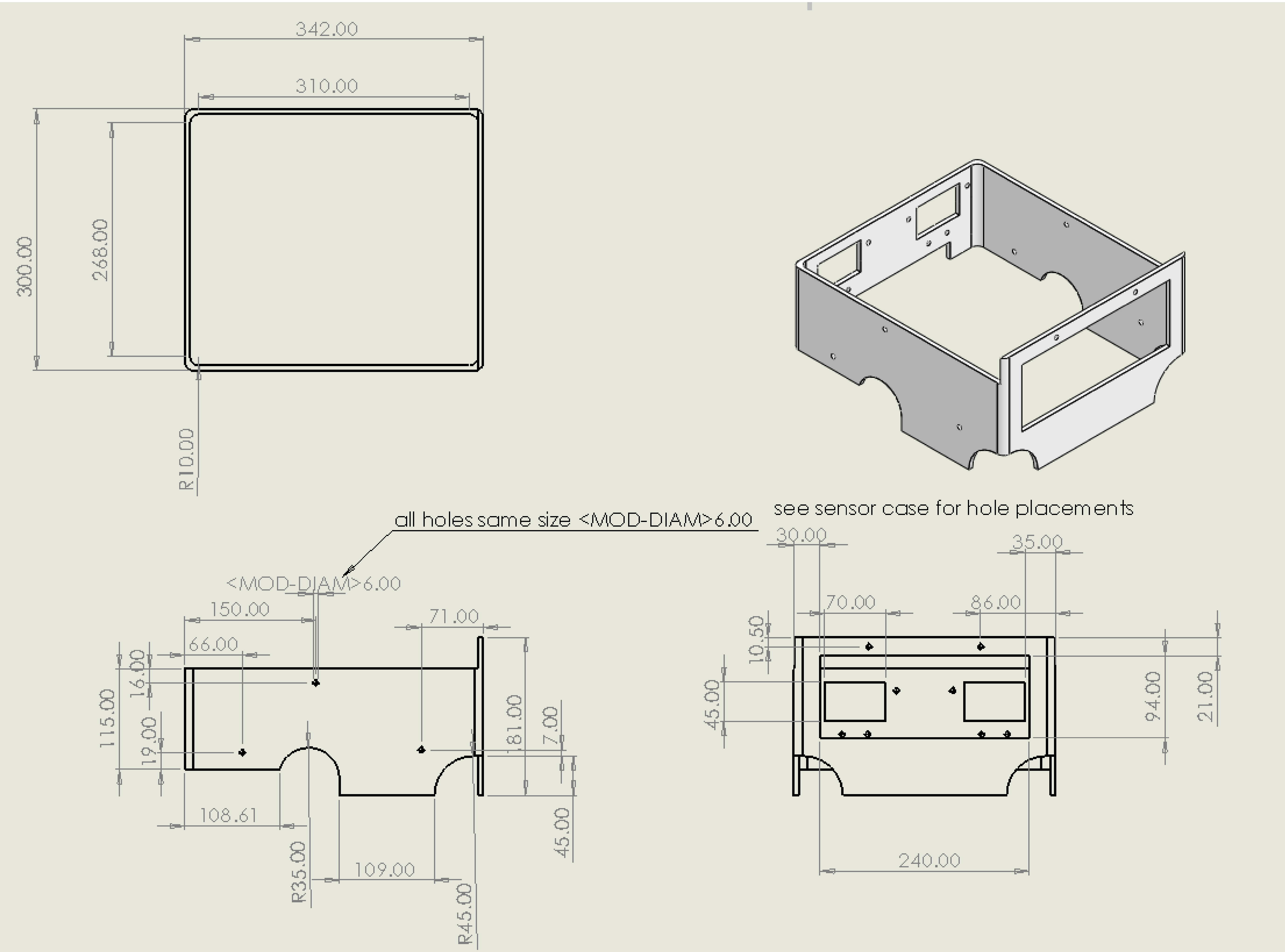


Finally, the hatch and its hinges were added too on to the back, still with the piece that would slot on to the mount. Thus the modelling of parts is complete and I can demonstrate the results with multiple angles and a rendering on the next page…

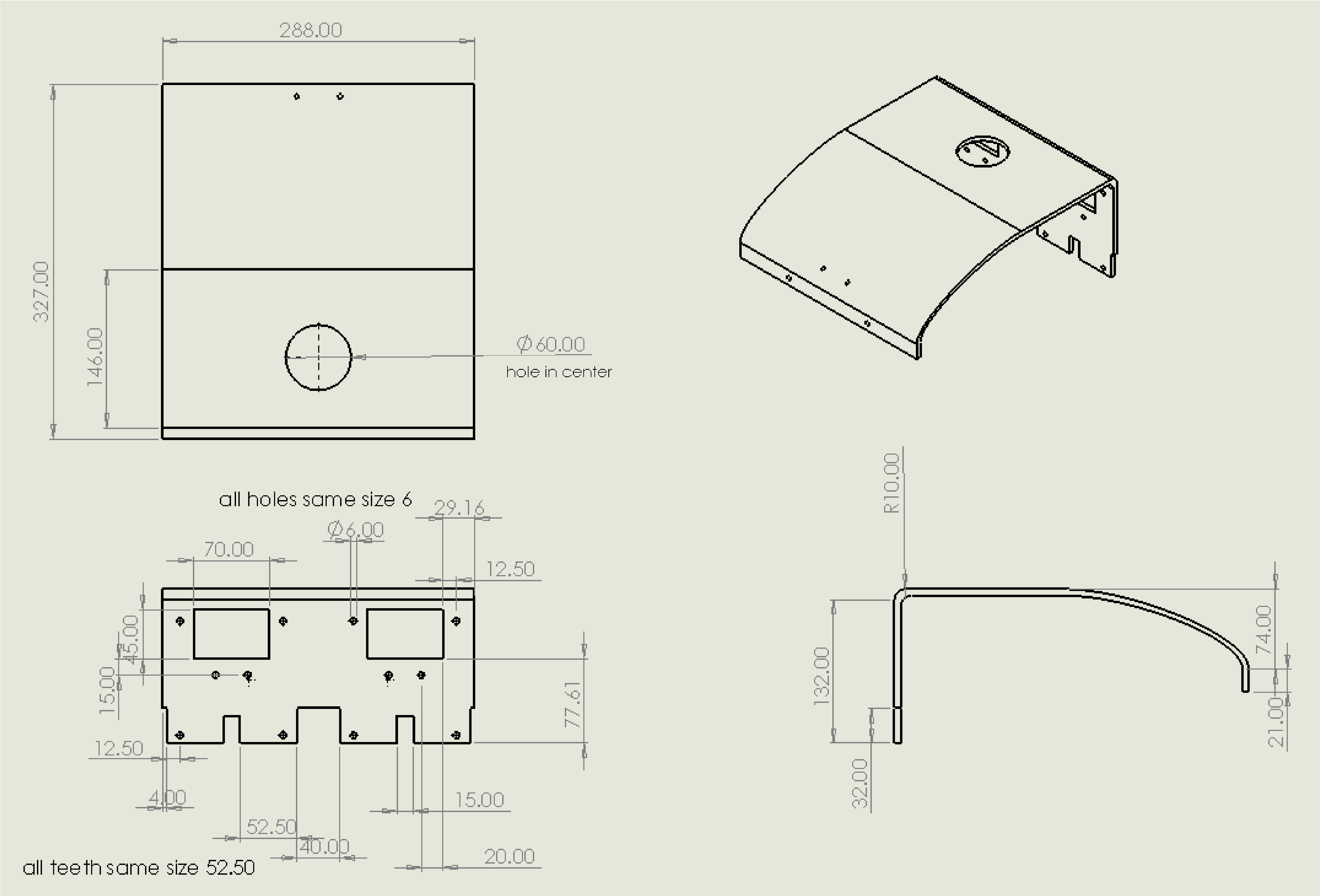




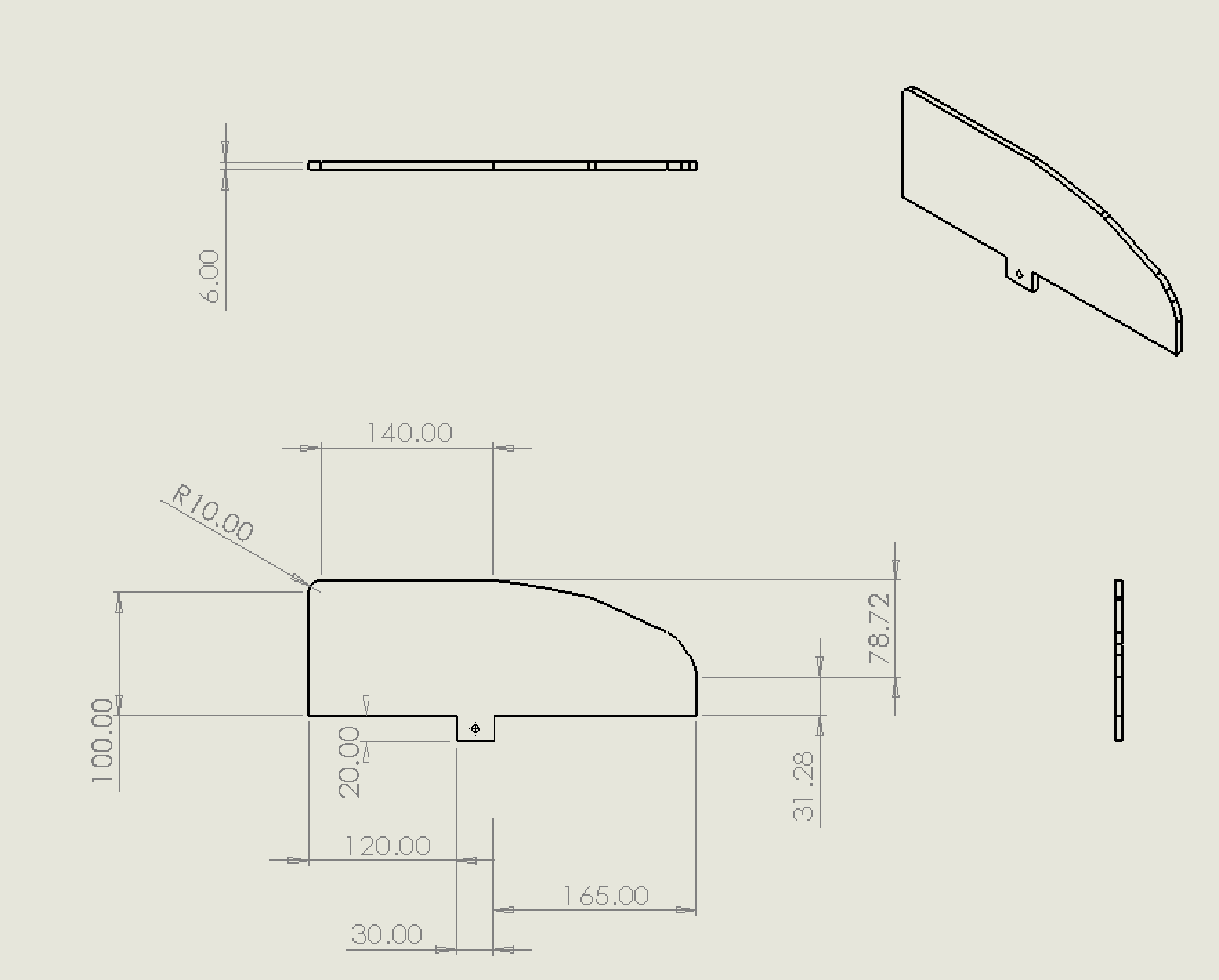
Working Drawings – Casing: Bottom Piece

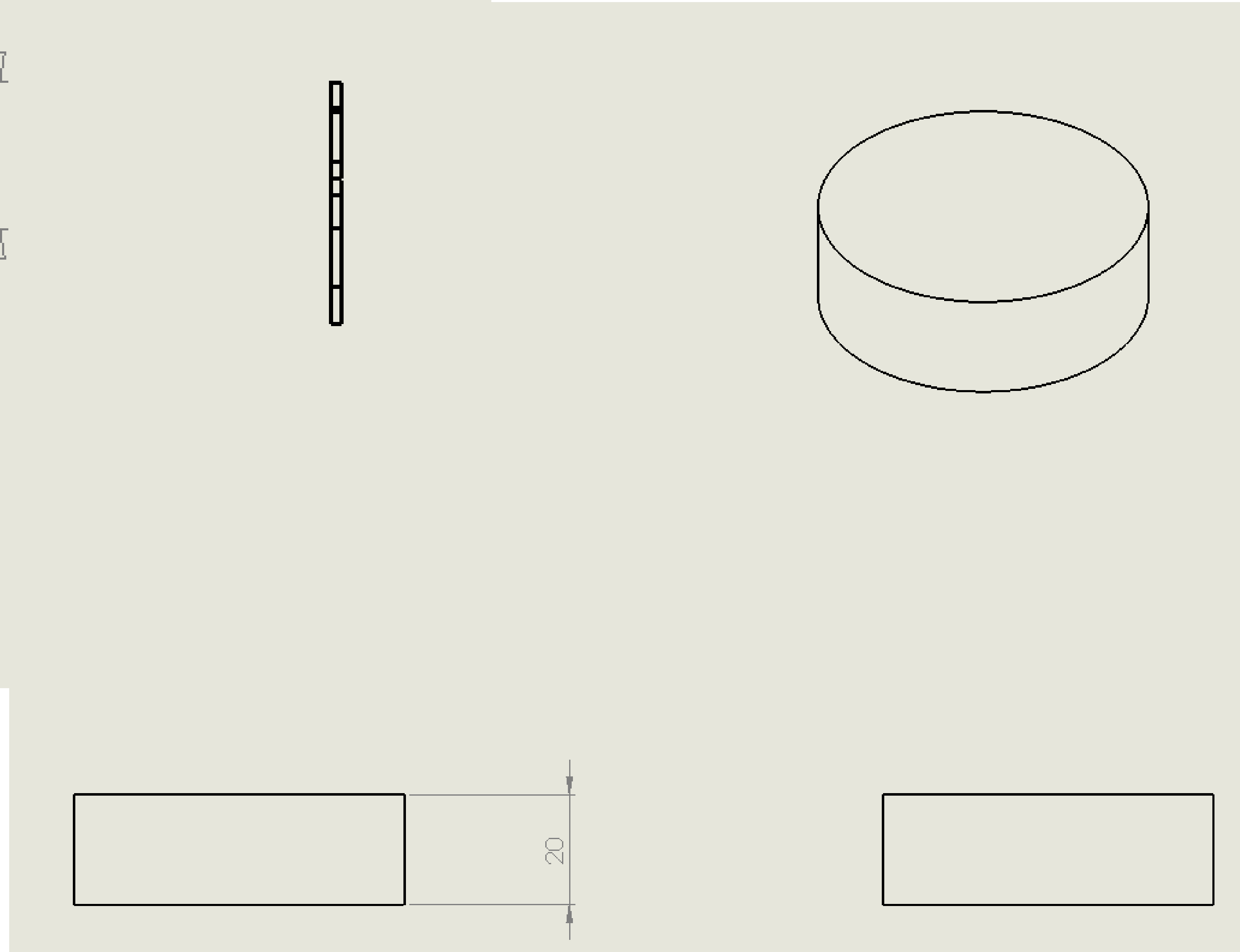


Working Drawings – Casing: Top Piece

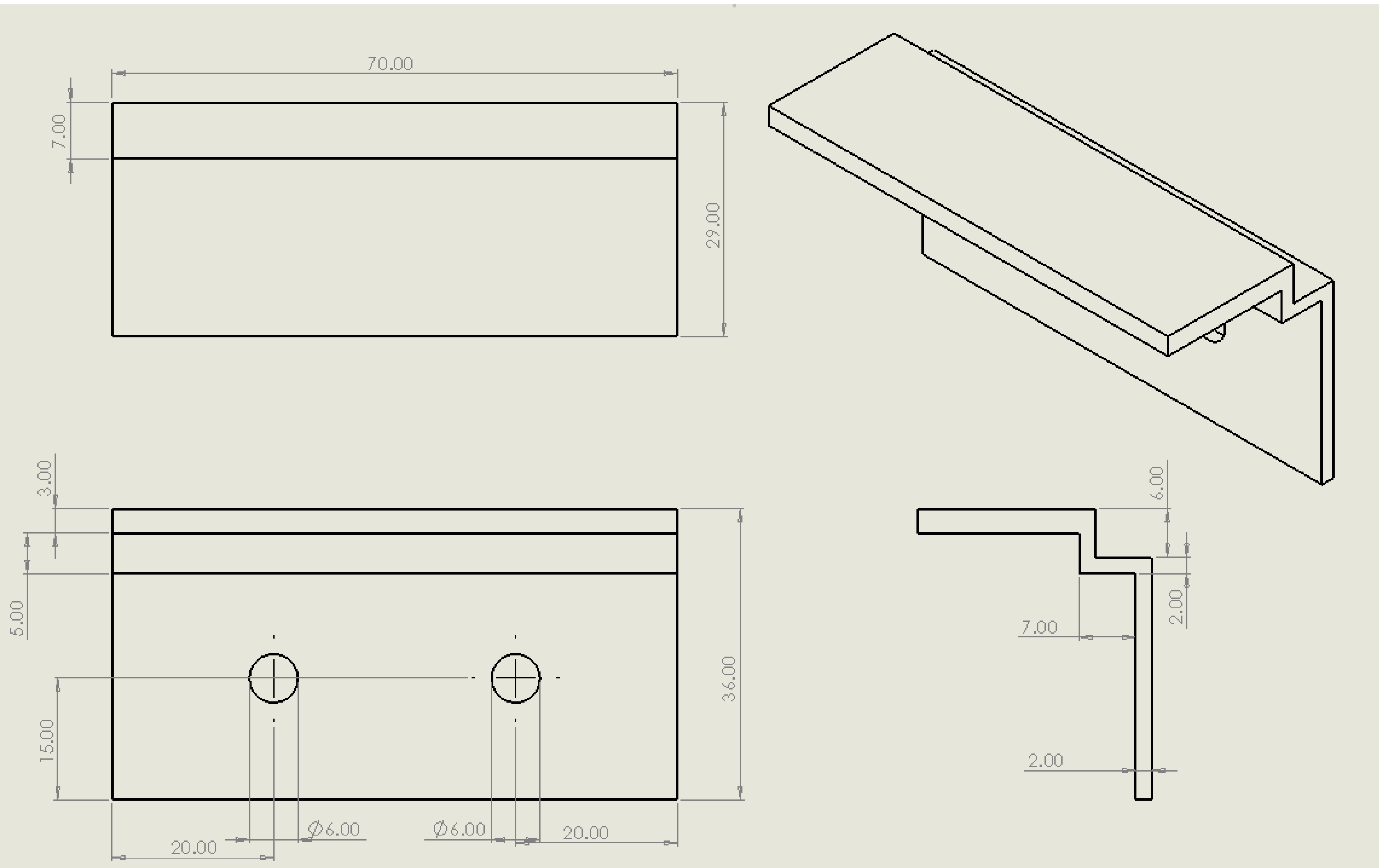


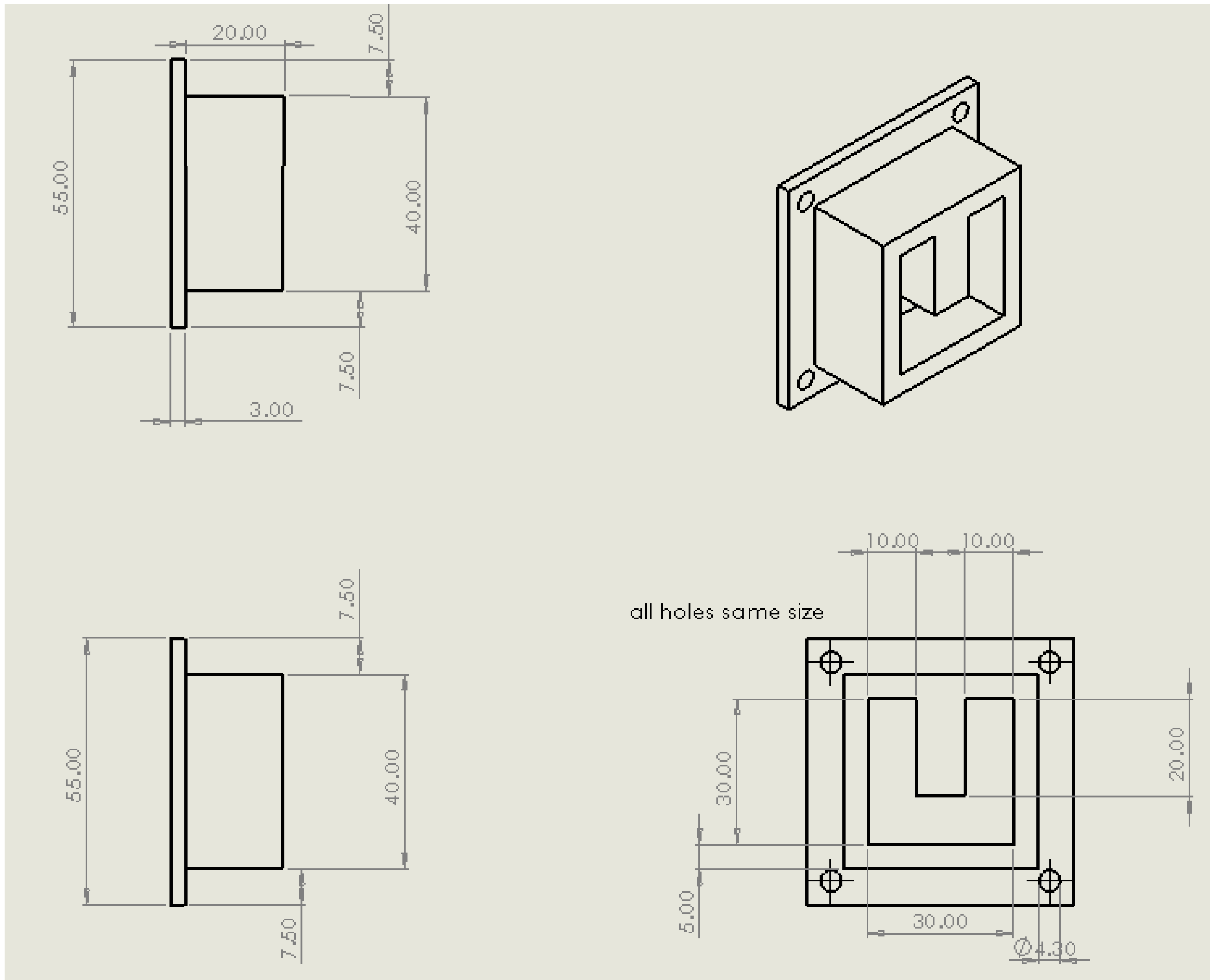
Working Drawings – Casing: Side Piece, Button

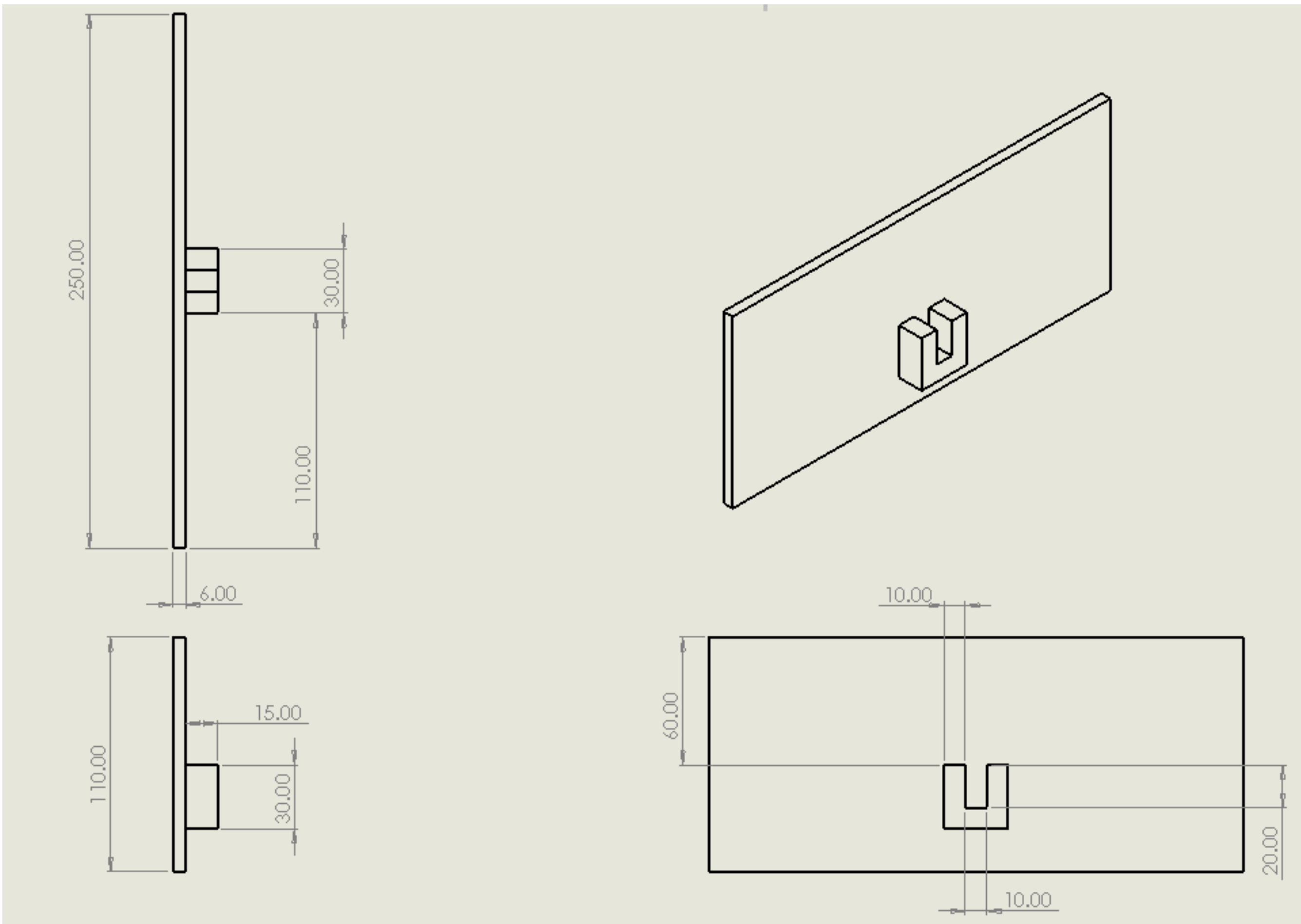




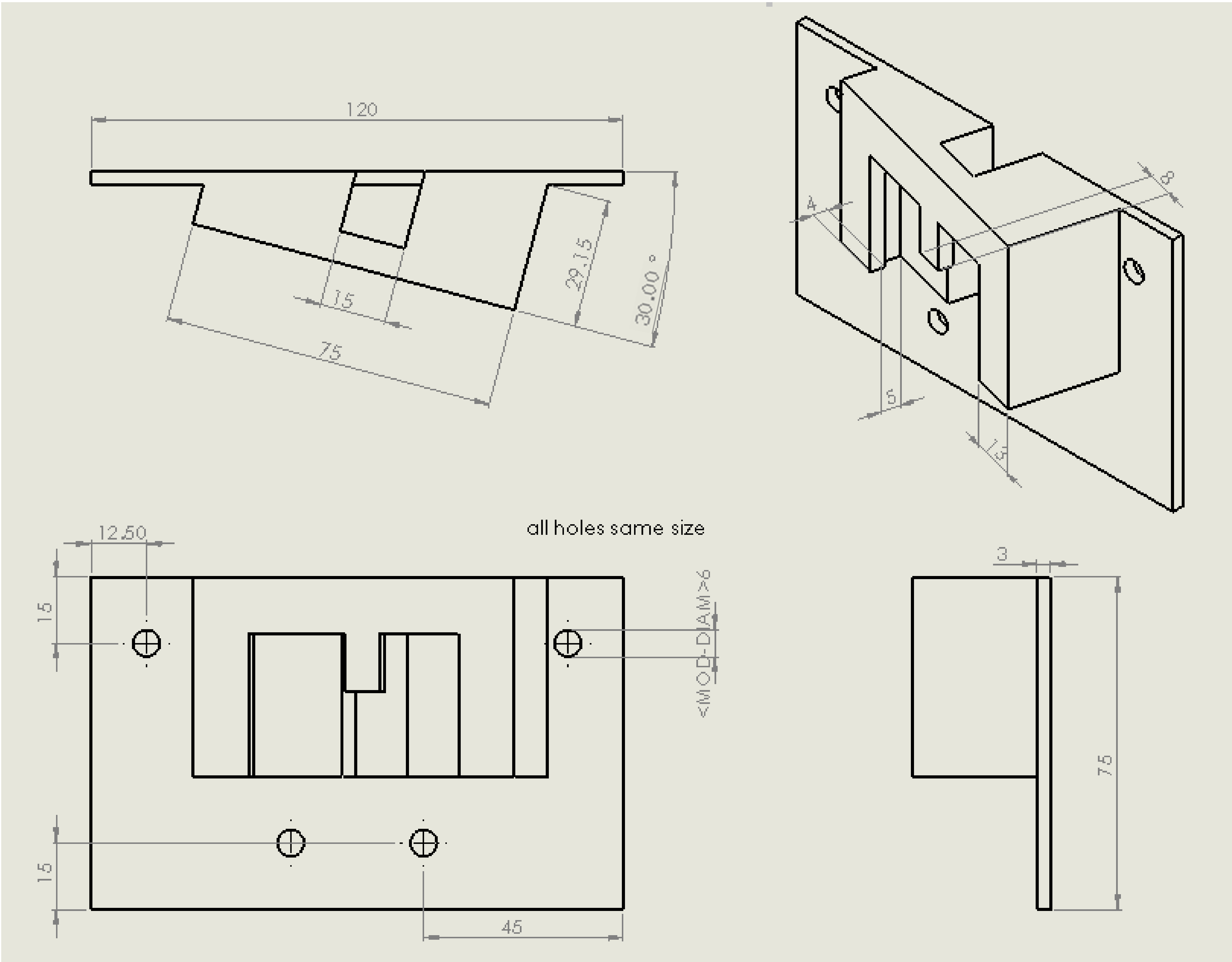
Working Drawings – Casing: Sensor Blinker, Hatch, Mount



