wAIste

End of Term Report

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v	Description	Date	By	Appr.	Client
A	Initial Release - Client/Director	12/7/2023	Team	KP	Dario

Executive Summary

Background

The University of Colorado Boulder (CU) discontinued composting due to contamination issues, making waste sorting challenging. Despite student interest, hand sorting at recycling centers remains a barrier. This project aims to provide a solution by creating a smart waste bin that scans and directs users to dispose of items correctly.

Project Purpose

The primary goal is to ensure clean waste streams by preventing incorrect disposal. The product guides users to the appropriate bin slot, promoting efficient waste sorting. The educational aspect helps users learn and remember proper disposal methods.

Selected Design

The proposed solution targets CU Boulder's athletic dining and practice facilities as the initial market. The system aligns with existing waste management programs and aims to address pain points, starting with a known user demographic. The broader target includes various public spaces, such as restaurants, campuses, and government buildings.

Next Steps

Version 3.0: Continue hardware and software improvements, reducing latency and enhancing functionality.

Consultation: Maintain collaboration with industry experts for insights on development, testing, and industry-level solutions.

In summary, the project aims to revolutionize waste management through a smart sorting system, starting with CU Boulder and expanding to diverse markets. The proposed design meets key requirements, and ongoing testing and collaboration ensure continuous improvement.

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1. Project Summary

1.1. Introduction and Background

As of last year University of Colorado Boulder has stopped composting materials as it was not beneficial. Each stream of compost was contaminated with non compostable materials which created very difficult sorting options since all streams are hand sorted. Compostable materials are the most difficult stream to sort as it covers materials that shouldn't be composted, so CU decided to get rid of it entirely. Even though there are students who want to recycle and compost, whether they do it or not seems a bit irrelevant as it is still being hand sorted at recycling centers. However, there are still benefits of recycling as it aids in a more efficient process for the recycling centers. The goal of this project is to guarantee a confirmed clean source in each bin collected at CU. By preventing students from throwing away materials in the incorrect containers we can guarantee a certain level of confidence of a clean waste stream. The product will individually scan each item being thrown away and inform the user where to throw it away by opening a specific slot in the trash bin with LED lights instructing the user the location. There are also educational benefits as the more a user interacts with the machine the more a pattern forms in their brain learning and memorizing where certain materials should be placed.

1.2. Target Market

The target market for this project is any public space that produces landfill-divertable waste. This is a broad scope that exceeds the bounds of this course so when we analyze a few levels deeper we concluded that our targeted beachhead market would be CU Boulder's athletic dining and practice facilities. This results in a known end-user demographic of athletes, and controls the scale of the use of our product as we develop and grow. For example, we assume that we can not support Folsom Field operations due to the volume of individuals and waste disposal rate. However, we can support the daily operations of breakfast, lunch, and dinner at the athletic dining facilities with a high level of certainty. From an interview with the CU Boulder Assistant Director of Athletic Facilities and Events, our team learned that this was a pain point for the campus' recycling and composting program. Currently, ALL waste is marked as landfill, and no waste is separated into other divertable streams. By initially targeting this market and utilizing the existing Zero Waste program structure at CU as well as the Ralphie's Green Stampede team, this allows for a streamlined collection of preliminary test data and enables timely design iterations. Our team will use this data to iterate our design and business models for eventual expansion to secondary markets. The secondary target market(s) include but are not limited to: restaurants, food courts, large business campuses, college campuses, government buildings, military bases, and other locations with a high volume of useful or contaminated divertable waste streams. The goal of these targeted sectors is to enhance the waste management efficiency in these environments, encourage education with respect to recycling impacts, and reduce carbon and methane emissions.

As concerns grow with respect to climate change and how we as a society can shift towards sustainable living, we are seeing a rise in tax incentives, regulatory mandates, and various organizational-level programs to drive lower greenhouse gas (GHG) emissions. Some notable examples include the U.S Securities and Exchange Commission mandating that publicly tradable companies disclose information related to GHG emissions. According to a Reuters article, "The new disclosure rules would require listed companies to not only disclose risks that are "reasonably likely to have a material impact on their business, results of operations, or financial condition," but also "to disclose information about its direct greenhouse gas (GHG) emissions (Scope 1) and indirect emissions from purchased electricity or other forms of energy (Scope 2)," as well as certain types of GHG emissions "from upstream and downstream activities in its value chain (Scope 3)."". Another example is the Zero Waste Challenge the CU Boulder has won several times and encourages campuses to move towards zero waste and be creative on developing best practices, whether it be directly through reuse, recycling, and composting or by working with partners to drive impactful changes. Partners can include concessionaires, merchandise vendors, haulers, campus departments, manufacturers, sponsors, and service providers." according to the Pac-12 conference website. Our team will utilize programs and rules like these to assist in capturing and creating value for the market outside of the "good Samaritan" philosophy.

1.3. Market Size

The industry for waste management is vast – virtually every person or company contributes to the 8,754 businesses, total revenue of $76.3 billion, and solid waste landfill market size of $11.2 billion. This market is trending toward a rise in operating costs due to initial investments, maintenance, and training for new technologies to improve sustainability. This trend gives way for this product to enter the market, as current industry leaders turn toward more advanced equipment for sustainability. The top four companies in this industry generate between 40% and 70% of industry revenue, which may make it difficult for a new company to enter the market but is promising for possible partnerships. The potential for this project to succeed in any number of these markets is significant, but first must be reduced to a market that is plausible and scalable initially, and grown out from there as user interest increases and the product becomes scalable.

For this, our team seeks to start with the CU Boulder athletics faculty members, allowing us to access the student-athletes as users which are assumed to be about 500 year to year. This creates a manageable user pool size and focus on developing the product. According to a study by GreatForest, of 100 commercial waste audits, 62% of landfill material was divertable waste material. Of that, 36% was organic compostable material. Just in the United States alone, this contributes to millions of pounds of recyclable or compostable material going to landfills. According to the most recent EPA Inventory Report, U.S. landfills released an estimated 122.6 million metric tons of carbon dioxide equivalent (MMTCO2e) of methane into the atmosphere in 2021; this represents 16.9 percent of the total U.S. anthropogenic methane emissions across all sectors. While this project scope captures only a small portion of this market, the results are compelling and the problem is worth solving. According to IBISWorld, there are 2305 colleges and universities in the United States. According to RRS, 63% of US schools have an established recycling program on campus. Therefore, 1452 schools are obtainable. If wAIste can gain 1% of the market then 15 schools will be serviced.

1.4. Market Growth

The market for sustainable and technologically advanced waste management is experiencing significant growth due to the increasing awareness and uncertainty caused by global warming. In the United States specifically, we experience a high amount of waste per capita. According to Sensoneo the value is approximately 811 kilograms per person per year. Additionally, according to Worldbank, the amount of global waste is expected to rise 70% by 2070. The anticipated increase in these statistics is the primary driving force behind this project's mission, as there is certainty beyond any doubt that there will be demand for smart and sustainable waste management solutions for the foreseeable future. With pressure mounting towards sustainability, the project aligns with market trends and is capable of leveraging that growth. The rapidly increasing adoption of AI and smart device technology further enhances the market growth potential for the product in the waste management industry.

1.5. Market Penetration

Looking directly at our Serviceable Obtainable Market there are currently a total of 35 colleges in Colorado, with a total of 355,130 enrolled students attending. Our initial one-year goal would be to have at least 10 bins in 5 colleges around Colorado. We would begin this by talking to each college's waste management system and determining which location has the worst amount of contaminants in each bin. From here we would set up our bins to allow for a cleaner stream for their system. Assuming that all campuses are doing at least what CU Boulder is doing in their waste management system, it would be a clear decision to state that they would be interested in adding these products to their system.

Looking at what most colleges struggle with, there is a clear issue with contamination in each bin. It is stated that a comprehensive waste management system needs to have collection points where the waste is being generated such as dorms and cafeterias. Students are relied on to sort their trash out of goodwill. Some key questions asked about the contaminants include bin locations and the effectiveness of the bin markings [7]. With WAIste solution, no bin markings are required as the device simply shows the user where each item goes. There have also been reports that Colorado is one of the worst states when it comes to composting [8]. While the state average is 32% Colorado is currently sitting at a 16% compost/recycling rate. There is one main aid as well for this industry in Colorado which is the RecycleColorado Organization. This organization's main goal is to spread awareness and invest in recycling and composting contributions. The most noticeable aid they have added has been more than 100 million in grant funds over ten years to communities in Colorado's Front Range to invest in new recycling and composting programs.

The team's strategy for market penetration involves a phased approach as mentioned above. Initially, this was set to focus on direct salespeople initially targeting college campuses, assisting our team in gathering data, and user feedback, and refining the end-user experience with iterative improvements. Upon successfully completing the final prototype design using data and feedback from CU Boulder's students, faculty, and industry experts this project is set to expand into several other markets. These markets include the following market sectors including but not limited to: restaurants, food courts, large business campuses, college campuses, government buildings, military bases, airports, and other locations with high volume of useful waste disposal. Collaborations with local waste management companies, educational institutions, and business partners will be crucial to the success of the widespread adoption of our project. Direct salespeople will additionally be significant in helping businesses and other locations understand the customizability, ease of use, and overall need for WAIste. WAIste's closest competitor is Oscarsort. However, Oscars Sort does not include closing doors around the trash hole, meaning that WAIste has an opportunity to provide a cleaner sort than OscarSort.

1.6. Business Model Analysis

The following details within this section provide insight into our projected business model which drives the fundamentals of our financial plans and analysis. Our model operates based on the foundational insight statement created which states "We need to tackle the issue of divertable waste being taken to the landfill. Our university needs a way to educate people on how to divert more materials to recycling and compost streams. It is oftentimes complicated for our users to understand where things go." Some characteristics that were considered in our model were customer needs, customer benefits, market truths and friction points, as well as reasons to believe in our product.

1.6.1. Product Sales

The core driver of our revenue stems from the sale of our cutting-edge sorting hardware. This device facilitates efficient waste sorting and opens and closes bin access, visually segments and categorizes waste in real-time, and displays information to users via a television or monitor device which is provided as an optional add-on for customers that may or may not already have a monitor or device capable of displaying our product. Its multifunctional capabilities make it a comprehensive solution for modern waste management. Our current financial model predicts that or sales will break even at approximately 3.5 years, with 308 unit sales and $508,367.81 in revenue as seen in Figure 1.1. In year 5 of business operation we estimate $1.3 million in total revenue, a gross profit of $1.2 million, and a net operating income of $578,528. Several assumptions went into calculating this value, which will continue to be refined as we optimize our supply chain, find cheaper options for hardware, and improve our manufacturability. Our customer retail cost is 5 times the value of our variable costs, a value of $2,066.30 which yields a 75% gross profit margin. The values and results of our financial model are subject to change as we research and learn the intricacies of business startups and how to model most appropriately.

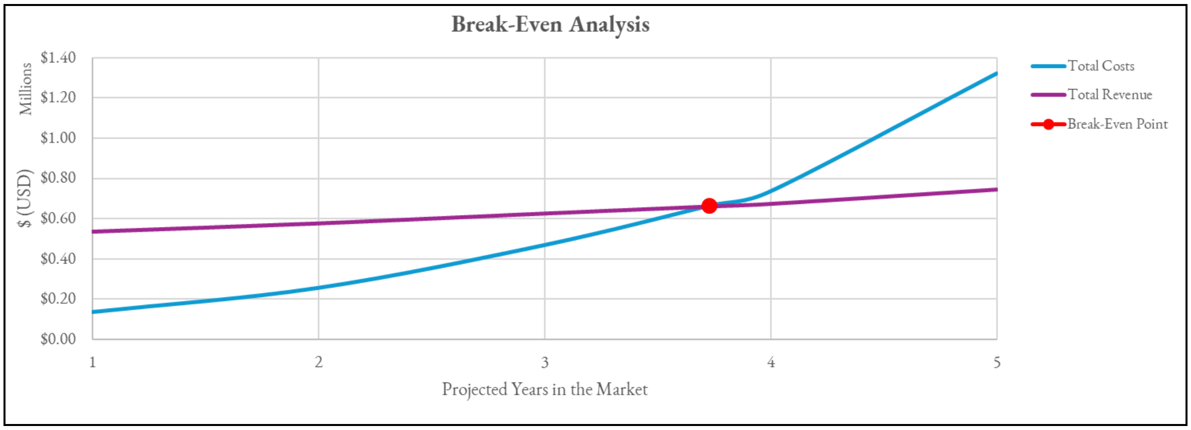


Figure 1.1: Breakeven cost graph that displays the total revenue and costs versus the number of units sold.

1.6.2. Advertisement

Advertising serves as a strategic avenue to offset operating costs and generate revenue during periods when wAIste products are not being sold. Advertisers can leverage various formats, including physical paper or posters on the bins, dynamic digital ads displayed on screens, and the option to feature custom wAIste bags with distinctive colors and logos available for purchase. This approach provides a flexible and impactful advertising platform for a diverse range of customers and environments. In our initial efforts to design what this would look like to the user, we created sample displays that will develop to be our finalized display for the final product. This can be seen below in Figure 1.2. The intent with this display is to generate revenue for our company and it's advertising partners, without distracting the user from the educational experience of viewing the AI as it predicts and identifies in realtime what the user is disposing of, and opening the appropriate bin accordingly.

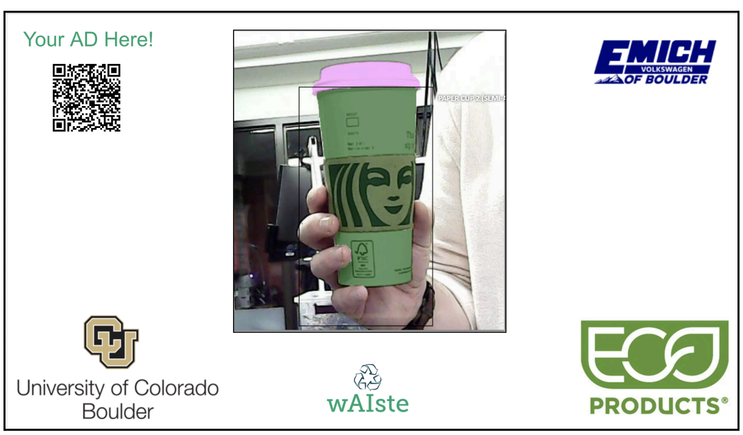


Figure 1.2: Sample display for wAIste system.

