Integrative Summary

Studio 0112 Team 0112A

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S0: Summary of Revisions

Aspect/Article	Change Made	Justification
Value proposition	Reworded	Value proposition from phase I discussed the technical goals in light of the intended value generation. The reworded proposition retains this information, but shifts focus towards the stakeholders, and key ideas and goals in context of the Ghanaian community, not just the technical engineering aspect. This change was made based on Dossier I feedback.
Conceptual Design	Gate added to updated concept design	A gate was added in front of the input area to prevent the waste from falling out onto the alignment mechanism when the machine is loaded with waste. This increases control over the flow of materials through the machine. This change was made based on Dossier I feedback and observations during the prototyping stage.
Conceptual Design placement	More specification to the framing	Though the team had initially focused on the Ghanaian context for opportunity framing, some specificity was lacking in terms of machine placement. Reconsidering the socio-political landscape and the machine's capabilities, the chosen placement was ghanaian neighborhoods where citizens struggle to dispose of waste and often pay for third-party waste collection. This would particularly benefit those living in areas with waste lining the streets. This change was made based on Dossier I feedback and prototyping observations.
High Fidelity prototype design	A ramp-like dropper instead of the recycling sweepers	This change was made because the recycling sweepers were unnecessarily complicated and the sorting could be better demonstrated through a different mechanism. Details concerning this change can be found in the iteration document and lab notebook.
	Arduino UNO instead of nano	To accommodate the front-end interface using megunolink, an UNO microcontroller had to be used since only that is compatible with the chosen software. This change can be found in the lab document.
	DC motors to stepper	The team noticed that the conveyor belt and the sorting base required higher torque, and stepwise movement for better control. Hence stepper motors were used. Details can be found in the iteration document.
	Sorting base attachment	In the initial prototype design, the sorting base was attached to the exoskeleton. It now has an additional support propping it in place
Stakeholder representation	Changed to show relationships more clearly	Earlier representation of stakeholder relationships implied value generated but did not explicitly flesh out the relationships and externalities. Current representation solidifies the framing by expanding these details.
Team Charter	Time efficiency as a value	Addition of time management and efficiency to the revised Team Charter as a value to prioritize focus on getting tasks done. Also to allow crisp, short team meetings which prevented productivity plateaus.

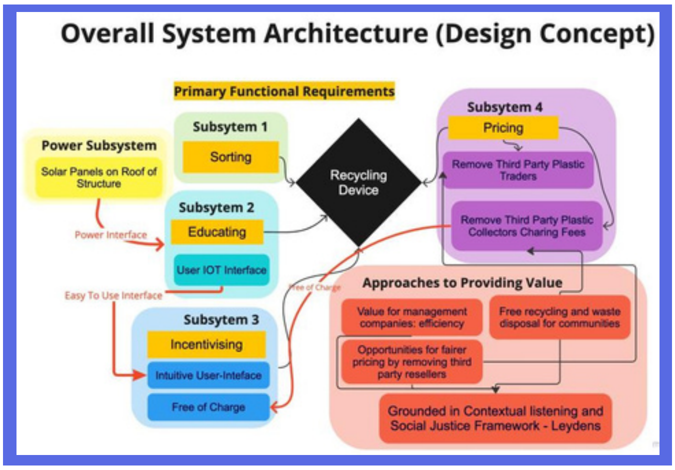
U-Sort

Value Proposition: A Mechatronic Device That Promotes Recycling on an Individual Level with an Educational Interface to Combat the Waste Crisis in Ghana by Utilizing an On-Device Sorting Mechanism to Differentiate between Recyclables

Design Challenge

Makafui Awuku, this design challenge's opportunity champion, mentions the need for an engineering solution to address the recycling concerns in **Ghana**. The challenge is to design a solution to ensure plastic sorting, assess quality and support waste management personnel. At the centre of the design is social justice. Pains resulting from informal collection should be minimized and the misuse of power from informal resale will be limited. The design concept should also promote education and awareness of recycling to benefit communities

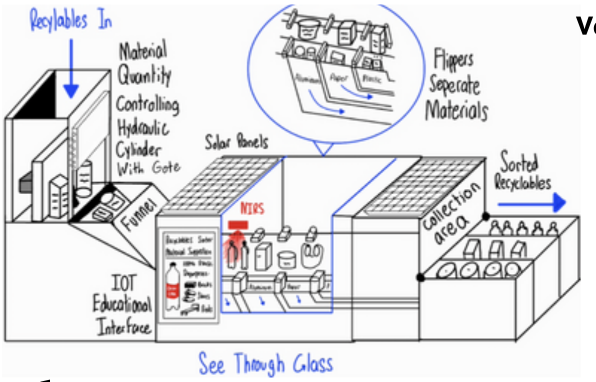
By Framing We Scoped Down To Tackle Multiple Pains of Our Stakeholders



Design Concept

1. Inputting the recyclables into the machine
2. Aligning the recyclables for sorting
3. Sorting the recyclables based on composition
4. Placing them in categorized collection bins

These will be located in neighbourhoods to ensure accessibility to waste personnel who will be collecting sorted waste and providing residents with free waste-disposal services.