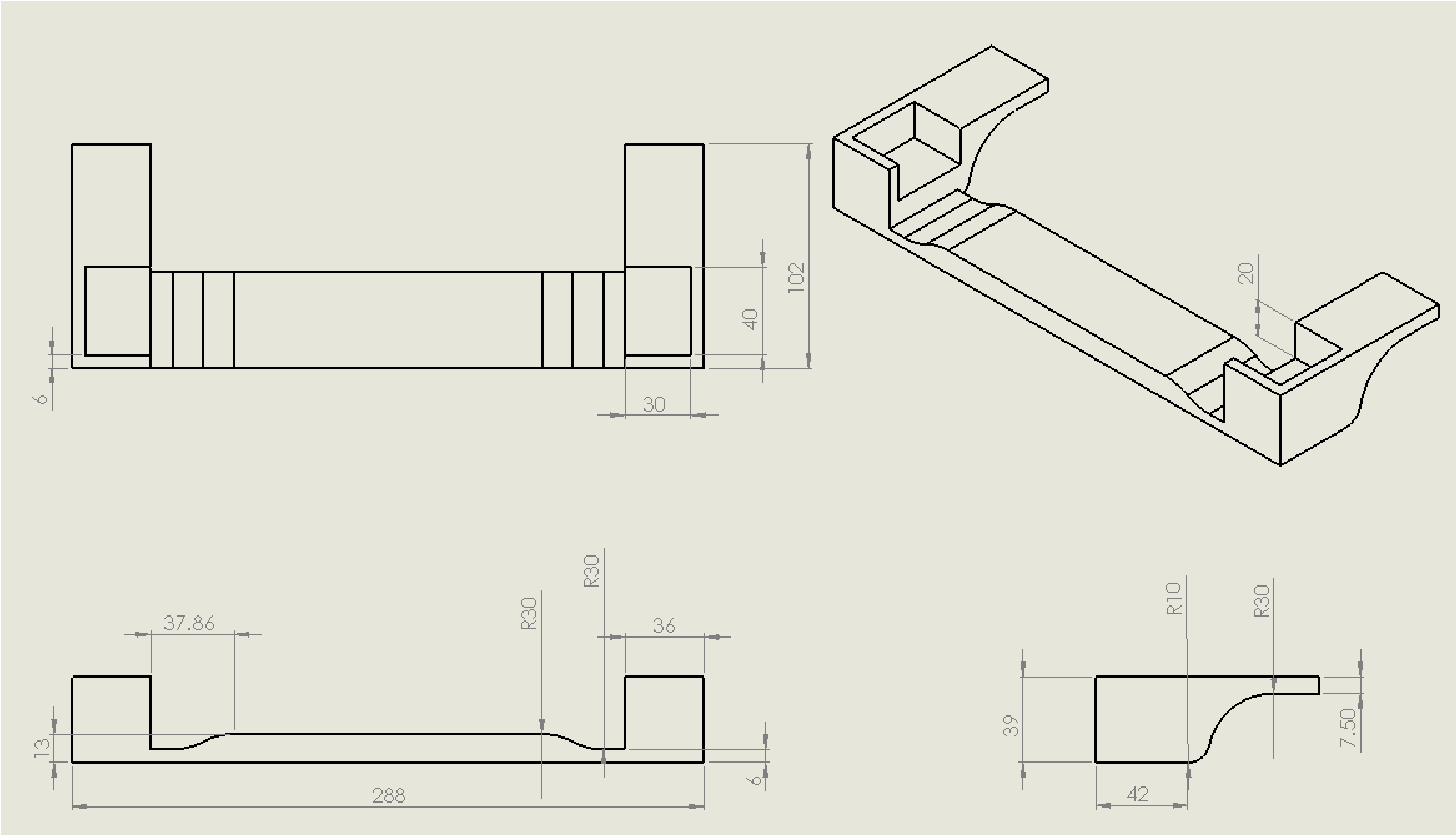




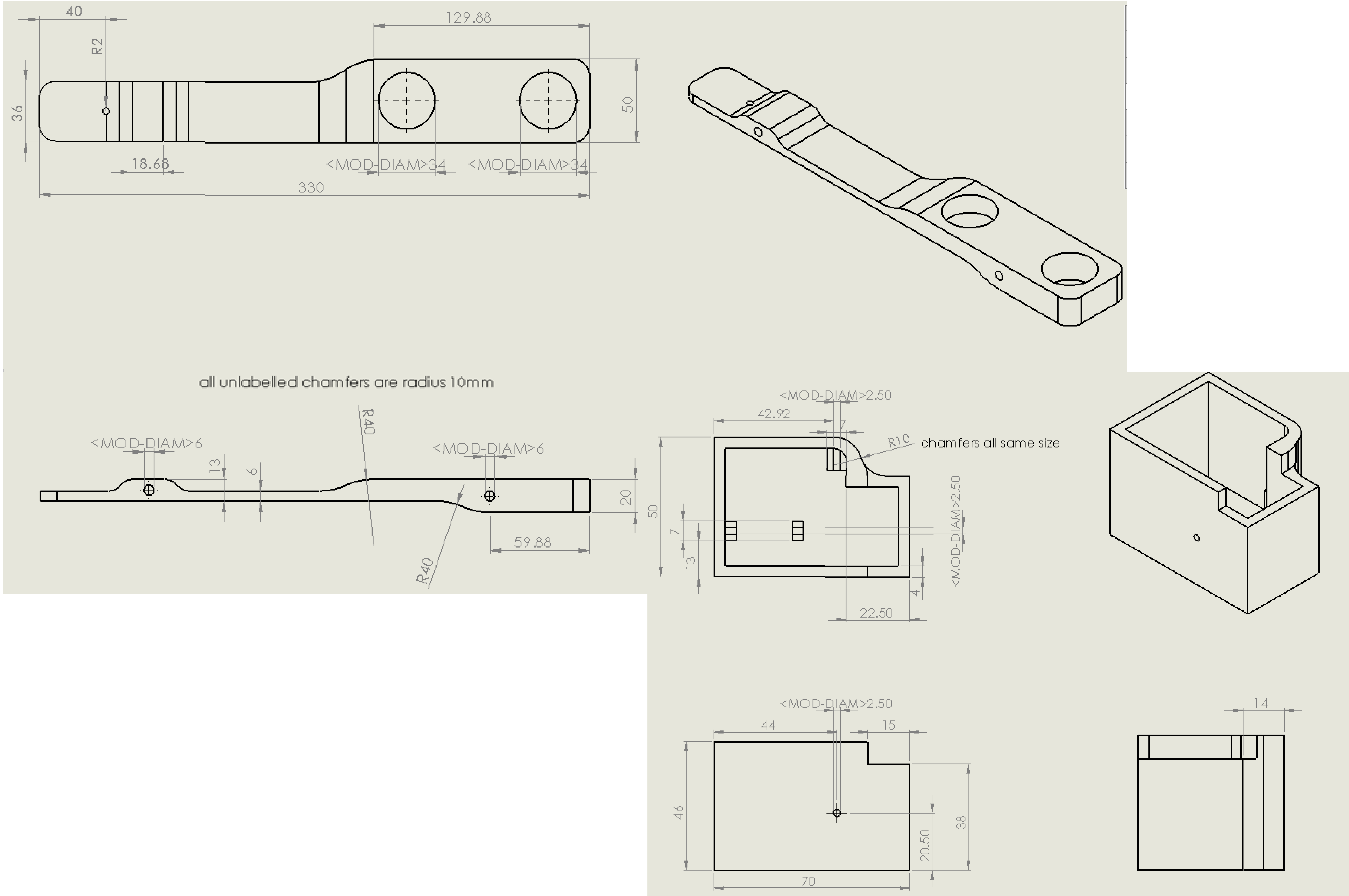
Working Drawings – Casing: Sensor Holder



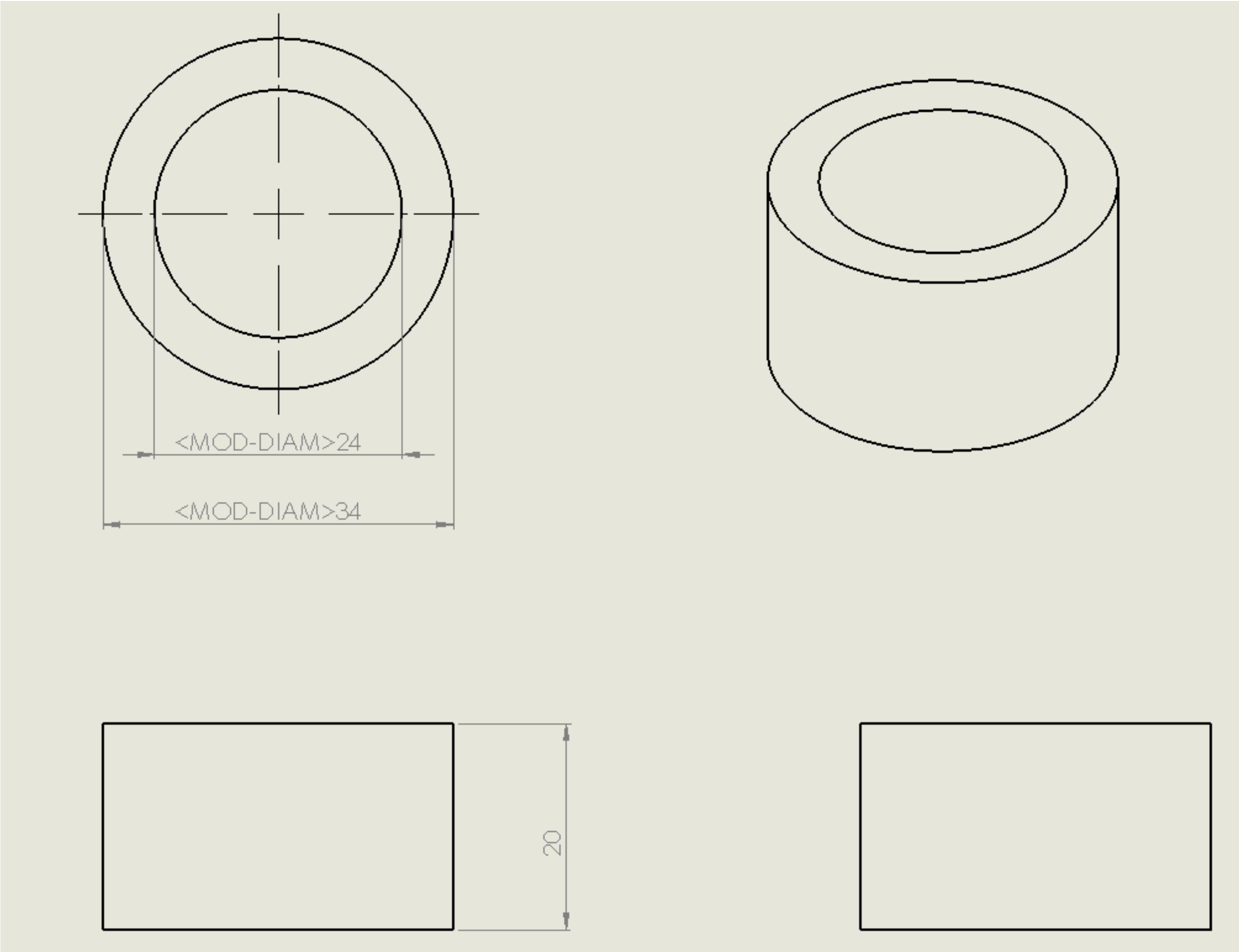
Working Drawings – Chassis: Under Piece

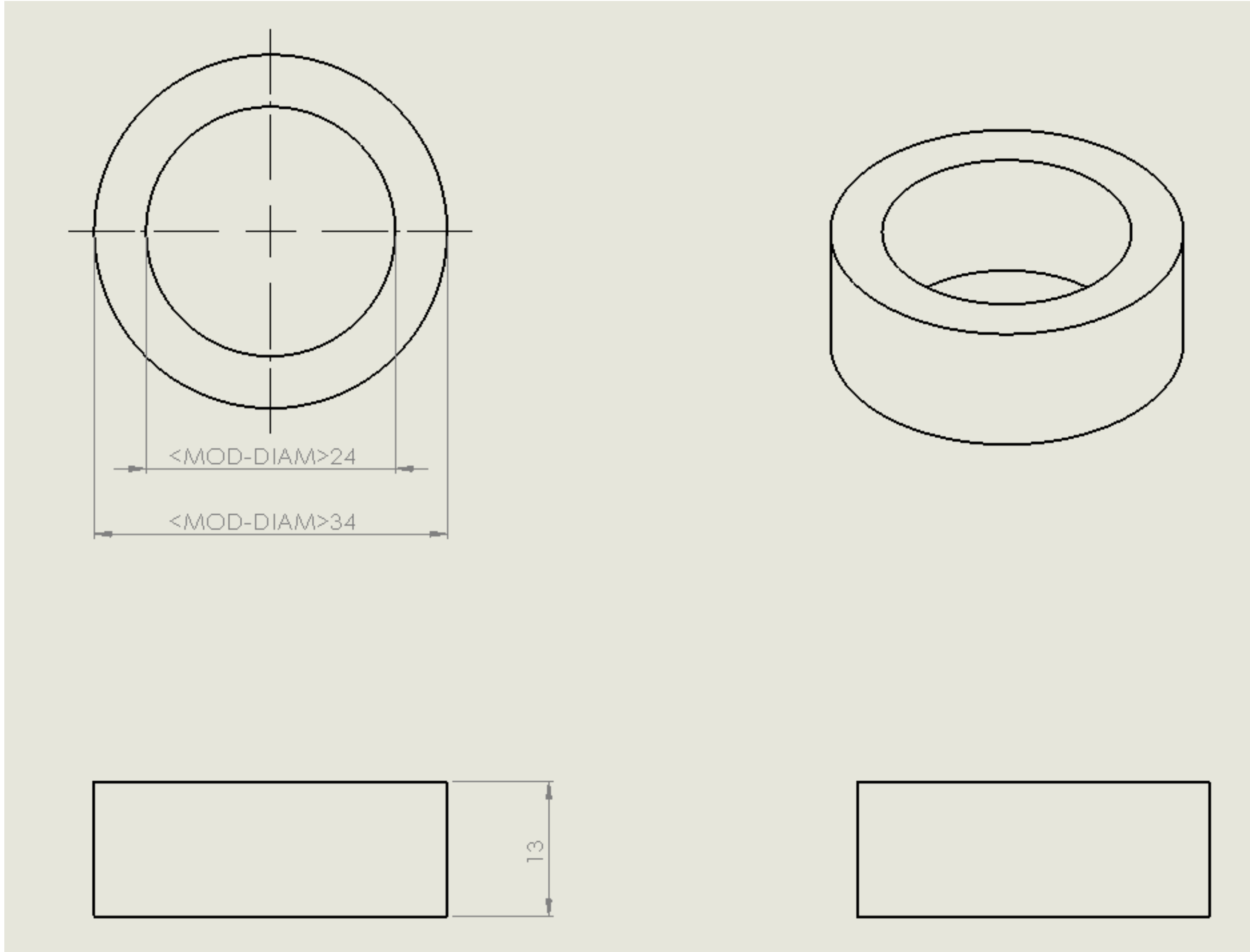


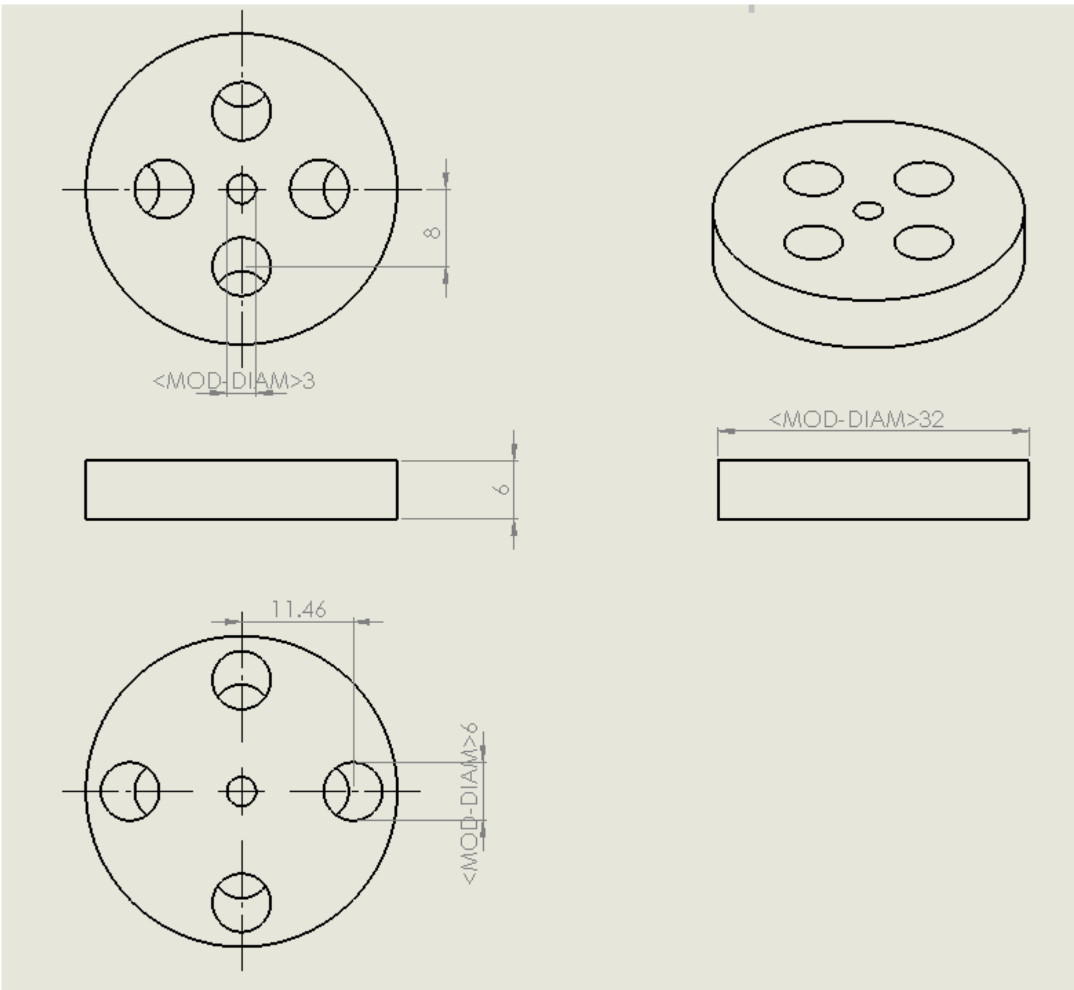
<u>**Working Drawings – Chassis: Side Piece, Gear Box**</u>