1.6.3. Data

Our subscription model for data collection is another strategic offering to the wAIste business portfolio, providing valuable insights such as waste volume, material composition, and successful waste diversion metrics. Tailored to meet regulatory requirements and compliance standards outlined in Section 1.3, this subscription service caters to customers seeking data for regulatory audits, investor documentation, and program compliance. By subscribing to our data service, customers not only contribute to sustainability goals but also gain actionable insights for optimizing their waste management strategies.

2. Project Requirements

2.1. Codes and Standards

The following are codes and standards that are acceptable for this project:

- ANSI American National Standards Institute;
- ASME American Society of Mechanical Engineers;
- ASTM American Society for Testing and Materials;
- IEEE Institute of Electrical and Electronics Engineers;
- ISO International Standard Organization;
- NEC National Electric Code;
- RCRA Resource Conservation and Recovery Act;
- WHO World Health Organization;
- IPX8 (Waterproofing).

2.2. Design Requirements

2.2.1. The System Should not require the purchase of a new bin.

During interviews with the prospective customer, **Jason Tavares**, head of the **CU Recycling Center**, it was expressed that there is not enough in the Center's budget to support the costs of entirely replacing the school bins. It would be difficult to convince the allocation board that new bins were needed when the existing bins are relatively functional and recently purchased. After the purchase of EcoBin, the remainder of the budget will be allocated to a compost dehydration system. A design that fits into the existing bin is not only more cost-effective but also leads to a more convincing pitch as the product operates as an accessory for technical improvements and direct support to student endeavors.

The solution is to design a system that easily **integrates into the 4-hole cabinet bins** that currently exist on campus. The team is leaning towards **bespoke models** for each **major client** (modified to their specifications) and a partnership with the bin production company for users who are looking to purchase small numbers of bins.

2.2.2. The Doors of the device must not interfere with normal operation of waste removal.

During user testing of the V1.0 device in the spring of 2023, our team discovered that there was a significant opportunity for damage to the doors, motors, and the frame of the device if the devices doors opened down into the trash bin. If the bin was to be removed during operation of the V1.0 device, the axels that the doors rotate about would displace and bend, resulting in the motors overheating as they attempted to self correct. This would result in increased device downtime, significant device malfunction, and a need for maintenance to be rendered to replace damaged parts and troubleshoot a restart.

The device doors entering the bin also proved to be a cleanliness issue as the edges of the swinging doors would touch the lip of the trash, picking up any waste material present. These doors would then close, presenting whatever disgusting material they touched to the user and passerby.

The current team's attempts to solve this issue are already fully underway. Upwards of 6 designs have been considered and weighed based on manufacturability, cost, resistance to abuse, and effectiveness. The clear winner was a motorized swinging door design that can be seen in the Design Overview section directly below.

2.2.3. The Device should be intuitive for new users.

From user testing of the V1.0 device, it became clear that user confusion was going to be a central issue. The V1.0 had an array of four sensors (two infrasonic to sense proximity and two infrared to sense material composition). This sensor bank required the user to hold the object in a way that all 4 sensors could see the object. This was not stated anywhere on the physical device or the LCD display. The success of the users understanding this without outside instruction was less than 5%, and those instances can be attributed to chance.

An extension of this issue was the user's lack of understanding they had to hold up their trash in front of the sensors at all. Test users frequently attempted to just go for the bin hole they believed was correct for the article of trash they were holding. This did not give the sensor bank enough time to register what the object was and open the door. User confusion was the main result, and users frequently turned to ask one of the test proctors for help. The behavior in which users just go for the hole they know is a validating data point for the idea that the device needs to use doors to inhibit interaction.

The device also confused users when it incorrectly labeled an article or trash and the thinking behind the sorting system. During our testing we asked the single set of doors to open no matter what the material was. The material class was displayed on an LCD screen attached to the sensor bank but very few people read what it was displaying. This resulted in the user not trusting that the system was working correctly and they often checked with a test proctor to see if the device was malfunctioning.

Children in particular presented a problem for the test trials. Children were often not tall enough to effectively use the bin, not being able to see the 4 holes, the screen readout, or that the device doors were open. They very often had to be held up and slowly walked through how to use the device. They also became frustrated very quickly and were prone to pushing on the device doors or grabbing at them when they were opening and closing.

This presented a danger to their small fingers and to the device's mechanics. The current team is playing with the idea of a locking mechanism for the doors to prevent stream contamination in cases of device abuse. Our team also needs to design with safety in mind as the V1.0 device's only protection against user injury was the use of relatively weak stepper motors that were incapable of significant bodily injury. The highest chance of injury would be in the case that the doors closed on a user's finger and they quickly pulled it out (as is instinctual). The doors were not designed to open again unless a new object was accepted so the user's finger would be pinched and the skin damaged.

To correct these moments of user confusion it is imperative that the team design the V2 and V3 versions of the product to include a fully fleshed out user instructional path. This path will be developed using the V1.0 model which will be installed in a high traffic area on the CU Boulder campus. The user testing with the V1.0 device will be used to test general assumptions like "What do users do when frustrated by our device?", "Will users leave trash on top of the device if it is operating slowly?", and by covering the holes not integrated with the device, "How quickly will users decide that using another bin is preferable to interacting with our product?". The creation of this pathway will allow for small improvements to be made as new features and tests are conducted. The pathway will be modeled in an online tool called coggle.

2.2.4. The Device must not hinder frequent users.

Alongside an easy and intuitive learning curve for new users, it is imperative that frequent users do not feel hindered by the devices during operation. To avoid this situation the team must select an artificial intelligence model with very low latency. This will be supported by specialized hardware that allows the model to run as near instantaneous speeds as can be managed. The ideal run situation would be for the correct doors to open as quickly as possible, with the screen providing more detailed information and instructions for users who linger. The intention is that educated users would be able to dispose of their waste nearly as quickly as a standard disposal system.

2.2.5. The Device must not invade the privacy of its users.

During our customer discovery interviews, user privacy was a frequent talking point. It is important for the team to understand that the public is not nearly as accepting of new technologie with artificial intelligence being a point of recent acute fears. It would not be appropriate to display a camera feed into an open room in all applications and even with limited field of view some users may still become uncomfortable.

There are several strategies the team intends to employ to combat this. Firstly, disclaimers should be displayed on the user interface that display whether or not the system is recording the user interaction. Secondly, a proximity sensor can be employed to only activate the display when a user enters the area of interaction. Lastly, simple methodologies exist for background blurring, background elimination, and focal length blurring on the physical camera to prevent an entire room being displayed.

2.2.6. The Device must be adaptable to the codes, regulations, and waste of varying industries.

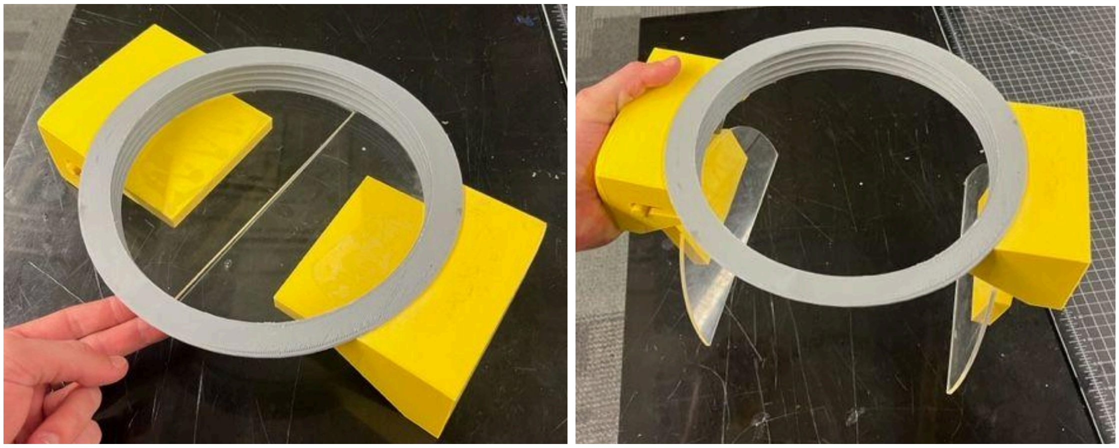
2.2.7. The Device must provide ease of maintenance and cleaning.

As this is a waste management device it is expected to come into contact with some genuinely unpleasant things. This device should be liquid resistant which can be achieved by using non-porous materials, placing electronics and circuitry far from the waste stream disposal area, and making cavities that house electronics and circuitry water resistant. These considerations will be discussed in section 3. Design Overview.

2.2.8. The Device must be easy and intuitive to fix with easily accessible replacement parts.

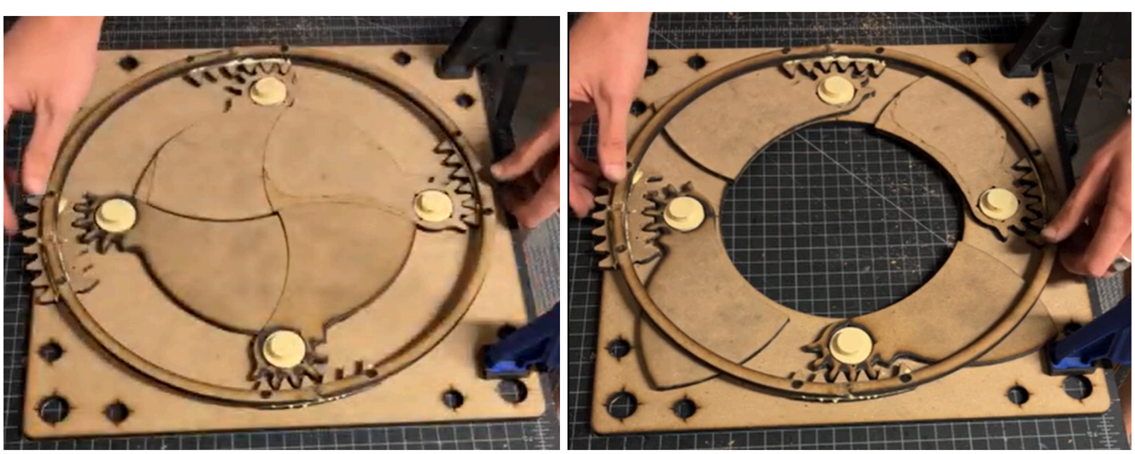
3. Past Design Iterations

On the course of creating the finalized version of wAIste, the team has gone through several initial designs and revisions. These took multiple shapes and processes, with much consideration behind each one that led to the product seen in section 4. Firstly, this project was started by another team in a different class over a year ago, and their final product became a starting point for Team 44 to learn from and improve upon. The previous project, titled "Clever Composter," was meant to deter users from placing material that is not compostable in the compost bins on campus. This had a limited scope, and an incomplete design that would be unsatisfactory for senior design, so the team had a long way to go.

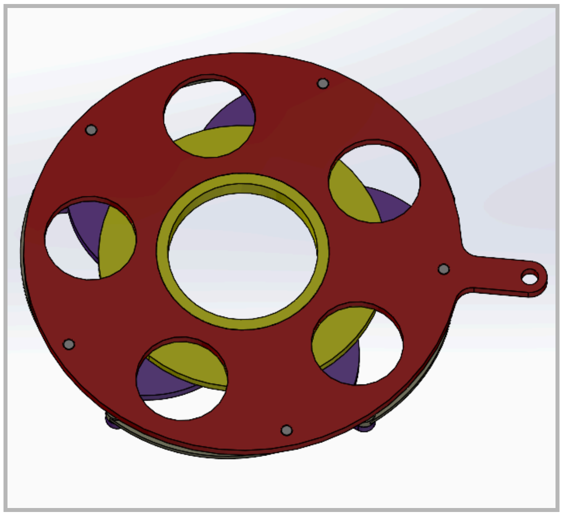


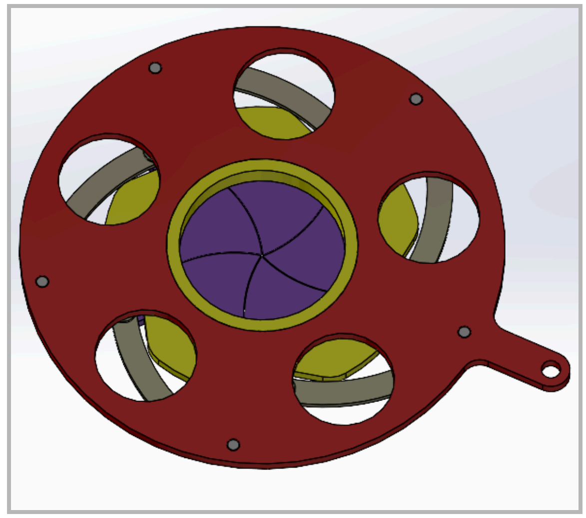
Figures 3.1 & 3.2: Clever Composter mechanical design, featuring 2 swing doors.

The team's initial response to the Clever Composter was to pivot away from the design, and come up with something more visually appealing and interactive for the user. This came in the form of an aperture design, which would open parallel to the surface of the bin, rather than into the opening. After several iterations and tests, though, there were no simple design solutions that made sense for the project. Firstly and most importantly, since the doors would open parallel to the surface of the bin, the design would need a much larger footprint to function than is available with the bins on campus that are being targeted by the design. Furthermore, the design has a significant complexity in manufacturing, assembly, and operation. Though the apertures could be powered by just one motor, they feature many points of failure with the use of gears and pivot points for the doors. Wear would not only be possible but would be expected. These pivot points also allow for waste contamination to gum up the system, and would not do well with viscous liquids that could be expected to be disposed of here. For these reasons the team decided to move back to a swing door design that opens into the bin.