Value to Stakeholders

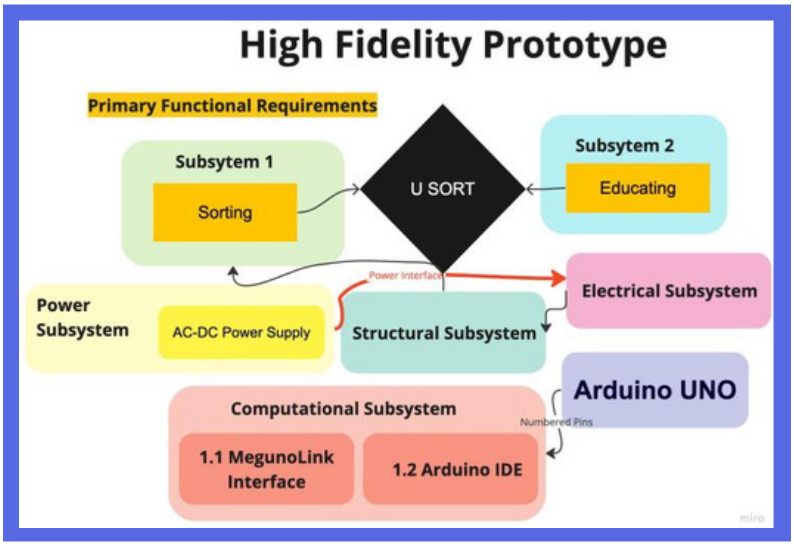
1. Alleviates Pain to gain accessibility to recycling services for communities
2. Limits misuse of power from informal resale avenues
3. Increases capacity for sorting and collection
4. Alleviates pain from dump site collection

High-Fidelity Prototype

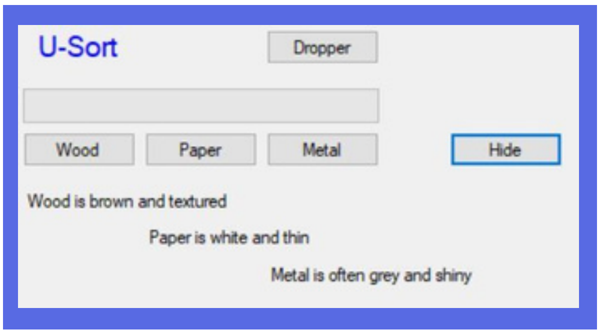
The sorting and educational aspect was identified to be the most complex aspects of the design concept and were de-risked.

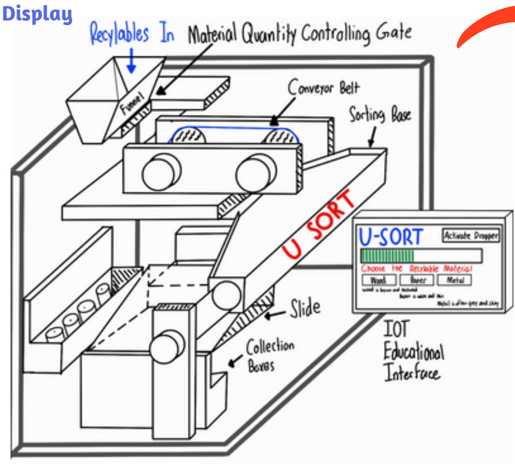
<u>Description:</u> The prototype consists of **7** main subsystems

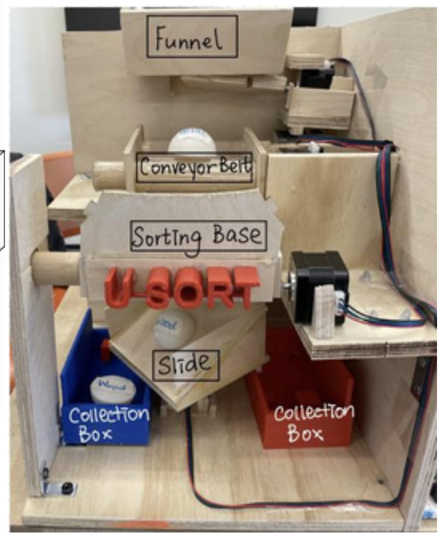
-**Exoskeleton** provides structural integrity for the subsystems
-**Funnel** allows for the input of recyclables but the output of aligned recyclables for sorting as mention in design concept
-**Conveyor Belt** transports recyclables to the slide for sorting
-**Slide** sorts recyclables based on composition via IOT interface
-**Electrical system** connects drivers, microcontrollers & motors
-**Software** provides the IOT educational interface via a Front-End GUI **Meguno Link**