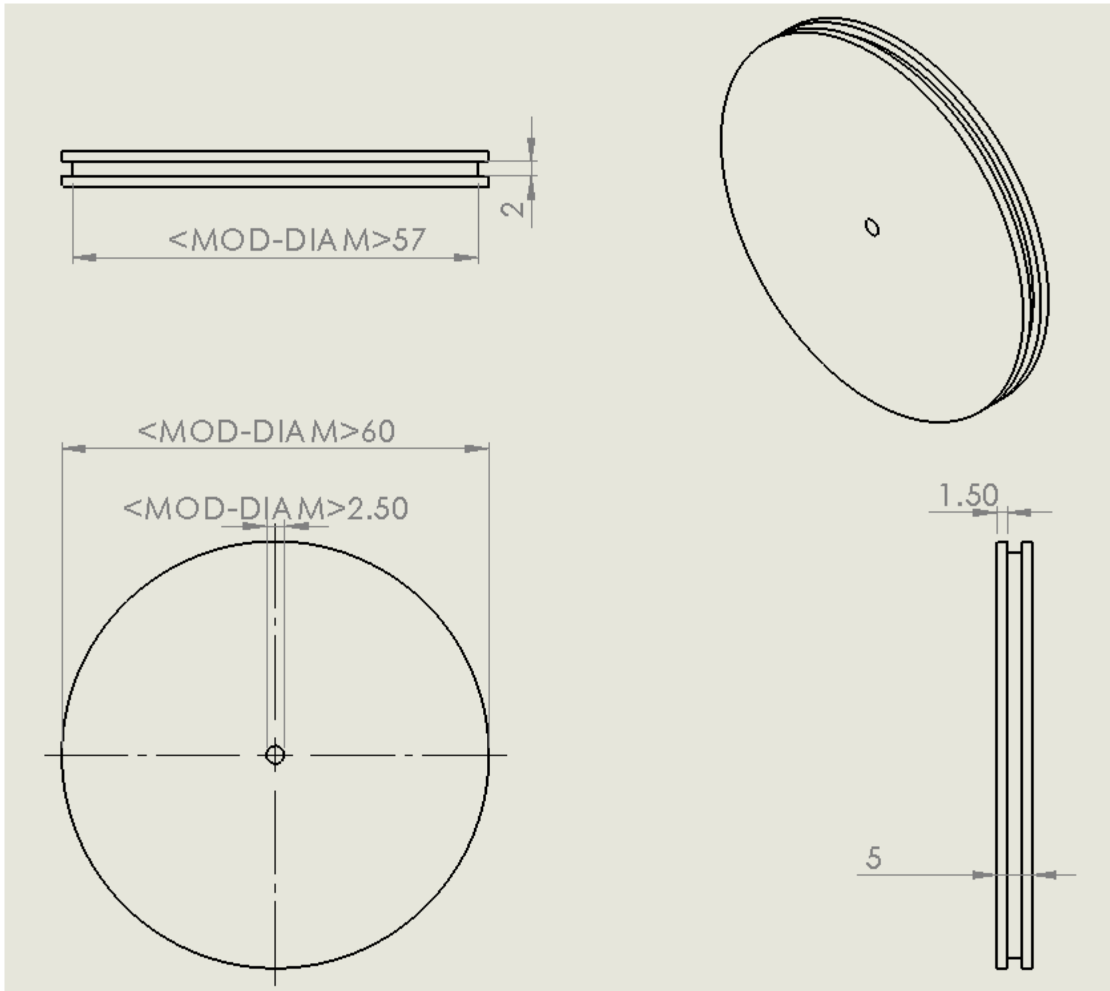


Working Drawings – Chassis: Motor Holders, Sweeper Holder, Wheel

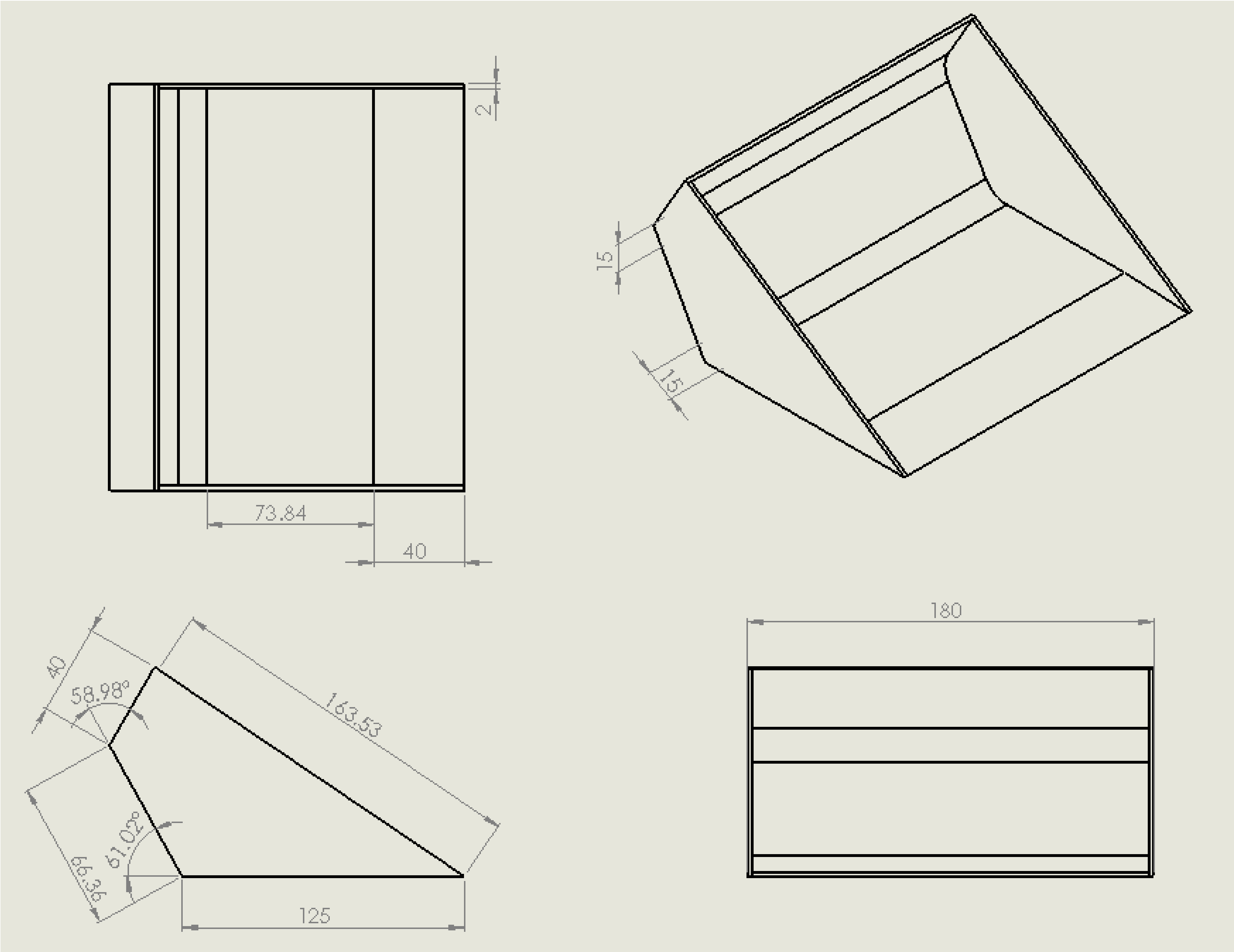




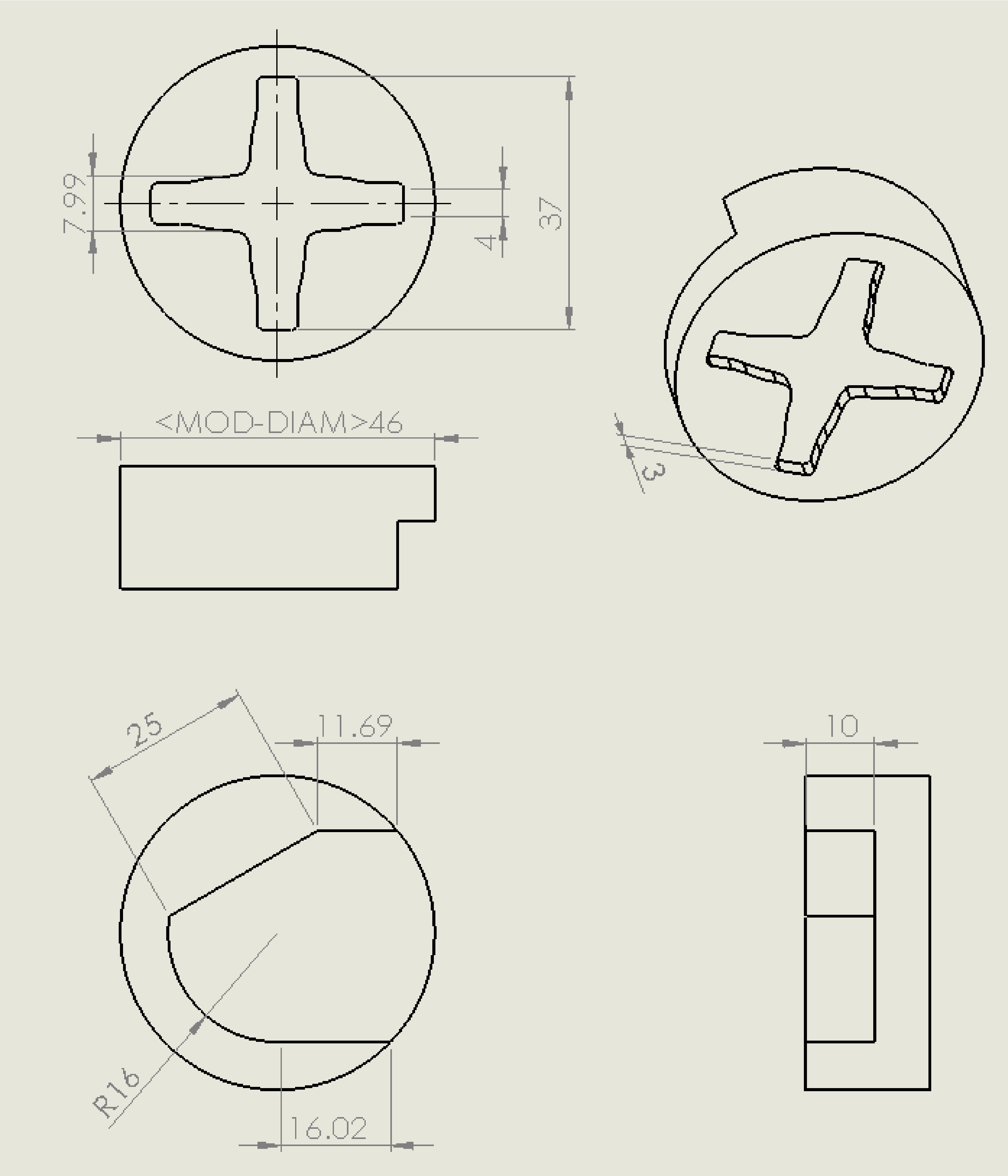


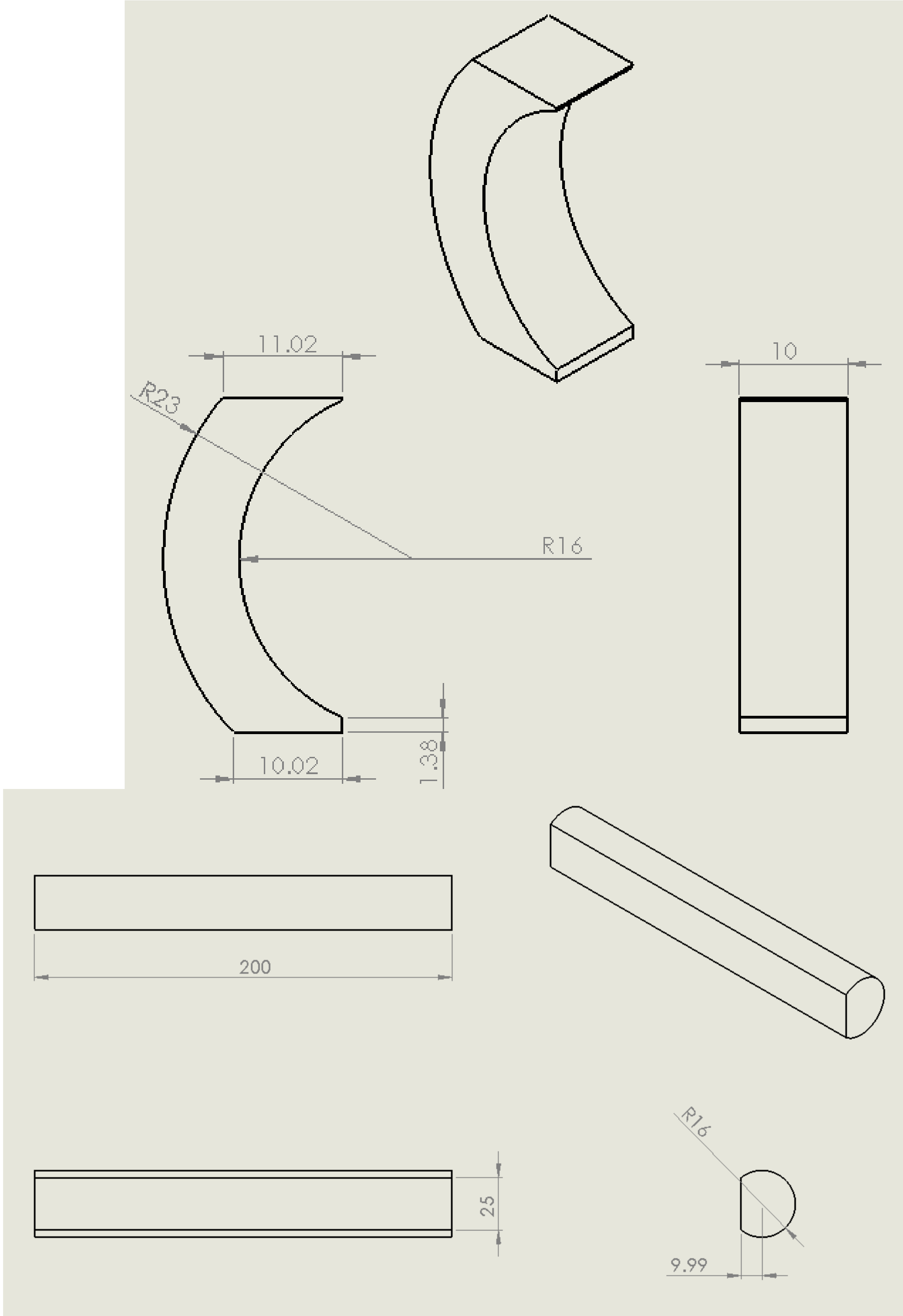


Working Drawings - Scoop

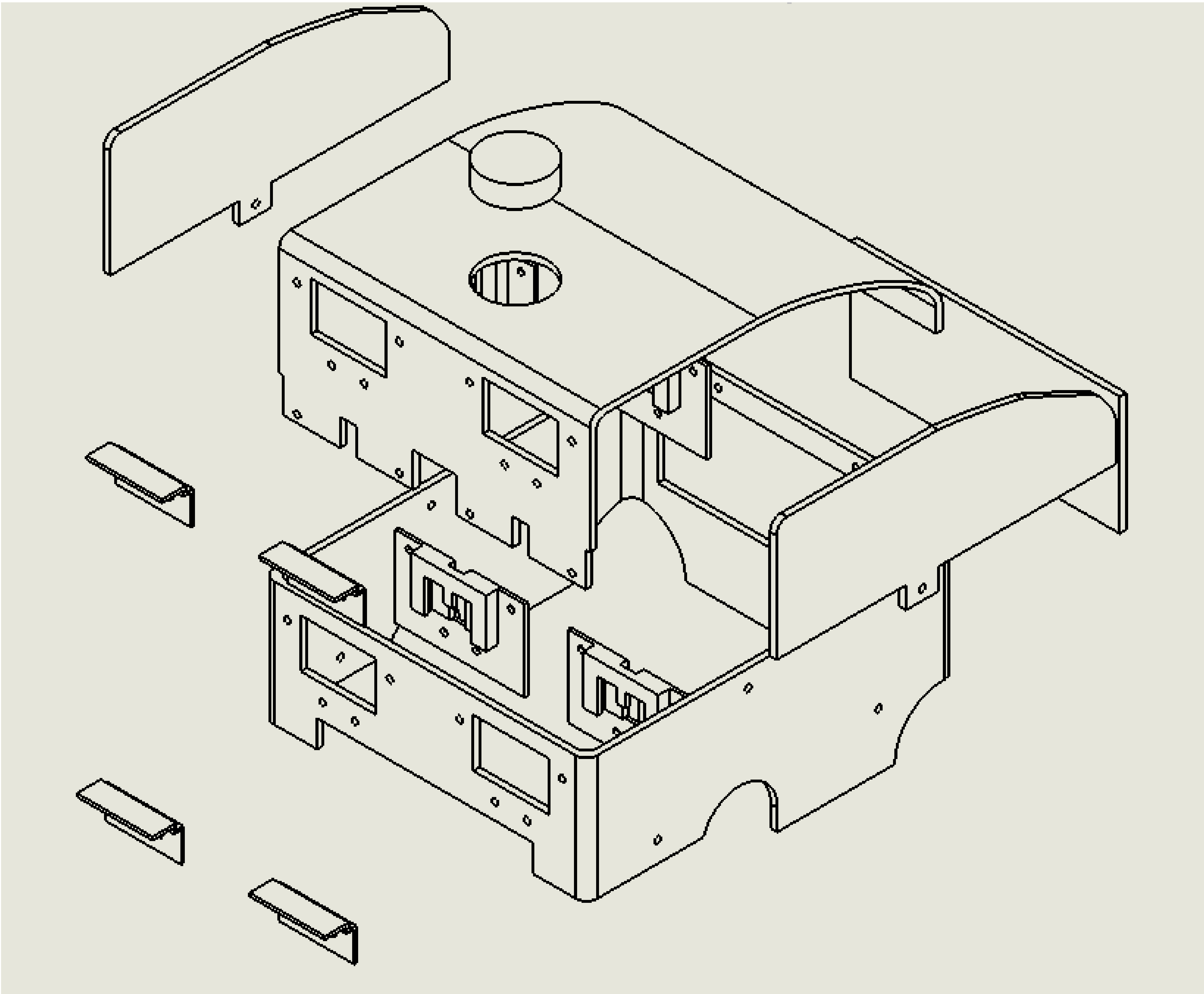


Working Drawings – Scoop: Servo Connector, Connector Insert, Scoop Cylinder

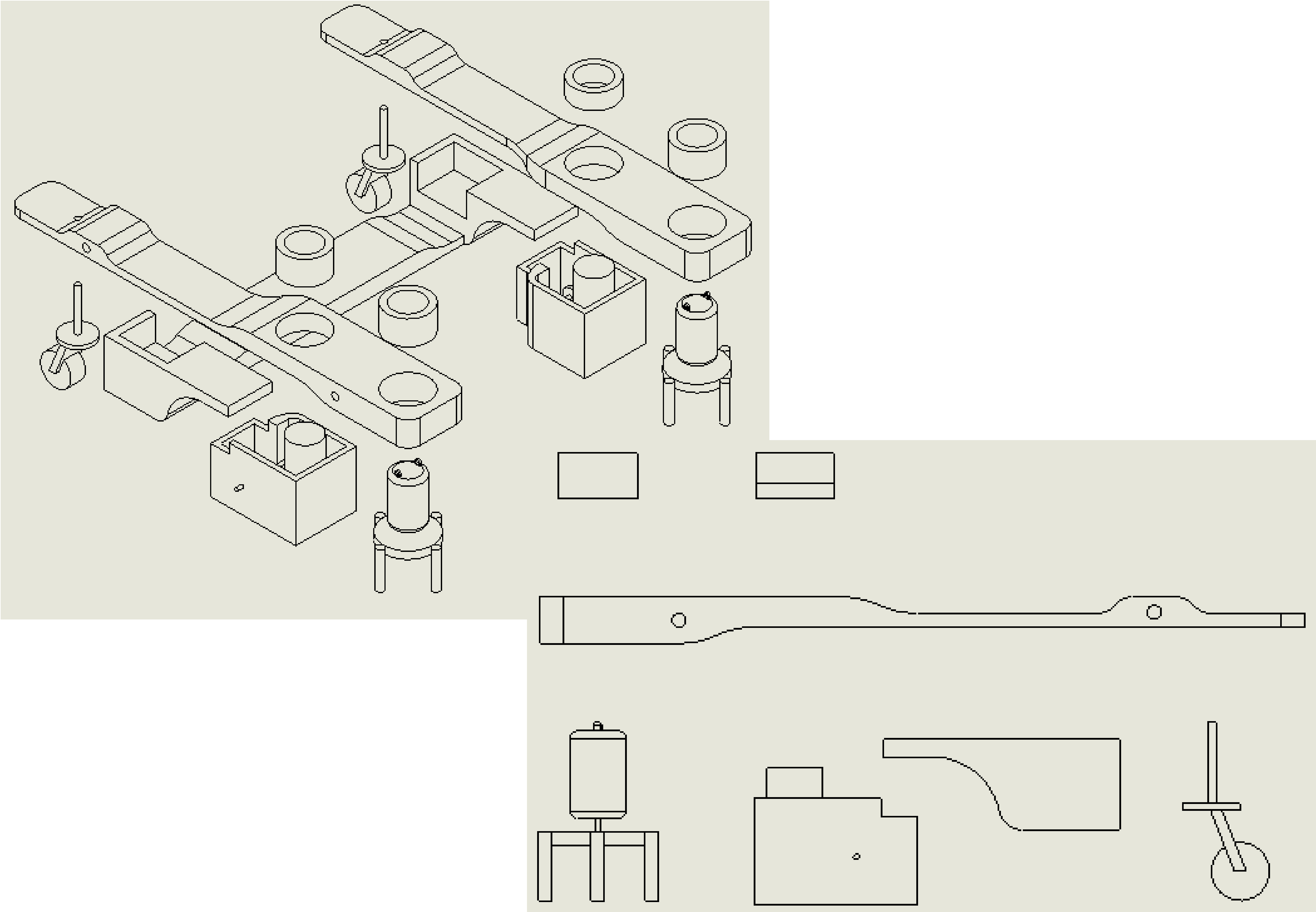




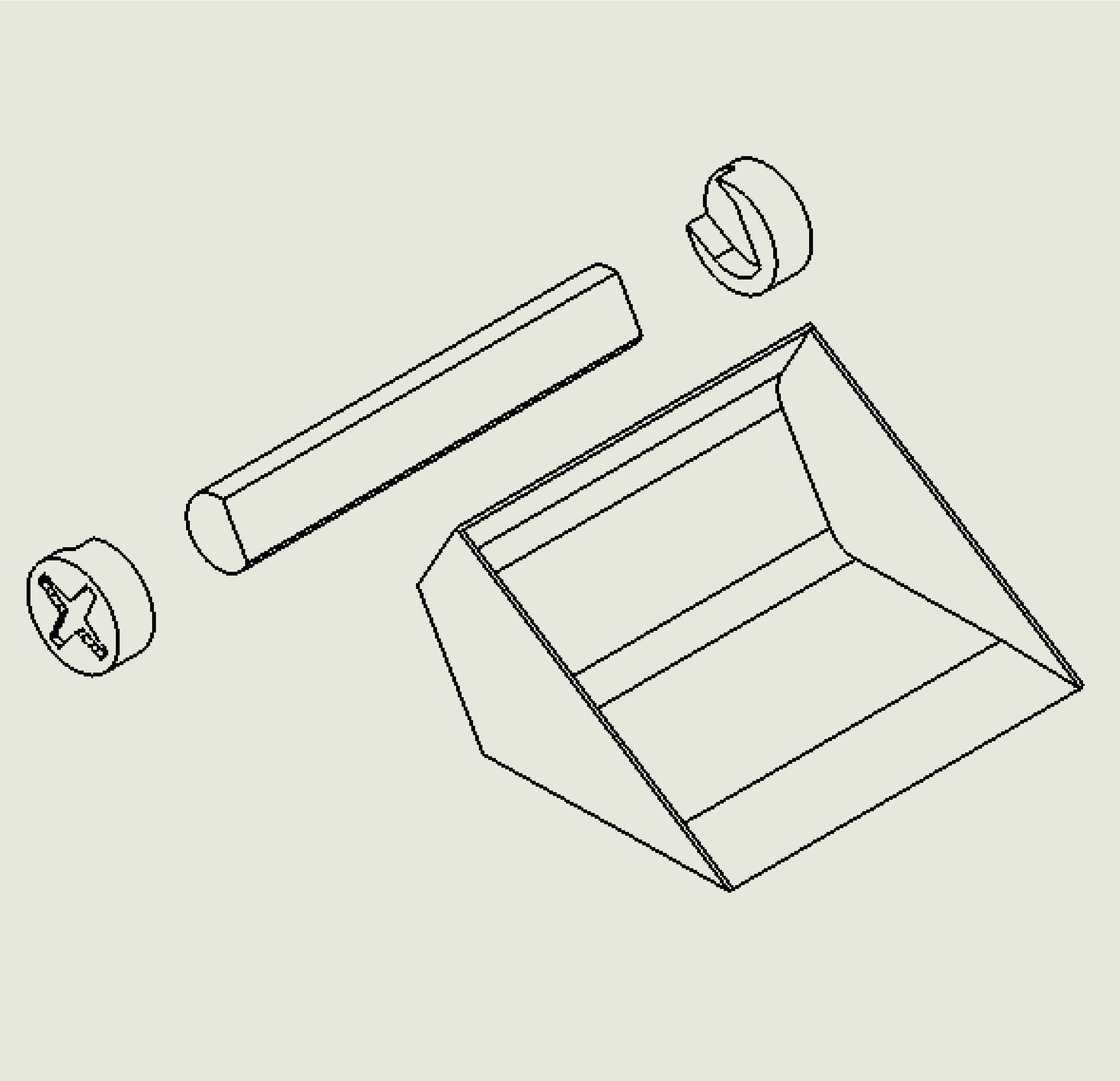
Working Drawings – Case Exploded Assembly

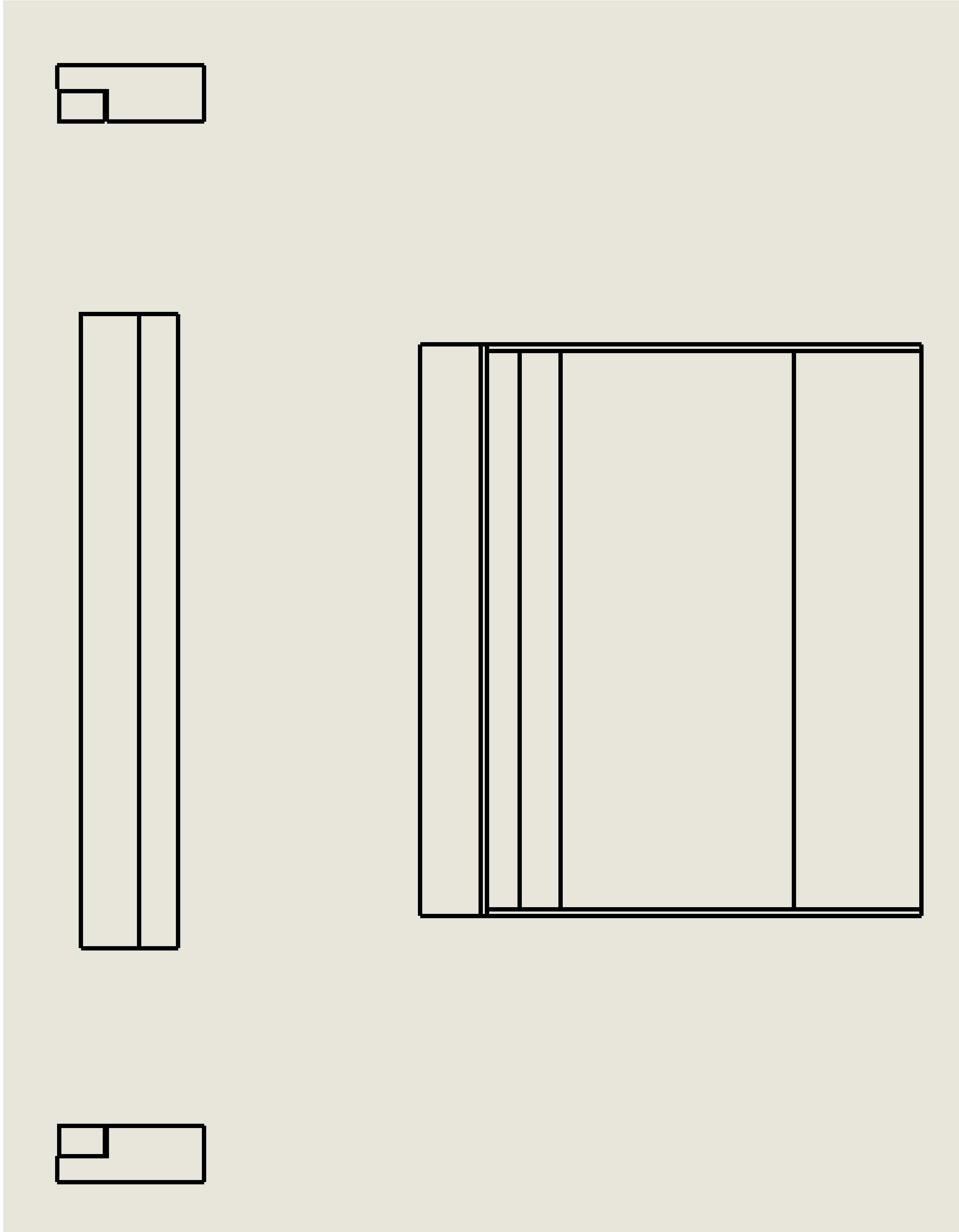


Working Drawings – Chassis Exploded Assembly

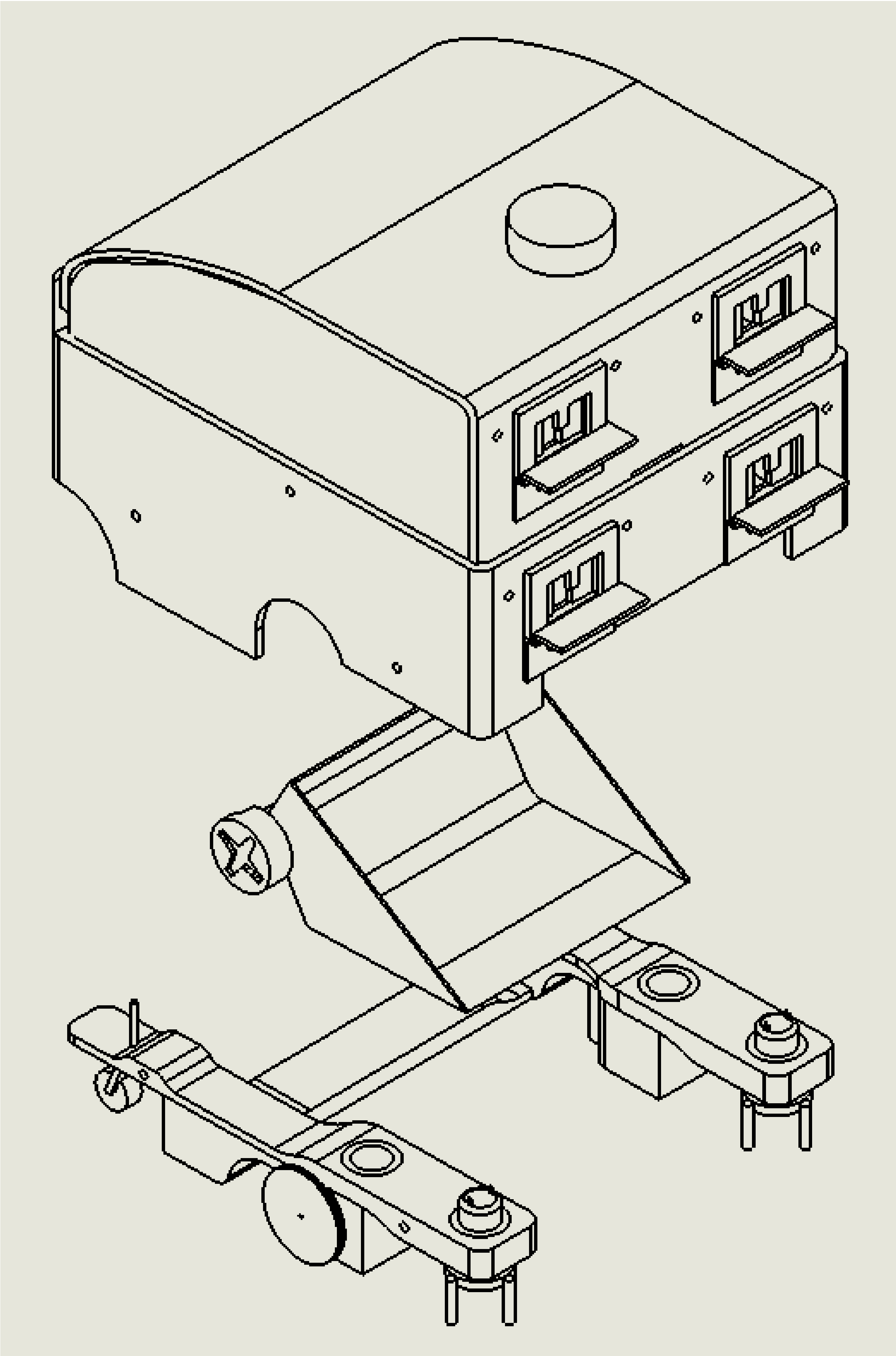


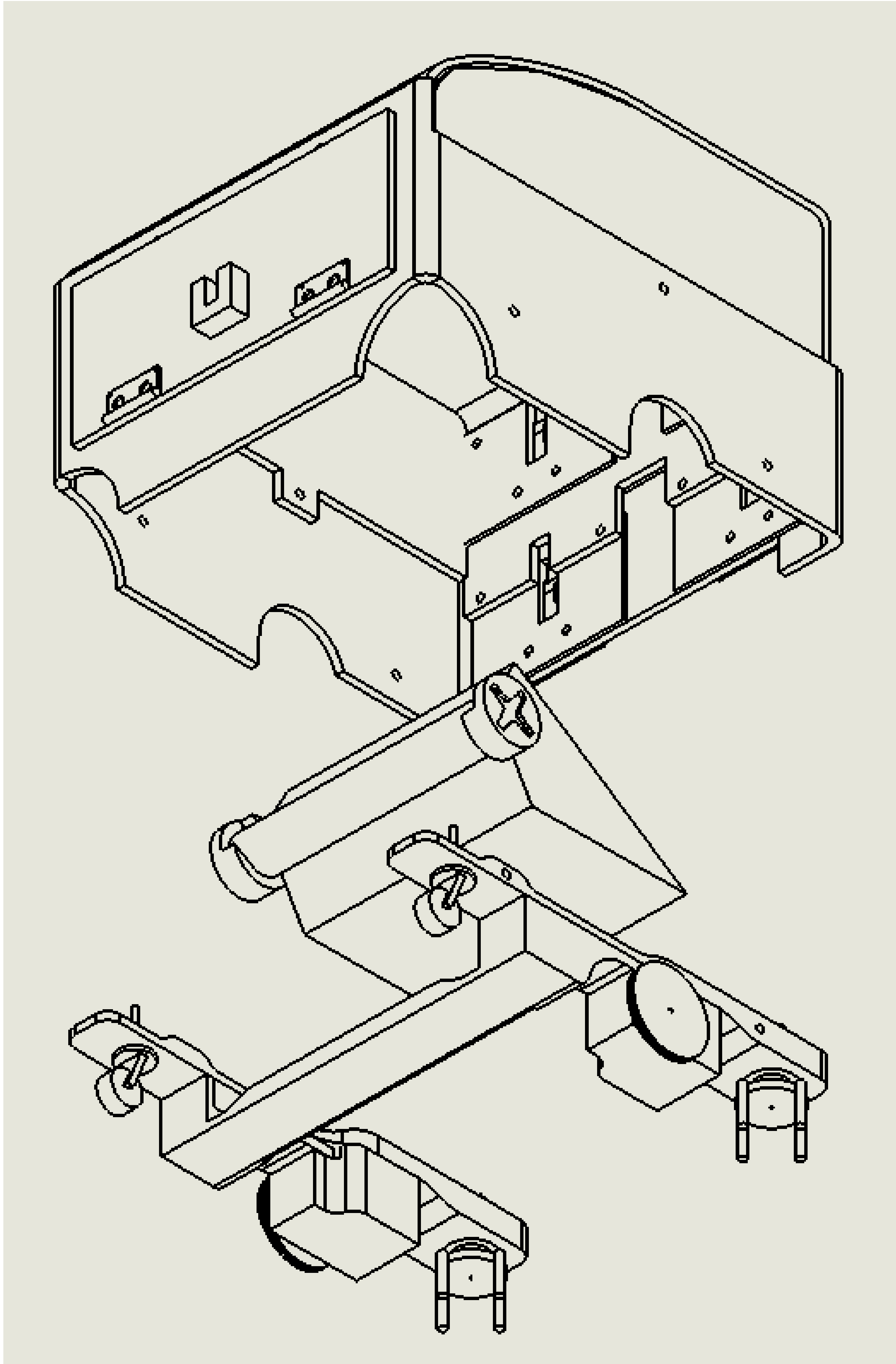
Working Drawings – Scoop Exploded Assembly





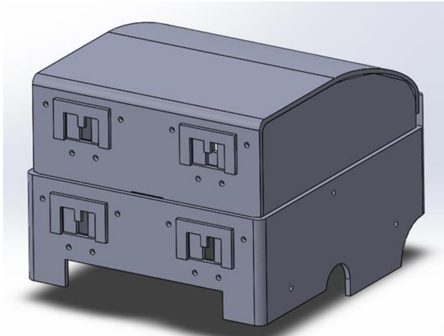
Working Drawings – Full Exploded Assembly



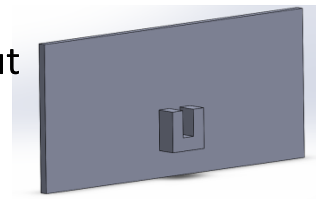


Planning a Prototype

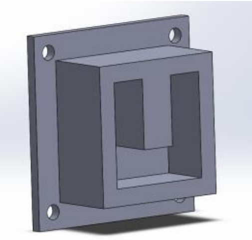
While a 3D computer model can help visualise what a product would look like, an accurate prototype can allow potential investors and manufactures to gather hands on experience with the proposed final product. Additionally, real world testing can be done on it and thus its functional performance demonstrated. Ideally, the prototype would be made in the exact same way as the proposed methods described, however I do not have access to much of that equipment so need to change how some parts are made in order for me to make the model. On this page I mention each of the parts, their mass manufacture method, and the method I propose I use to make them. Details of their methods will be on subsequent pages, grouped by their process. Initial manufacture methods can also be found on these three pages.



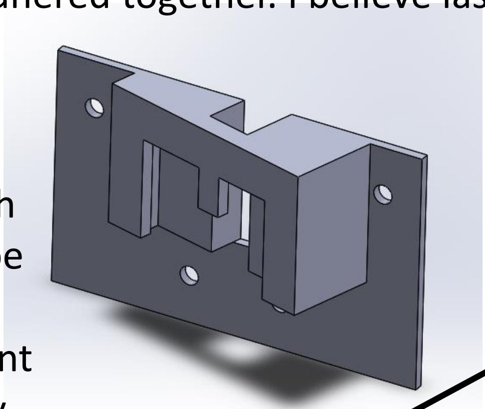
The casing was previously described as being rotationally moulded but was changed on this page to instead be made from multiple laser-cut and line-bent pieces. This can be done in the workshop too so I will do that. It can be done full size



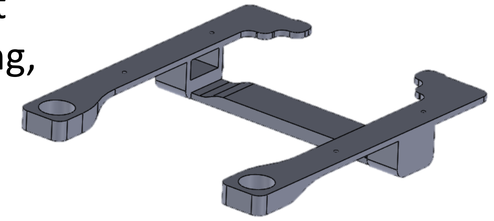
The mass manufacture method for the hatch is to injection mould the piece, however for a prototype I think I could laser cut a piece and stack small laser cut pieces for the mould insert due to its simple shape and form. The stack of parts can be adhered with acrylic cement, more info on the laser-cutting page…



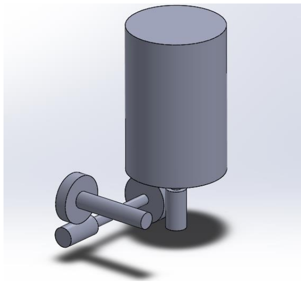
Similar to the insert, the mount itself is planned to be injection moulded but without that equipment, there is the option to either 3D print or laser cut multiple layers that get adhered together. I believe laser cutting would be quicker.

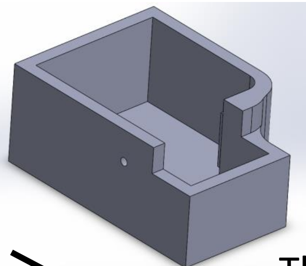


Due to the angle involved, and the precision to which that angle must be kept, it is more suitable to 3D print this piece entirely.

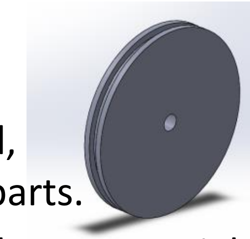


These chassis pieces were, like many other parts, supposed to be injection moulded. The simple straight line side pieces should be easy to make via laser cutting, while the more complex under piece can be made by assembling multiple correctly sized parts into shape

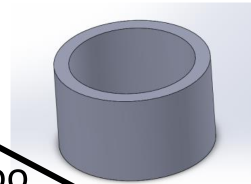




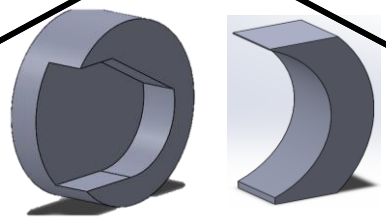
In the original design, there was little detail on the construction of the gear box, however having fully designed the makeup of it, I can now decide strongly that rather than buying gears I can make bespoke ones with injection moulding. The box would also be injection moulded. In the prototype I can 3D print the gears, laser cut the sides of the box (to adhere together) and 3D print the inside parts of the gear box. In both mass manufacture and prototype, 2.5mm diameter Aluminium rods can join up the gear train sections.



The wheel would have been easily injection moulded, however for a prototype, I can easily stack laser cut parts.

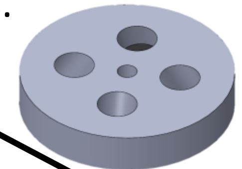


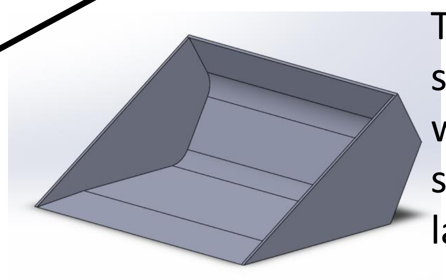
My school conveniently has a material similar to TPE that allows moulding, however the material they have is for 3D printing so I will do that.



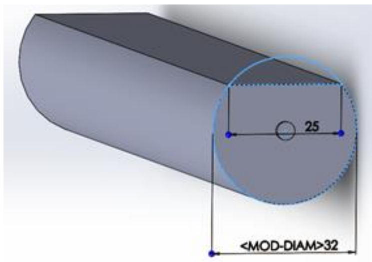
Just as I have a multitude of times, the servo connector is too complicated to do anything but 3D print (without having to make complicated moulds for the small injection moulder we have). The servo connector and its insert can be joined with a similar method to what was proposed for the mass manufacture: adding button clips.

The rope holder can also be easily 3D printed to get the right angles.





The scoop can be made exactly as it is supposed to in mass manufacture which is to laser cut and line bend to shape. The sides will likely be separate laser cut parts adhered on.



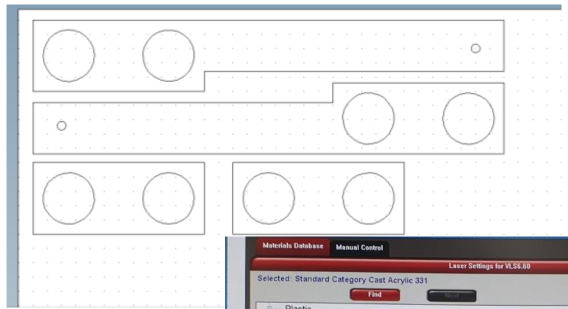
The scoop cylinder would have been blow moulded, however the school workshop does not have that. For the prototype the same method as the testing model can be used – utilising an existing tube and hand sanding to shape

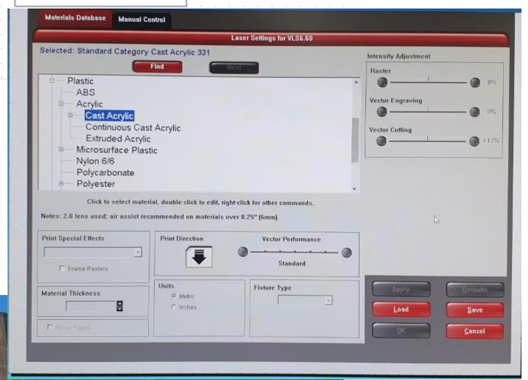
Planning a Prototype – Laser Cutting

The Laser Cutter is one of the most simple CNC machines but is still just as useful for prototyping and modelling as anything else. This machine is used to cut and etch lines on to materials like thin woods, polymer sheets and even in some cases, soft metals.

Method

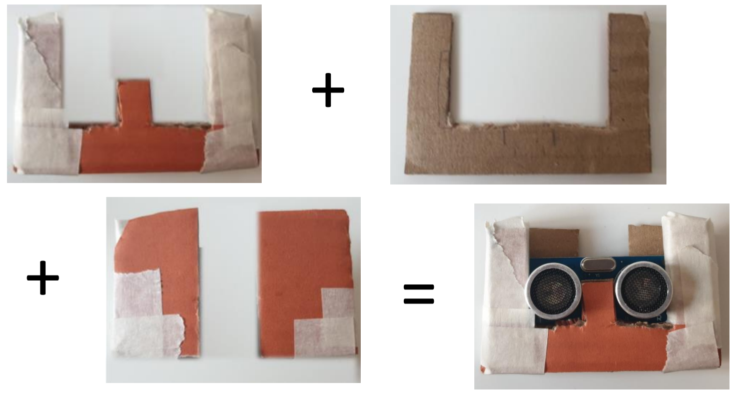
The first step to Laser Cutting is making a template. For this I use 2D Techsoft Design, where you can plot lines that the laser will cut. Red is meant for lines to cut, blue is for lines to etch, black for an area to etch. Of course, outlines would be red to cut the main shape, but then lines being etched can help for marking out (such as lines to line-bend on). Once the Techsoft File is correctly transferred to the VLS6.60 program, the machine should be prepared. The correct material should be loaded in (shown right), then the machine turned on along with the dust extractor. Then simply press GO. Pictures below.





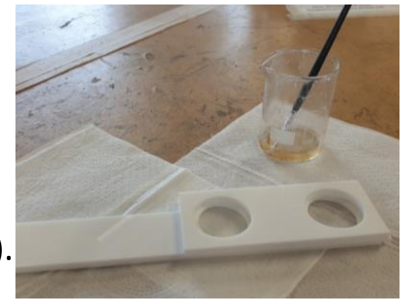
Stacking

Most of the parts for my product would be injection moulded in mass manufacture, but as shown on this page, the injection moulder in my school lab is very small and can produce parts of limited quality with a very small range of material/properties. Therefore, rather than injection mould parts for the prototype I must find another method and have thought up my own way which I call 'stacking'. This method is quite simple, and speaks for itself – multiple layers are laser cut and then stacked to make one part of a more complex form. I first introduced this method on this page when designing a prototype for the Sensor casing as shown right, and I used what I learnt from this to try it with actual laser cut polymer pieces.



In this design process I used 2mm thick cardboard pieces and cut them to different shapes before assembling them with Pritt Stick. The real one would be injection moulded and thus faster and more accurate, but this clearly serves well as a workshop prototype alternative.

4 layers of 3mm acrylic were first laser cut (for a prototype, the parts do not necessarily need to be aesthetically perfect, only perfectly functional).



I used Acrylic Cement as an adhesive in between the layers to reach the final model piece.

Risk Assessment (via)

To ensure a high level of safety in my particularly circumstance, there are certain measures I can take. To keep my eyes safe I can wear **tinted safety goggles** or a **visor** when around the cutter but generally should make efforts not to look directly at the working machine. I had planned to use PVC but may use Acrylic for some testing too – neither of these polymers produce any toxic chemicals, nor are they flammable, however before laser cutting, I should check for the presence of a **fire extinguisher**.

Laser Light

- The invisible high energy laser beam can cause severe eye damage, including blindness and serious skin burns. The doors are interlocked such that the laser beam will be disabled when the doors are opened. This will completely contain the laser beam under normal The invisible high energy laser beam can cause severe eye damage, including blindness and serious skin burns. The doors are interlocked such that the use.
- Improper use of the controls and modification of the safety features may cause serious eye injury and burns.
- **DO NOT** modify or disable any safety features of the laser system.
- **DO NOT** operate the laser unless all covers are in place and interlocks are working properly.
- **DO NOT** look directly into the laser beam.

Fire

- The high intensity laser beam can produce extremely high temperatures and significant amounts of heat as the substrate material is burned away while cutting.
- Some materials can catch fire during cutting operations creating fumes and smoke inside the device.
- Dirt and debris may cause fire and a poor quality cut or mechanical component failure
- It is important that users remain with the laser during operation to ensure that any flare-ups/ flame are properly contained and extinguished.
- Obtain the Safety Data Sheet (SDS) from the material's manufacturer when handling or processing the materials.

Additionally, the onetouchlaser **exhaust system** should always be on during use as an extra layer of protection from any fumes, along with **lab doors open** at all times.

- **DO NOT** use materials that are highly flammable, explosive or produce toxic byproducts.
- **DO NOT** remove material from the cutting bed before it has cooled.
- **DO NOT** leave a laser cutter operating unattended.
- **ALWAYS** clean up clutter, debris and flammable materials in the laser cutter after use.
- **ALWAYS** keep a properly maintained fire extinguisher nearby.

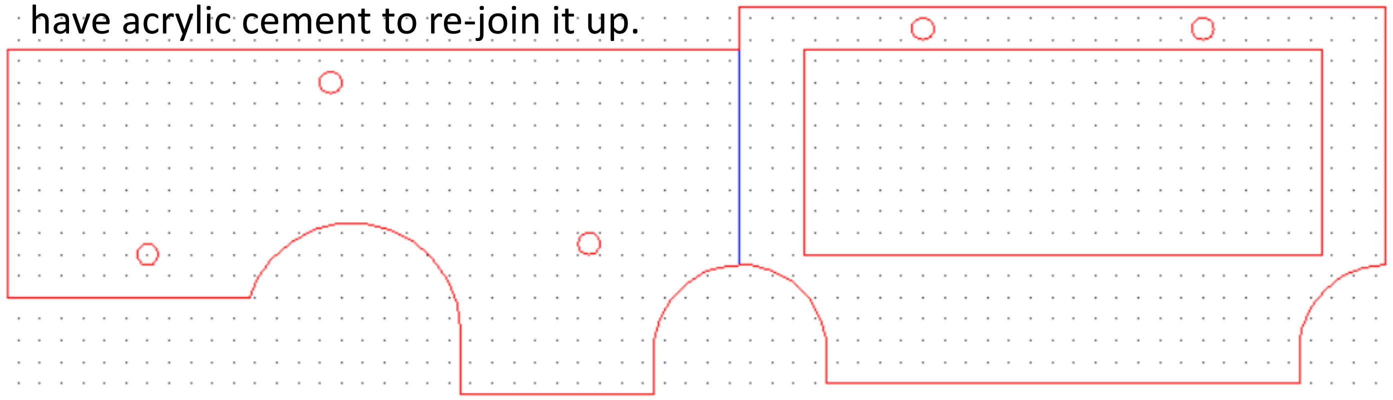
Air Contaminants

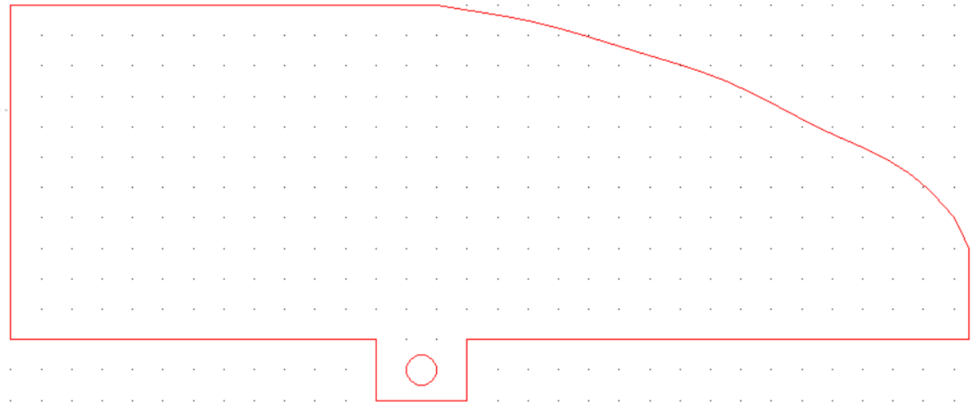
- Laser cutters will generate fumes, vapors, particulates, and metal fumes from substrate that can be highly toxic (plastics and other combustible materials).
- All laser cutter systems must be equipped with a fume exhaust system and filtration system that meets manufacturer specifications.
- These fumes or air contaminants can damage the machine and harm your health. If the air filter or exhaust system is malfunctioning, immediately stop operating the laser cutter and notify your supervisor.
- Filters must be changed regularly according to the frequency of use or as specified by the manufacturer.
- **DO NOT** cut a material that has not been approved by the manufacturer.
- **DO NOT** use a laser cutter with a malfunctioning exhaust system or clogged air filter.