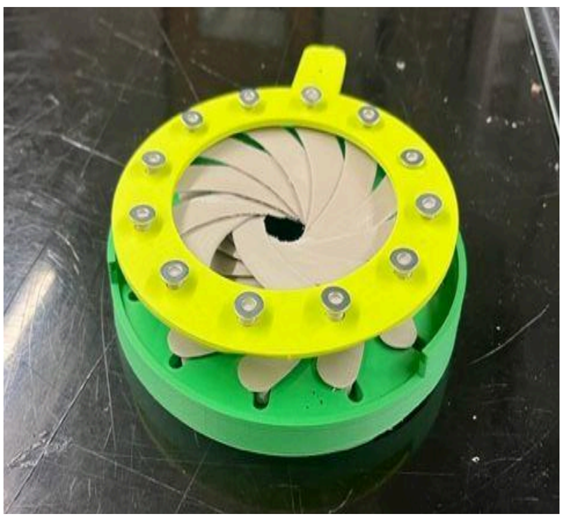


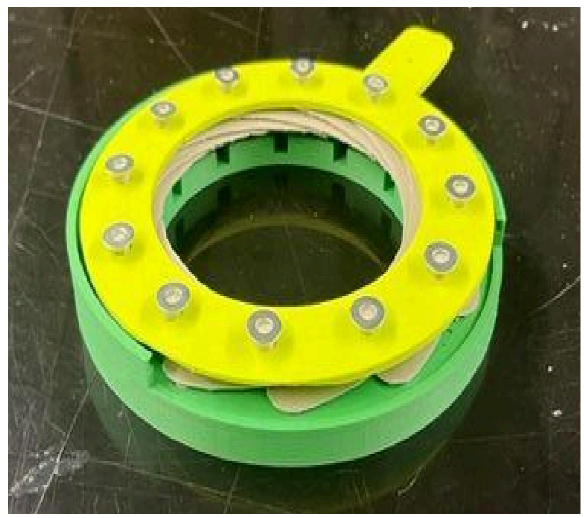
Figures 3.3 & 3.4: First iteration of aperture prototype, made from laser cut MDF and 3D printed components.





Figures 3.5 & 3.6: Second iteration of aperture design.





Figures 3.7 & 3.8: Third iteration of aperture prototype, notice high complexity of parts.

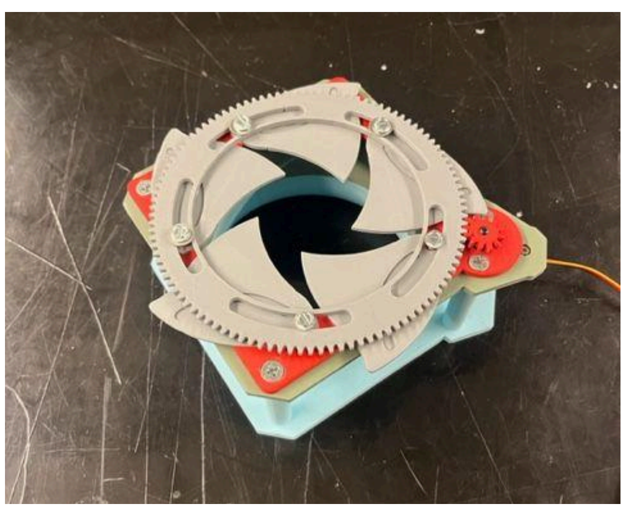
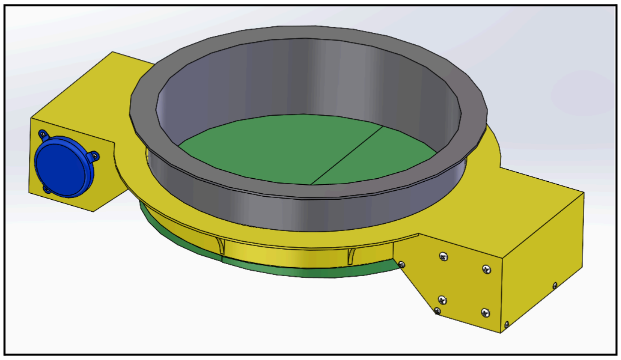
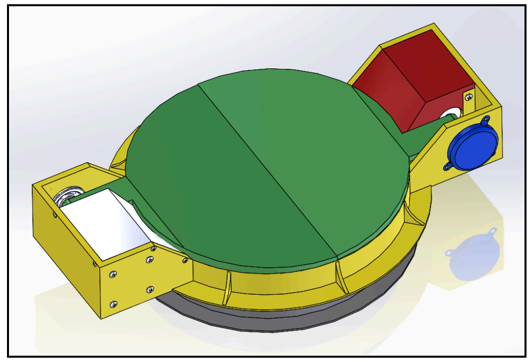


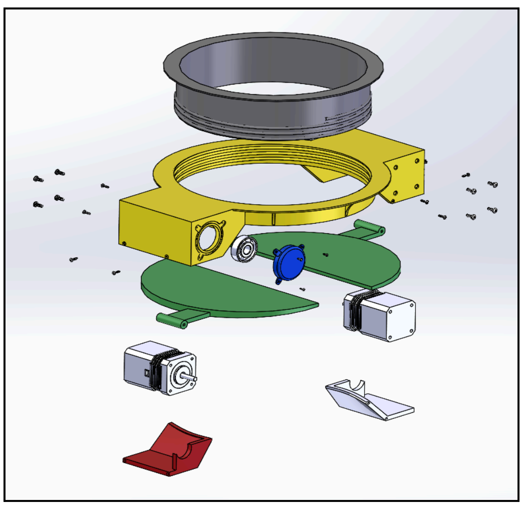
Figure 3.9: Functional automated aperture design.

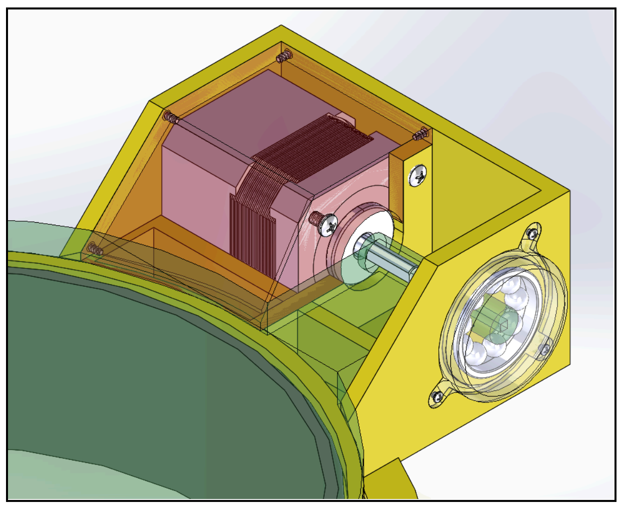
The transition back to a swing door design was necessary, and though the team did not want to emulate the Clever Composter's design it was a good starting point for improvement. The designs shown in the CDR were an improved version of the Clever Composter, featuring far more design application as well as manufacturing and assembly considerations. This design's main features include a threaded inner hub and top ring for easy installation, bearings for smooth rotation and function, and caps to protect the motors and bearings from debris.





Figures 3.10 & 3.11: Swing door design top and bottom view.





Figures 3.12 & 3.13: Swing door exploded view and detail view.

The team's CDR discussion revealed some points of improvement for the swing door design before moving on to the mechanical design. The threads would be difficult to machine with most traditional techniques, and since wAIste is planned to be mass produced using injection molding manufacturing this is an impossibility. The inner walls and screw holes shown in figure 3.13 would be extremely difficult to manufacture as well. The bearing caps would need adjusting, and three points of contact is excessive for the low stresses encountered. The motor caps would be difficult to call out and manufacture as well, since the front edge is curved using a draft and has some thin features. Finally, the wall thicknesses throughout are inconsistent, and often too large to be reasonable for injection molding.

4. Finalized Mechanical Design

The major mechanical design dictating this project is the bin door assembly. Though there are many other components involved in the overall design of the product, the rest of these are simply purchased and assembled, whereas the doors will be manufactured by Team 44.

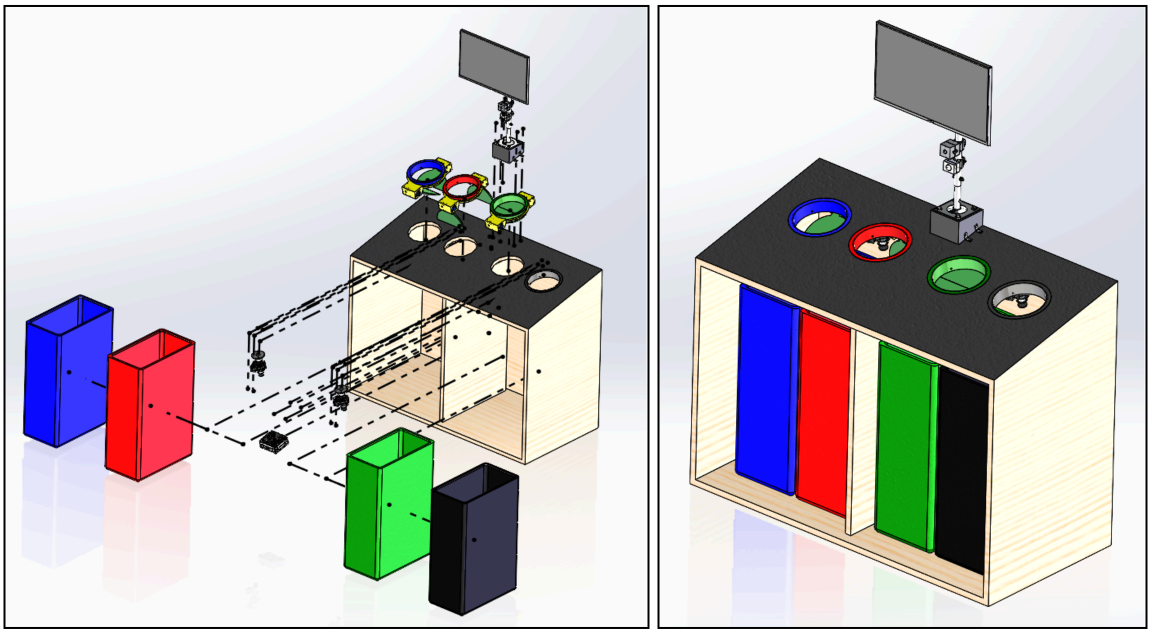


Figure 4.1 & 4.2: Models of Final Product Integration.

4.1. Bin Door Assembly

This door design has been chosen for simplicity, strength, and adaptivity. The green swinging doors (4.1.2) prevent users from placing waste in the incorrect receptacle, and they cannot be pushed open without overcoming the torque provided by the motors that manipulate them. Each door is press fit into the motor shaft, and a ball bearing (4.1.6) on the opposite side to decrease friction and increase stability. The motors are pressed into place in a cavity on the yellow hub (4.1.1) and then screwed in at four points of contact with the inner door hub. Bearing caps (4.1.4), shown in blue, are fit into place to cover the ball bearings and prevent buildup of dust and grime, then screwed in at two points. Shown in red are the motor caps, which are screwed in at four points of contact with the inner door hub, protecting the motors from solid and liquid waste that pass through the opening as well as fully securing the motors. The yellow inner door hub with assembled components is then placed inside a bin (Figure 4.1) with the flat portion pressed to the bottom of the bin lid, and the gray rim (4.1.5) is slid into the bin opening and four holes are matched between the two before being screwed together. The overall footprint of this assembly is 13.375” x 9.5” x 3.39”.

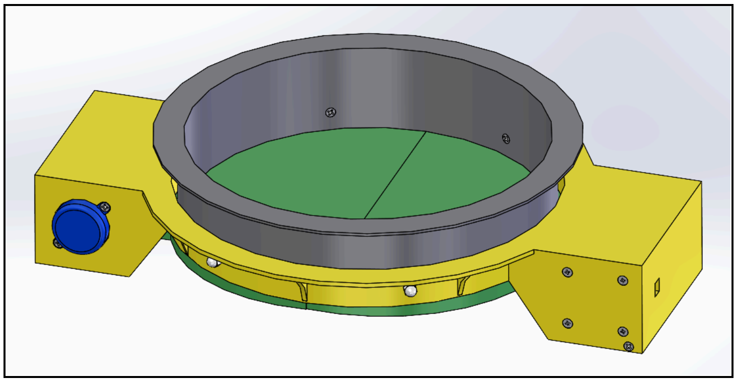


Figure 4.3: Model of Bin-Door Assembly.

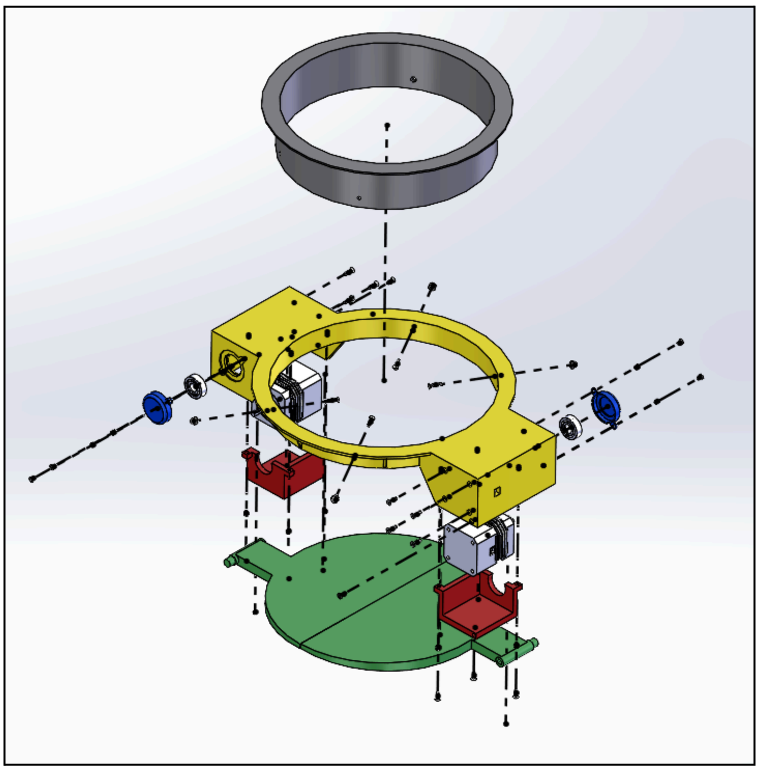
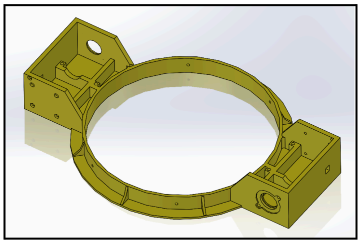
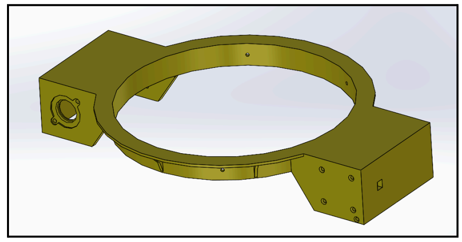


Figure 4.4: Exploded View of Bin-Door Assembly.