Meguno Link Software Provides the Following Interactive IOT Display







Justification for Prototype

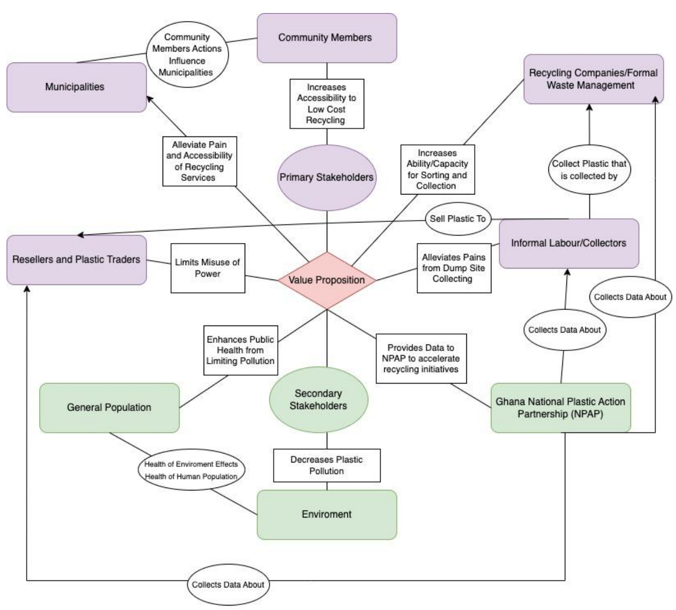
1. Communicates the feasibility of our sorting mechanism to differentiate waste materials
2. Tests the ability to teach users about the recycling process via an IOT Education Interface
3. De-risks uncertainties in sorting recyclables given user interactment

S1: Visual Abstract

S2: Summary of Design Activities

S2.1: Design Context:

The opportunity space presented by Makafui, the team's Opportunity Champion, required an engineering solution to address recycling concerns in Ghana. The overarching goals presented by the Champion focused on ensuring proper plastic sorting and assessing quality, supporting waste management personnel, and creating technologies that help in the process of plastic transformation. With this opportunity space, the team decided to focus more on the sorting aspect of the recycling as this was found to be a crucial part of the value chain, which also hosted multiple pains for the stakeholders [1-AB]. To formulate a firm stance, and unified framing regarding the team's interpretation of opportunity space, secondary research was consulted. Existing infrastructure for plastic sorting, the human rights violations involved in the overall process, and the holistic Ghanaian waste crisis was investigated to inform the team's understanding of Ghana's socio-political landscape. It was found that lack of policy was the overarching antagonist in the waste crisis [2-AB]. However, tackling policy issues was not within the scope of the established opportunity space defined by the ESC204 cours. Hence, the team used a requirements model approach, supplemented by research to establish contextual background to understand the opportunity space better and decide how to best provide value to relevant stakeholders. Given the team's shared values of honesty, responsibility, effective communication, equity, and social awareness as outlined in the Team Charter, there was a unanimous decision that the opportunity space should be structured such that value is provided through social justice means by promoting equity, the design should minimize pains, and the design should benefit key stakeholders. The key stakeholders identified and of interest, as well as the relationships between them and the ways in which value can potentially be provided to them are outlined in Fig 1. We understood our limitations in understanding the opportunity space often showed up as blind spots when we ran into contextual questions. To facilitate bridging gaps, we tried to look for resources written by Ghanaian authors and sought a conversation with the opportunity champion, frequently asking the teaching team for assistance to make sure we were not tone deaf in our interpretations.



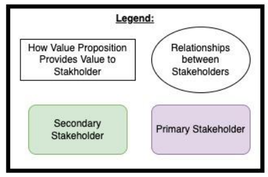


Figure 1. Diagram of relevant stakeholders.