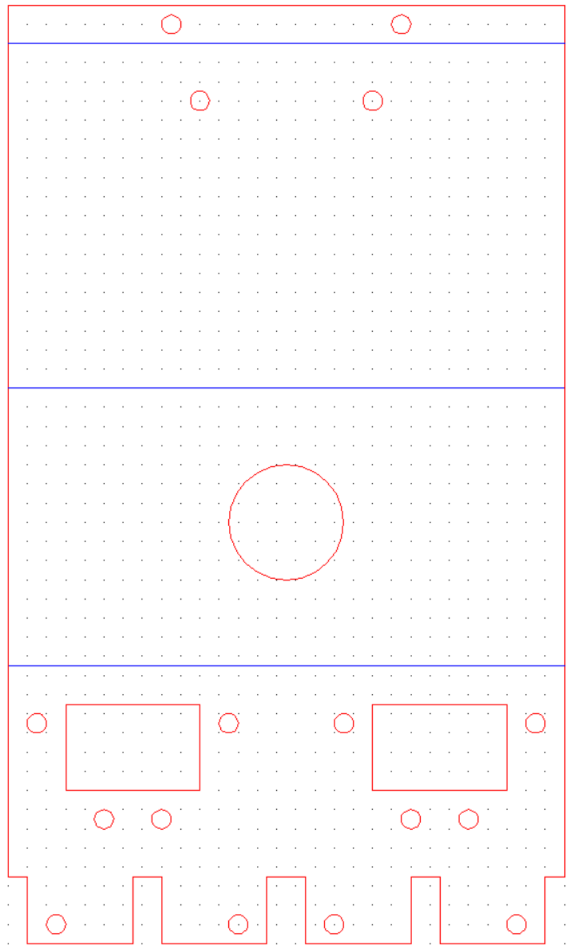
Planning a Prototype – 2D Templates

The Container

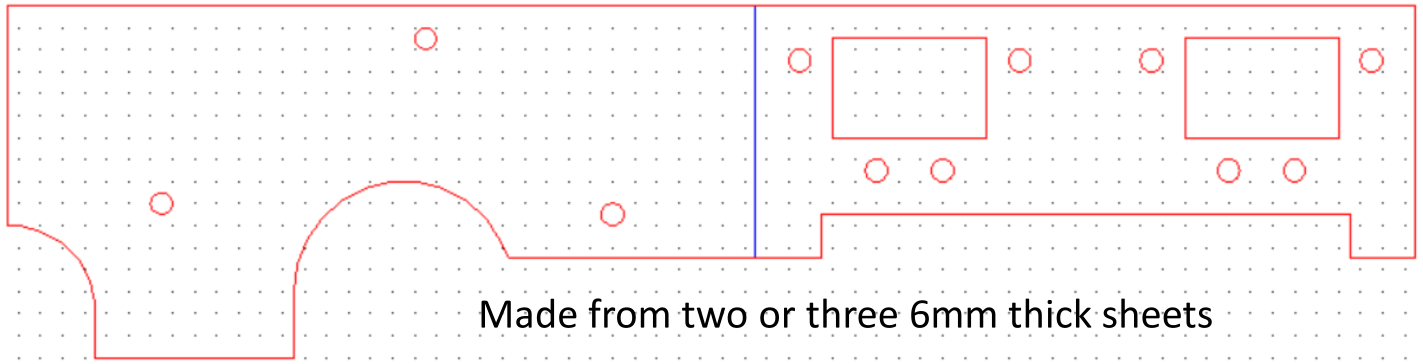
This does not require any stacking, but it does have quite a few very large pieces. The top and bottom pieces will require line-bending across the blue lines. The preference on the piece below is that it is all four sides on one plastic piece, however this would be too large for our school laser cutter so I split it in half to have acrylic cement to re-join it up.







It is important to consider that line bending with the level of machinery that we have at school is not an exact science, so parts may need to be remade or redesigned within certain tolerances to fit properly. One such prime example of this would be designing the curved part of the container side piece to fit with how the line bend of the top piece went.

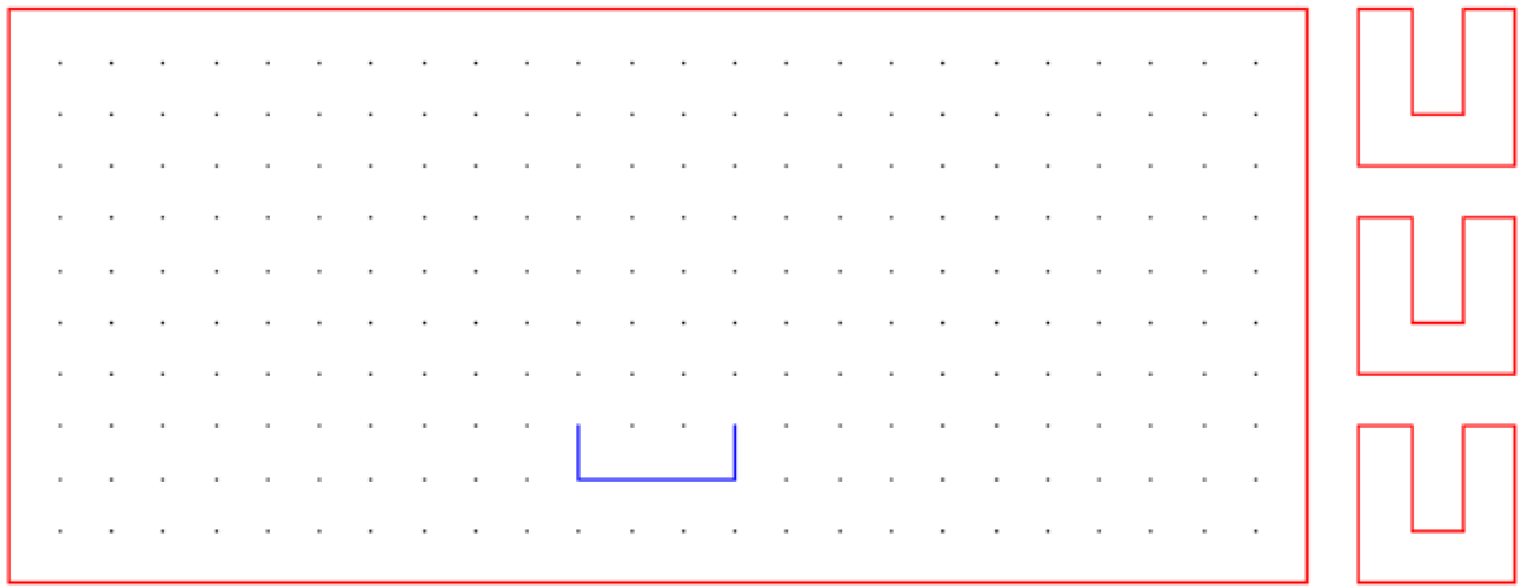


Made from two or three 6mm thick sheets

Hatch

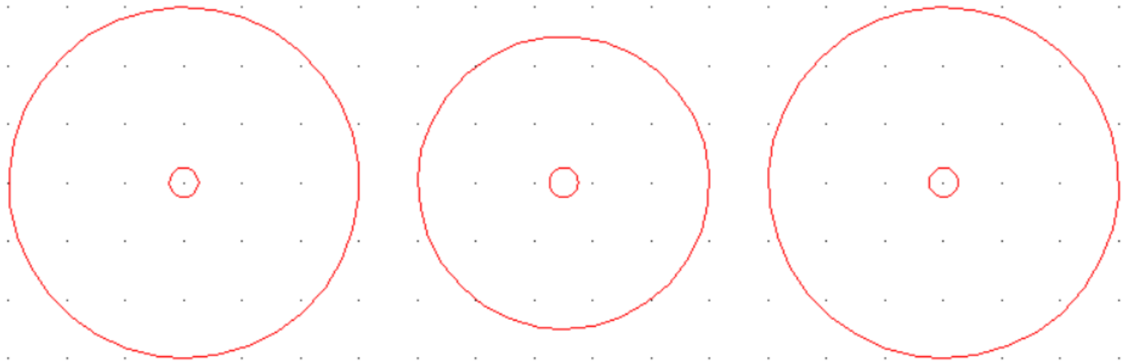
A very simple 2D design to make, but to ensure the arrangement of the mount insert on the hatch is in the perfect place I have added a small etch line to show where it should go.

Made from one 6mm thick sheet



Wheels

To make the groove in the wheel, I can just make three wheels where one is slightly smaller, then stack them such that the holes line up.

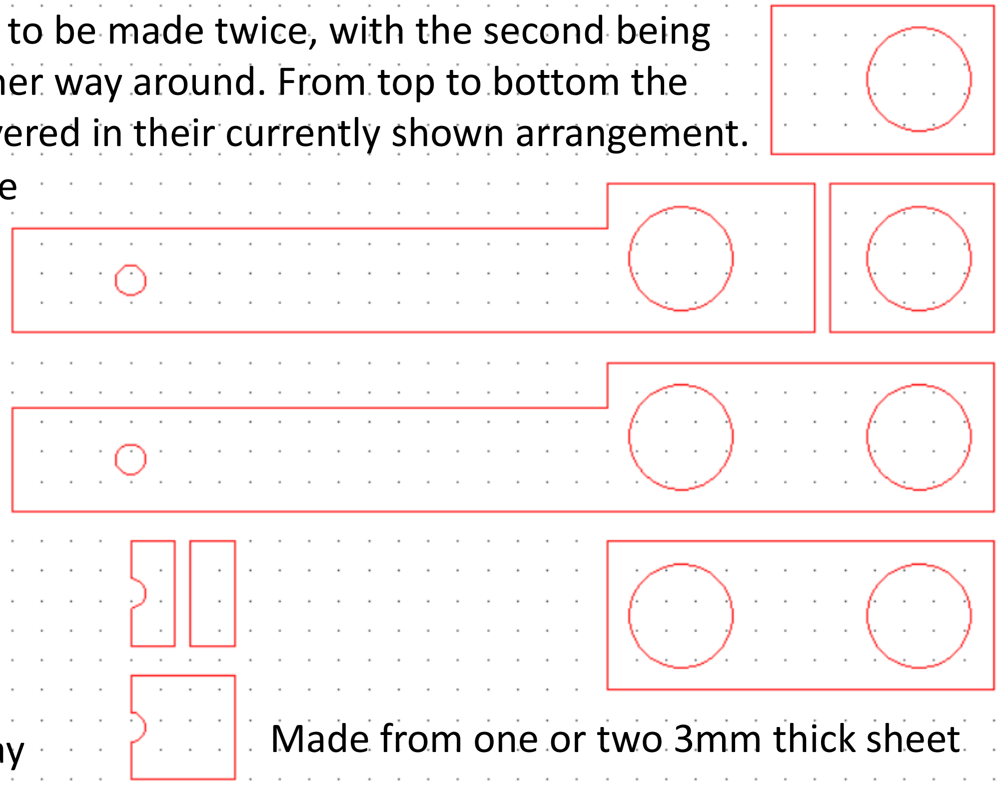


Made from one 2mm thick sheet

Planning a Prototype – 2D Templates

The Chassis Side

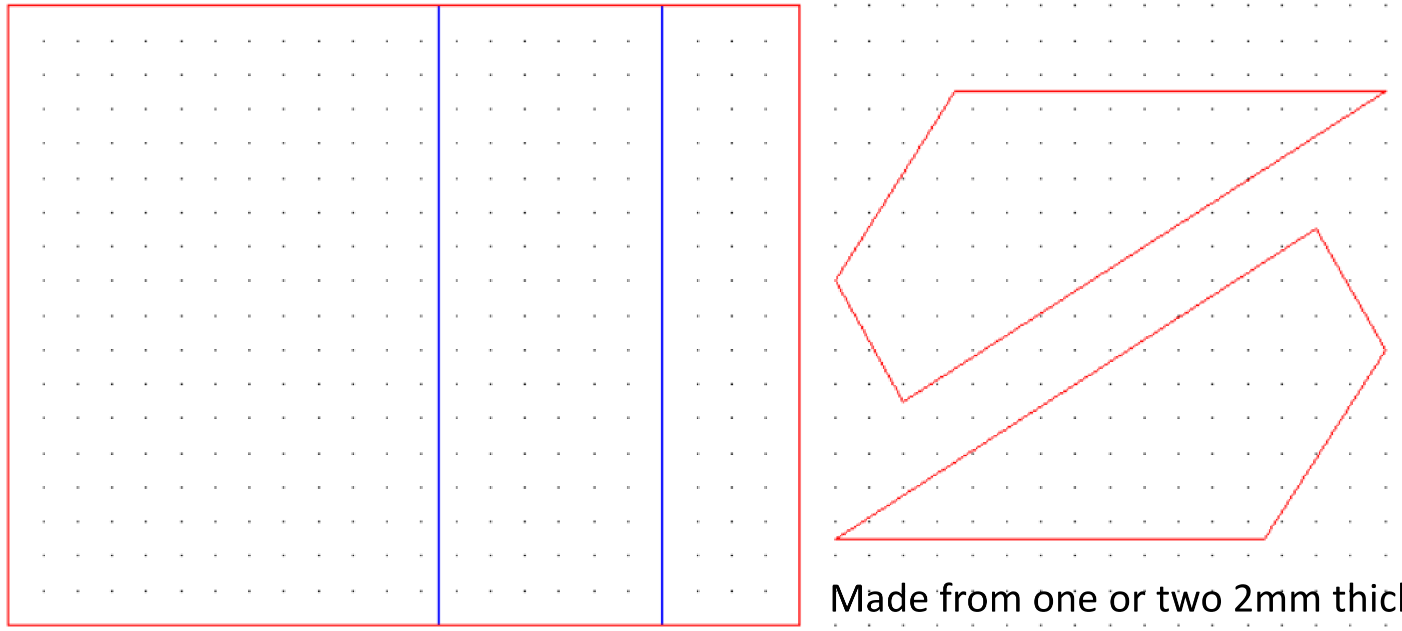
This piece will have to be made twice, with the second being constructed the other way around. From top to bottom the pieces would be layered in their currently shown arrangement. There are also some openings shown, which are a way of having space for screws. There is no point using etch lines to mark placements, however, as all stacked parts interact with a certain edge anyway



Made from one or two 3mm thick sheet

The Scoop

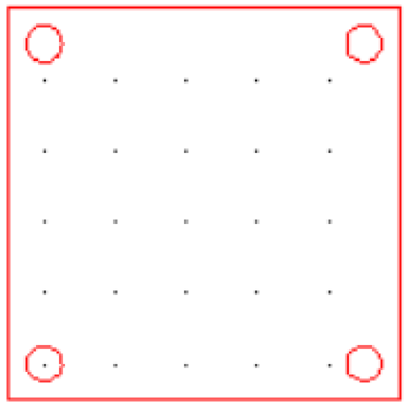
Having already made a test rig of this piece, it was easy to make an accurate model. This time I also had to make the right sides. Again, the blue etch lines are for line bending.

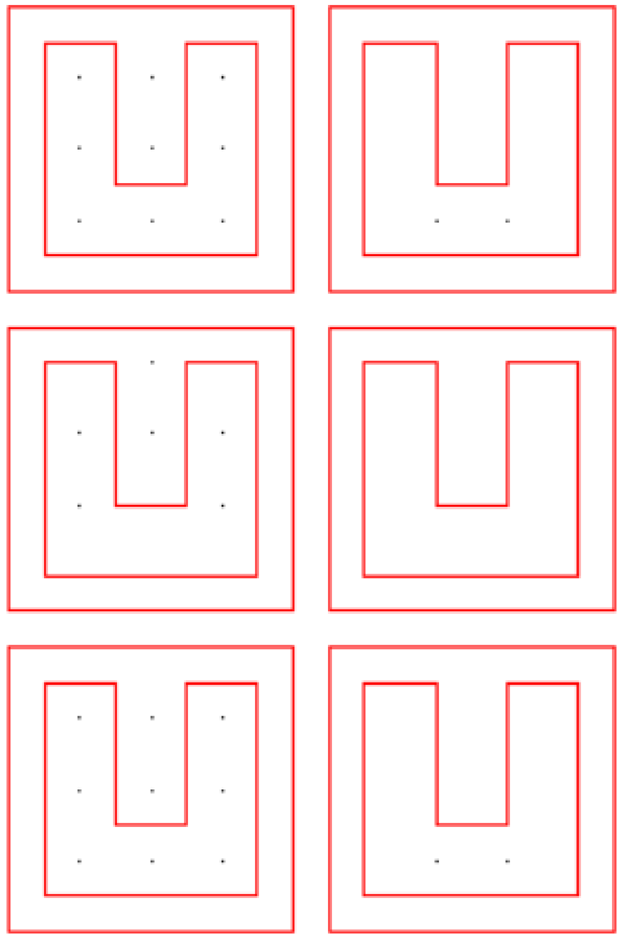


Made from one or two 2mm thick sheet

Mount

The mount is a simple build. The shapes are arguably the most simple of all the pieces and the layers that need to be stacked are almost all exactly the same.

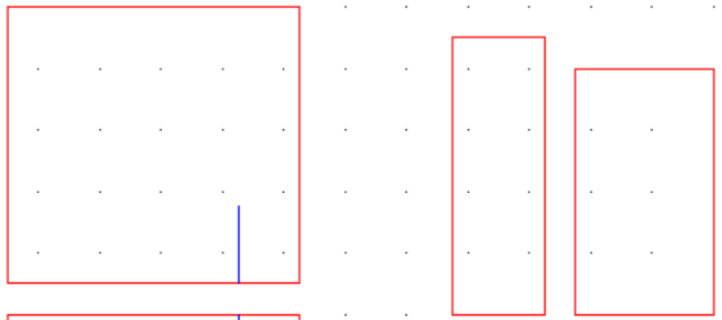


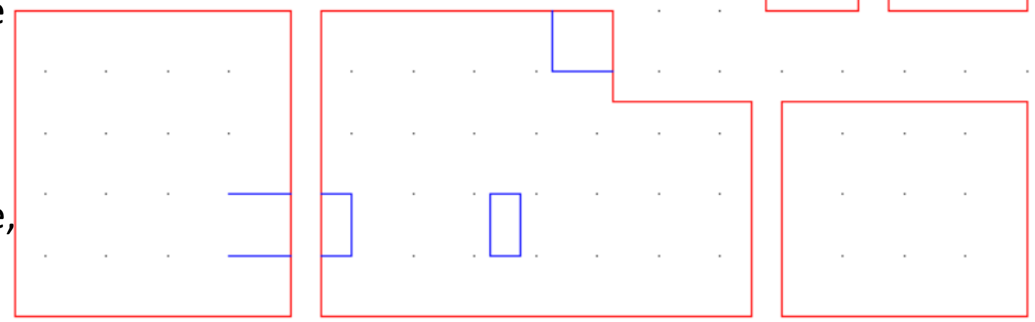


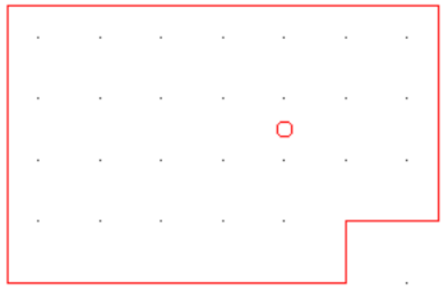
Made from one 3mm thick sheet

Gear Box

Chamfers ignored cos it's a prototype and this increases ease of manufacture when pieces are laser cut. Additionally, since it is so important, the parts that would hold up the shafts would be 3D printed to ensure precision. While it is possible for there to be fewer pieces and just line bend some of this, there is a requirement for all the parts on the inside, including gears, to fit perfectly – which would be very easy to do with simple laser cut pieces, but much harder to make perfect line bends. As to not risk it, therefore, it is more suitable to only use acrylic cement to assemble these parts. Blue lines on this template, like the hatch, help the placement of the other pieces.





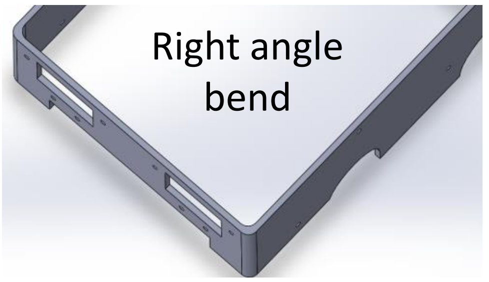


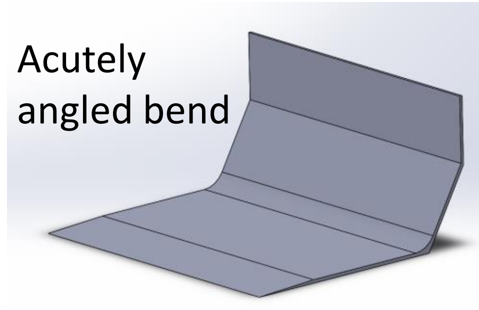
Made from one 4mm thick sheet

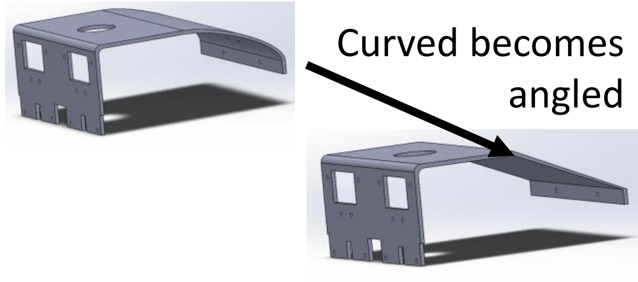
Planning a Prototype – Line Bending

The Line Bender is a simple machine that is used, as the name suggests, bends sheets along a line. How it does it is a wire is heated to a high heat (roughly 420K for polymers) which can make the sheet malleable – allowing it to be manually bent.

The two pieces I will need to line bend are the container parts and the scoop. Most of the container bends are 90 degree angles which can be done by bending up against a right angled surface such as the desk as shown bottom left. For other angles it is slightly harder as with the small line bender we have at school has no part for measuring angles. This means it has to be done separately such as with a specially made mould or rotating combination square as shown. Curves can be done with industrial level machines, however as the school line benders heat slowly, and polymers lose their malleability quickly, a curved face is unlikely, instead it is realistic to just have a shallow angle bend on the top container part shown.

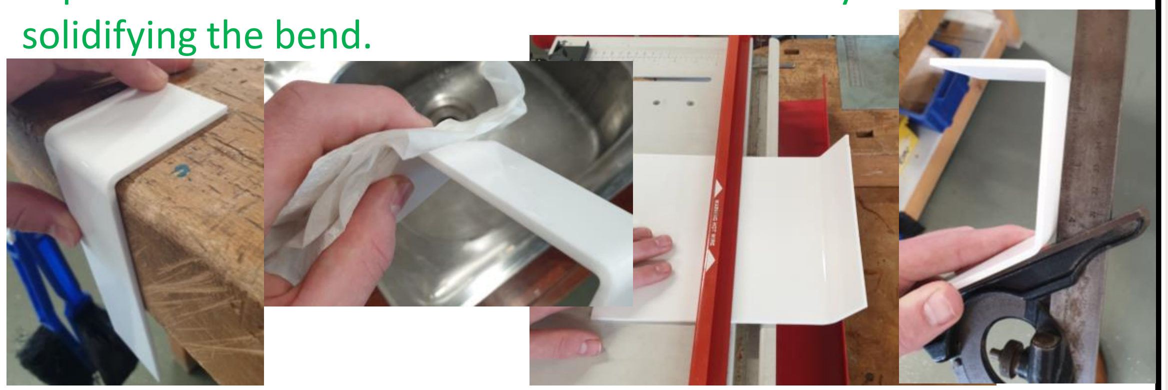




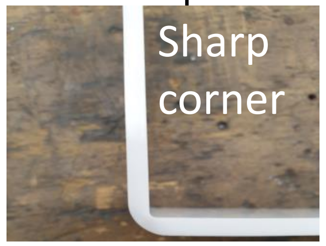


Method

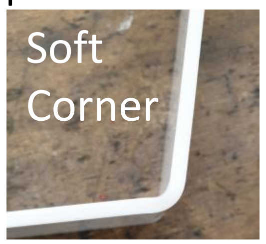
Before doing anything with the machine, a sheet needs to be made to the right size as it will be far harder to cut after deforming, one such method of making the right shape is laser cutting. The sheet should also be marked out some way, such as drawing or etching lines – this will ensure higher accuracy of the placement of the bend. Using the machine, the sheet should be slid under the guard to keep it in place, making sure the line to bend it parallel and directly over the hot wire. One should be constantly checking the malleability of the sheet so as soon as it is ready it can be bent to shape. The correct angle can be made by a variety of tools described right, but once the shape is made, one should hold the piece exactly as it is and wipe down the corner with a wet cloth to slowly cool it down - solidifying the bend.



Additionally at school we have a thicker strip heater (shown below). This would be used to heat a thicker part of a material and therefore make a softer bend which would definitely be beneficial when bending the scoop, as on this page I explicitly mentioned the need to avoid sharp corners to stop dirt being trapped.



vs.



Risk Assessment (via)

What are the hazards	Who might be harmed and how?	What are you already doing? What should be done when using the equipment?	Action required
Electric shocks	Person using machine	Regular maintenance & electric survey should mean machine is safe to use. extra low voltage on machine and wire insulated.	Isolate Electric supply and call for medical assistance. Check conscious status of victim and address accordingly.
Burns	Person using machine	Obvious risk – caution should be taken when using machine and gloves worn. Pupils reminded to pay attention to their work and others around them	I burns occur place area under cold running water for 10 minutes. For serious burns as above and call for medical support

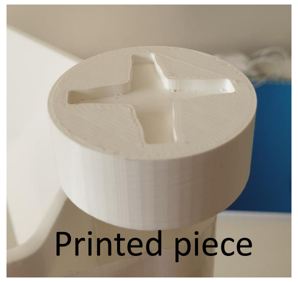
The line-bender has by far the most daunting safety hazards to be aware of. The very premise of a line-bender is that there is a very hot open wire heating a polymer sheet. This immediately means throughout use I must be totally **aware** of what I am doing and avoidant of touching the wire for risk of electrocution or burns. To increase awareness of the situation, it is important I have trained **professional supervising** the activity. Some say, including Risk Assessment, that protective gloves should be worn. However, a discussion with engineering professionals at school led us to the conclusion that using the thick and oversized gloves we have at school could pose more of a threat (due to the inability to precisely mould the work piece and a certain clumsiness that can be dangerous in high temperature areas) than not wearing gloves as long as sufficient concentration on the work is maintained. **Safety goggles** should be worn as always in a workshop and in the case an accident does occur, I should be relatively close to a **tap** and be aware of its location.

Planning a Prototype – 3D Printing

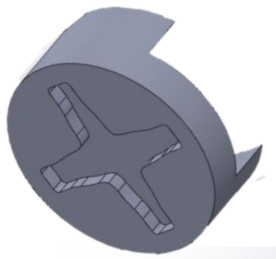
3D printing is quite a new concept, but one that has become very popular for iterative design and is one of the most common rapid prototyping methods. It consists of a machine with a nozzle squeezing out a line of material in such a pattern to make up layers of a 3D shape. There are many different types for different purposes but the one we have at school is Stereolithography (SLA) which has tight tolerances to give an accurate and precise result (to the point it is often used for the medical industry even). There are other forms such as SLS which improves in the strength of the created part, however this is not necessary and I do not have access to such a machine. 3D printers can be used in an industrial setting, however are usually replaced with something else (like injection moulding) due to speed of continuous mass manufacture; nevertheless for prototypes and modelling it is perfect as it is faster for making individual pieces. Additionally, there are multiple material choices: normal ABS SLA 3D printing, and while our school's printer cannot use TPE, a similar rubbery material called TPU can serve as a reasonable replacement due to its slight flexibility and level of firmness matching that which I need.

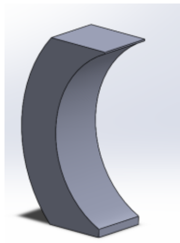
Method

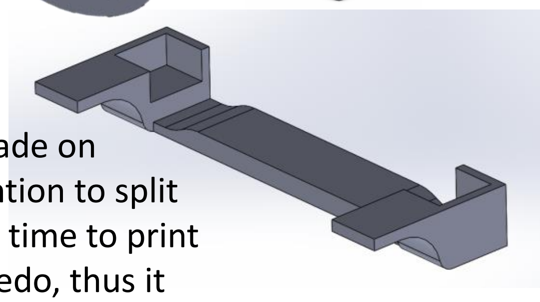
Before being able to 3D print, a model has to be made. For this I use SolidWorks, as can be seen on many previous pages, as it has a wide variety in options of modelling. Using combinations of Extrudes, Cuts, Fillets and Lofts, such models as those to the right can be made. Simply by uploading them on to a special data card, the model can be downloaded by the printer and directly used to 3D print. The only other key thing to remember is to keep the printing floor clean and lubricated to ensure printing is accurate and the piece can be removed from it on completion easily.


Printed piece

The servo connector needs to be printed for both left and right orientations, however the insert is the same for both so needs to be printed twice

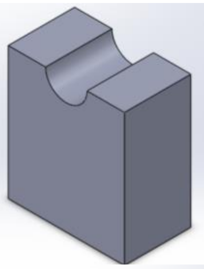




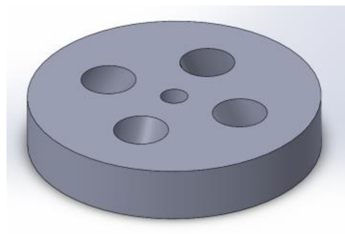


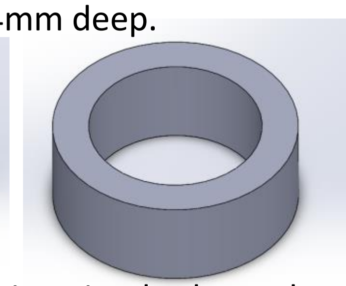
The chassis under-piece is 288mm wide, which can be made on 210x250mm 3D printer (diagonally), however it is convention to split such a large part into chunks. This would take a very long time to print so if anything went wrong it would be a long process to redo, thus it should be made in smaller parts (which could be specially made to have a shape join e.g. finger) which are super-glued together for example.

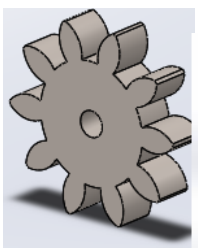
As mentioned, the gear box can be laser cut and assembled, but the axle holders should be 3D printed to ensure precision. The same goes for the worm gear parts shown below.

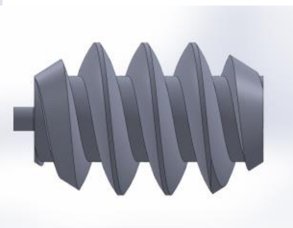


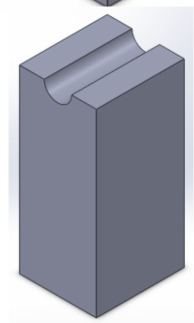
There are two rubbery pieces for the sweeper motors that are 20mm deep, then two for the wheel motors that are 14mm deep.











The sweeper rope holder is a simple shape that can potentially be made with stacking, however in the interest of maintaining precision for the angles, 3D printing is more suitable.

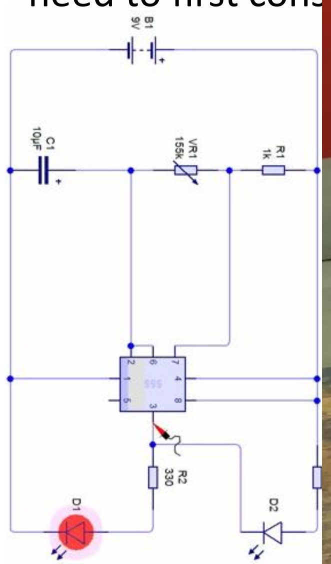
Risk Assessment (via)

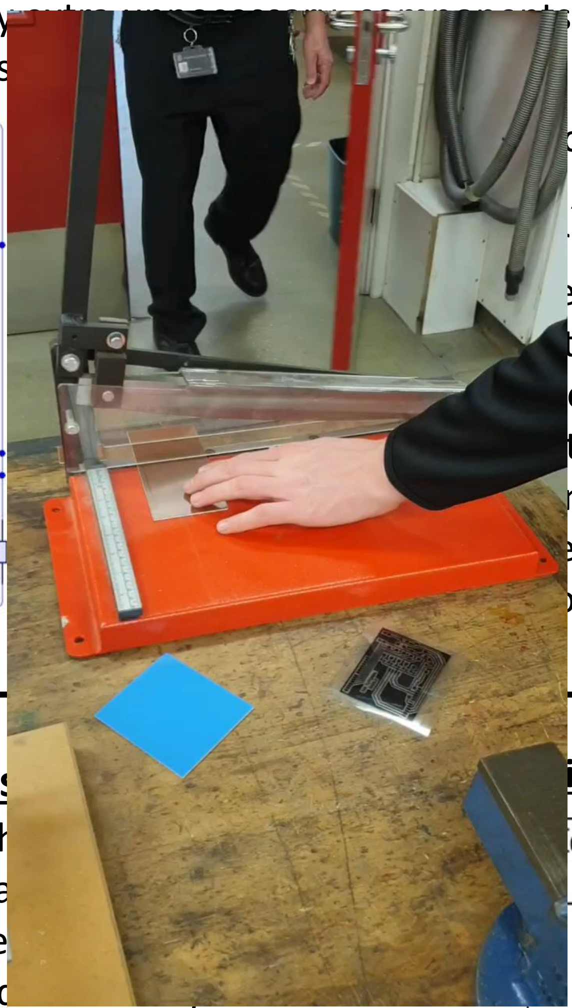
Hazard	Control Measures and Consequence of Failure	Likelihood (0 to 5) ×	Severity (0 to 5) =	Level of Risk
Burns	Clear signage to indicate risks. Allow 30 minutes after printing to allow the printer to cool before removing 3D print. Avoid making contact with any components of the printing chamber. Any burns should be irrigated immediately with copious amounts of cold running water.	2	3	3
Potential headaches/nausea from styrene fumes which may be liberated when printing in ABS	ABS printing should only be undertaken out of hours so no individuals are affected.	1	2	2
Lacerations from sharps	Lab coat, gloves and eye protection should be used when finishing the 3D prints. Care should be taken when using sharp tools. Lacerations should be reported to the facility manager. Sharps should be disposed of in a sharps bin. A first aid box is available in the area.	2	2	3
Potential headaches/nausea from styrene fumes which may be liberated when printing in ABS	ABS printing should only be undertaken out of normal working hours so that no individuals are affected.	1	2	2

3D printing does not really have any terrible risks associated with it as it is a process generally suited to leaving running and returning to it on completion – i.e. entirely automated once it has begun, in terms of work and monitoring. To stop those around it inhaling any potentially harmful fumes, the printer should not be used in crowded rooms and ventilation can be made by opening doors and windows. This means not having the printer in a classroom is best. Efforts should be made to stop both myself and any passers by from touching the machine when in use as it could cause burns too – this again is solved by secluding the machine.