4.1.1. Inner Door Hub

The inner door hub contains all of the main components to the mechanical design excluding the top ring, and is integral to proper functionality. It features four screw holes to interface with the top ring, ribbed for high strength and support, as seen in figure 4.5. The motor cavity shown in figure 4.7 allows for easy assembly, as the motor is pressed into place and screwed into the left wall. On the right wall the ball bearing is pressed into place before the bearing cap is screwed into place. The motor cap is placed in the top left corner of the view shown in figure (4.7), and screwed in at four points. The inner door hub receives many screws to hold all of its relying components in place, for these it has several heat set threaded inserts to interface with the necessary hardware.

Figures 4.5 & 4.6: Inner Door Hub Bottom and Top Views.

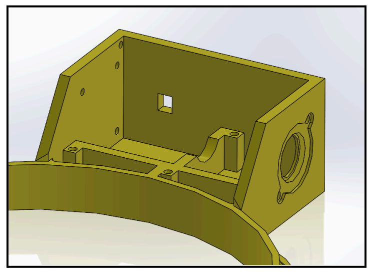
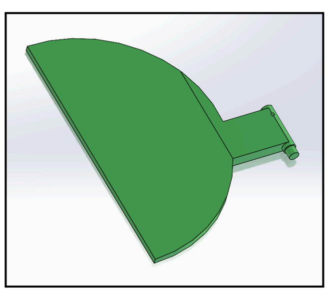
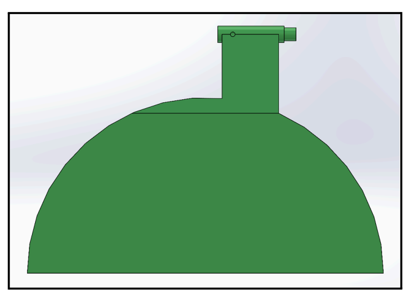


Figure 4.7: Inner Door Hub Motor Cavity.

4.1.2. Doors

The door components are angled to increase strength and decrease weight, and an arm interfaces to the motor. When closed, the doors will be flush with the bottom of the inner door hub. The door will be press fit to the motor on the left side of the arm in figure 4.9 then secured with a set screw and the right into a ball bearing. There is also a feature on the shaft to limit the distance between the door and the motor as well as the door to the wall to ensure smooth rotation and minimize friction between components.

Figures 4.8 & 4.9: Isometric View and Top View.

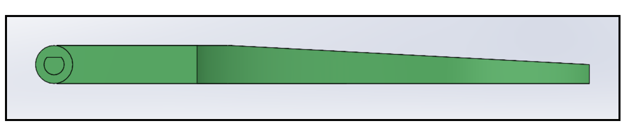


Figure 4.10: Side View.

4.1.3. Motor Cap

The motor cap is designed to cover and protect the motor from solid and liquid waste. The circular feature in Figure 4.14 is meant to snap onto the curved edge of the motor and provide a seal. The three tabs shown in Figure 4.13 are fastened down to the inner door hub, and the hole visible on Figure 4.12 is meant for a heated thread insert that interfaces with a screw from the inner door hub. Tolerances will need to be tight in order to make this as protective as possible for the motor.

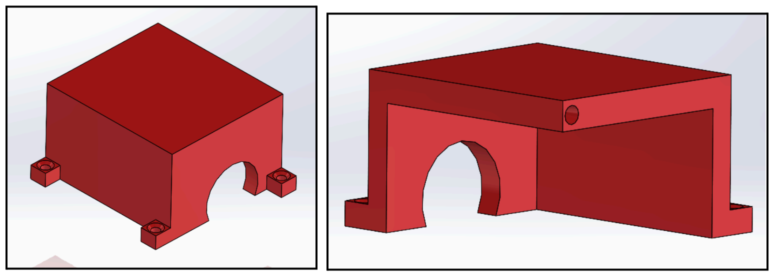
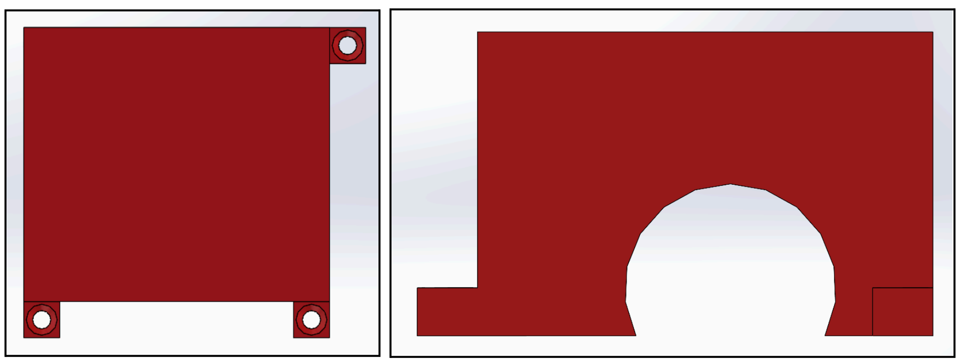


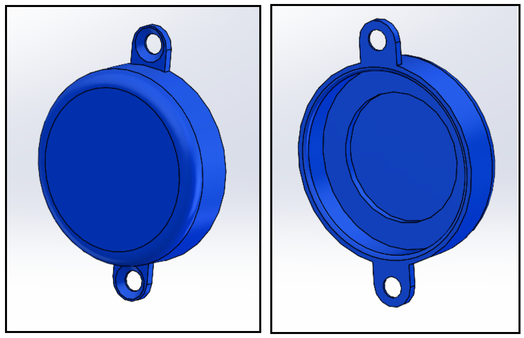
Figure 4.11 and 4.12: Isometric Views.



Figures 4.13 & 4.14: Top View and Side View.

4.1.4. Bearing Cap

The bearing cap protects the ball bearings. They fit into the depressions on the outer side of the inner door hub and are screwed into place at two points. These two features are designed to fit flush together. The three screw tabs are 0.05" thick and should not undergo significant stresses during use, and there is an inner fillet on the cap to allow for smooth fitting. The bearing caps also feature a limiting inner ring that prevents the bearing from moving side to side but still allows the inner rings to move freely as the doors rotate.



Figures 4.15 & 4.16: Bearing Cap Front and Back.

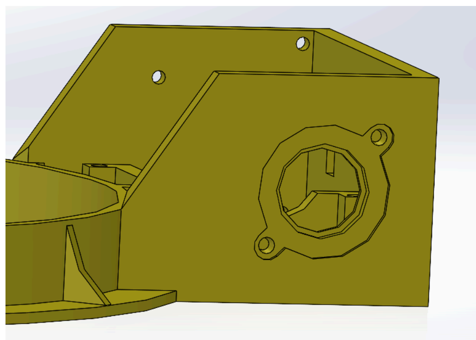
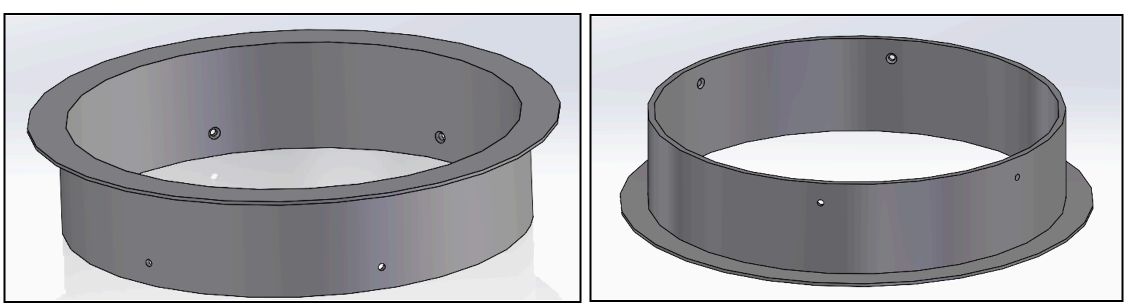


Figure 4.17: Bearing Cap Fit.

4.1.5. Top Ring

The top ring is responsible for holding all of the components in place and screws into the inner door hub via the top of the bin. The rim feature at the top of the part in Figure 4.18 rests on top of the bin around the opening and is twisted to meet the four screw holes with matching features on the hub inside the bin, then screwed together. This creates a tamper-proof fit that will prevent the device from moving during use.



Figures 4.18 & 4.19: Top and Bottom Angled Views.

4.1.6. Bin Door Assembly Fasteners

The bind door assembly features 8 unique fasteners for 44 total fasteners in the assembly.

P/N	Description	Material	Cost Per	Quantity	Location
97163A137	4-40 Tapered Heat-Set Inserts for Plastic	303 Stainless Steel	$0.59	12	Inner Hub / Motor Cap
92010A120	M3x0.5mm 10mm Phillips Flat Head Screws	18-8 Stainless Steel	$0.06	8	Inner Hub / Motor Cap
94355A142	6-32 ⅛" Flat-Tip Set Screw	18-8 Stainless Steel	$0.04	2	Swing Door
91771A935	4-40 5/16" Phillips Flat Head Screws	18-8 Stainless Steel	$0.10	8	Inner Hub
680_ball_bearing_8x22x7	608 Ball Bearing	Stainless Steel	$0.59	2	Inner Hub
91771A933	4-40 3/16" Phillips Flat Head Screws	18-8 Stainless Steel	$0.10	4	Bearing Cap
90507A209	4-40 5/32" Distorted-Thread Cap Locknuts	18-8 Stainless Steel	$0.10	4	Inner Hub
91771A938	4-40 ½" Phillips Flat Head Screw	18-8 Stainless Steel	$0.10	4	Top Ring

Figure 4.20: Table of Bin Door Assembly Fasteners.

5. Finalized Electrical Components

5.1. Circuits Modeled

The electrical system is composed of the follow parts:

- Six (6x) Nema 17 stepper motors;
- Three (3x) DRV8825 stepper motor driver;
- Four (4x) HC-S04 ultrasonic distance sensors;
- One (1x) HC-SR312 passive infrared (PIR) sensor;
- One (1x) Jetson Orin Nano;
- One (1x) USB camera;
- One (1x) 24 inch display monitor.

The Jetson computer and the display monitor are powered by an outlet (or 12V battery), while all other components are powered by the Jetson. The motor drivers use the most GPIO pins, with six connections per driver. Each driver controls two doors, with reverse connections (A1 = **A2**, A2 = **A1**, B1 = **B2**, B2 = **B1**) so the doors swing in the same direction (see appendix for circuit diagram views).

The ultrasonic sensors are all powered in parallel, which allows the team to control the current to each sensor while providing equal voltage to all four. Each ultrasonic sensor is controlled by a GPIO pin and, similarly, the PIR sensor has the same three connections of power (5V), ground (GND), output (GPIO pin). It is important to note however, that the selected sensor is specified for 5-12 V and its working current can be adjusted with the use of a potentiometer. The team must either select a 5V-rated PIR sensor, or create a circuit layout that controls the power supplied to the system while providing enough power to all components.

5.2. Jetson

Once we understood what our software needs would be, we investigated what kind of hardware was within our budget. Single-board computers for computer vision are widespread, and Google, amazon, and Nvidia all produce boards that meet our needs. Nvidia produces the best consumer GPUs on the market right now, so almost all of the significant software models we will be using will have easy formatting options to access an Nvidia GPU system. For this reason, as well as exceptional performance per dollar, our team zeroed in on the Nvidia Jetson line of development boards. Lexi's experience and input were critical in this decision-making process. Our team first selected the Nvidia Jetson Nano as its powerful dedicated GPU seemed to be a night-and-day improvement over the Raspberry Pi's and the relatively low price would keep the cost of our product down. What Lexi suggested, however, is that it is prudent to develop, build, and train your AI on a more powerful machine and then optimize and shrink it to fit on a more economical board. For this reason, we opted for the Jetson Orin Nano, which is some 100 times more powerful than the Jetson Nano, which in turn is 100 times more powerful than a RaspberryPi 4B.

5.3. Directive LEDs (Removed)

Our team planned on adding LED light strips attached to the bin opening. The LED strip was going to be hugging the interior of the opening with the adhesive provided. With addressable LED strips we can program individual LEDs with different colors, hues, temperature, and brightness. With a little bit of programming, these interactive lights can create some visual appeals for both the overall project and for demonstrative purposes when presenting our overall product. Using an Arduino UNO, we were already able to code some actions with the LED.

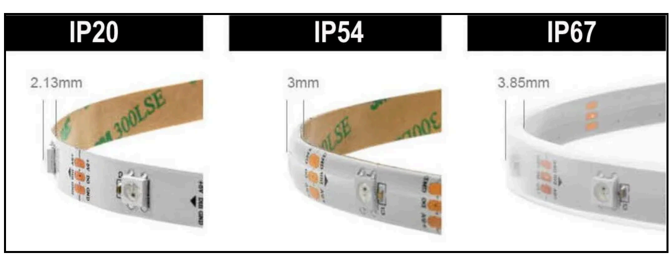


Figure 5.1: Types of LED Strips.

These LEDs required a constant supply of 5V. Each individual LED requires 50 mA when set to full brightness, given an input of 5V. There are a couple of options we are able to choose from with the LED IP rating. The IP ratings are represented with two numbers: the first number represents its level of protection against solids, and the second number represents its level of protection against liquids. With our current project, we will likely have chosen an LED with high protection against both.

Due to team discussion, the location and constant wear on the LED and its adhesive would have cost too many potential future complications. There are also simpler solutions to the problem the LED's would solve. The main goal of the LED was to light up a certain color that would match the LCD screen depicting the item lighting up recognized from the camera. However, by simply having each door attachment being a different color and highlighting the individual garbage pisces to match that color lets us simplify the overall product, cutting cost and manufacturing time.