Planning a Prototype – Circuit Building

Up to this point, I have created and tested individual parts of code with an Arduino board and in some cases used a driver such as for the motor. Now for the actual product I will need to make my own bespoke circuit board that can handle all the inputs and outputs at once without any ... . To do this I need to first cons... .





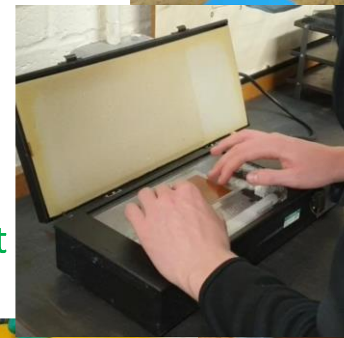
...clude inputs of ..., 2 ... source ...r, and ... ...tors. ...e be re... ...ts to co... ...nto one ...n be m... ...mpone...

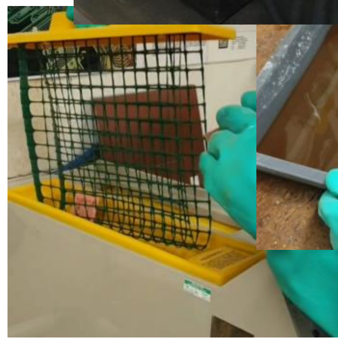
...t to fun... ...t. Usua... ...pload c... ...ash me... ...to the ... the co...

...must have code ... C# or Java as it is for ...g pins to reach the ...an external ...is allows code to be ...ss to the computer.

Method

Print the circuit on to a sheet of acetate and, with **Safety Goggles** on, cut a piece of printed circuit board so that the whole circuit would fit on it with a small bit of leeway space. Peel the film off the PCB and place it in an Ultra Violet ray box with the circuit sheet – this prints the circuit on to the board. Now wearing a **Lab Coat** and **Protective Gloves** too, the board can be taken out to sift in Bromine Water. This begins to reveal the tracks on the board. After rinsing, it should be put in to the PCB etchant chemical tank to complete the ... ...insed, the holes for ... can be ... ...ich completes the circuit ... for com...





Joining Methods

Th... ca... fe... ac... that in my opinion is best to use is Acrylic Cement as it is optically invisible, very easy to apply, and often a thermoplastic i.e. recyclable.

First the components of the Cement need to be mixed (for double component only). Held in a glass container, Acrylic Cement can be applied via paintbrush. The joint intended to adhere should be held in place and the adhesive painted over it – temporarily softening both parts so they fuse somewhat similarly to welding.

...isk Asse...

...dentify the...		...trol Measu...	...mation
1. Highly Fl...	rubber solutions and polymer cements produce highly flammable vapours.	...s of ignition s... Adhesive is still potentia... drying time.	...e used if ...bber solutions and polymer cements must be used in accordance with the manufacturer's instructions.
2. Inhalation of Vapour	Inhalation of vapours can be harmful.	Sufficient ventilation should be provided. Seal the labelled container immediately after use to limit vapour levels.	LEV can be used.
3. Skin and Eyes Irritant	Solutions can irritate the skin and eyes.	Suitable eye protection PPE should be worn. A barrier cream on hands or gloves should be used.	Suitable eye protection conforming to BS EN 166:2002 1B should be used.

Acrylic Cement is made up heavily of strong solvents, which instantly means it has the potential to cause harm. Whenever I use it, it is important to have a face mask to reduce inhalation as well as goggles to protect my eyes. Ventilation in the room by opening windows and doors could help this out too.

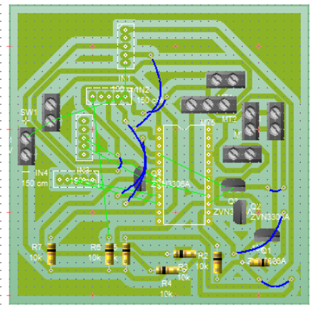
Threaded Joins – Nuts & Bolts vs Screws

Screws have the benefit of not requiring access to the other end of it unlike N&B, however nuts and bolts can easily be undone, making them suitable for disassemble-able parts. Fittingly, I have designed the casing so that the inside can be accessed by removing the top layer, not the whole thing, so the join between container parts can use nuts and bolts. Alternatively, the chassis piece is too wide for a bolt to go all the way through so a screw is more suitable. Additionally, using screws instead means the joint can be disassembled, but the user is dissuaded from doing so themselves.

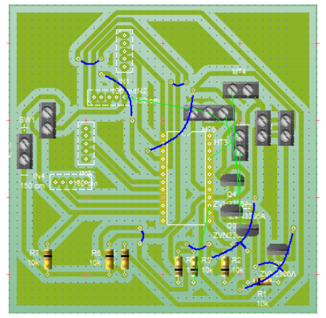
Planning a Prototype – Component Summary and Circuit Designing

The product I have designed does not just require material work, there is also a full electronic system that allows communication between components. I need to design a full PCB that can control inputs and outputs to allow the rover to move and pick up mess as required.

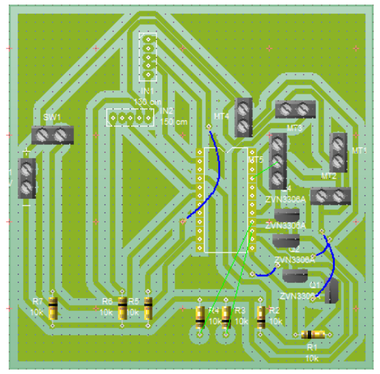
In order to see its surroundings and also accurately locate debris, 4 input Ultra-Sonic Range Finders are necessary. Additional Inputs are the Rechargeable Battery power source and the Push Button which acts as an Emergency Stop button and can dual purpose as a Start Button too.
In order to manage the information received from the sensors and button, a Microcontroller is necessary to do processes and decide what output is necessary. In order to manage the current and Voltage of a circuit with these inputs and outputs, high resistance resistors must be used too.
To act upon the decisions made by the controller, there are some outputs necessary too. So that the rover can move, there are two DC Motor outputs which are accompanied by another two which rotate the sweepers. Additionally, one or two Servo Motors are required to stably lift the scoop. For the lower end model, this would only need to be one provided it was the better servo (see here for more details). These motor outputs require transistors such as MOSFET in order to work.



1st iteration works out 77% of lines. This was single side thick line at 91x91mm. This one had components and routes auto-placed.

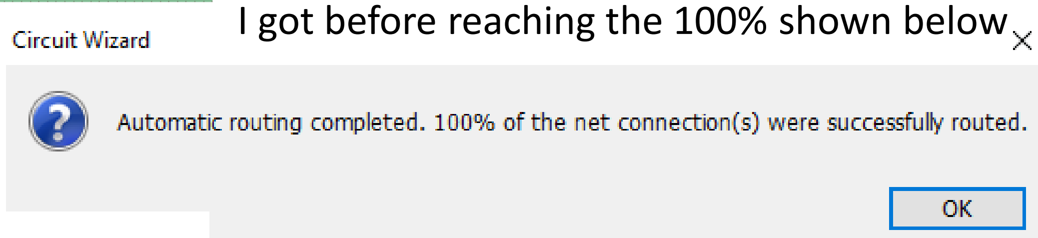


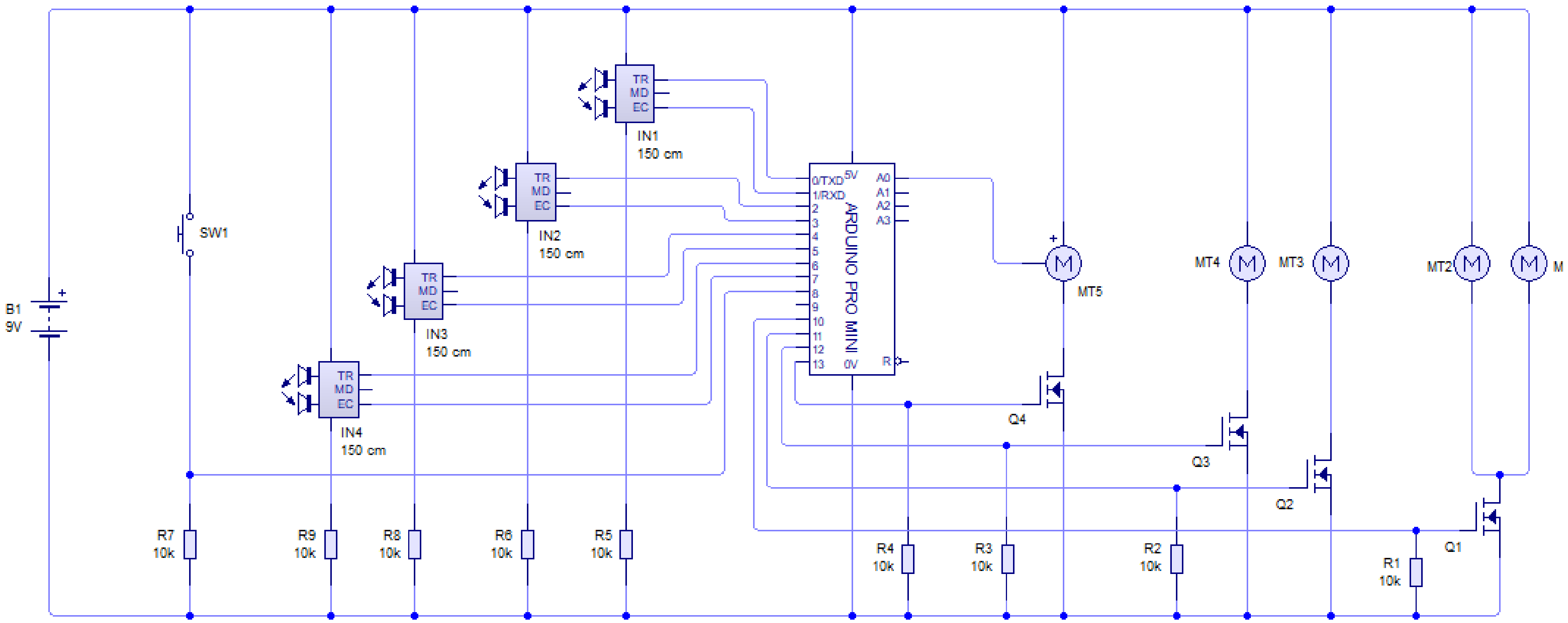
2nd iteration works out 85% of lines. This was single side thick line at 106x106mm. This one had components and routes auto-placed.

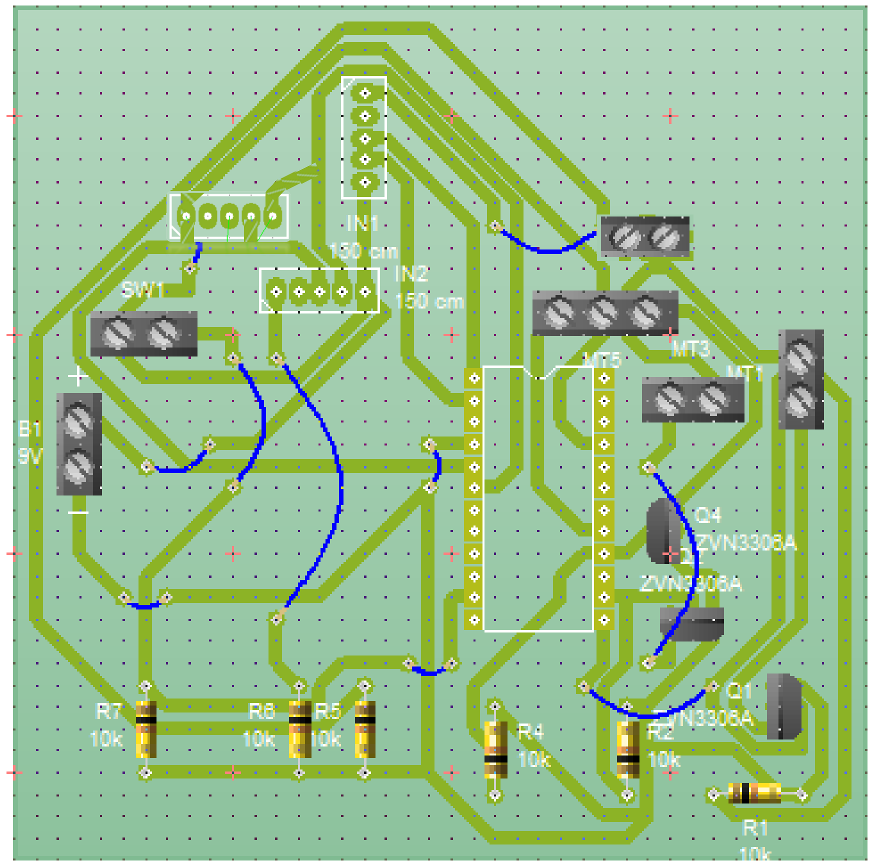


I continued iterating from there, moving around the components and re-routing the wires. Each time I could pay attention to the green lines that showed up and then move or rotate the component accordingly. The shown circuit is 93%, which was the last one I got before reaching the 100% shown below

Putting all these components together, I got the Circuit Diagram shown below. From there I had to create a circuit board. The iterative process is shown right while the final, 100% routed CB is in the bottom right corner. While this is mostly embedded copper lines, due to the complexity of the circuit, some jumper cables (blue) would also be required. With this I can create the PCB with the method described on the last page.

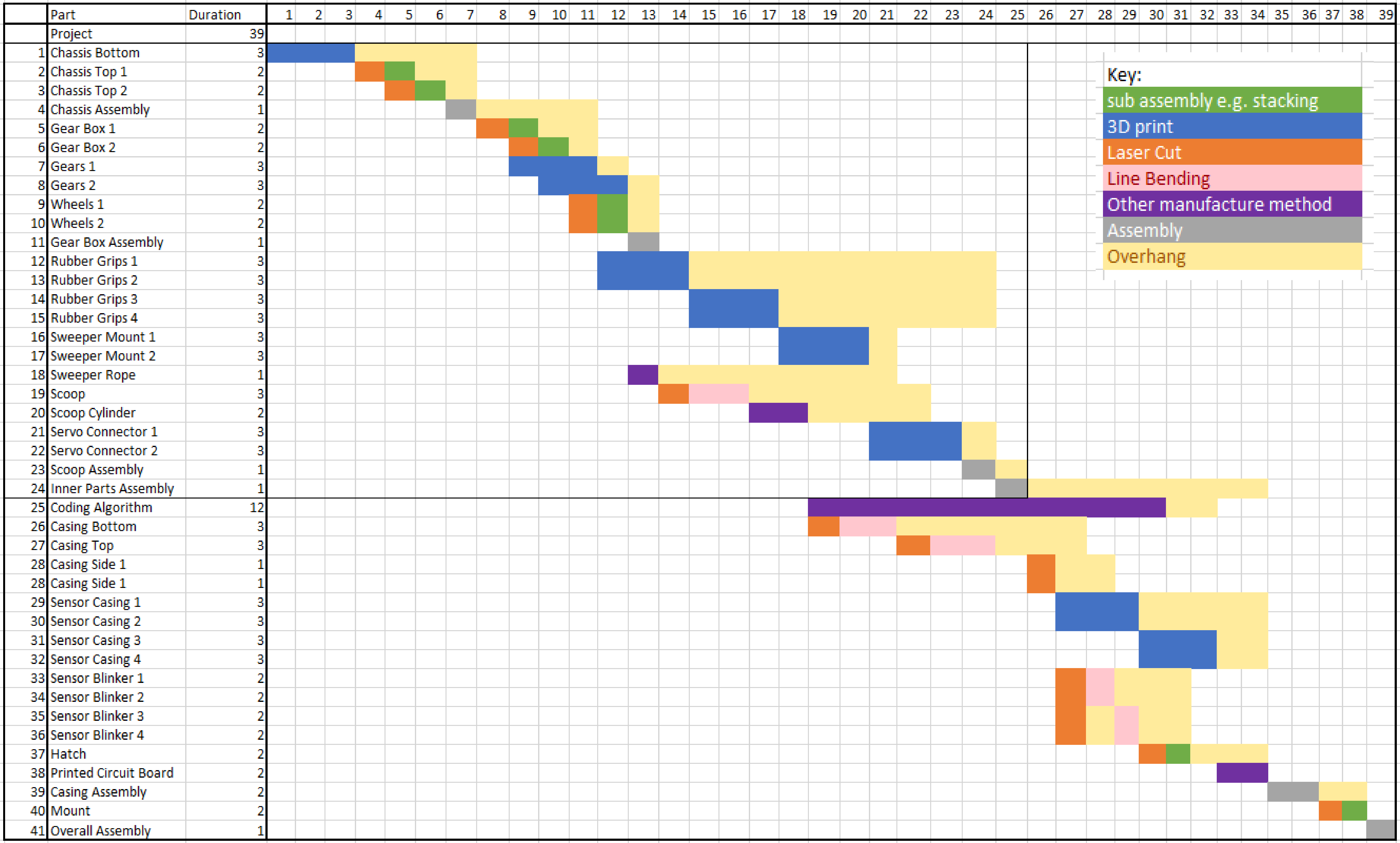






Planning a Prototype – Time Management

If this were a normal year, I would make the prototype in the workshop, however this year is different as Covid-19 has reduced the access to certain facilities as well as dramatically reduced potential time in the workshop. Nevertheless, I have created a Gannt Chart Timetable as if I were able to make the prototype as planned. There is a line drawn where the inner parts are completed and the primary functional parts should be useable. Overall, the manufacture plan came to 39 40 minute lesson periods; this, while having 7 periods per week (Monday, Wednesday, Thursday), would amount to just under 6 weeks of work.



Testing and Evaluation – Stakeholder Review

With a completed design, usually I would build the prototype to test its function. Due to restrictions from Covid-19 that I have previously mentioned, I instead had to show proof of concept of my ideas (which I have done in the last section), and for evaluation all I can do is review the 3D computer model and other small elements. This means discussing the design and potential product with stakeholders, as well as comparing it against the requirements I initially laid out.

I spoke to all three café stakeholders I had previously spoken with. While I have discussed, with them, small individual features in the mean time, I have not discussed the whole system since the presentation. I was interested in seeing what they thought of the functions and features of the product, as well as costing (the product, I worked out, would cost about £60 plus set-up mapping, packaging, shipping, etc. reached £185).

Overall, all the stakeholders I spoke to seemed to be very happy with the outcome. They all agreed that the problems that were discussed during the presentation had all been solved to a high level, which was relieving to hear (e.g. sizing, debris locating, manoeuvrability, the use of tyres to reduce noise and stop marks on the floor). In terms of things to work on, they agreed that the scoop would benefit from the servo being cushioned to stop vibration, and that a buffer should be added on the front so that if the rover does hit something, both it and the rover are safe from damage. Tamsin said that Yellow should be the primarily marketed colour as it fills the need to be bright and hard to miss, while Amelia confirmed that it would still be good to have black (and others perhaps) to make it accessible to cafés and restaurants of all colour schemes. Discussions led to the conclusion that a beginning price of £250 is fair due to the fact that independent manufacturers such as myself would not be immediately trusted by new customers, which opens up the opportunity to increase cost to a maximum of £400 as my 'company' increased its reliability while the product itself was also improved bit-by-bit. Finally, Amelia expressed a few negatives about the product which mostly came to aesthetics, to which I agreed I had not focused on how it looked enough. Also mentioned was that, once a prototype was made, I would have to do rigorous testing to see which shade of yellow (or another colour) was best to not break the café atmosphere while still being very visible. Moreover, testing might ensure the corners are all smooth enough too.

Comparing to Initially Written Requirements and Design Briefs

General requirements where laid out here. In bold is how the final product solves these necessary requirements

- All places on the floor must be able to be reached – **the specialised code allows the rover to path the whole café and pick up all debris it finds**
- All forms of mess/dirt must be able to be cleared – **the use of a sweep and scoop makes the rover very versatile and able to pick up objects of a wide range of size and weight**
- The floor must be made cleaner by the product – **while I cannot fully test this, the ability to clear objects or dust means the floor should inevitably be in a cleaner state after finish**
- Comfortable and easy to use – **this ended up not being a factor, due to changing to a robot cleaner, however the UI is at least very user friendly – being made up of simply an ON and Emergency Stop button**
- All mess/dirt must be efficiently collected for easy disposal – **all debris is immediately, safely, stored in the scoop container that can be easily removed for disposal**
- No unnecessary strain placed on the user – **due to the product being a robot rover, there is no strain on the user at all**
- Versatile for use in any café whatever the floor plan – **it has been mentioned that the dimensions of each cafés floor plan should be able to be measured and inputted into the code to create a digital floor plan and thus path to follow**
- All cafés can buy and use this product and even places that are not cafés – **while this is mostly equipped to handle debris you might find on a café floor, there is nothing to stop its use in other similar indoor establishments like restaurants**
- Will not harm or have negative effect on the floor or objects it touches – **efforts have been made to tyre the wheels, additionally the rope used is soft so not damaging to that which it hits, finally, the only part of the scoop that would touch the floor is the rubber tip which, like all pans, does not damage the floor.**

Additionally, on this page, Hygiene regulations were mentioned. They are all effectively combatted. The sweep scoop design was created to ensure removal of all substantially sized particulates like large crumbs, additionally the sweeper can greatly improve the level of smaller dust on the café floor. Moreover, the easily removed scoop-container means this food can be immediately disposed without effort

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My initial design brief was "My design will be one that solves the need for a higher level of cleanliness in cafés while also improving speed of customer flow." – **by being able to constantly clean, unlike regular workers, the floor can be kept cleaner and those workers have more time to dedicate to tasks that must be done by a person (e.g. cooking and talking to customers), therefore increasing speed of customer flow**

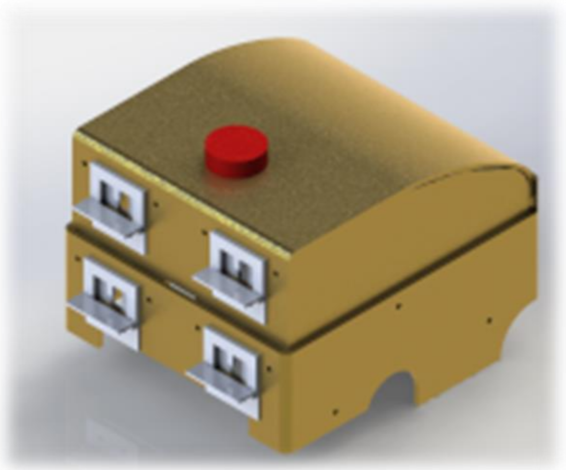
My revised design brief was "I will design a product that quickly clears a floor space so that it is ready for sterilisation. The product should maintain a clean working place and thus reduce the spread of diseases in social spaces such as cafés" – **the ability to clean the floor constantly throughout the day keeps the floor clear of most visible debris and dust so can effectively be sterilised at the end of the day immediately. The cleaning of the floor without being human has a knock-on effect of combatting the spread of disease (by reducing interaction) while allowing a functionally social society to continue.**

It is clear the product I finished with, in theory, fully encompasses all the initial requirements lain out and carries out the design brief needs to a successfully high level.

Testing and Evaluation – Comparing to Specification

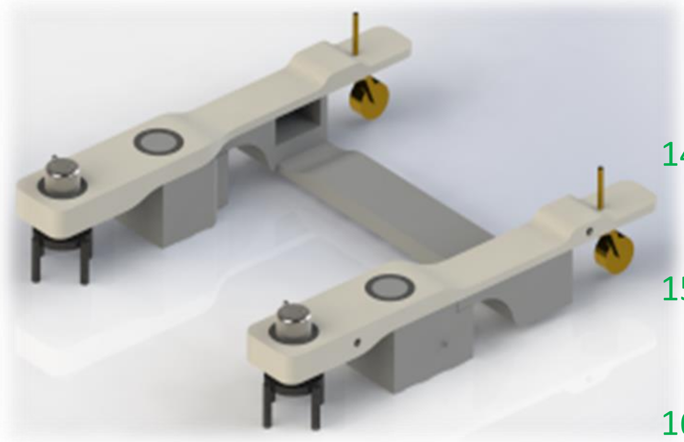
Point by point I can analyse what I have and have not achieved in the final product that I wanted in the specification. The points are numbered accordingly.

Casing



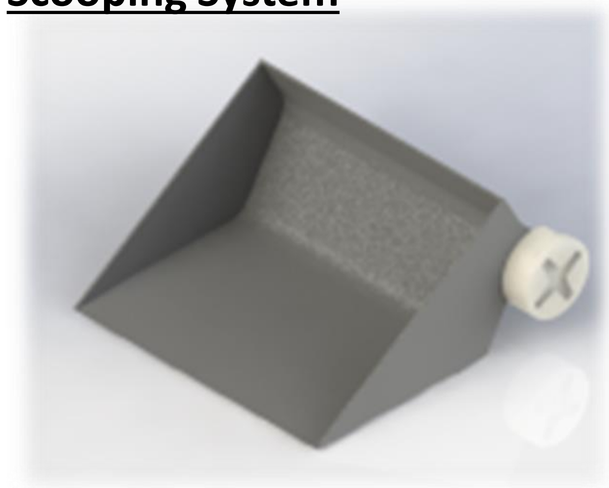
1. While there could be a second more expensive model with a screen, the main model does not have a screen and this means that the UI is incredibly simple to manage being only a few buttons
2. The code should dictate that the rover can be taken back to the mount, however this requires perfect precision so small human intervention may be required on some occasions.
3. The PVC casing can easily be of Yellow colour, however there would also be options for a black one. Potentially more colours down the line
4. I correctly limited the size of the model to 255mm tall, perfectly fitting under most chairs just as required
5. According to Solidworks simulations the top piece is comfortable with 800-900N alone, the sides around 2000N and the bottom nearly 3000N (when comparing to breaking stress 52MPa) so collectively they should easily support each other under a load of 1000N, however this is only theory as physical tests on a prototype cannot be done
6. The screen is removed so cannot be distracting and the chosen yellow is, in mine and my stakeholders opinion 'not too bright'. Also, of course, black is a possible colour instead
7. All edges are chamfered due to the fact they are to be line bent
8. The new casing is only 5mm off the ground, so in the event of a break of joints, the inner parts should not be affected unless tremendous force is used to break through the case.
9. The sensors are fixed in a safe, but effective position.
10. Blinkers were made to block the sensors from seeing anything below them to allow for my described position finding method
11. PVC for use in high paced manufacture that I am using usually is sourced by polymerising ethylene in oil
12. According to the coded pathing and the fact the scoop is not directly touching the rest of the design, no PVC should be contaminated enough to make it non-recyclable.

Chassis



13. Lockdown has stopped me from making a testing the construction of the chassis pieces, however discussion with my teachers showed that the right polymer glue could hold the chassis together with incredible strength equivalent to being one piece of plastic
14. By swapping the position of the motor and caster wheels, and also casing the gears for the motor, the user should not be at risk of inside sharp parts while extracting the scoop-container
15. All wheels have been designed to have tyres of some form to stop squeaking and also remain kind to whatever surface they are on
16. While I cannot test the speed without a completed prototype, the gear ratio fits with the current motor such that v = 0.4m/s
17. While the Servo Motors are placed such that they should be difficult to remove by the user, they are by not fully safe from too heavy vibration, however this is something that I would ideally test
18. While I cannot test the final model, there was proof of concept of the sweepers working exactly as desired here
19. My overall design is 30x35cm, one cm more in both axis than the specification demanded. Despite this, the switch of motor and caster wheels allows far more manoeuvrability anyway
20. The change to line bending the casing made it very easy to assemble everything using nuts, bolts and screws – thus it is very easy to disassemble
21. Line bending the Case has little wastage if done efficiently, however what is left can be crushed for injection mould granules

Scooping System



22. Tests revealed that with the right servo, over 1.5kg can be confidently held and lifted by the scoop. In terms of size, there is a height space of 20cm (top of case) and a length max of 22cm
23. I of course cannot currently test the use of a Nylon scoop however perhaps a more lubricating finish could be applied?
24. The use of a microcontroller and PCB means the servos can be accurately controlled to turn only as much as necessary
25. The scoop is exactly 180mm wide as required. It is also between 125 and 150mm long depending on the placement of an object
26. In use, the use of buttons to open and close the servo connector means that the scoop should be easy to extract, especially with the wheels out the way. The only problem is this part is a very precise and fiddly piece to manufacture.
27. Use of a thick line bender would make the corners of the scoop very soft, therefore preventing the trapping of debris or dust
28. I correctly showed proof of concept of a 30 degree tilt here
29. I proved here that two servos with my designed connector can stably hold the scoop. This is provided the servo does not vibrate (see above)
30. I have not been able to test the use of the servo connector's strap but I chose the button over Velcro as a button should hopefully be resistant to any dust. This needs lifespan-testing to check
31. The scoop cylinder extends past the scoop slightly, thus making a type of handle. PVC and Nylon are both smooth, comfortable materials in my opinion, which my stakeholder agreed with too.
32. Shown in this testing, even school-issue single component Acrylic cement was of sufficient strength

Testing and Evaluation – Potential Future Changes and Additions

With the comparisons made, I can evaluate the success further by discussing potential changes or additions that I could have made in **future iterations** of this product.

Coding Possibilities of Future Models

The current base model has a simple set of code that allows the rover to move forward, back, left, and right in order to path its way around the whole café before returning to its mount. There is a lot of room, however, to increase the functionality and accuracy of the pathing.

Just as a higher end model might use the push button feedback loop or a more powerful motor, more expensive iterations can bring back the LED screen. This screen, along with the many lines of code associated, can expand the functional capabilities to pathing toward specific tables etc. A different method to increase the function could be to link the rover via Wi-Fi or Bluetooth to a mobile device. Additionally, there is a possibility that if the pathing the rover uses is not flawless, it might not perfectly return to the mount as it should. This can be quickly solved with a small amount of human intervention, however it is preferable to have the pathing perfect – this goes for the general path made too. Perhaps a system can be set up with signal senders around the walls and receivers on the rover to provide information to it about its position relative to the room. This would take a long while to perfect, but would save a good sum of money due to the removed need to map the room to set up the pathing.

Preventing Breakage

A key reason as to why I had to change the container (on this page), among others, was to allow it to be more easily removed in order to access the inside for repairs or remove entirely to be placed. Having the casing be able to be replaced means that if great weight is dropped on the rover, it can be fixed instead of having to buy a new one – this is cheaper for a customer and also combats fast fashion therefore making it more ethically viable. During the manufacture process, extra container pieces therefore need to be cut and line-bent for separate sale. A benefit of using nuts and bolts is that the user can assemble the new casing themselves too.

Tamsin mentioned the use of a buffer on the front of the sensor blinker. The purpose of such an addition would be ensure, if the rover somehow hit something, that both the US sensor and the object (e.g. chair leg) would not be damaged. As shown, I could use Expanded Polystyrene due to its cheapness but a rubber compound Would likely by more durable and thus more appropriate.

Recycled Materials

The more a material is recycled, the more the compounds it contains will separate. This means to keep the structure full, new material must be added during each recycle. Additionally, most plastic (while it is supposed to), does not actually get recycled and instead gets sent to landfill. To solve this, and End of Life (EoL) scheme should be set up, which involves getting customers to give back used-up products instead of binning them. As an independent designer who would only be able to rent manufacturing machines, I would never have the facilities to create an entire EoL set-up, instead there are companies like ExxonMobil who can help ensure plastics are re-used for new production while maintaining a very high quality of material.

Smoothness of Scoop

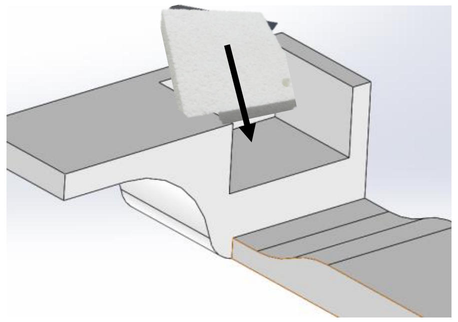
It was mentioned that tests should be done with a final prototype to ensure that the sweepers and self-lubricating Nylon is enough allow free movement of debris. While I still cannot test this without a prototype, potential lubricating finishes are Polyimide (also chemical resistant and cannot trap dust) or PTFE (high resistance to wear and by extension long life). Testing with these would reveal an easily solution. If no method seemed to work still, perhaps a redesign would be necessary such as the basket one.