5.4. Display

The project involves an interactive interface on a trash can, it's crucial to have a screen that provides clear visuals, is durable, and possibly has touch-screen capabilities. The team had looked at a variety of potential displays as the following: LCD, OLED, Touchscreen, Rugged Screens, and LED Backlight LCDs. Each of these displays have their own positives and negatives and the team decided that the clear choice for this project was an LCD display. The LCD is very energy efficient, has great visibility, is cost effective, and is widely available giving us a lot of options. Some potential issues we will need to consider, is the fact that the LCD has a slower response time compared to OLED screens and depending on our frame rate might need to be looked into more. The LCD screen energy consumption varies between 15-30W for any standard size. When looking for pricing and options of LCD displays the best option found is an LCD Controller 21.5 inch display screen panel. The price varies from $61.50 - $68.00 per unit. This display provides 1920x1080 resolution, 30 pin LVDS interface, and is suitable for industrial use allowing for potential damages.

5.5. Sensors

5.5.1. Infrared Distance Sensor

The infrared distance sensor sensor over the bin serves the function of identifying a user and triggering the camera and other systems. The sensor has a maximum range of 5 meters (16.4 feet) and minimum of about 2 centimeters (1 inch). It's current is controlled by a potentiometer, which depending on the configuration may change the scan time of the sensor. For the selected potentiometer, the team expects to see a timing range of 0.2 to 200 seconds. As mentioned in the circuit breakdown in Section 5.1 above, the sensor will be powered

5.5.2. Ultrasonic Distance Sensor

The ultrasonic distance sensors (EPLZON HC-SR04) are mounted underneath each door, facing the openings. On the other hand, the sensors under the openings have the function of recognizing when something is thrown into an opening and tracking the quantity in each bin given the quantity assigned by the software.

6. AI/Image Recognition

Artificial intelligence was the clear choice for addressing the intricate challenge of developing an intuitive user interface (UI) capable of promptly detecting object presence, categorizing materials for appropriate waste streams, offering user guidance on material separation and disposal, and managing the timely operation of mechanical doors. The nearly infinite variations in material as well as anticipated user behavior, required that our device be able to make inferences about what an object might be and what material it is composed of. Our solution relies on visual data to not only handle objects but also provide the user with real-time instruction that is intuitive and responsive. This requires an artificial intelligence model that is optimized for the task, is run on specially designed hardware that can handle trillions of operations per second, and features edge computing techniques. An issue of concern is that our team is composed of exclusively mechanical engineers, so we will have to rely on third party mentors and consultants.

6.1. Feasibility Testing/Prototyping

We are fortunate to possess a team with secondary skill sets in mechatronics and computer science; however, our experience with computer architecture at this advanced level was virtually nonexistent. There was frequent discussion at the beginning of the semester as to how to solve this issue, with some solutions being to hire an outside company with promises of equity, bring on an upperclassman or graduate student with the necessary capabilities, or learn the process ourselves. The first two had obvious drawbacks in terms of company equity and team independence, but the last of the options appeared unrealistic. To test this last assumption, we challenged a team member to investigate the process of, and attempt to run, a rudimentary artificial intelligence for object recognition. This was successfully achieved with our V2.0 prototypes which included a Raspberry Pi 4b single-board computer, a pi-cam 2 camera, and Google's tensorflow-lite object detection model. We also modeled a 3d printed gantry arm to provide a consistent platform for camera testing. From these results, we determined that our team was capable of software development for the V3.0 device iterations.

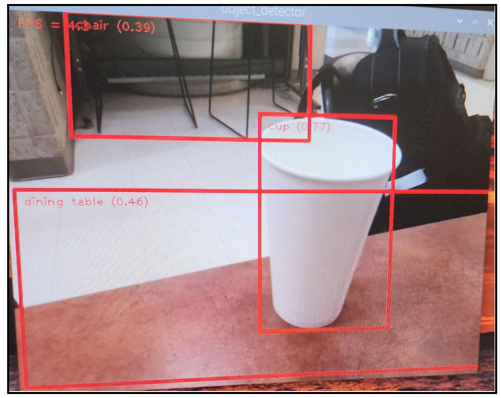


Figure 6.1 & 6.2: Prototype testing setup and Tensorflow-lite object detection model, labeling waste.

6.2. Version 2.0 Planning and Development

With the conclusion of the prototype testing phase, our team recognized the need for an improved hardware and software system. The latency between physically moving an object and the screen displaying the movement was greater than 2.5 seconds on average. This was inadequate for our design constraints, and the Raspberry Pi4 was only being asked to run a bare-bones version of what the real tensorflow object detection was capable of. At this point, the team recognized the need for an outside consultant with industry experience to advise us in creating a functional prototype that would meet our design requirements. It was then that we were put into contact with **Alexis Winters.** Lexi is an industry professional who is currently working for John Deer developing machine learning models for autonomous forestry and agricultural machines. More importantly, she spent two years working with AMP Robotics which specializes in AI waste sorting on an industrial scale. AMP Robotics is conveniently located right down the road from the CU Boulder main campus. She has been integral in advising the team in creating a realistic development timeline and test procedures and suggesting industry-level solutions to proposed features (see section 10.8).

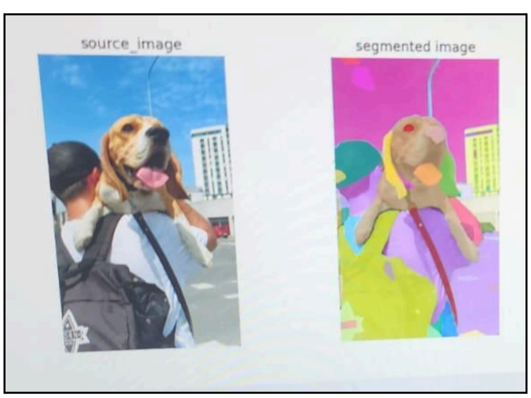
6.3. Software Selection

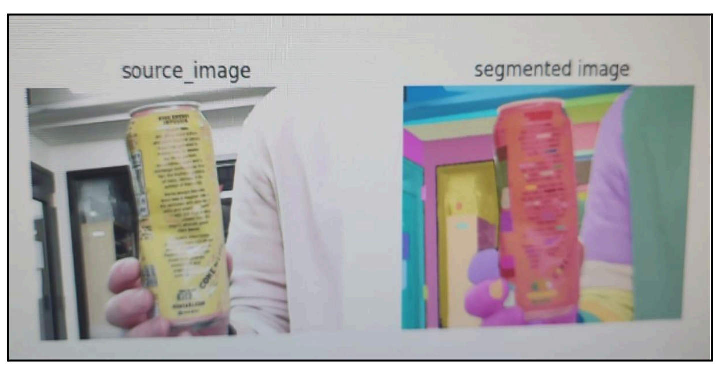
The first step in our AI planning procedure was to identify the kind of model we would be asking our hardware to run. Our team is interested in both object detection and real time instance segmentation, which are subsets of the computer vision branch of machine deep learning. Luckily for us, this is one of the more significant utilizations of neural networks, and there are many open-source models that we can use without IP concerns. The models we investigated were as follows (supporting diagrams in appendix):

- **Faster Region-based Convolutional Neural Networks** (Fast R-CNN)
  - Pros: Highly Accurate and Robust, widely used in various applications.
  - Cons: Slow due to the two-step process of region proposal and object classification.

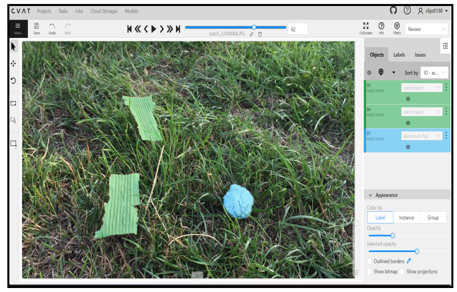
- **You Only Look Once** (YOLO)
  - Pros: Blazing fast inference speed, real-time detection capability.
  - Cons: Not as accurate as some other models, especially for small objects.
- **Single Shot Multibox Detector** (SSD)
  - Pros: Faster than Faster R-CNN, provides a good compromise between accuracy and speed
  - Cons: Will not perform as well on small objects.
- **EfficientDet**
  - Pros: Achieves an outstanding balance between accuracy and efficiency.
  - Cons: not as fast as Yolo (generally more accurate).
- **Mask R-CNN**
  - Pros: This model performs instance segmentation alongside object detection, which greatly increases deep learning ability.
  - Cons: Slower than Faster R-CNN because of the extra processing power required.

The last of these models brings up an interesting element that our team is working to validate. Segmentation is the process by which an image gets broken into smaller sections called masks. A single mask can be considered all of the parts of one object. This is not the same object we might be holding in front of the device, but a mask is what the AI model believes to be a grouping of like things (Figures 6.3 and 6.4). We then select which of these masks belong to the object, and the model can determine which attributes make up the "object" you made from that grouping of masks. This has traditionally been an extremely tedious and time-consuming procedure, but with the implementation of Facebook Research's Segment Anything Model (SAM), this process can be run at 10x the speed. The figures below demonstrate what we have accomplished using the SAM model. In Figure 6.3 we see an image of a dog that has been segmented by the SAM model. Each color represents a different mask that can be selected for training. These masks can also be grouped to define an object for training. If our team decides that our device should be able to adapt to its environment and learn how to sort new objects that it has never seen before, we will need to run a segmentation model before we run the object detection model, greatly increasing our operations per second and the hardware needs of our system.





Figures 6.3 & 6.4: Images segmented using SAM model. Each color represents a single mask.



Figures 6.5 & 6.6: Segmented Coffee Cup and Image from the TACO dataset being segmented with SAM inCVAT.

With the completion of around 300 segmented images the team set itself to training a custom artificial intelligence. This was found to be significantly easier said than done. The jetson orin nano that was purchased has a very specific architecture that does not lend itself to first time users. It can easily be classified as a supercomputer for its size and was therefore not designed with hobbyists in mind. To train a model it is important to first download a training and operational library specifically designed for computer vision. There are 3 main libraries that the various models are built to use but by far the most prevalent are tensorflow and pytorch. Pytorch is the most commonly used, especially for models that prioritize speed over accuracy, but unfortunately due to the jetson platforms unique architecture and the orin nano model's recent release date, pytorch doesn't properly access the devices gpu's, which is the entire reason our team bought the device. Using tensorflow limits our options a bit but we managed to train a rudimentary intelligence with pretty miserable accuracy. Below is a graph of the AI's confidence levels alongside a video of the SSD-Mobilenet-v2 model in motion.

There is still quite a bit of room for improvement in our model and increasing the database size along with training the model for longer periods of time should increase the functionality to a point that the device will be expo ready and provide a strong proof of concept.

7. Manufacturing Plan

7.1. Version 4.0

All components covered in section 4.1 will be 3D printed. The top ring and inner hub will be printed using the MarkForged printer in Onyx, and the rest of the components will be printed using a Lulzbot with PETG. The other components in the top level assembly will be purchased from varying suppliers and assembled by hand.

7.2. Large Scale Manufacturing

The components covered in section 4.1 will be modified to be injection molded using FDM guidelines laid out by Protolabs. The best material for these is expected to be PET. The other components will be purchased from varying suppliers at a lower cost than the prototype due to bulk purchasing and partnerships.

8. Testing

8.1. Test Equipment

All of the test equipment required for the test procedures described in section 8.2 below are:

1. Calipers
2. Voltmeter
3. D-Shaped Bit for Hex Driver Adapter
4. Screwdriver and Bit Set L Shaped 1/4 Inch Hex Socket Wrench
5. Push/Pull Force Gauge

8.2. Test Procedure

The critical specifications will be tested as follows:

8.2.1. Stress Test

ID 5.1 Computational Power/Dollar

To test for the computational capacity of the Jetson Orin Nano, the engineer will run all components (camera, active and passive sensors, motors) for a long period of time and run benchmarks to quantify computer power at high payload conditions.

ID 6.2 Reset Mechanism

Place object on closed door and inspect how it functions. The expected results are for the door to open after a few seconds of sensing weight on the doors.

ID 6.3 Anti-jam System

Block the trash can cover and inspect if the door opens when the system scans waste that belongs in full trash can.

8.2.2. Voltage Test

ID 2.1 Voltage Supply

Check the voltage through each of the motors and sensors with a voltmeter while the system is running.

ID 2.2 Scan Range Trigger

Check the voltage across the PIR sensor when the system is on "stand-by".

8.2.3. Torque Test

ID 3.2 Torque Capacity

Use D-shaft to Hex adapter to connect to Hex Allen wrench. With the hook end, clamp the force gauge on the end of the Allen wrench and pull the force gauge until the motor locks.

8.2.4. User Test

ID 5.2 Price Per Unit

Customer interviews to confirm viability in the market price.

ID 6.4 Easy to Use

Observe several people interacting with the product and note how fast they last and their responses to the product.

8.2.5. Wear Test

ID 1.3 Waterproof Coating

Slowly pour water onto doors and motor housing and observe if any droplets leak through the material. Pour viscous fluid on door and take note on the impermeability of the door.

8.2.6. Inspection and Demonstration

ID 1.1 Inner Diameter

With a caliper, measure inner diameter of the top ring.

ID 1.2 Maximum Outer Diameter

With a caliper, measure outer diameter and overall footprint.

ID 4.1 Database Generation

Run trials with the ultrasonic sensor, counting each piece of trash thrown into the opening. Also confirm cross-matching algorithm stores data properly.

ID 5.2 Price Per Unit

Customer interviews to confirm viability in the market price.

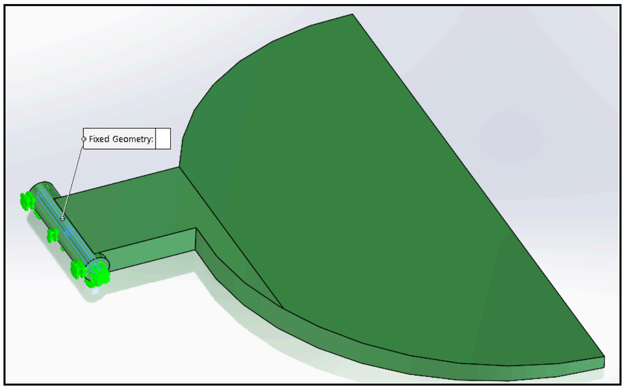
ID 6.1 Light Safety

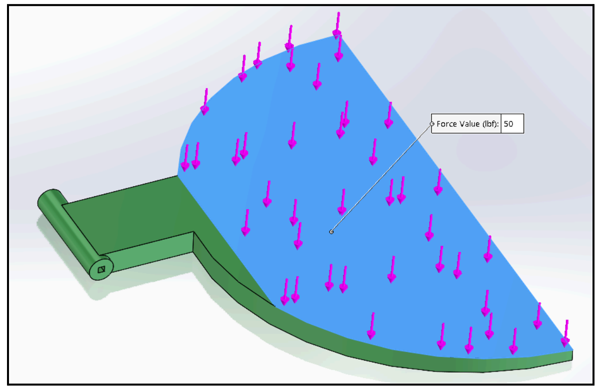
Note that the infrared sensor is of class 1 or 2, so it is safe to the user.