Aesthetics and Size

The Stakeholders and I concluded that, while the primarily marketed colour should be yellow, there should be options for many other colours depending on a places colour scheme while also Amelia expressed that the gold colour was too close to a normal wood floor so would likely need to be more yellow. I would need to workshop different colours to ensure the perfect yellow (or other colour) is arrived at that can be easily seen without drawing too much attention. Also, throughout the product designing process, I greatly prioritised function over the look of the product. While this was a fair choice to make, some iterative aesthetic designing would be necessary to make this product more marketable. Perhaps during this process I can also reduce the width slightly (to <29cm) by reducing the servo connector size.

Reducing Vibrations

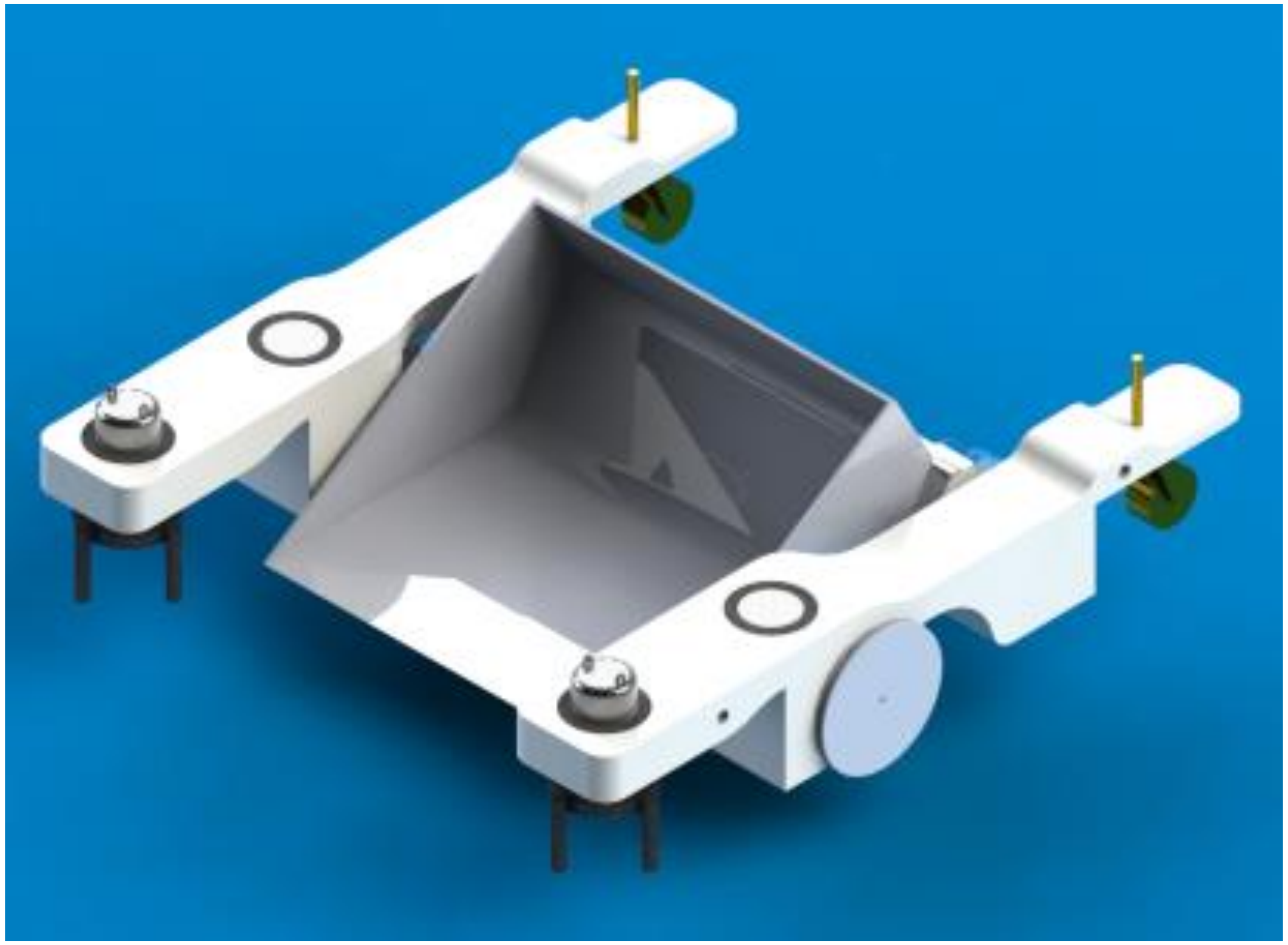
Tamsin agreed with me that, like the DC motors, the Servo motors should have some form of cushioning to reduce any potential vibrations that could make the scoop unstable. Of course this would require testing before truly knowing. Nevertheless, a



way of cushioning it could be to add a thin Expanded Polystyrene lining (cheap and light) which can be made in individual strips laid inside the servo hold as shown. To ensure other parts do not vibrate too much either, bolts and screws can have rubber washers added, and the rubber tyres used on the wheels should also reduce vibration.

Following slides are planning slides. They include pictures and notes that may become useful eventually so ignore them

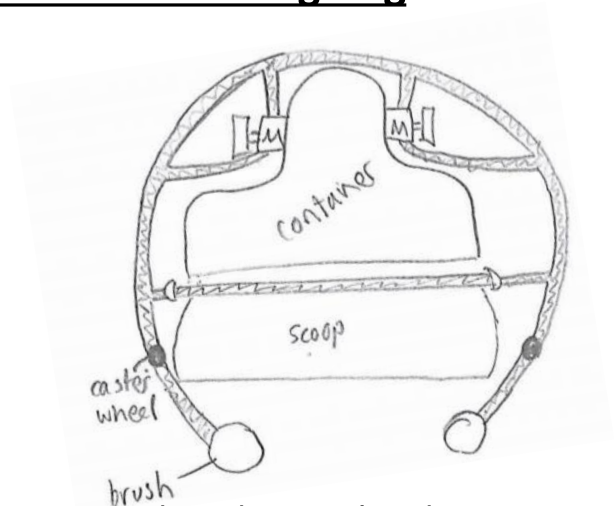
Business stuff such as costing, packaging and branding, potentially LCA (multiple page) and thus market performance



Making a Prototype – 27/04, 30/04, 07/05, 11/05, 13/05: Coding Microcontroller Algorithm

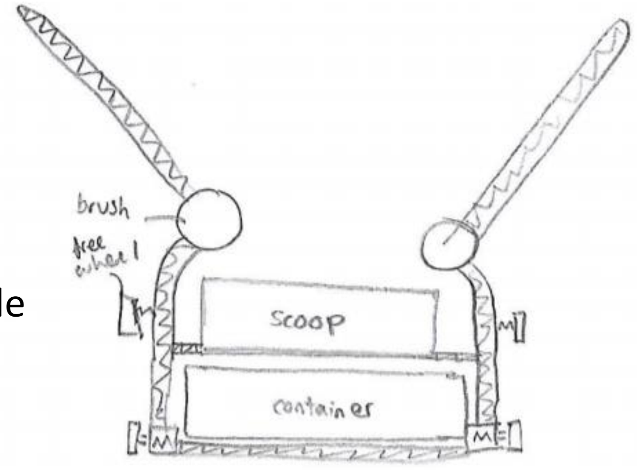
Pictures of test code that I used

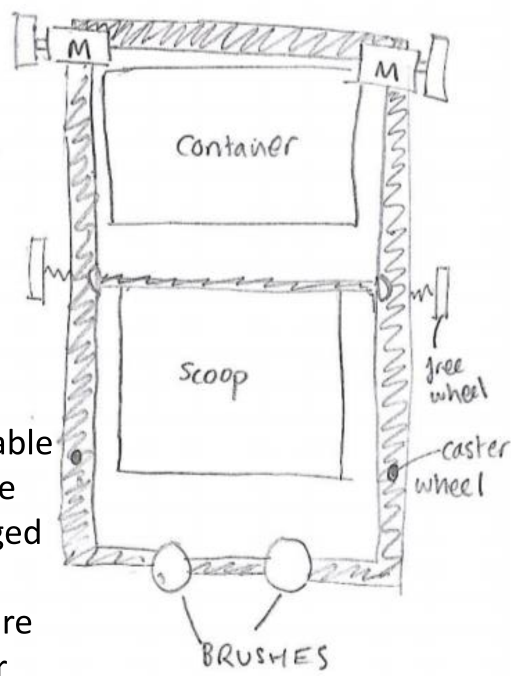
Final Chassis Designing

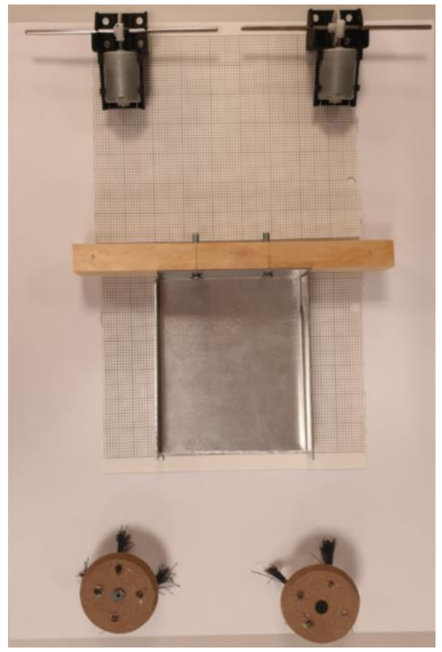


First I considered a similar design to a Roomba. While aesthetically pleasing, it led to inefficient use of space as well as a shapes of parts that would make them unsuitable for picking certain objects up.

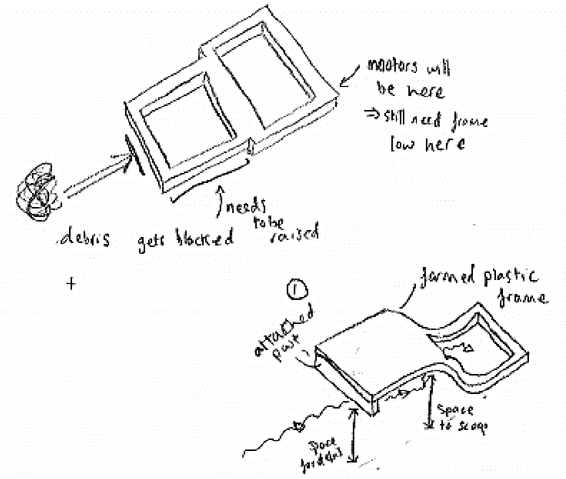
Next I looked back to some previous broom designs for a more rectangular shape. While more reasonable form for its function, the container and sweeper should is right to have a lot of width for large objects however a big length should improve how much can be picked up at once. Also the arms are more a waste of space.

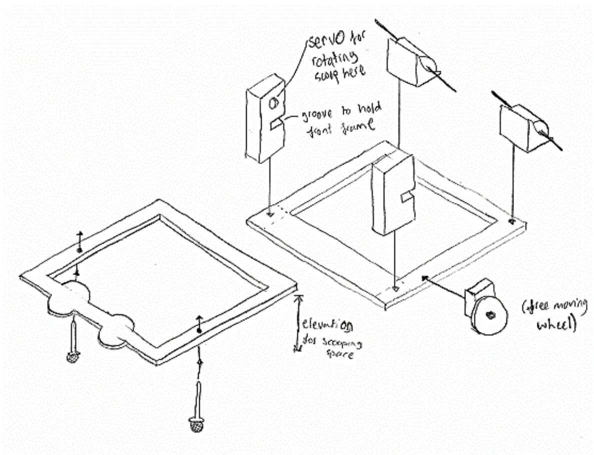




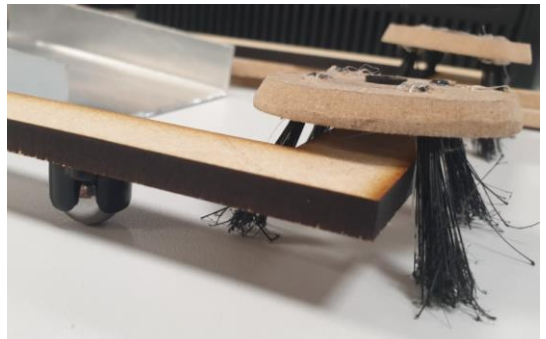


A simple rectangular arrangement quickly became the most reliable and simple option. The parts are easily arranged and the shape of the container and scoop are more than suitable for their function. More study needs to be done to reach a final chassis, however.



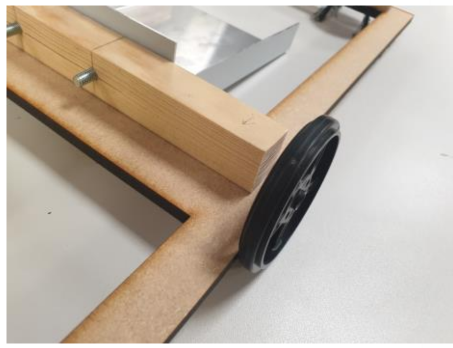


For the chassis to be high enough for the brushes, the caster wheels would not be able to touch the floor. Furthermore, the height required to let all debris into the scoop (~80mm) is far higher than the height of the brushes (40mm). A solution to this would be to move brushes to the sides of the design:

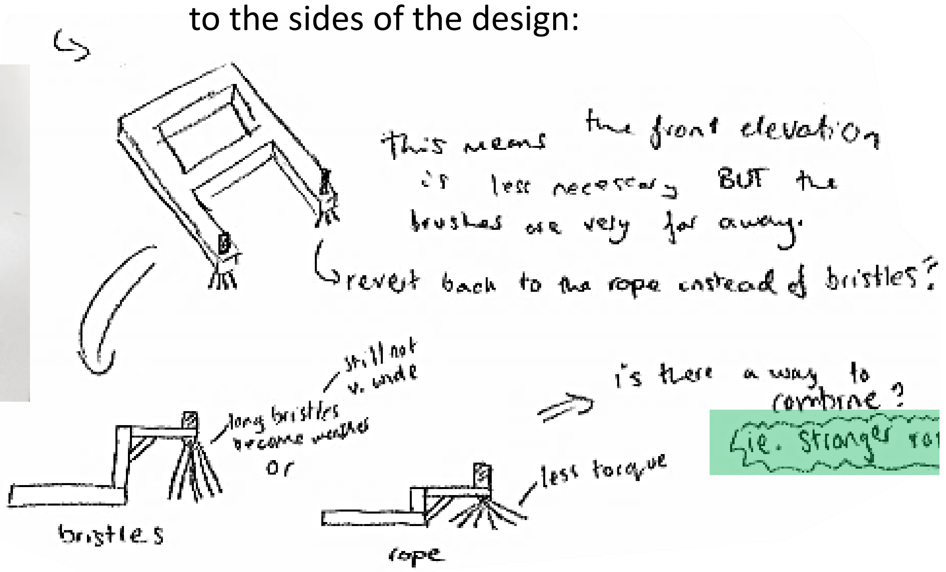


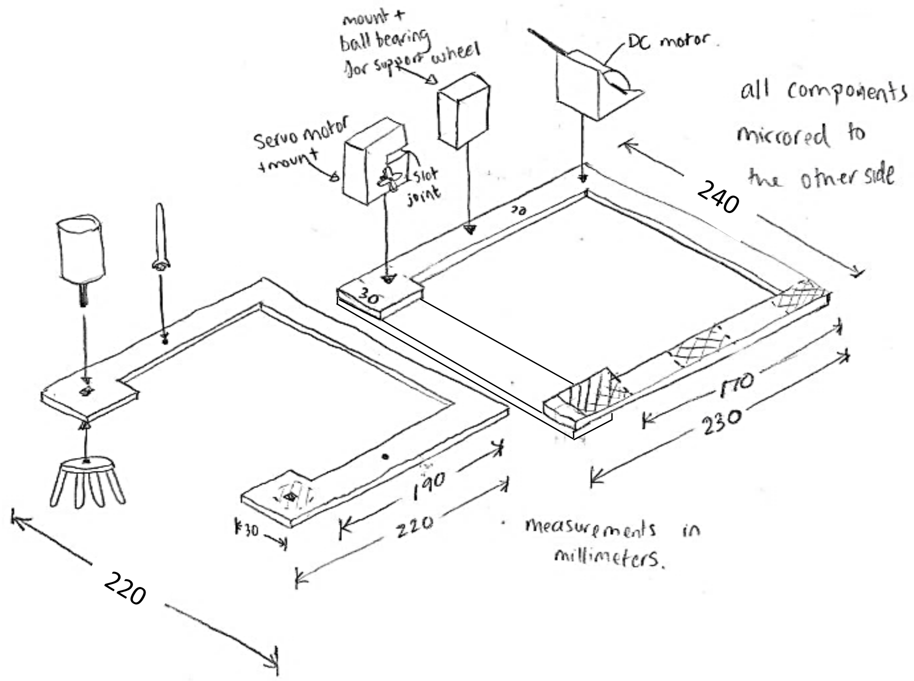
Solution to the caster wheel problem could therefore be to effectively put them on stilts, which I can test when building on the next page...

Even the free-moving wheel needs a mount, so it would be difficult to put it directly beside where the servo for the scoop as shown in the designs above. For a final design, I need to ensure the scoop's servo is as close to the floor as possible (to reduce scoop slope so it is easier to pick things up), and therefore the wheel should be moved aside.



As both the motor and free wheels are so far back, it would be idea to utilise caster wheels at the front as mentioned.



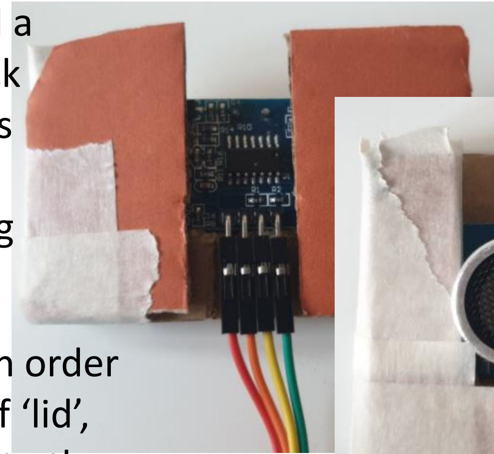


Workshop Additions – Container Changes

Continuing what I started looking at on the previous page, the container is in need of some redesigning to best secure all the parts on it as well as improve the ease of manufacturing by splitting it into multiple parts.

The Ultra Sonic Sensor would be safest if snuggly contained within the casing, but there is a necessity for the wires at the back to be accessibly from the inside too. I took to cardboard modelling to figure out a solution.

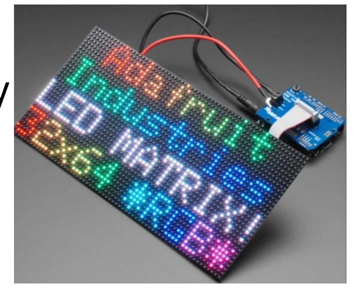
I therefore added a not-filled-out back to reach the wires but also stop the sensor from being too loose.

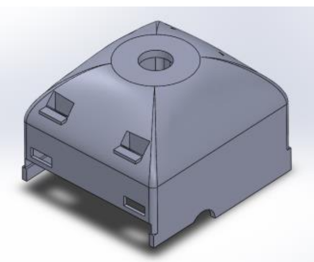


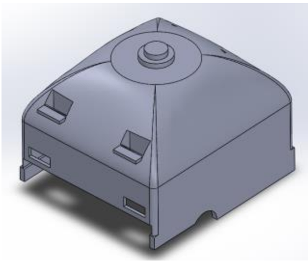
From there I added a base part that could fix to the rest of the casing. I also thought, in order to prevent the sensor from being pulled out, another piece could be added as a sort of 'lid', fixed to the base by screws which also (along with the ones at the bottom corners) fix to the casing. In the case of the top sensors needing a small blocker, this lid is in such a position that it carries this function too. Of course the real one would angle inwards, but that is quite hard to do with card models – this will be represented when I make its 3D model.

In reality this would of course be injection moulded, likely from PVC again.

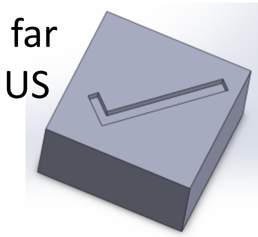
While I am trying to increase ease of manufacture, it makes sense to also see if prices can be decreased. The main increase of costs came from electrical components, so ridding unnecessary ones would be of great importance. I immediately thought to the increased functionality provided by a screen and buttons, this feature (introduced here) was always a handy addition however not in any way necessary and thus the product functions perfectly and fulfils its purpose without it. Ridding it would decrease price of parts, but more importantly massively reduce the work needed to code it as more options means more different paths have to be worked out. I asked my primary café owner stakeholder what she thought of this and we were in agreement.

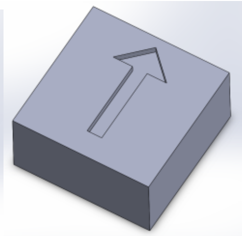




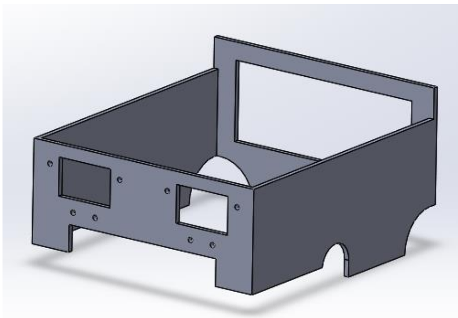


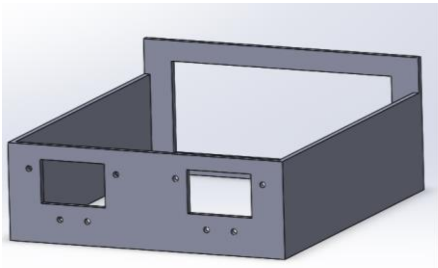
I can also neatly rearrange the container to have the STOP button on the top as shown as this would be far easier to secure than having it on a curved face and it would not have to be squashed between the top US sensors. There is a possibility to remove a servo motor, this I will explore on this page…
Now I need to decide how the new reformed casing will look and fit together:



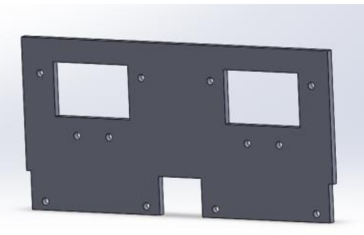


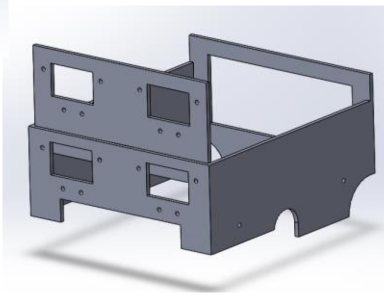
I started with the main casing part that joins to the chassis, modelling its form around the sensor holder I made above.





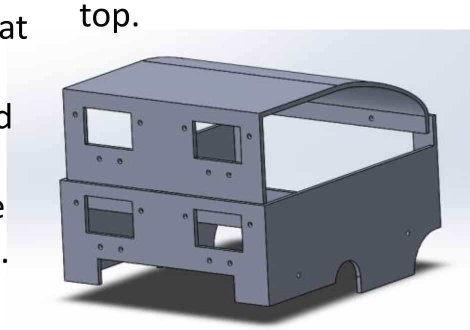
Then the addition from the last page was added, reaching closer to the floor but making sure to not be in the way of sweeper or wheel movement.





To have the top US sensors fit well, a top piece can be made that can use the screws that hold on the bottom sensors (to save on screw holes).

An extension on the top piece joins it to the back along with a flat piece on top.



My thought process is that simple flat pieces like this can be industrially laser-cut. They can then be line-bent to form full shapes. The bottom piece can have acrylic cement applied to join up the first and last side, and top-side pieces can be permanently joined to the top-front piece so it is one part, impermanently screwed to the bottom. This arrangement should allow the top to be removable to access potentially broken parts, or during disposal.

Simple to make it easy for uses

↳ velcro, ↳ button ↳ jubilee clip ↳ toggle latch

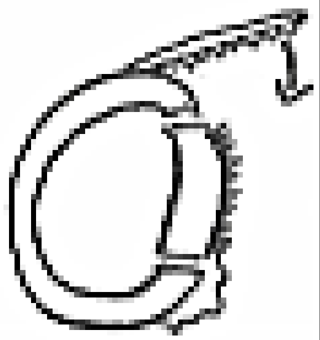
Velcro:
- quick to use
- easy to use
  ↳ + little effort
- can be tightened
- v. small system

Button:
- quick to use
- easy to use
- no tightening
- small system

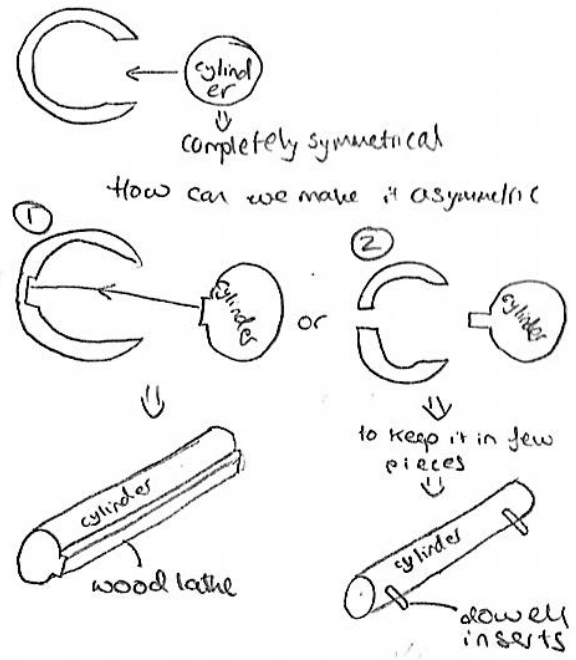
Jubilee clip:
- time consuming to put in.
- very secure
- can be tightened
- may require screw-driver

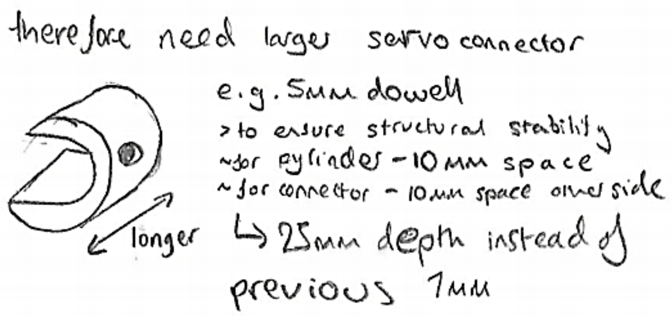
Toggle latch:
- quick to use
- very secure
- one tightness
- requires large metal parts

From the short list of pros and cons of each of the four latch types, it is very evident that Velcro would be the best. Velcro is very easy to use and is universally known how to use. Additionally, the stretchability of it means it can make the insert piece very tightly held. When the insert is taken out to remove the scoop-container, it can simply hang on a small string attached to the connector →

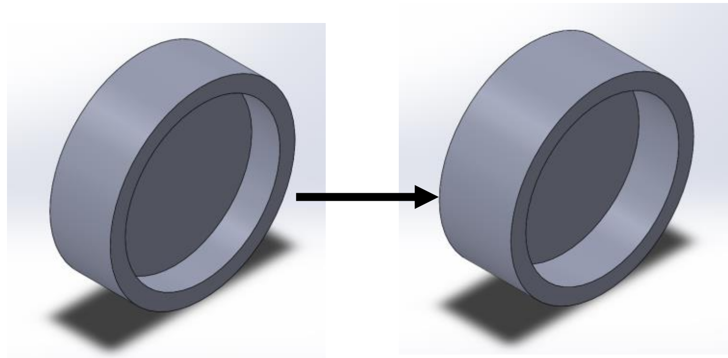


The scoop itself needs to have a certain orientation when the rover is in use and also will need to be in a certain rotation when holding the debris for temporary storage too. The user cannot be relied upon to put the scoop in in the perfect orientation.
There needs to be a way to ensure the cylinder will be put in the servo connector in the correct orientation.

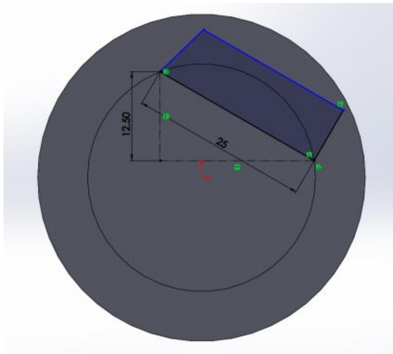




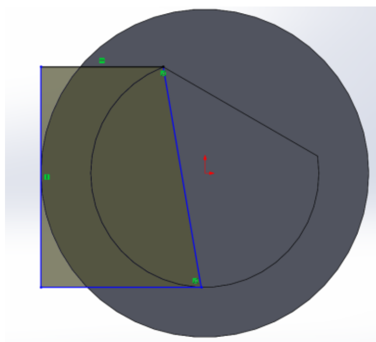
First I had to adjust the size of the connector to fit the 32mm cylinder. I decided to increase the clearance from 7mm to 10mm not 25mm as no screw is necessary and too large a clearance will either make the rover too wide or reduce the width of the scoop (the scoop could be designed to fit around the connector however then it would be unnecessarily more complicated to manufacture.

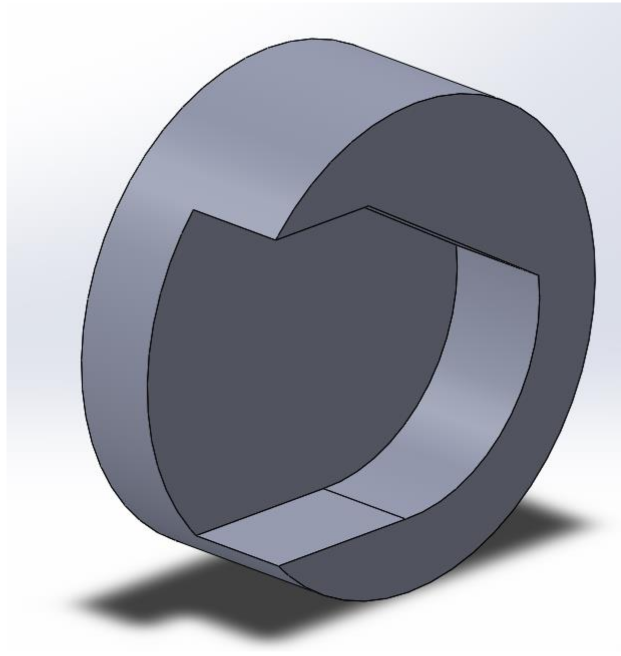


Next I needed to work out where the flat face would be. If the cylinder were inserted through the left side, the face would be on the top right. For the scoop to be flat to the floor, the flat face must be at 30 degrees to the vertical, so a substantial turn of 30 degrees to aid storage would leave the flat face at 30 degrees to the horizontal. Therefore I added a piece accordingly.



I then had to make space for the cylinder to enter through:

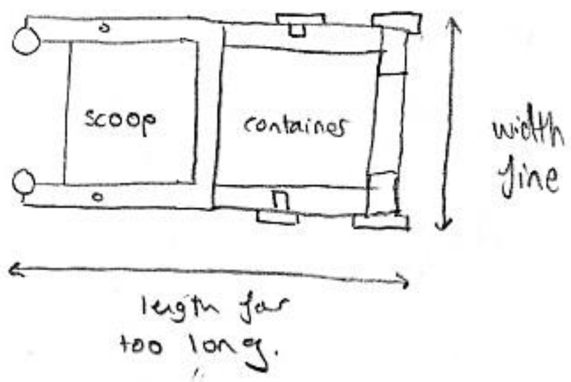




Actually, while this need to make the cylinder asymmetrical is a good idea, it actually already is due to the previous development on this page that added a flat edge to the cylinder to make the scoop easier to add I just need to update the servo connector to deal with that. An added asymmetric piece would stop the cylinder from being put in upside down, however I feel as though that is not something the user is likely to accidentally do.

Reducing Overall Length

As mentioned, there is a desperate need to reduce the length of the design to allow for greater manoeuvrability. There are a few ways I can do this…



① get rid of the container
↳ store above scoop
↳ make scoop store instead

② reduce size of scoop & container
↳ move them closer together
↳ reduce lengths

Before trying ① I should see if ② would work as a solution:
previously specified that I need
- around 2 Litres of space
- 180mm width of scoop & container

If the container length is moved from 170mm to 100mm which would take overall length to around 450mm, the container would need to be about 110mm tall.

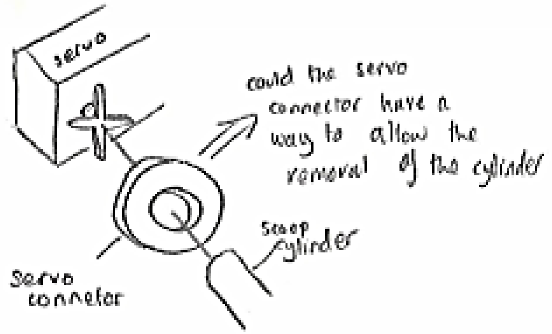
A 40mm increase in height where the overall length has little change. 110mm tall is not too much, however 450mm length still is. Reducing the container length more would exponentially increase height

② Previously mentioned I could make it so the scoop could double as a container. This could be done by tilting the scoop upward as to not allow debris to fall out.

ie.

the servo motor rotates to tip the scoop-container

the problem I had had was being able to remove the scoop-container to get rid of waste.



question: how can the hole be plugged up to stop the scoop falling out when in use?

Method 1: Interference fit
Similar to fitting motors into chassis - plug with rubber-like

pro: stop any vibrations of the scoop
con: difficult to get in & out
↓

handle?
↳ interference fit still very hard to move
if it is not interference it will not stay

Method 2: latch to hold in place
Rather than being tight with connector, a piece can fit tightly with the cylinder

Due to ill-fit with servo connector, needs securing

Simple to make it easy for uses

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- quick to use
- easy to use
↳ + little effort
- can be tightened
- v. small system

↳ button
- quicker to use
- easy to use
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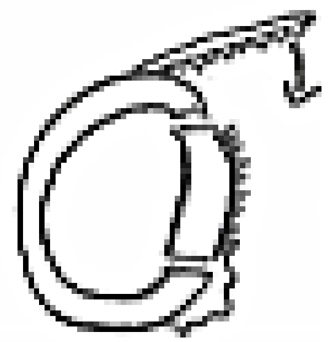


New Chassis Design – Strength and Safety

Before the model is complete, a consideration needs to be made about the safety of the user while interacting with the product, as well as the structural rigidity of the rover to prevent it from being damaged. For this I first need to organise a list of things that I should consider:

Threats toward damaging the rover:

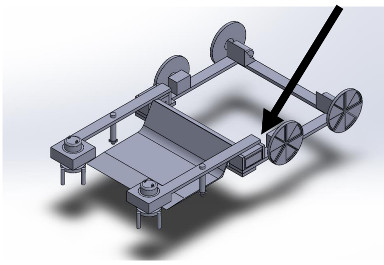
- Being stepped on from above
- Being knocked over or hit from the side
- It driving into a hard surface without realising
- Too much weight being put in the scoop

Threats toward the user:

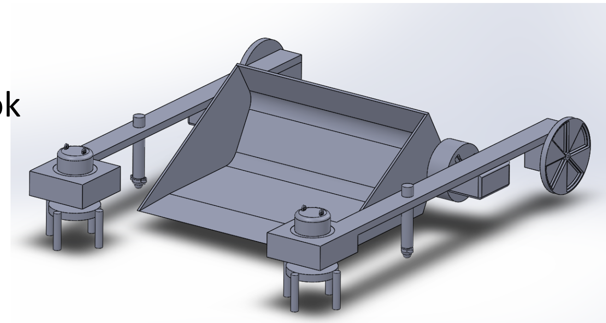
- Tripping over the rover
- Sharp edges
- Potentially exposed wires
- Are Ultra-Sonic waves safe
- Safety when removing the scoop from inside the rover

Threats to the Rover

The rover needs to be prepared to deal with someone stepping on it, or alternatively a weighted object being dropped on top of it.



When I had professional engineers who work at my school look at my previous model they pointed out there are weaknesses in the structure where there are joins as shown by the arrow, this was one of the reasons the new model is held with only one chassis piece on each side, not two joined by the servo between.



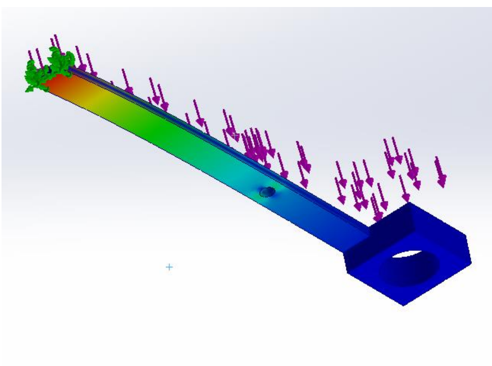
However, the smaller size of the model now means that there is only two wheels and two caster wheels holding it up, reducing its ability to hold weight above it. The 5th percentile of women is 50kg and the 95th percentile for men is 98kg according to hermanmiller.com. However, home testing I have done has revealed when accidentally stepping on an object of 200mm tall tended to be 54% of the persons true weight on average (table of values below).

Taking the value of force exerted by a heavier 98kg person at 54%, the design needs to be safe from a 53kg force being pushed on it. In the state that the design is in, it could only withstand a force like this if it is directly over the top of one of the wheels, the rest of the design would instantly break. A sort of casing would be required to stop the rover from being hit by such a force.

A case was briefly mentioned during the stakeholder presentation as something to protect the product from harm, and forces such as these would be ones to protect it from. Even with a casing, however, the fact that the product is a moving object means the casing is attached to the chassis, meaning the chassis will also have to deal with the great amount of weight too. I went to Solid Works to test whether the chassis arms would be able to stand taking 27kg to the centre if 53kg fell on to the top of casing and was distributed to the sides evenly. For this I am going to use Acrylic as a material to test off of.

I tested the comparison between a person's normal weight and the weight which they might exert if they accidentally walked over a box. Of course this action is acted so it will not be precise but a reasonable estimate at least.

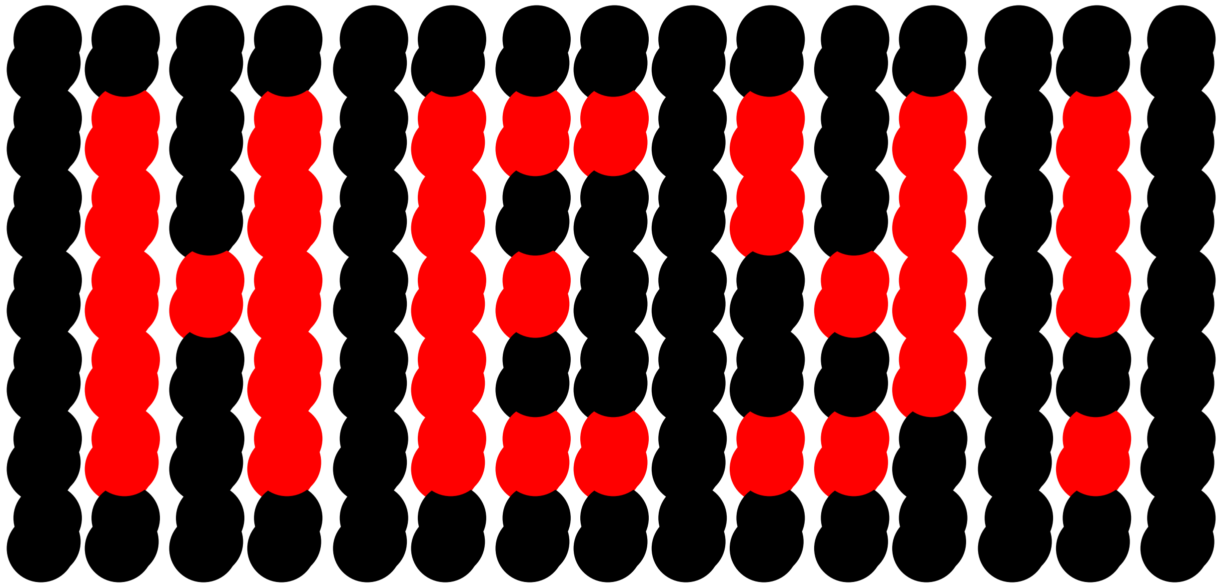
Person's Weight (kg)	Weight Over Box (kg)	Ratio weight to force
82	1/3(42+38+46) = 42.0	0.51
74	1/3(31+41+37) = 36.3	0.56
66	1/3(39+34+32) = 35.0	0.53
73	1/3(41+36+40) = 39.0	0.54



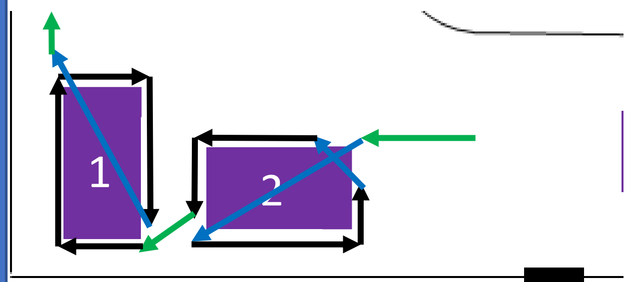
It became immediately clear that under this weight, the arm was under considerable stress. While it would not break, some deformities could arise. In extreme cases, deformities that would be especially bad for the sweepers at the front which if lowered too far down can hit things and permanently break the motor. Additionally, warping of the system could cause insides to be knocked which could damage wiring or the circuit board. All this damage too is only minimised by the incorrect assumption that the joints between all the parts are perfect and fixed.

I have thought of a solution to these problems and that is the use of sacrificial parts. How they work is when under extreme circumstances (such as great force), one thing breaks to ensure other parts of the system do not break. In this case I have devised that to be the joining between the chassis and the casing. While the casing is undesigned as of yet, the way to keep the rover safe from above forces, is to make a casing and have that casing's joint break at above BBkg and hold the force itself to prevent anything else from being damaged. Ideally the joint should be far easier to fix than anything else. The force of BBkg is what I have determined to be the worst amount of mass that the chassis might be able to endure.

New Chassis Design – Casing



Potential lock mechanisms



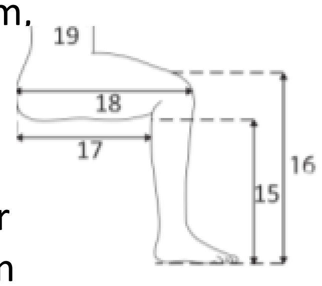
Size of back entrance

Points 4 and 5

To work out how tall the case should be I need to first analyse what makes something a tripping hazard. Hud.gov defines a trip hazard as 'Hazard caused by abrupt change in vertical elevation'. Usually this means anything larger than about 20mm, but I found it difficult to find a solid definition of an upper limit. The 2003 Tomlinson vs. Congleton BC court case ruled that a hazard can only be considered liable for damages it causes if the person who the damages are done toward do not carry any responsibility for the situation. In simpler terms, something is only a hazard if any person around it could act normally and would still be in danger of it. This ruling was used in a thrown out 2005 housing case about someone who jumped over a 400mm fence. It was clear from this case that 400mm was only a hazard if the person was jumping, and since walking is a lot lower, that threshold can be reduced dramatically. From this I would estimate the legal boundary for a trip hazard to be liable for walking person damages it causes to be about 300mm

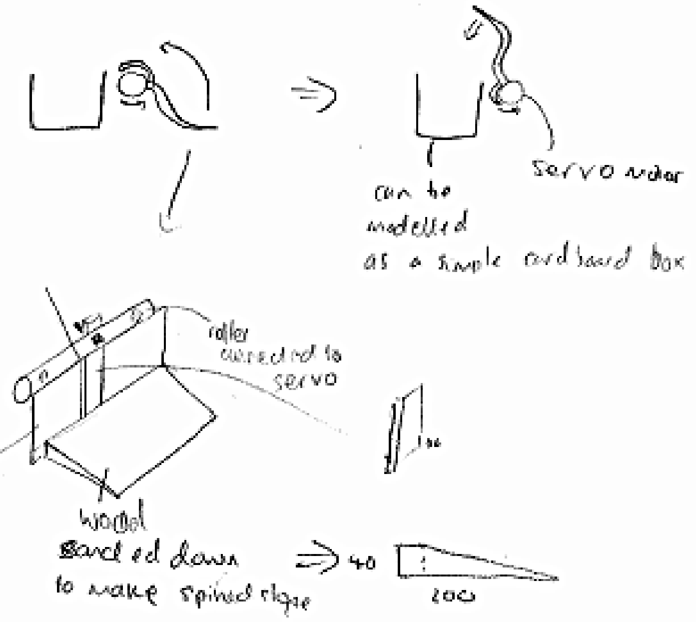
I tried testing myself to see what I might consider a tripping hazard. I would walk into an array of different height boxes to see how I reacted to them. First, I found that anything heighted above my knee was impossible to trip over – due to the fact my leg did not have the freedom to fall over it. Next, I realised as the boxes got smaller, my balance reduced, all until I reached the height of my ankle in the

position shown, when I did actually have the opportunity to trip over. Thus I ruled that the max 'tripping height' would be the height of a foot off the ground while walking + max length of foot. OCR Anthro data 5-95th percentile (cm) says this is 24-29 for men and 22-26 for women. Tests in both stationary and video form led me to the value of feet being max 3-6cm off the floor while walking. This would make the minimum height requirement of around 300-350mm, approximately agreeing with the legal requirement.



The upper requirement is for it to fit underneath chairs. Chair bases, I believe, are modelled after the lower leg length measurement which is (OCR Anthro 5-95th percentile cm) 36-48 for teens, 41-49 for men and 37-45 for women. From this I would estimate the maximum height for the rover to be 410mm however I am going to my mother's (currently closed) local café to test.

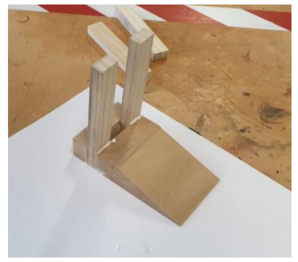
While the brush can help collect the loose pieces of food, food that is stuck to the floor is harder to clean up. One potential idea I referred to in the stakeholder discussion, on [this] page, was to scrape it up and then collect it. This current page will refer to doing that with a scooper, that can also help collect debris picked up by the sweeper(s) too. These scoopers would be rotated back using a servo or similar motor.

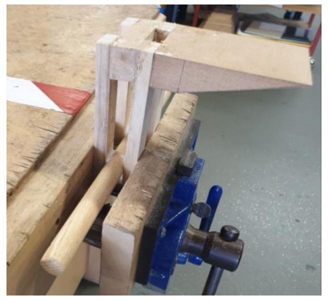


SCOOP MODEL 1

In the case of this, a low down automatic sweeper ~~may~~ may not be suitable. Perhaps an automatic way of picking things up could work

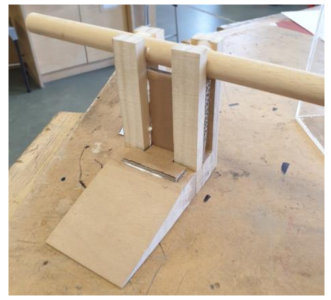
As there will be lots to clear up on every working day, the pan that debris is brushed on to will fill up very fast. To refresh the pan, it could perhaps up turn itself and tip all the collected objects into a separate container so it can then collect more.





To get this to work I decided to make a surface that can be spun over by a servo motor. I used a shallow slope for the 'pan' to make the front edge pointy (to help objects be pushed on to it).

Covering the empty spots with pieces of cardboard, the model was fit for testing – I just had to 3D print a bracket to securely hold the design in place on the servo motor that I will use.



A potential improvement to this model should be made to make it lighter as well as sharper (to scrape things up better).

Shovels can have many different forms. According to [this] website, rounded shovels are more used to dig into things while flatter ones tend to be scooping things from off of a harder floor. Additionally, the edge of the shovel is conditioned for the size of the objects it will be picking up: ranging from sharp edges for compressed finer particulates and flatter block edges for loose pieces of dirt. These ideas can be roughly translated to this context where I would likely look to use a flat headed, sharp edge shovel to be best for scooping off the hard floor and to pick up the wide range of debris (as I k all types, all the way down to fine dust) respectively.

Mini risk assessments

lot
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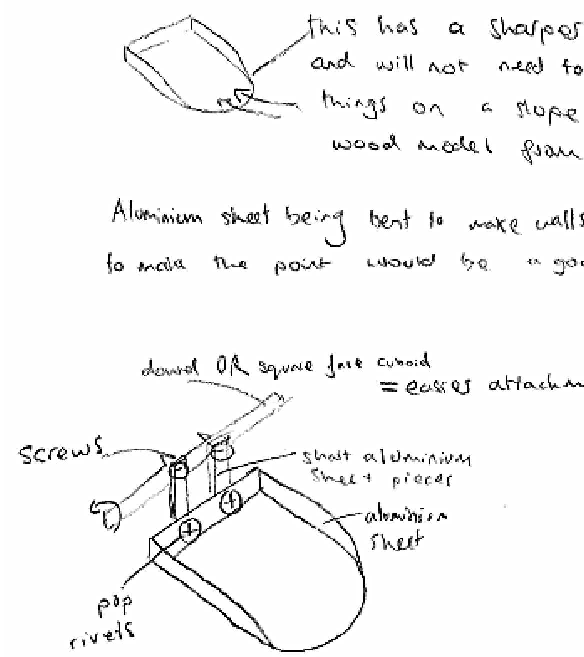
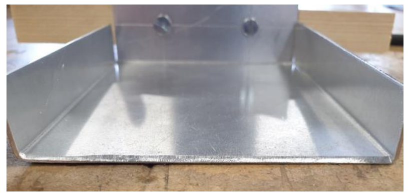


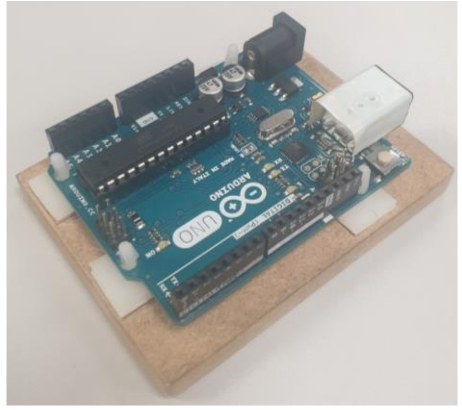
The second model made corrects the problems of the first. Using the design choices of a shovel (as shown left), I could make a scooper that is more suitable for scraping and picking up stuck food/drink. This was possible using metal (Aluminium in this case)

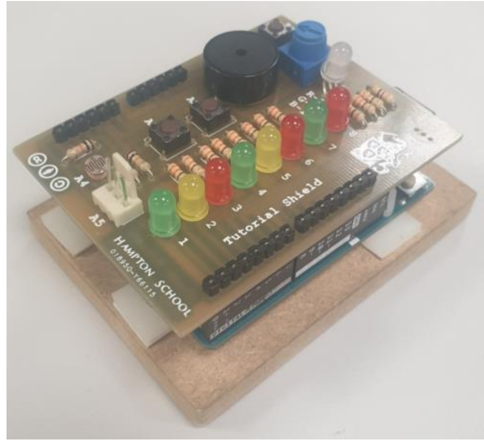


First bending the metal to shape with a bench folder, I could use a rasp to get the sharper edge I desired. Additionally, following shovels, the flat base would mean that objects could be held more stably.

Despite its higher functionality, this model is also lighter – being half the weight of Model 1 as shown below. Additionally, video comparisons shown here and here prove the increased effectiveness of the shovel shape

If I were to go forth with the idea of using a scraping scooper, a sharp, flat shovel would be the better choice.



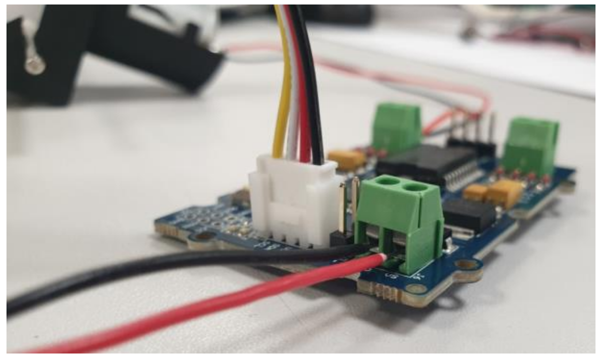


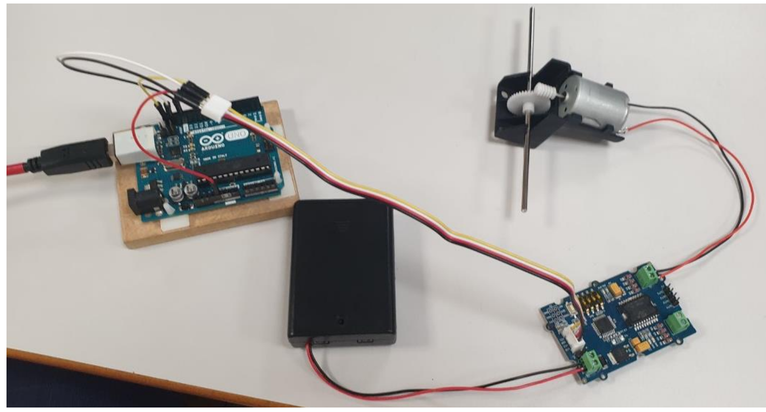
```
#include "Grove_I2C_Motor_Driver.h"

#define I2C_ADDRESS 0x0f

void setup()
{
  // put your setup code here, to run once:
  Motor.begin(I2C_ADDRESS);
  Serial.begin(9600);
}

void loop()
{
  // put your main code here, to run repeatedly:

  Motor.speed(MOTOR1, 50);
  delay(1000);
  Motor.speed(MOTOR1, -50);
  delay(1000);
  Motor.speed(MOTOR1, 20);
  delay(2000);
  Motor.speed(MOTOR1,-70);
  delay(500);
  Motor.stop(MOTOR1);
  delay(1000);
}
```

```
void setup()
{
  pinMode(1, OUTPUT); // R forward
  pinMode(2, OUTPUT); // L forward
  pinMode(3, OUTPUT); // R backward
  pinMode(4, OUTPUT); // L backward
  pinMode(8, OUTPUT); // check

  pinMode(A3, INPUT); // move backward button
  pinMode(A2, INPUT); // move forward button
  pinMode(A1, INPUT); // direction dial
  float dial = 0;
  int direc = 1;
}

void loop()
{
  digitalWrite(8, HIGH); // check on
  float dial = analogRead(A1);
  int direc = map(dial, 0, 1023, 0, 100);
  if (digitalRead(A2) == HIGH) // forward
  {
    digitalWrite(1, HIGH);
    digitalWrite(2, HIGH);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
  }
  else if (digitalRead(A3) == HIGH) // backward
  {
    digitalWrite(1, LOW);
    digitalWrite(2, LOW);
    digitalWrite(3, HIGH);
    digitalWrite(4, HIGH);
  }
  else
  {
    digitalWrite(1, LOW);
    digitalWrite(2, LOW);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
  }
  if (direc <= 15) // turn left
  {
    digitalWrite(1, HIGH);
    digitalWrite(2, LOW);
    digitalWrite(3, LOW);
    digitalWrite(4, HIGH);
  }
  else if (direc >= 75) // turn right
  {
    digitalWrite(1, LOW);
    digitalWrite(2, HIGH);
    digitalWrite(3, HIGH);
    digitalWrite(4, LOW);
  }
  else
  {
    digitalWrite(1, LOW);
    digitalWrite(2, LOW);
    digitalWrite(3, LOW);
    digitalWrite(4, LOW);
  }
}
```

Originally tried with 3 1.5V batteries before noticing that the requirements were 6-15V so I used a 9V battery pack which allowed it to work perfectly. Preliminary testing revealed that it did not favour moving at 'speed 10' or lower so to reduce speed one should consider using a gearbox however to test this I need to put a load on the motor.

Coding the movement + making circuits





Chair bases, I believe, are modelled after the lower leg length measurement which is (OCR Anthro 5-95th percentile cm) 36-48 for teens, 41-49 for men and 37-45 for women. From this I would estimate the maximum height for the rover to be 410mm however I am going to my mother's (currently closed) local café to test.

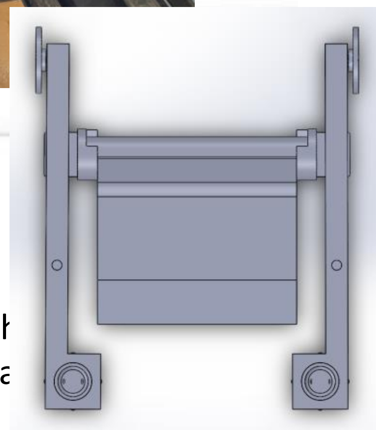
The extreme end of vacuums are industrial vacuum cleaners for dust extraction. They need a very powerful vacuum and require many layers of filtration.

In this, the actual fan is not really much larger than a normal vacuum cleaner. The difference is that the area through which air is ejected and sucked in.

The vacuum has a lot of area for exhaust of the air. It is especially large when compared to the very small end. As we look through the vacuum from fan to head, the air holes get progressively smaller. Smaller area to travel through means the speed of the air's movement is increased

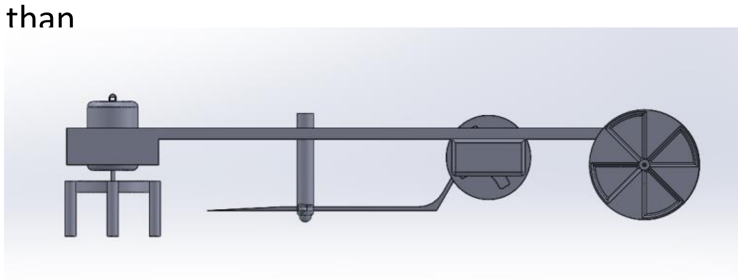
⇒ Bernoulli's Equation:

$$P_1 + \tfrac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \tfrac{1}{2}\rho v_2^2 + \rho g h_2$$

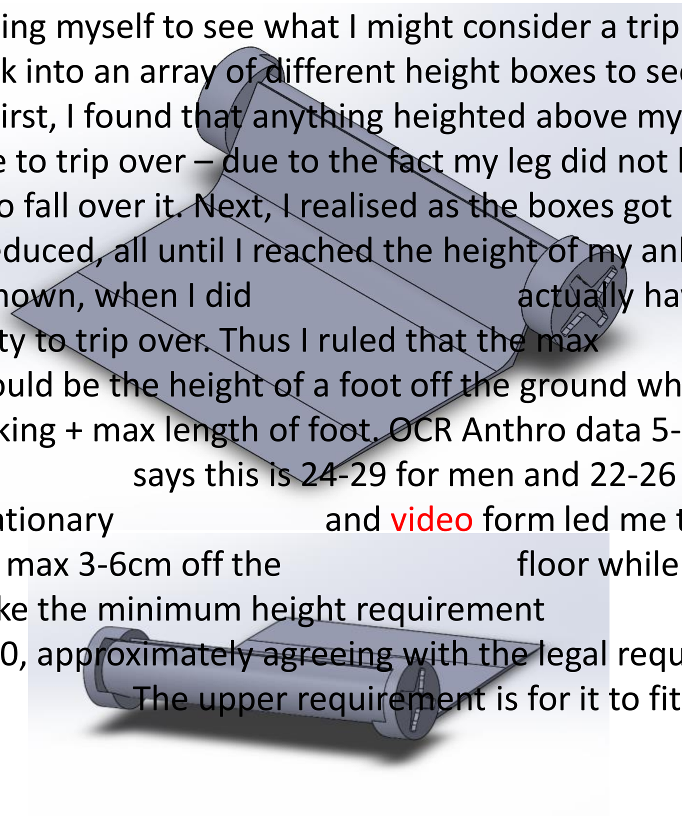


From Bernoulli's equation we can derive a relationship between pressure and velocity from which we can then derive that Area and Volume a directly proportional with a negative correlation. Thus as th surface area of the air intake decreases, the velocity of that air increa by the same factor.

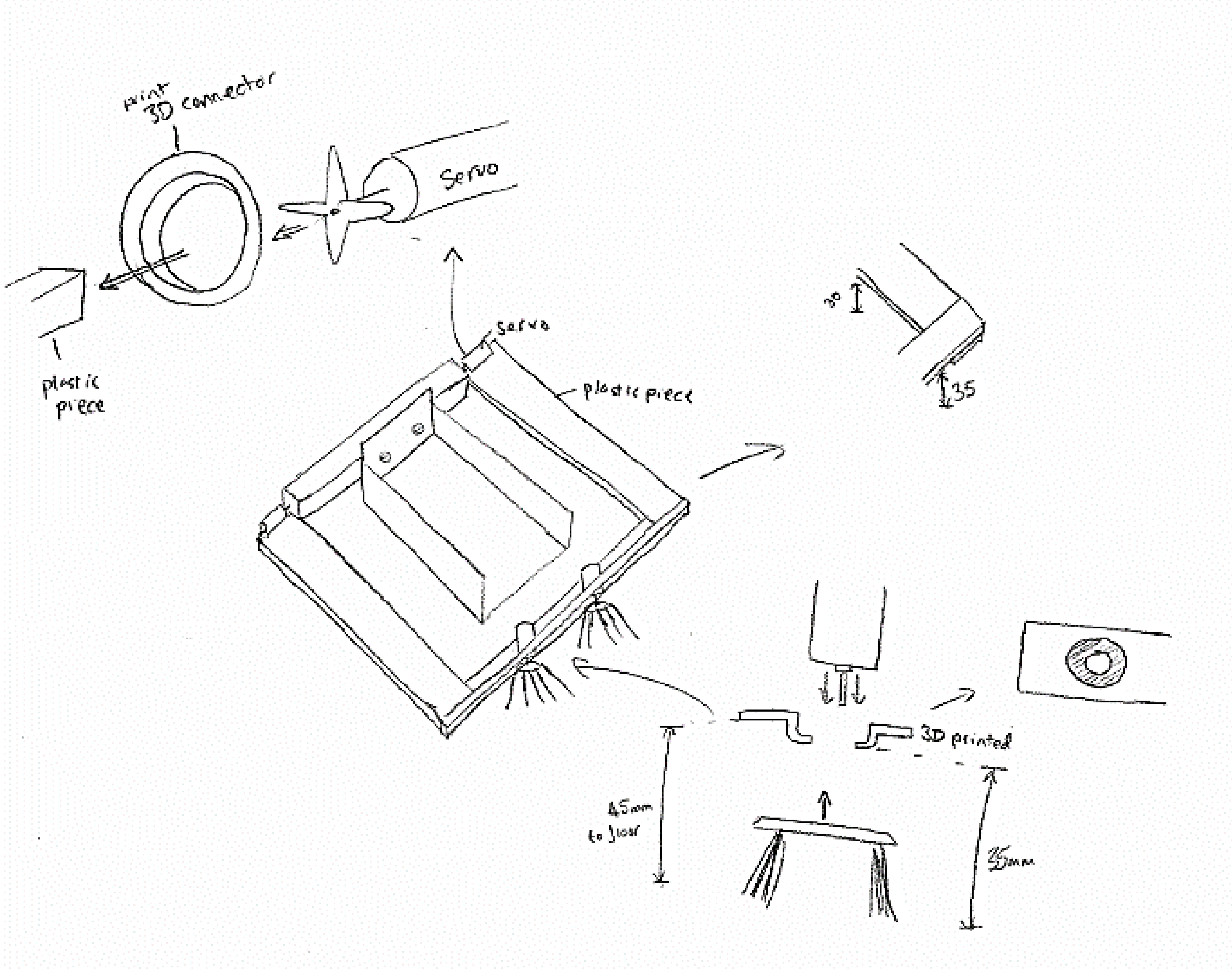
The following video presents the difference in speed. The smaller area head (2) can pick up dust from further away and also pulls it faster than the larger head (1). The video is found through this link.
This more visually demonstrates the Area, Velocity relationship.

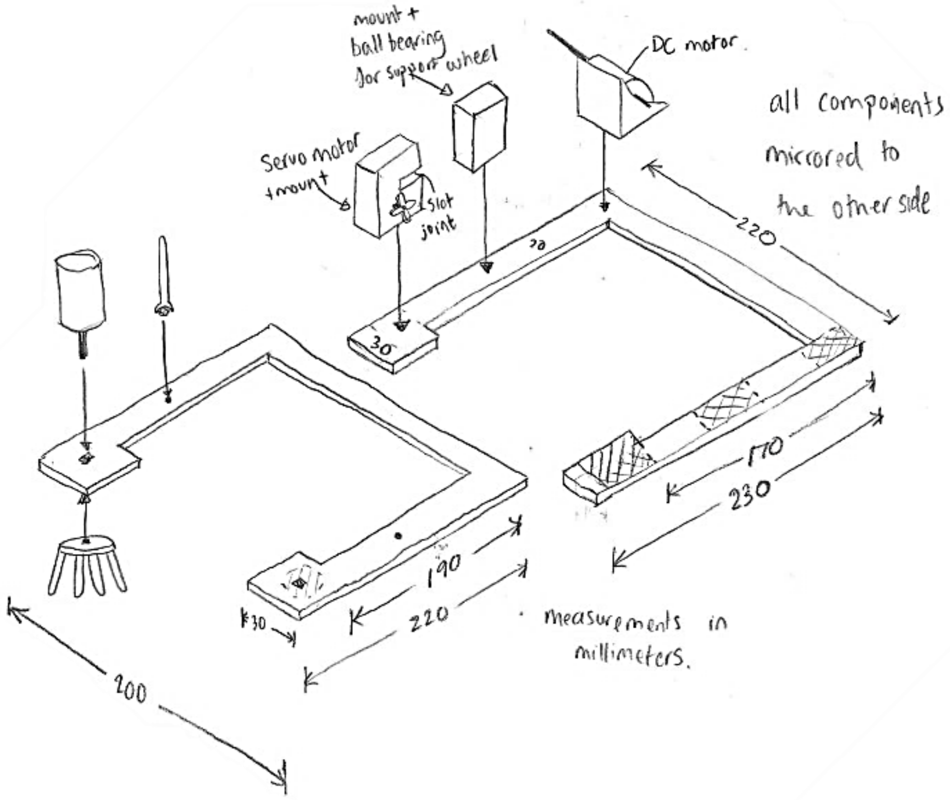


Sorting out sizes of exhaust etc.



I tried testing myself to see what I might consider a tripping hazard. I would walk into an array of different height boxes to see how I reacted to them. First, I found that anything heighted above my knee was impossible to trip over – due to the fact my leg did not have the freedom to fall over it. Next, I realised as the boxes got smaller, my balance reduced, all until I reached the height of my ankle in the position shown, when I did actually have the opportunity to trip over. Thus I ruled that the max 'tripping height' would be the height of a foot off the ground while walking + max length of foot. OCR Anthro data 5-95th percentile (cm) says this is 24-29 for men and 22-26 for women. Tests in both stationary and video form led me to the value of feet being max 3-6cm off the floor while walking. This would make the minimum height requirement of around 300, approximately agreeing with the legal requirement. The upper requirement is for it to fit underneath chairs.





Testing combinations between these systems

Modelling of the combination

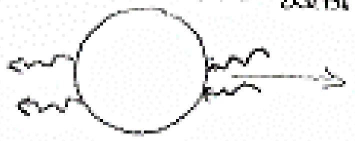
In the interest of reducing physical human input to the system it is likely the best option to go for a motor driven system. Examples of different motors to use would be DC motors, Servo motors or perhaps brushless motors. For the wheels to work best, they should be not too fast, having a strong torque (to push along the full weight of the product), and have a precise turning circle. Brushless motors are not ideal due to their high speeds, while something like a servo motor is precise however not useful for a wheel due to its oscillating motion instead of rotary. I believe that the best motor to use would be a stepper motor. This is because they turn through precise angles, meaning that the product can move to very specific points and make careful adjustments to their positioning. Stepper motors are also characterised as having high torque and very low vibrations at low speeds (via OrientalMotor) – perfect for a slow moving robot.

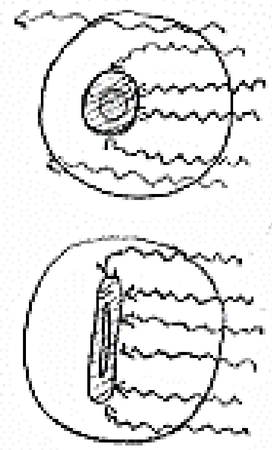
DC motors are also worth keeping in consideration as they are very often used for robots such as these for example being a key part of both Roombas and the mBot.