8.3. Predicted Points of Failure

8.3.1. FEA Analysis

This project is not expected to undergo significant stresses, other than possible misuse. The most likely candidate for target of misuse is the swing doors from section 4.1.2.





Figures 8.1 & 8.2: Swing Door FEA Simulation Setup.

The swing doors are expected to experience some wear due to misuse, so this simulation presents the feature with a fixture in the axle where the motor will be driving the motion of the doors and a downward force on the top of the door of 50lbs mimicking a user attempting to push the doors open. This simulation results in the lowest factor of safety of 1.234, which is enough to resist a sizable amount of force from the top of the bin. Figure 8.3 displays the highest stresses in red, where the factor of safety is below 1.5.

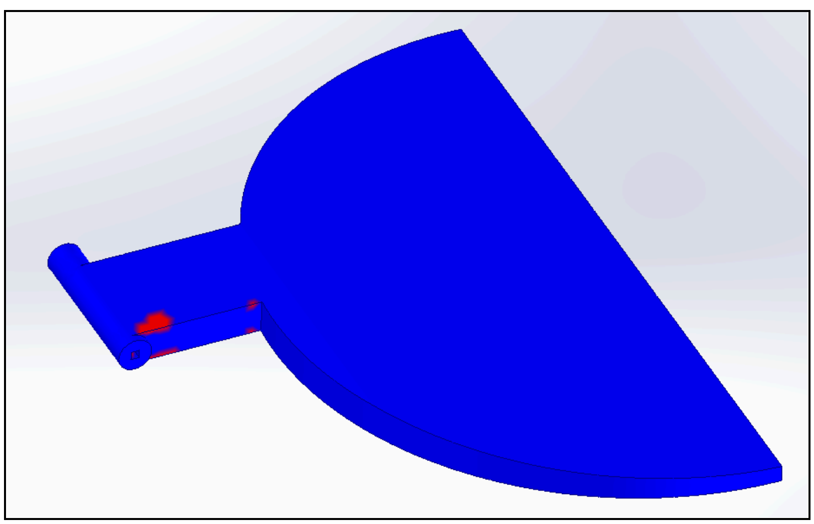


Figure 8.3: Simulation Results.

9. Budget

9.1. Estimated Material and Salary Budget

At the midpoint of the semester our team created a rough budget to allow us to anticipate points of high time and financial expenditure. This was useful as a forecasting tool to try and avoid bunching of responsibilities and to locate points where certain departments may need more resources and manpower. Our largest predicted expense by far was time invested in meetings and planning sessions. Our team has 2 morning work meetings per week, plus two afternoon planning sessions per week, and one director meeting with an occasional emergency friday meeting.

(Budgeted)	hours	cost
Meetings/ Planning	248	$ 15,451.88
Documentation/Presentation	170	$ 9,501.75
Device Development	175	$ 10,762.50
Business Development	27	$ 1,660.50
Accounting/ Records	15	$ 922.50
Equipment		$ 700.00
total	634	$ 38,999.13

Table 9.1: Budgeted Work Hours and Cost.

9.2. Committed Material and Salary Expenses

(Actual)	hours	cost
Meetings	186	$ 11,795.19
Documentation/Presentation	267	$ 16,389.75
Device Development	179	$ 11,008.50
Business Development	25	$ 1,537.50
Accounting/ Records	21	$ 1,260.75
Equipment		$ 854.28
total	677	$ 42,845.97

Table 9.2: Actual Work Hours and Cost.

In our actual time allotment, documentation and presentation preparation very quickly took over many of what we had proposed as meeting times. We can see this transition as meetings came in around $4000 under budget and presentation prep came in around $6000 over budget. Apart from that balance adjustment, the rest of our expenditures landed within a reasonable deviation from expected.

9.3. Financial Status Assessment

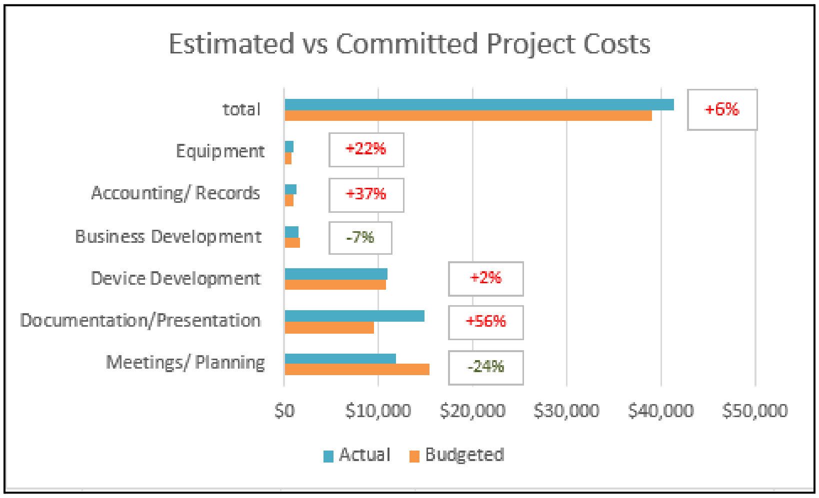


Figure 9.3: Chart of Estimated compared to Committed Project Costs.

Our team is in excellent shape in terms of overall budget commitment. As a disclaimer, I believe our team to be about $4,500 short of our actual hour commitments this semester. The team has put in place a much stronger system, and a set of incentives, to encourage and enable more accurate hour reporting next semester. This improved system includes an intuitive hour reporting spreadsheet, delegation of the task of reminding the team to report their hours at every opportunity to the project manager, and a small pot of winnings and company ownership to be divided at the conclusion of the project based on hours committed to the project.

We have spent 18.4% of our liquid capital budget with $3,795.72 remaining in the tank. I believe some of the device development could have been completed more efficiently, but each department minimizing the individuals involved in developmental segments was a huge cost savings when compared to working in pairs or as a group. Early in the semester we experienced excess inefficiency and expenditure as members were learning new skills and practicing new roles. This was especially true during device and business development. Overall, the team came in 6% over budget which should be considered exceptional. This was aided by our accounting team making periodic adjustments to budgeted resources as departments requested them.

	Budgeted	Actual
Meetings/ Planning	$ 15,451.88	$ 11,795.19
Documentation/Presentation	$ 9,501.75	$ 14,790.75
Device Development	$ 10,762.50	$ 11,008.50
Business Development	$ 1,660.50	$ 1,537.50
Accounting/ Records	$ 922.50	$ 1,260.75
Equipment	$ 700.00	$ 854.28
total	$ 38,999.13	$ 41,246.97

Table 9.4: Budgeted Compared to Actual Costs of the Entire Semester.

10. Schedule

		Name	Duration	Start	Finish	Predecessors
1		**EcoBin Completion**	**214.875 da...**	**10/2/23 9:00 AM**	**5/3/24 5:00 PM**	
2	✓	**Project Refinement and Planning**	**12 days?**	**10/2/23 9:00 AM**	**10/14/23 9:00 AM**	
3	✓	Scope and Goal Setting	4 days?	10/2/23 9:00 AM	10/6/23 9:00 AM	
4	✓	Deisgn Basis	10 days?	10/2/23 9:00 AM	10/12/23 9:00 AM	
5	✓	Performance Goals	2 days	10/12/23 9:00 AM	10/14/23 9:00 AM	
6	✓	**Proof of Concept Prototypes**	**19 days?**	**10/12/23 8:00 AM**	**10/30/23 5:00 PM**	
7	✓	CAD Modeling	7 days?	10/12/23 8:00 AM	10/18/23 5:00 PM	3
8	✓	Manufactoring Materials List/Cost	7 days?	10/23/23 8:00 AM	10/29/23 5:00 PM	2
9	✓	Prelimenary Electrical Analysis (Timeline)	12 days?	10/12/23 8:00 AM	10/23/23 5:00 PM	
10	✓	Camera/Sensors Investigation	1 day?	10/30/23 8:00 AM	10/30/23 5:00 PM	9
11	✓	Prelimenary Mechanical Anlysis (Timeline)	12 days?	10/12/23 8:00 AM	10/23/23 5:00 PM	
12	✓	PDR and Oral Presentation	6 days?	10/24/23 8:00 AM	10/29/23 5:00 PM	
13	✓	Peer Feedback	2 days?	10/30/23 8:00 AM	10/31/23 5:00 PM	
14	✓	**Pre Electronics**	**3 days?**	**10/17/23 8:00 AM**	**10/19/23 5:00 PM**	
15	✓	Install and run AI software	3 days?	10/17/23 8:00 AM	10/19/23 5:00 PM	
16	✓	Idependant image captures	3 days?	10/17/23 8:00 AM	10/19/23 5:00 PM	
17	✓	**FEED Phase**	**15 days?**	**11/1/23 8:00 AM**	**11/15/23 5:00 PM**	**6**
18	✓	**Electronics**	**11.875 day...**	**11/2/23 9:00 AM**	**11/13/23 5:00 PM**	
19	✓	Implement Light Sensors into Rpi 4	11.875 days?	11/2/23 9:00 AM	11/13/23 5:00 PM	
20	✓	2nd Iteration Prototypes	6 days?	11/1/23 8:00 AM	11/6/23 5:00 PM	
21	✓	Research on Sensors	3 days?	11/2/23 8:00 AM	11/4/23 5:00 PM	
22	✓	CDR Completion	8 days	11/8/23 8:00 AM	11/15/23 5:00 PM	
23	✓	Peer Feedback 2	5 days	11/27/23 9:00 AM	12/2/23 9:00 AM	
24		**Manufacturing Review Process**	**20 days?**	**12/1/23 8:00 AM**	**12/20/23 5:00 PM**	
25	✓	Manufacturing Production Scheduled	1 day?	12/5/23 8:00 AM	12/5/23 5:00 PM	
26	✓	AI Modeling Running on Jetson	1 day?	12/5/23 8:00 AM	12/5/23 5:00 PM	
27	✓	CAD V4.0 Mechnical Parts	3 days?	12/6/23 8:00 AM	12/8/23 5:00 PM	
28	✓	3D Printed Model of Parts	1 day?	12/6/23 8:00 AM	12/6/23 5:00 PM	
29	✓	Circuit Manufacturing Plan	0.875 days?	12/6/23 9:00 AM	12/6/23 5:00 PM	
30		AI to Door Code	14 days?	12/7/23 8:00 AM	12/20/23 5:00 PM	
31	✓	Design Jetson Board Hookups	1 day?	12/7/23 8:00 AM	12/7/23 5:00 PM	
32	✓	Submit CAD Models for Injection	1 day?	12/8/23 8:00 AM	12/8/23 5:00 PM	
33	✓	Submit CAD Models for Review with Dan,Pat	1 day?	12/8/23 8:00 AM	12/8/23 5:00 PM	
34	✓	Design Points of Customer Truth	1 day?	12/8/23 8:00 AM	12/8/23 5:00 PM	
35	✓	Model Sample User Displays PPT	1 day?	12/8/23 8:00 AM	12/8/23 5:00 PM	

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		Name	Duration	Start	Finish	Predecessors
36	✓	AI Development Plan	2 days?	12/8/23 8:00 AM	12/9/23 5:00 PM	
37	✓	CAD Sensor Housing	1 day?	12/9/23 8:00 AM	12/9/23 5:00 PM	
38	✓	CAD Screen Display	3 days?	12/9/23 8:00 AM	12/11/23 5:00 PM	
39	✓	Integrate Jetson to Motors	1 day?	12/11/23 8:00 AM	12/11/23 5:00 PM	
40		Model Sample Advertisements	1 day?	12/13/23 8:00 AM	12/13/23 5:00 PM	
41		Finalized Design	14 days	12/1/23 8:00 AM	12/14/23 5:00 PM	
42		End of Term Report	12 days	12/4/23 8:00 AM	12/15/23 5:00 PM	
43		Manufactoring Review Prep	15 days?	12/4/23 8:00 AM	12/18/23 5:00 PM	
44		Schedule and Cost Update	1 day?	12/19/23 8:00 AM	12/19/23 5:00 PM	43
45		**Winter Break**	**25.875 day...**	**12/15/23 9:00 AM**	**1/9/24 5:00 PM**	
46		Review Feedback from Review	1.875 days?	12/15/23 9:00 AM	12/16/23 5:00 PM	
47		Order Materials	20 days?	12/21/23 8:00 AM	1/9/24 5:00 PM	24
48		**NVC Requirments**	**45 days?**	**12/20/23 8:00 AM**	**2/2/24 5:00 PM**	
49		**Rough Draft of the following Complete**	**31 days?**	**12/20/23 8:00 AM**	**1/19/24 5:00 PM**	
58		Polished Draft (All team members read through an...	4 days?	1/19/24 8:00 AM	1/22/24 5:00 PM	
59		Slide deck complete	8 days?	1/19/24 8:00 AM	1/26/24 5:00 PM	
60		2 minute video pitch	15 days?	1/19/24 8:00 AM	2/2/24 5:00 PM	
61		**Testing/Manufacturing**	**44 days?**	**1/15/24 8:00 AM**	**2/27/24 5:00 PM**	**45**
62		Printing Inner Door Hub	12 days	1/15/24 8:00 AM	1/26/24 5:00 PM	
63		Printing Top Ring	9 days	1/15/24 8:00 AM	1/23/24 5:00 PM	
64		Printing Swing Door	9 days	1/15/24 8:00 AM	1/23/24 5:00 PM	
65		Printing Motor Cap	6 days	1/15/24 8:00 AM	1/20/24 5:00 PM	
66		Printing Bearing Cap	15 days	1/15/24 8:00 AM	1/29/24 5:00 PM	
67		Prototype Results/ Testing	20.875 days?	1/15/24 9:00 AM	2/4/24 5:00 PM	
68		Redesign	4.875 days?	2/5/24 9:00 AM	2/9/24 5:00 PM	
69		Final Manufacturing	15.875 days?	2/12/24 9:00 AM	2/27/24 5:00 PM	
70		**Project Adjustments and Analysis**	**109.875 da...**	**1/15/24 9:00 AM**	**5/3/24 5:00 PM**	
71		CU Engineering Project EXPO	2 days?	5/2/24 8:00 AM	5/3/24 5:00 PM	72;73
72		Final Report/Presentation	15 days?	4/1/24 8:00 AM	4/15/24 5:00 PM	
73		Adjustments	77.875 days?	1/15/24 9:00 AM	4/1/24 5:00 PM	

11. References

[1] "The Ultimate Guide to Addressable Led Strip." *LED Lights Manufacturer in China*, aidiwattlighting.com/the-ultimate-guide-to-addressable-led-strip/. Accessed 11 Nov. 2023.