Technology professionals at seedstudio wrote about the advantages and disadvantages of different motor types. It classed both DC and Stepper motors as very good motors for torque, especially Stepper at low speeds. It also regarded both as very easy to control with a microcontroller. The differences however present the choice between the two motors as a clear decision – Stepper motors are quite loud and incredibly inefficient, especially compared to DC motors, additionally Brushed DC motors are quite a bit cheaper. Brushed DC motors work slightly differently from Brushless DC motors, where brushed are have some noise will brushless have almost none, while brushless motors tend to be more expensive even than Stepper motors.

Talking to my teachers, who are themselves professional Engineers, they were in agreement with me that for these reasons, DC motors would be the best option. The main line of reasoning they used was that the increased accuracy of Stepper motors is not worth spending extra money to purchase – Stepper motors usually provide an accuracy that CNC machines will need, not wheels on my design.

vacuum moves over debris



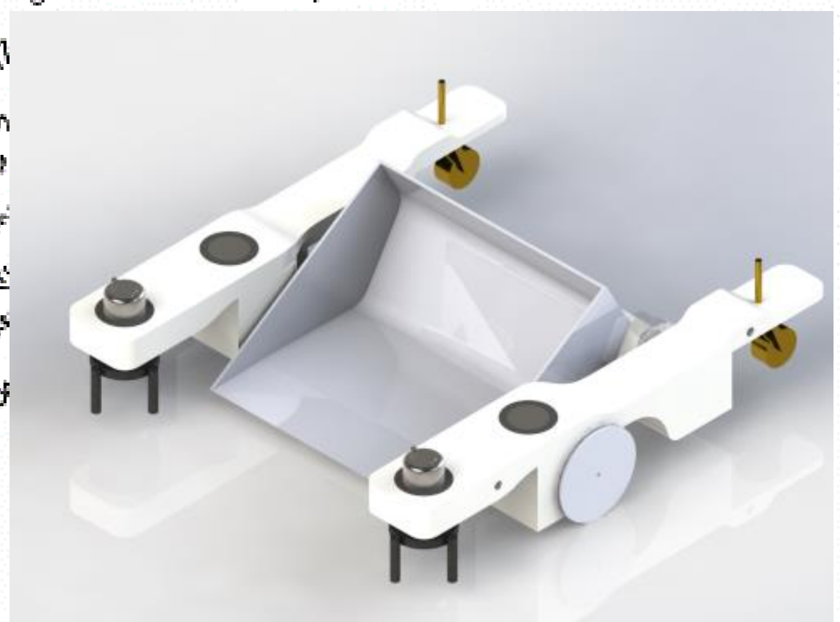


⇒ vacuum opening shape likely one of these two

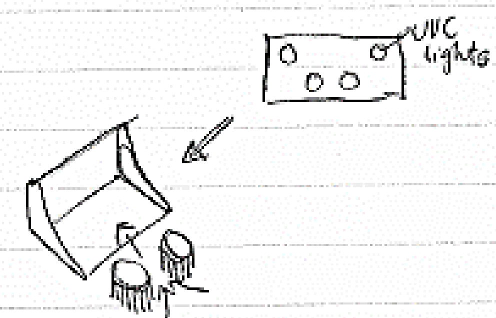
⇒ elongated shapes can covers more of the product's width while maintaining the same surface area

This means the product does not need to go over the debris many times to pick it all up

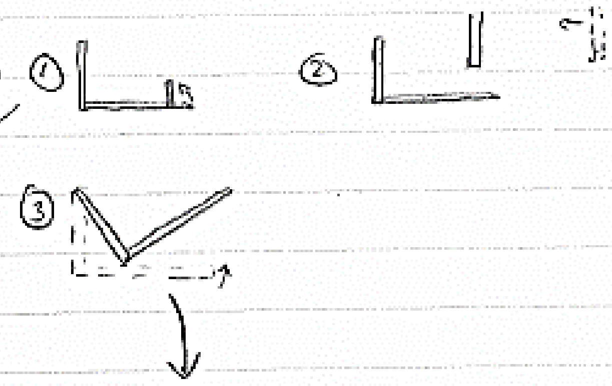
The vacuum exhaust needs to be quite large when compared to

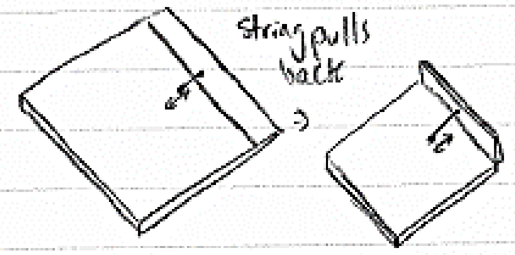


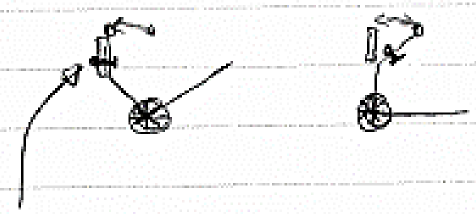
Having many



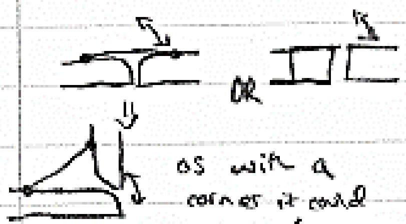
When taking out / when brushes stop pan, how do things stay in? ⇒



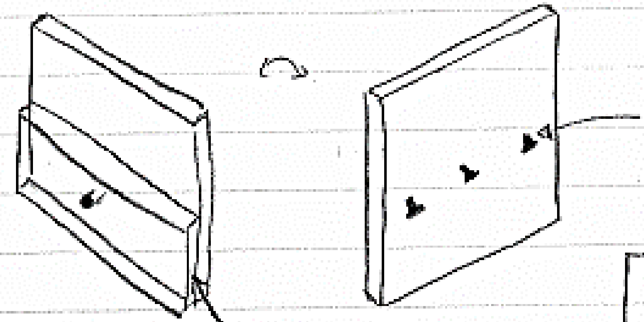


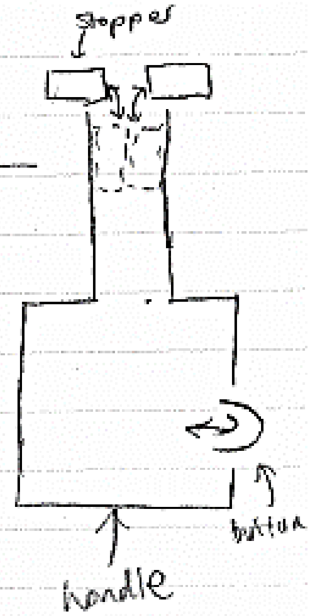


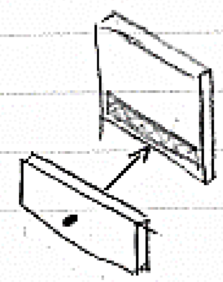
BUT would need a gap :/



as with a corner it could not turn (corners would coincide)







contact to connect circuit (for lights) [as otherwise there would be no way of powering lights]

MATERIALS

In creating a product that can fulfil all the material properties required for it to complete its task in an environmentally friendly and safe way, studying the materials of the products in my product analysis should inform me which properties are important to focus on. This initial look at materials in relation to their properties should help me for when I look at materials in more detail and make final decisions.

Maple Wood as used in the handle of the Eto broom:

- Hard and resistant to shocks and dents
- Even grain and fine texture
- Not that expensive
- Relatively strong (~7000psi)
- Can be finished to be slightly more water and chemical resistant

Aluminium as used in the handle and mechanisms of the folding dust mop:

- Not Ferrous and hard to corrode
- Relatively soft
- Very lightweight
- High Strength (~13000psi)

There are also natural bristles such as Plant Veins on Eto brooms or broomcorn (a plant grown especially for old brooms). They are therefore biodegradable, and has hair-like follicles which trap dust and are waterproof. They do however have a tendency to break and split.

Nylon as used in the handle and end of the modern plastic broom:

- Hard and resistant to shocks and dents
- Thermoplastic and easily shaped
- Very cheap
- Very strong (~12000psi)
- Chemical & water resistant
- Quite stiff

PET bristles were used on the modern plastic broom:

- Thermoplastic and easily formed
- Relatively stiff
- Chemical resistant
- Good heat resistance
- Waterproof

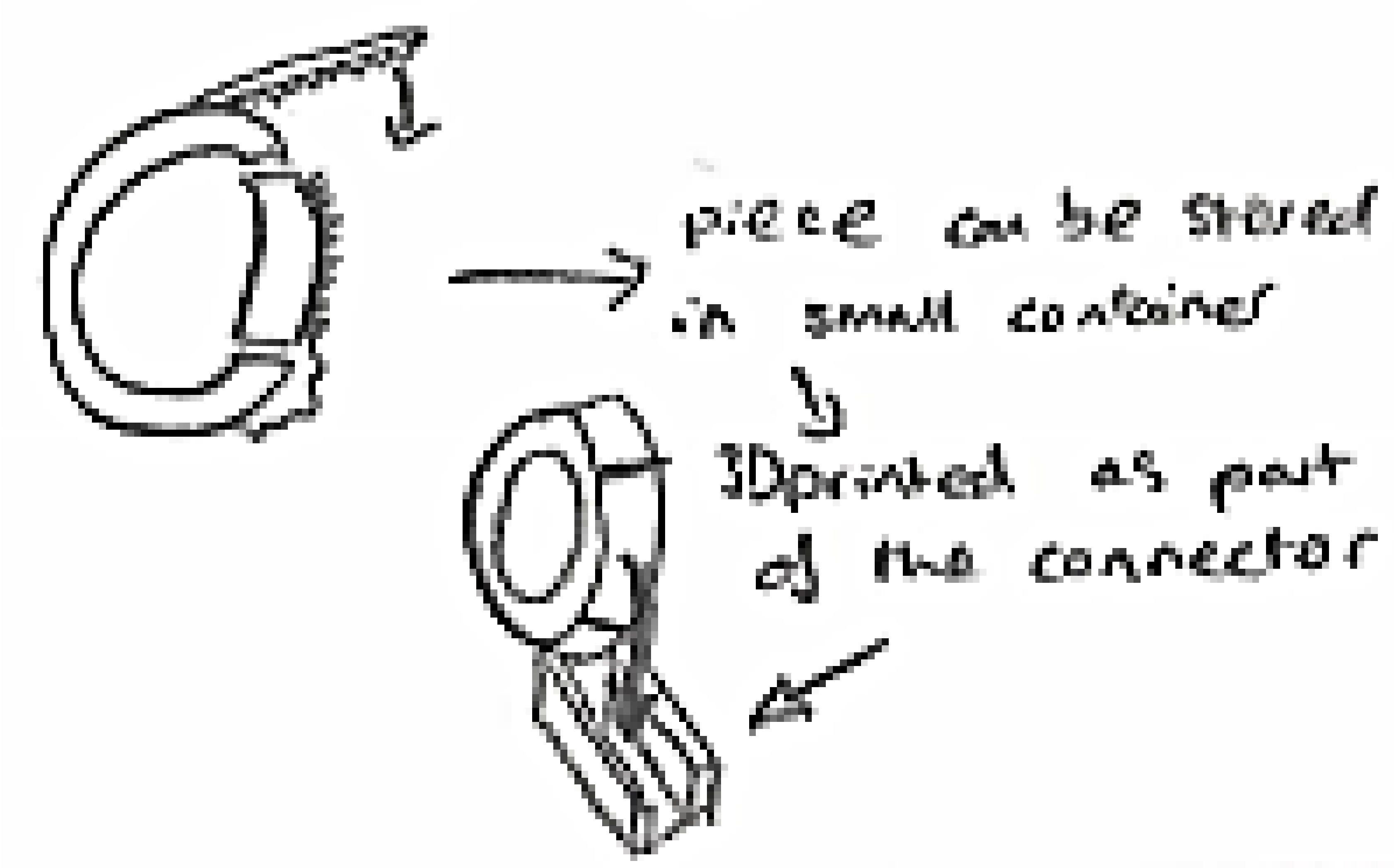
For PET, bristles are made to have either flagged or unflagged ends. Flagged ends are split ends which are more ideal for fine dust particle. Unflagged means the bristles are solid and so stiffer, better for wet surfaces and larger objects.

From this data we can understand what properties we need to focus on. For the handle I should look to get a hard, smooth material which is therefore comfortable to hold and use for a long time. Strength is also important as the product would likely be knocked against many things. To help with versatility of its use, the design as a whole should be quite lightweight, even with any mechanisms it contains.
For the bristles, I need to have my material be relatively stiff, and it is imperative it is water and chemical resistant. To decide whether to use a flagged or unflagged material end, I must first fully understand the surface dirt types I aim to clean which I will later explore. Obviously the bristle material must be reliable for long term use and have some positive environmental output (e.g. biodegradability or recyclability). Finally, to mass produce a product like this, the parts must be easily made, which rules out the use of Broomcorn as it must all be grown slowly and carefully for its use in bristles

WORKING SPECIFICATION

A short temporary specification with more vague points should help encapsulate the research thus far to help figure out what is to be further explored.

	Point	Justification
Purpose	a) Can clean up larger rubbish easiest b) Can fit between a chair c) Able to clear all forms of debris	a) Most common inside floor b) Smallest gap it must enter c) Useful for all terrain and places
Function	a) Change of size accessible automatically or through one input b) Can pick up dust still c) Has a method of reaching corners	a) Easy to change size while using it. b) Useful for all terrain c) Every bit of debris reached
User Requirement	a) Input ergonomically placed b) Soft material for holding c) Allows all spaces to be reached	a) Easy to use mechanisms b) Comfortable for long periods c) Faster and easier cleaning
Performance	a) Must be delicate on floor surface b) Method of picking up all debris and dirt	a) No unnecessary damage caused b) Truly clear the floor area
Materials	a) Material soft & hard on handle b) Bristles chemical resistant c) All environmentally friendly	a) Comfortable & no scratches b) Able to be in harmful liquids c) We should help the environment always
Size & Form	a) At least 1.5m tall b) Width between 30 and 45mm c) Bristles at least 50mm	a) Low 5% of women height b) Either limits of grip size c) Raised enough for all debris
Safety	a) Bristles not too sharp or too flagged b) Handle hard and strong c) No sharp corners d) No exposed mechanisms	a) Doesn't scratch skin b) Ensure splinter-proof c) No opportunity for scratching d) Cannot be caught in them
Quality	a) Mechanism is hidden b) Built for disassembly	a) Encapsulation & no extra user input b) Easier to recycle parts



higher angle → more accurate position fix

lower angle → larger distance

I would say just over 2m is enough space as 1m means there is enough space to maneouver but not enough time to necessarily read the bots surroundings fully.

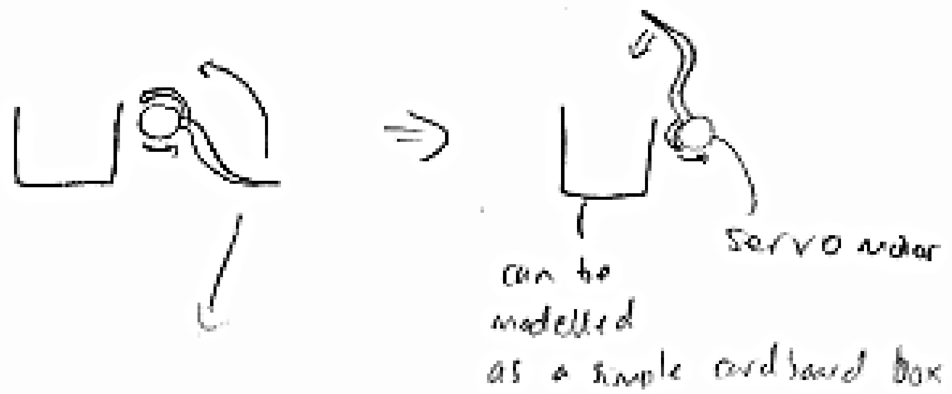
∴ I think $\theta = 50°$ should be best.

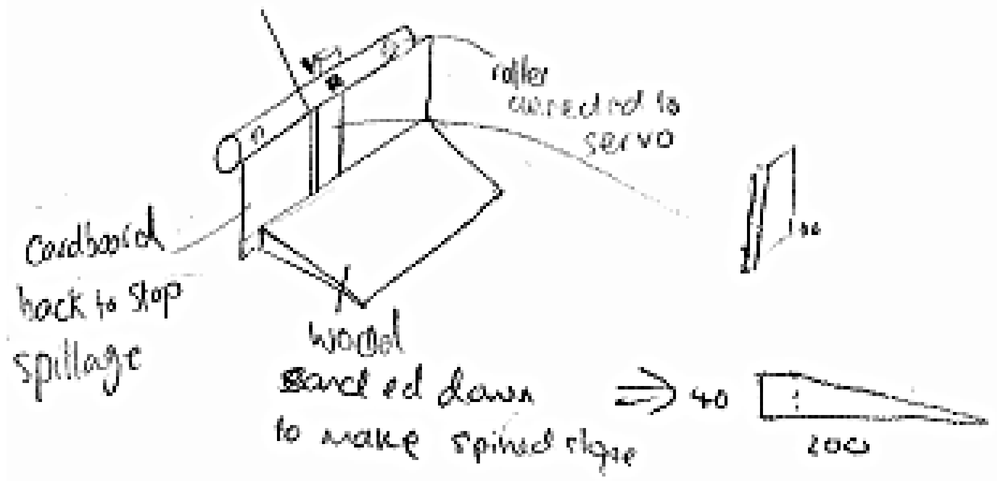
HEAVIER RESEARCH INTO BRISTLE MATERIALS AND HOW THEY WORK/WHAT EACH ONE DOES AND IS GOOD FOR

Microfibre bristles-
Some hair brushes utilise compact bulbs of microfibre which are especially good at absorbing and holding moisture and fine particles. For this reason they are also used in dust mops, however their incredible lack of structural rigidity would make them unsuitable for sweeping anything more than dust and water. Therefore I could look to implement a combination of microfibre chunks and [ ] bristles as this would allow management of both clearing waste, and leaving the floor with a shinier and drier finish. (reference pic to remind me →

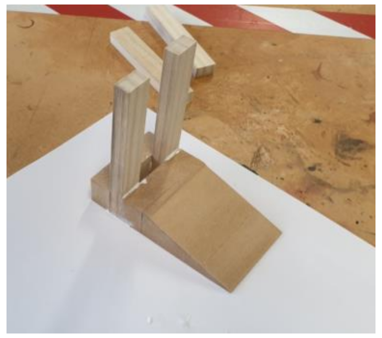
Additionally, squashed food also needs to be scrubbed up. According to the café workers, brushing can quite often not fully work and it may require manual scrubbing or a dust pan & brush.

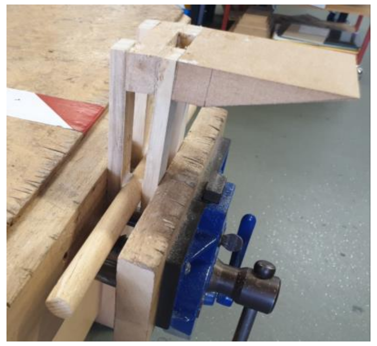
In the case of this, a low down automatic sweeper ~~~~ may not be suitable. Perhaps an automatic way of picking things up could work





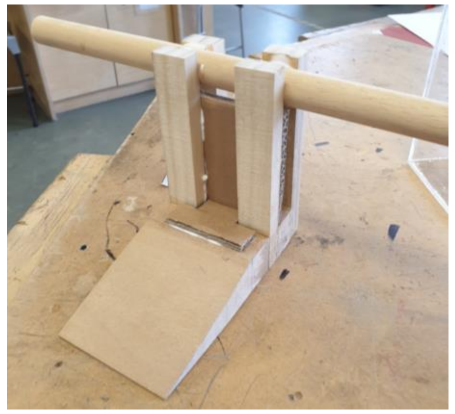
As there will be lots to clear up on every working day, the pan that debris is brushed on to will fill up very fast. To refresh the pan, it could perhaps up turn itself and tip all the collected objects into a separate container so it can then collect more.





To get this to work I decided to make a surface that can be spun over by a servo motor. I used a shallow slope for the 'pan' to make the front edge pointy (to help objects be pushed on to it).

Covering the empty spots with pieces of cardboard, the model was fit for testing – I just had to 3D print a bracket to securely hold the design in place on the servo motor that I will use.



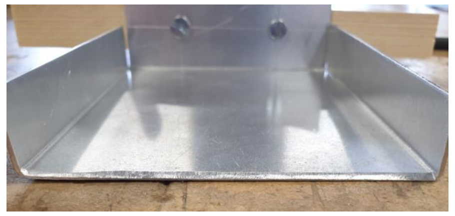
Evaluation of testing inc video testing

The wood in this case takes a lot of effort to make smooth and is very difficult to shape. The alternatives, plastic and metal, are far more shapeable with better working properties

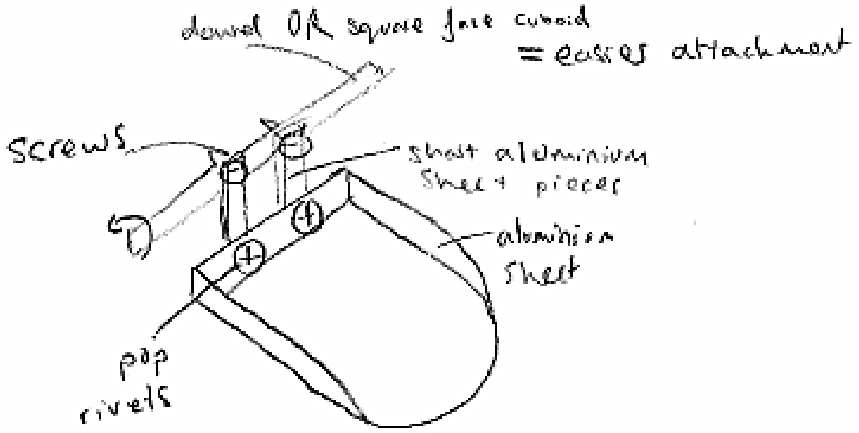
Additionally wood is far heavier than plastic and metal (if used as a sheet). Perhaps instead I could replicate a shovel or spade

Shovels can have many different forms. According to [this](#) website, rounded shovels are more used to dig into things while flatter ones tend to be scooping things from off of a harder floor. Additionally, the edge of the shovel is conditioned for the size of the objects it will be picking up: ranging from sharp edges for compressed finer particulates and flatter block edges for loose pieces of dirt. These ideas can be roughly translated to this context where I would likely look to use a flat headed, sharp edge shovel to be best for scooping off the hard floor and to pick up the wide range of debris (as I want to pick all, all the way down to fine dust) respectively.

this has a sharper point and will not need to collect things on a slope like the wood model from before



Aluminium sheet being bent to make walls and sharpened to make the point would be a good start



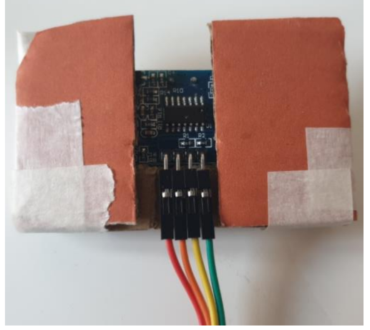
Evaluation of testing inc. video testing

Workshop Additions – Container Changes

Continuing what I started looking at on the previous page, the container is in need of some redesigning to best secure all the parts on it as well as improve the ease of manufacturing by splitting it into multiple parts.

The Ultra Sonic Sensor would be safest if snuggly contained within the casing, but there is a necessity for the wires at the back to be accessibly from the inside too. I took to cardboard modelling to figure out a solution.

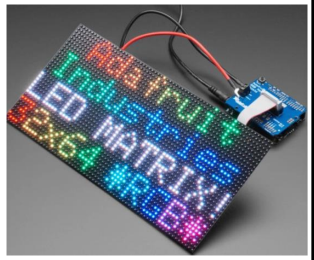
I therefore added a not-filled-out back to reach the wires but also stop the sensor from being too loose.

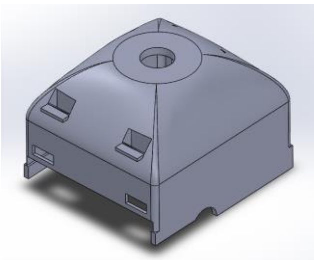


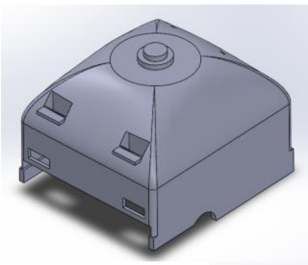
In reality this would of course be injection moulded, likely from PVC again.

From there I added a base part that could fix to the rest of the casing. I also thought, in order to prevent the sensor from being pulled out, another piece could be added as a sort of 'lid', fixed to the base by screws which also (along with the ones at the bottom corners) fix to the casing. In the case of the top sensors needing a small blocker, this lid is in such a position that it carries this function too. Of course the real one would angle inwards 30 degrees, but that is quite hard to do with card models.

While I am trying to increase ease of manufacture, it makes sense to also see if prices can be decreased. The main increase of costs came from electrical components, so ridding unnecessary ones would be of great importance. I immediately thought to the increased functionality provided by a screen and buttons, this feature (introduced here) was always a handy addition however not in any way necessary and thus the product functions perfectly and fulfils its purpose without it. Ridding it would decrease price of parts, but more importantly massively reduce the work needed to code it as more options means more different paths have to be worked out. I asked my primary café owner stakeholder what she thought of this and we were in agreement.



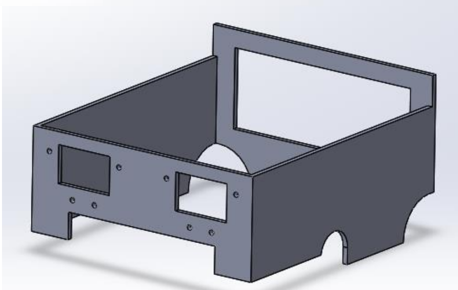


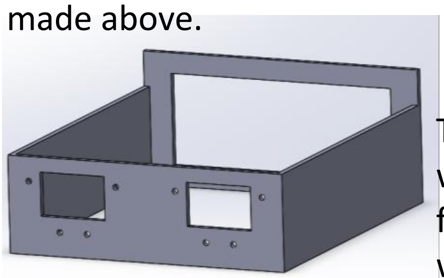


I can also neatly rearrange the container to have the STOP button on the top as shown as this would be far easier to secure than having it on a curved face and it would not have to be squashed between the top US sensors. There is a possibility to remove a servo motor, this I will explore on this page…

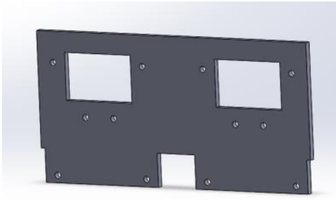
Now I need to decide how the new reformed casing will look and fit together:

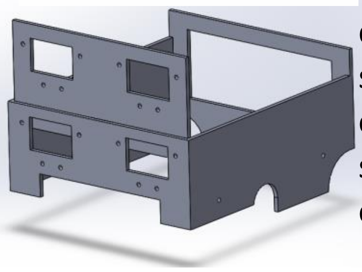
I started with the main casing part that joins to the chassis, modelling its form around the sensor holder I made above.





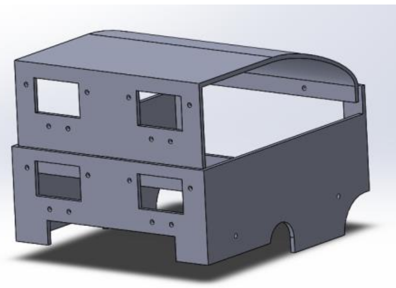
Then the addition from the last page was added, reaching closer to the floor but making sure to not be in the way of sweeper or wheel movement.





To have the top US sensors fit well, a top piece can be made that can use the screws that hold on the bottom sensors (to save on screw holes).

An extension on the top piece joins it to the back along with a flat piece on top.



Monitoring a Servo Motor Overload

As mentioned on this page, If too much weight is placed on the servo, it could irreversibly damage it so precautions need to be set. Already there is a bar underneath the servo cylinder that should provide protection, but more contingency must be made. Only very expensive servo motors have closed feedback loops, so instead I have to find a way to make my own.

Forums about coding closed loops into Servo motors included the mention of using a Potentiometer to monitor the output of the Servo. Using this incredibly cheap Potentiometer, I created a circuit that did what was required – in which I used standard code straight from the Arduino Library to test. Therefore I will have to factor that in to my code and flowcharts.

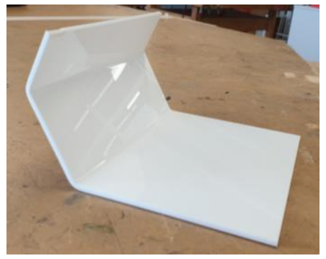
Pic of potentiometer or whole circuit

My thought process is that simple flat pieces like this can be industrially laser-cut. They can then be line-bent to form full shapes. The bottom piece can have acrylic cement applied to join up the first and last side, and top-side pieces can be permanently joined to the top-front piece so it is one part, impermanently screwed to the bottom. This arrangement should allow the top to be removable to access potentially broken parts, or during disposal.

Workshop Additions: Scoop's Weight Limits

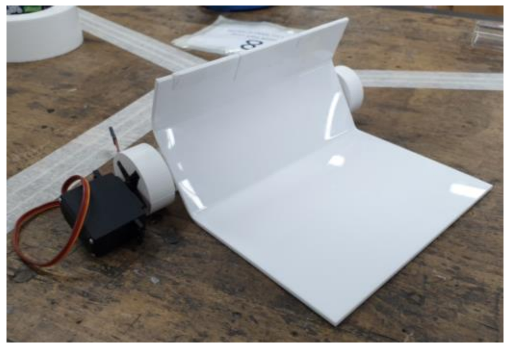
The Servo Motor I had been using due to its very high availability and cheapness was the Tower Pro MG 996R (here on amazon), it is clear they go down in price dramatically in bulk. My initial design made use of two servo motors, one on each side, which would lift the scoop together, however I can reduce the price of components if one servo motor is enough. If neither one nor two servo motors can lift the scoop with the required weight added, I should look to use a different servo motor, or a different scoop design such as that discussed on this page.

In order to conduct the function testing I need to build a test rig which is similar to the actual scoop I would use (in form and construction). This would ensure moments and forces are in the same proportion. To add a layer of confidence, however, I can make the parts out of a slightly heavier material. My actual design is planned to be made from Nylon (1150kg/m3), so by using Acrylic (1200kg/m3), the described effect can be made. Meanwhile, I still used PVC tubing as it was the most available to test with, but used a 6mm thickness not 5mm as described. I began construction by laser cutting an acrylic sheet to make the correctly sized and market out scoop before line-bending it to make the desired form (method for line-bending will be discussed during prototype manufacture).



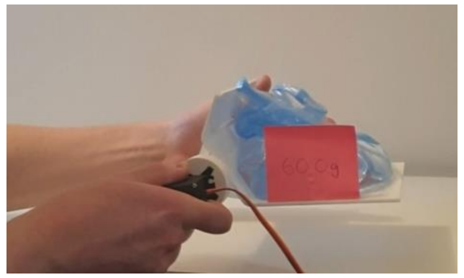
I ran the 3D printer to make one servo connector for each side between lessons, having modified the design to account for the fact that I did not need to remove the scoop from it (i.e. no insert).

The next lesson I took the PVC tubing and draw filed it down to create a flat face, this was quicker than 3D printing it (for a small scale like testing), which allowed adhesive to be more easily applied to the scoop to create the desired joint.
Once this was done, I used single component acrylic cement to join the pieces and interference fitted the cylinder to the servo connectors as shown to complete my model. I also quickly made some test code (shown below).



```
#include <Servo.h>
Servo tower_pro;

void setup()
{
  tower_pro.attach(9);  //  Arduino pin 9 = servo motor
}

void loop()
{
  tower_pro.write(0);   //  reset position
  delay(5);
  tower_pro.write(40);  //  extra turning to add confidence
  delay(5); }
```

With my new model I could test the scoop's proficiency at holding itself up. When empty, the scoop easily and smoothly moved just as intended (shown here), but what really mattered was how it functioned with weight. When deciding size requirements of the scoop I mentioned the height of a water bottle as the largest object, so I could model the weight requirements around this too – being about 700g when full. There are other items, however, that are also quite heavy – such as (possibly broken) mugs being 600g or plates being 400g. Ideally, the scoop should have the ability to hold multiple objects of this weight range which led me to decide that the scoop must be able to hold (and tilt backward) at least. Weight data for these items were from parcl.com. I therefore tested with ascending weights to find the limits. As planned, I began by testing with only one servo, and held up the other side to grant some stability. I tested 100g, 200g, 500g, 600g and 700g to see how it faired (videos linked on respective numbers).



The servo motor could lift the 100g and 200g bags with ease as I had hoped. The 500g bag there was a slight lag on the down stroke (which as discussed above is not a primary function) but it worked with good results; the 600g gave more resistance to motion, which meant that the servo succeeded but did so slowly and could not quite reach the full 40 degrees, then finally it failed at 700g. Initially I had thought that by simply adding a second servo on the other side I could double the torque, however this was not the case. Another servo likely did not increase force only improved stability to allow it to fail at 800g instead. Despite failure to reach 1000g, this test was a very solid proof of concept: the design that I used effectively tipped the weights back to hold them in place and had the ability to carry significant mass and therefore is a successful design. What this means is rather than redesigning the scoop, by investing in slightly more powerful servo motors the 1000g requirement can be easily reached. A limit of 800g is still sufficient in almost every occasion but the extremities, so the current servos can act as a lower-end model easily, but a higher end model (with the 1000g requirement) can be easily reached by swapping out the servo for one like this which is the same size, slightly more expensive, but nearly doubles the force output. Nevertheless, no matter what the weight limit, there should be a protocol for if the scoop is overloaded – perhaps a closed loop - explored here.