[2] "Overview of Materials for Polyethylene Terephthalate (PET), Unreinforced." *Overview of Materials for Polyethylene Terephthalate (PET), Unreinforced,* www.matweb.com/search/datasheet.aspx?MatGUID=a696bdcdff6f41dd98f8eec3599eaa20. Accessed 15 Nov. 2023.

[4] "How Can I Get People Not to Put Trash in Recycling Bins?" *User Experience Stack Exchange*, 1 June 1961, ux.stackexchange.com/questions/76019/how-can-i-get-people-not-to-put-trash-in-recycling-bins.

[5] 13, Renee Cho .|March, et al. "Recycling in the U.S. Is Broken. How Do We Fix It?" *State of the Planet*, 18 Oct. 2022, news.climate.columbia.edu/2020/03/13/fix-recycling-america/.

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[8] *US Composting Council*, www.compostingcouncil.org/. Accessed 1 Dec. 2023.

12. Appendix

A.1. Past Design Images

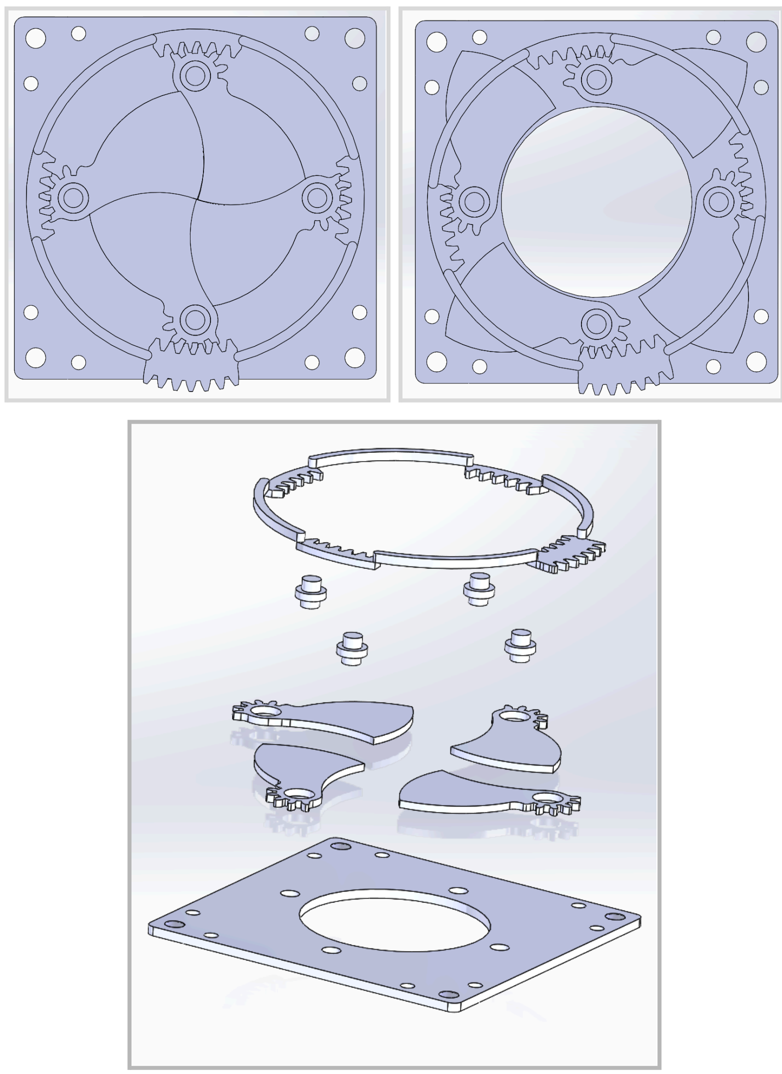


Figure A.1, A.2, A,3: Aperture Design 1

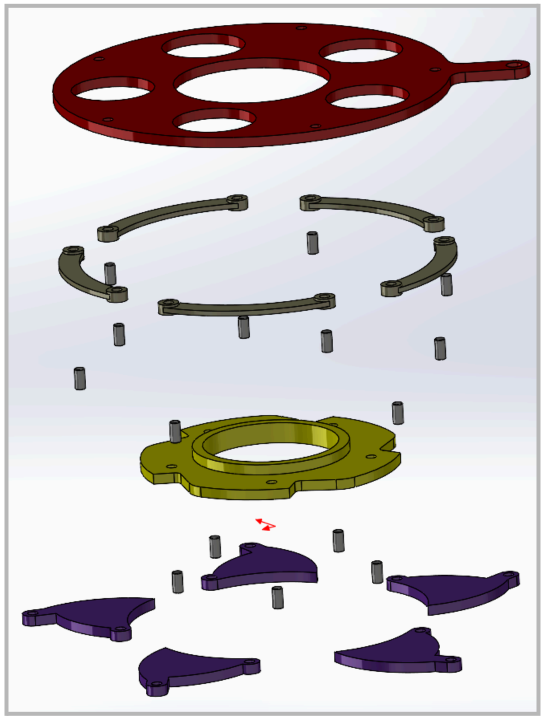
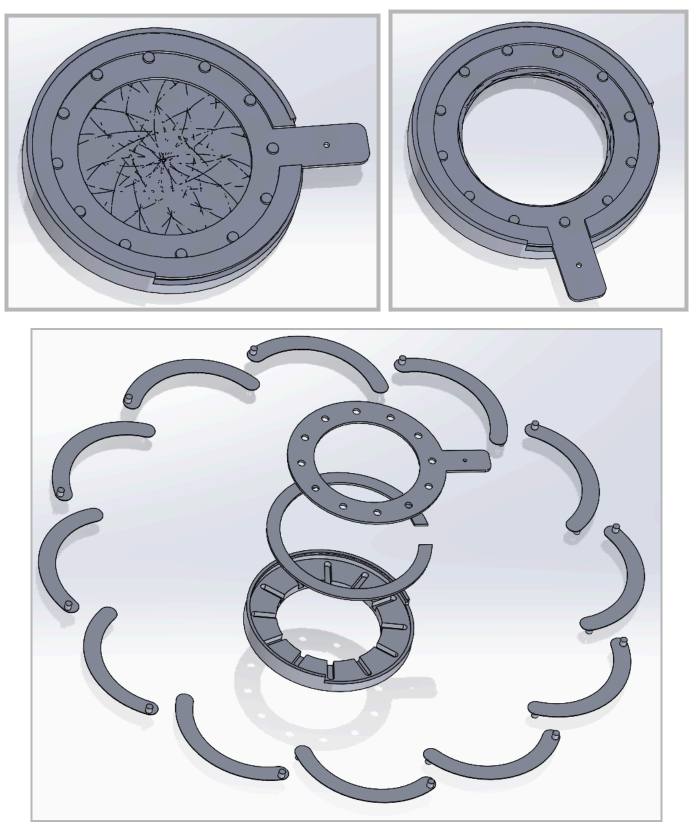


Figure A.4: Aperture Design 2



Figures A.5, A.6, A.7: Aperture Design 3

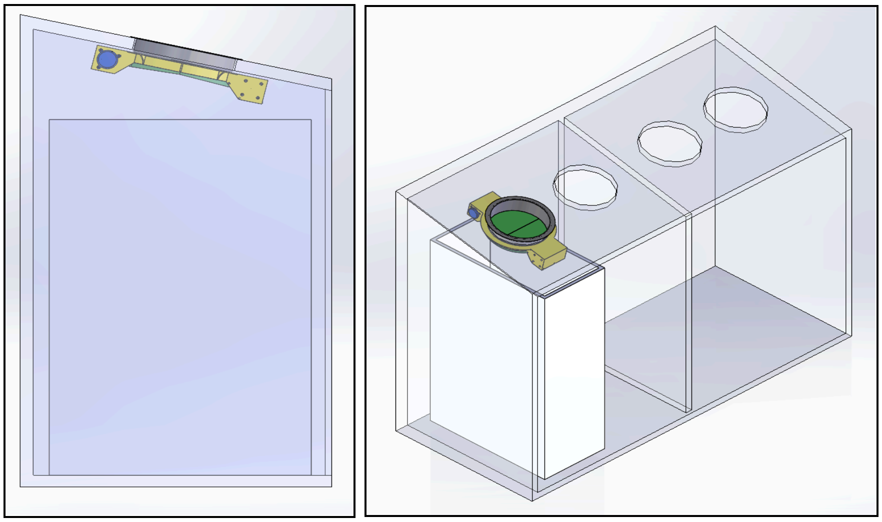
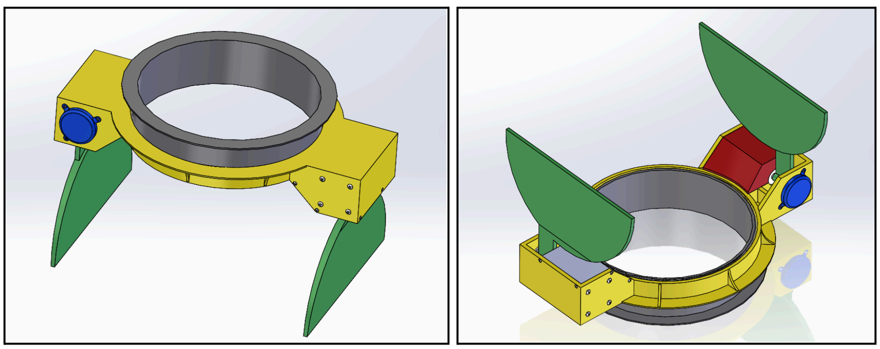
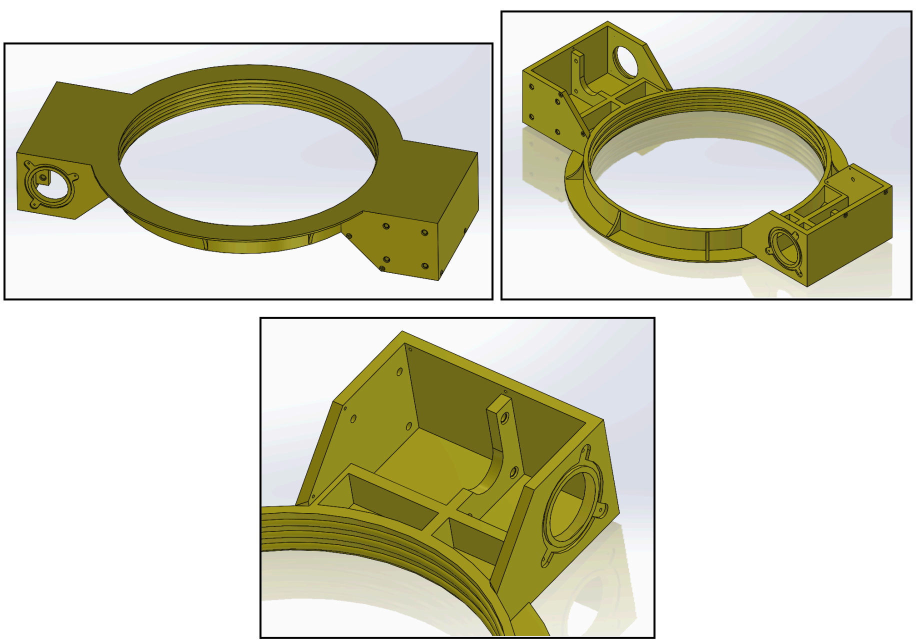


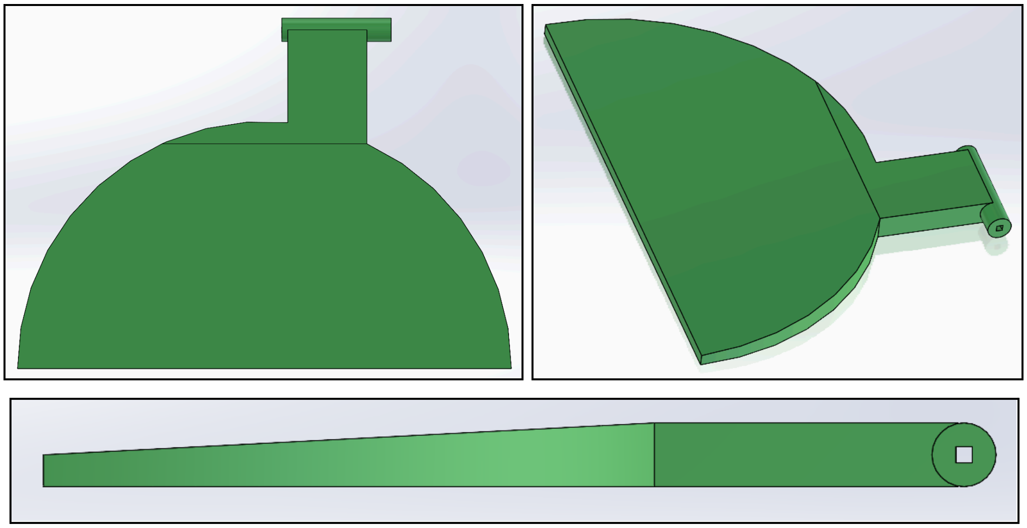
Figure A.8, A.9: Bin Cabinet and Door Assembly.



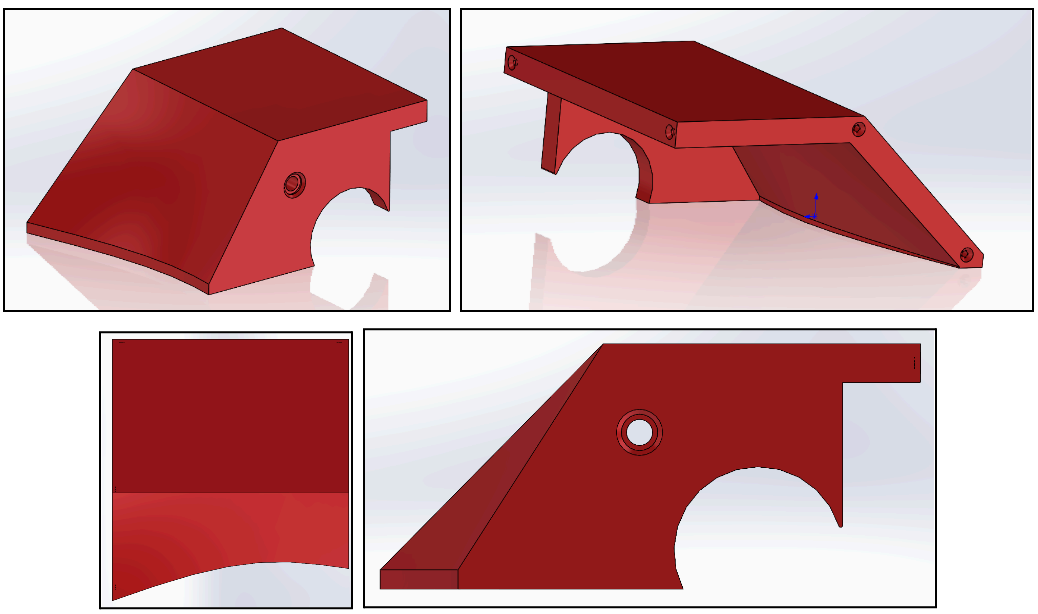
Figures A.10, A.11: Door Design Assembly.



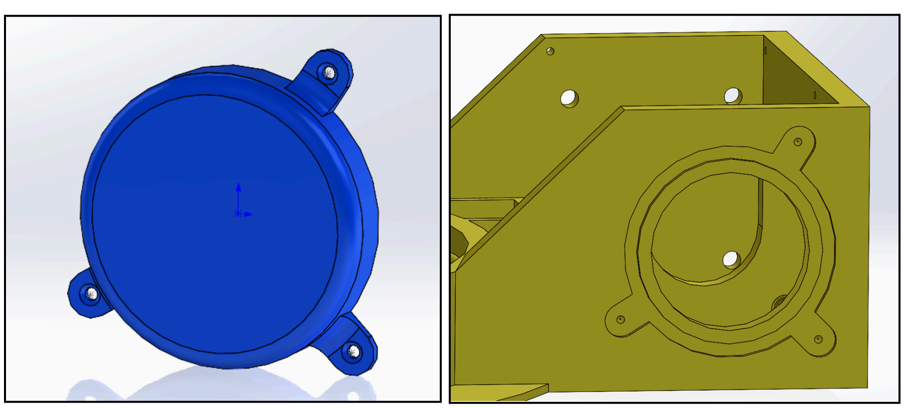
Figures A.12, A.13, A.14: Door Hub Component Design.



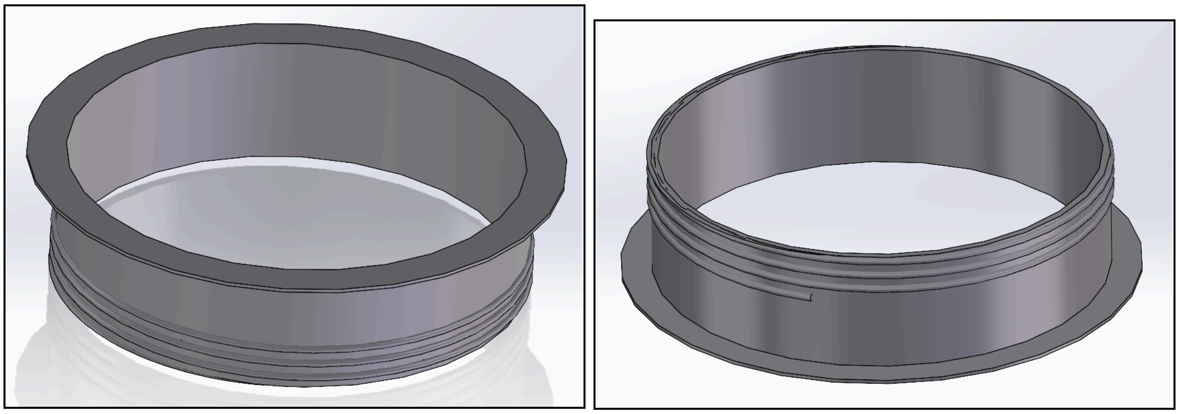
Figures A.15, A.16, A.17: Door Component Design.



Figures A.18, A.19, A.20, A.21: Motor Cap Component Design.



Figures A.22, A.23: Bearing Cap Interface Design.



Figures A.24: First Iteration of Top Ring Component Design.

A.2 Circuit Diagrams

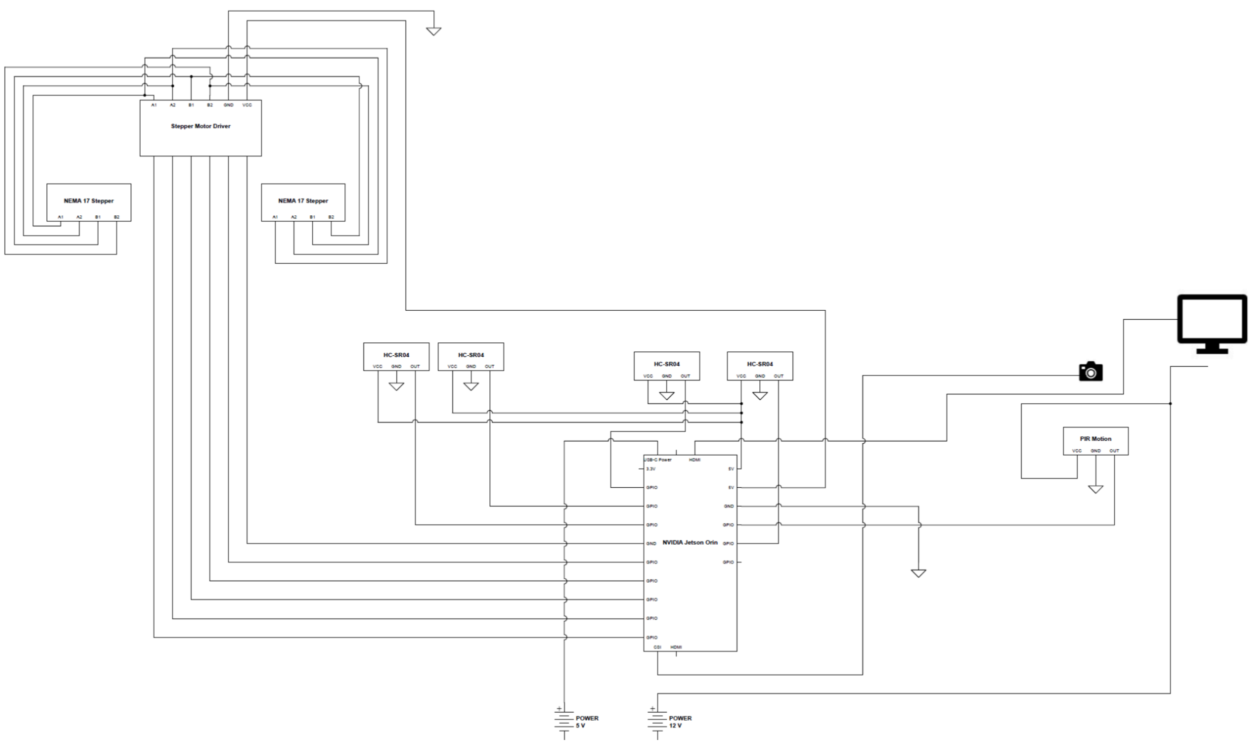


Figure A.25: Full Circuit Diagram Simplified Design.

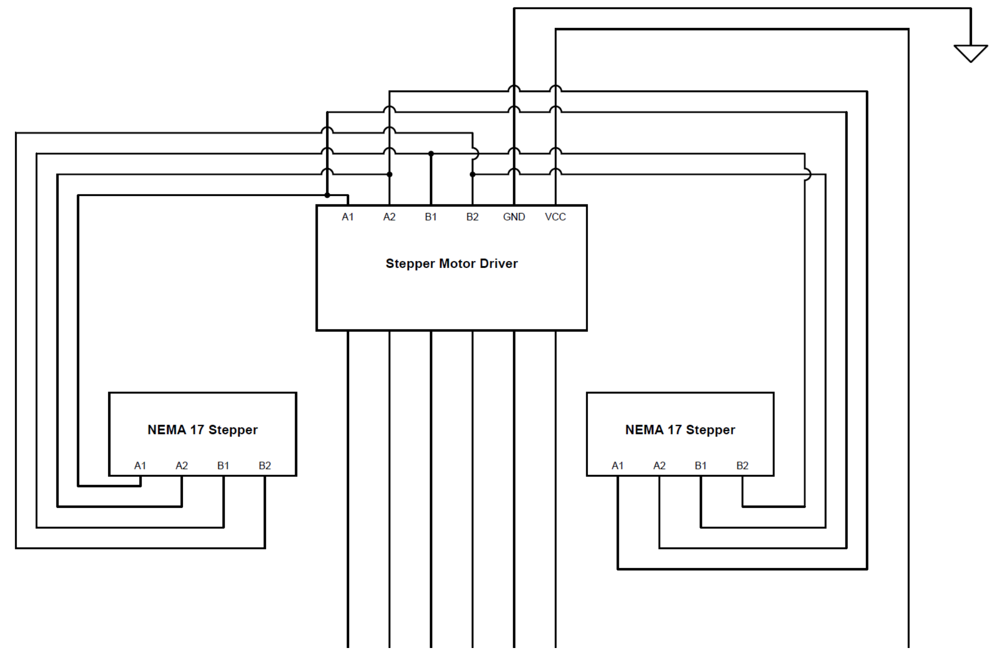


Figure A.26: Stepper Motors and Driver Close-Up Wire Diagram.

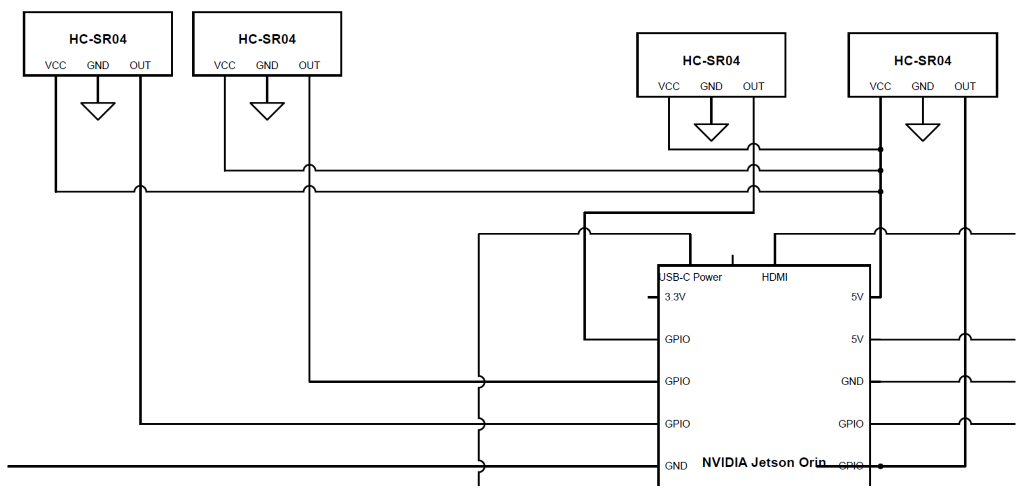


Figure A.27: Ultrasonic Sensors Close-Up Wire Diagram.

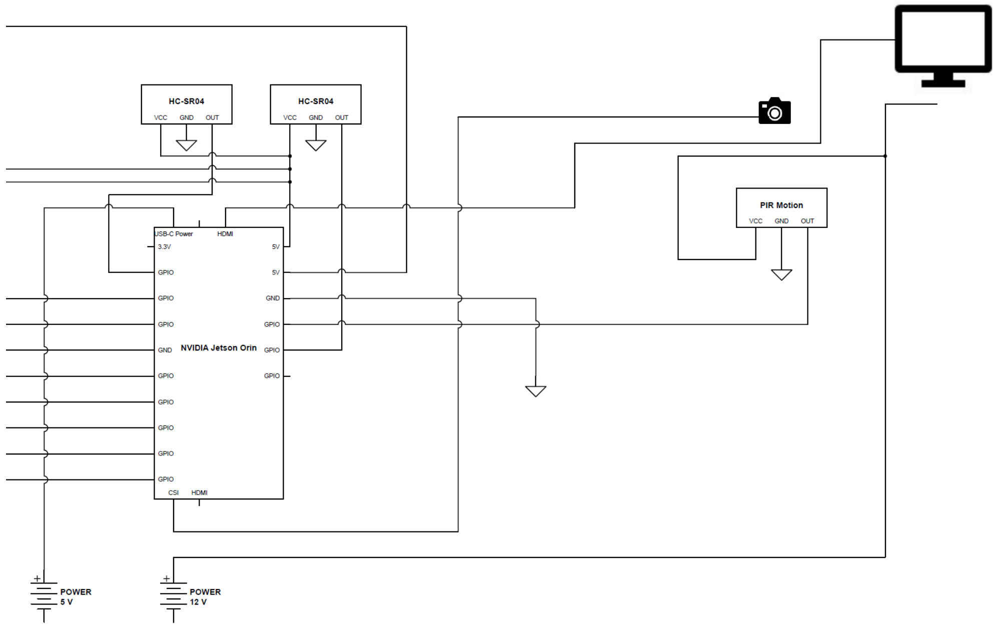


Figure A.27: Camera, PIR Sensor, Display Close-Up Wire Diagram.