2.1.1 Primary Stakeholder Analysis - Pains and Gains

The primary stakeholder in this opportunity space are informal collectors, recycling companies, plastic resellers, municipalities, and community members. Informal collectors earn their livelihoods from collecting, sorting and aggregating waste found in streets and landfills, or sourced directly from households. They then sell recyclable waste, including plastic items, to buy back centers or formal recyclers. For example, in South Africa, a country also subject to waste issues, some researchers estimate that there are up to 215,000 waste reclaimers [2-AB]. While the collection has provided opportunities to many groups of people through the expansion of the informal market, informal collectors are faced with pains such as handling unsanitary waste from landfills and then bringing collected waste to resellers to be sold for unfair compensation for their collection services. The pains experienced by informal collectors are coupled with the misuse of power that is associated with those who facilitate the resale of recyclables as buying is typically done at inaccurate prices [1]. Moreover, a local Ghanaian informal collector explains the landfills in which the collecting is done, “Is a terrible place, but it brings us materials that help put food in our stomach. I wish I didn’t have to do this”[1]. By implementing a design that limits the requirement to go through landfills and by removing the intermediate step in the recycling chain of the resale buyer, there are gains that can be brought towards informal collectors.

Formal waste management is also another key stakeholder as these groups are largely responsible for the sorting stage of the recycling process. The sorting stage is crucial since the majority of plastics manufactured are not recyclable [2] and thus it is important to distinguish between plastic types. However, there is limited infrastructure and capacity for collection and sorting [2-AB], thus there is value to be gained for management companies through the design allowing for more efficient sorting.

Municipalities and community members are of importance since the design will be situated in communities and places of population density to fulfill the value proposition. As lack of policy is one of the largest factors contributing to the waste crisis [7-AB], if municipalities and community members are not willing to accept and participate in the design, it is of no use in alleviating pains of other stakeholders. Furthermore, a pain municipalities and community members face is the price and inaccessibility of recycling services. The design must be able to decrease these pains and provide accessible recycling services.

2.1.2 Secondary Stakeholder Analysis - Pains and Gains

The environment and general population are also stakeholders as plastic pollution significantly contributes to the health of the general population and environment from causing pains such as polluting groundwater, the burning of plastic waste releasing hazardous toxins, plastics entering the ocean and posing a threat to the marine environment and more [3]. There is potential gain to be made by removing the amount of plastic that ends up in landfills or is disposed of by harmful means. A formal collection and sorting site can potentially accomplish this.

The Ghana National Plastic Action Partnership (NPAP) is a multi-stakeholder cooperation that facilitates initiatives and funding to accelerate recycling in the country [4]. The lack of policy stems from the fact that there is an absence of data pertaining to recycling efforts[5]. Thus, current information on waste generation is important to determine the most suitable waste disposal options [6]. The Ghana NPAP collects data and creates a baseline analysis upon which solutions can be built, bringing leaders together to develop national action roadmaps that use data analysis and expert-informed action to drive local change. Thus, potential gains can be made for several other stakeholders if the design can collect data through its sorting component.

2.1.3 Value Proposition

The collection and recycling of plastic and other waste are important activities in a circular economy as they help to divert plastic waste from landfill and thus reduce plastic leakage into nature. These services – collection and recycling – are largely the responsibility of municipalities and, more recently, product producers as mandated by emerging Extended Producer Responsibility (EPR) regulatory frameworks [21-AB].

Furthermore, communication with the Opportunity Champion, outlined in the Opportunity Champion Meeting Notes, was made to understand the context of the opportunity space better and ensure that we had real time input from community representatives. Discussion with the Opportunity Champion helped the team understand that recycling alone is not sufficient in tackling the waste crisis and that recycling needs to be incentivized to be successful. This includes not only education but also equipping people with the ability and skill set to make changes. Moreover, it was found that it is often difficult for Ghanians to find recycling centers close to them and this then takes incentive away from recycling efforts. The Opportunity Champion mentioned that in order to have a successful recycling program, waste must aggregate and be picked up altogether. This is much cheaper than alternative methods and is the most feasible recycling option for Ghana.

Through additional research, it was found that concrete infrastructure related to waste management and plastic recycling is only found in a few larger cities in Ghana and that substantial improvements in the management and recycling of plastic waste will be achieved only when a *clearer* and *higher* economic value can be introduced in the plastic waste value chain. It was also found that the information related to the amount of plastic waste is also sometimes contradictory and has not been collected systematically enough [3-AB].

Equipped with this contextual information the team converged on the following value proposition:

> *The team will design a mechatronic device that promotes recycling on an individual level with an educational interface to communicate the differences between materials and their potential repurposability and transformability. Value will be provided to informal collectors by removing misuse of power from informal resale avenues since the device will remove intermediate recyclable traders from the plastic collection pipeline. Value will be provided to communities and the general public through providing a method to incentivise recycling within communities. Value will also be provided to the general public and communities through providing education about recycling, ensuring long term positive change. This will be executed through an on-device sorting*

mechanism that differentiates between recyclables based on material, mass, and/or quality that simultaneously educates the user about recycling.

S2.2: Approaches to Providing Value

2.2.1 - Choosing a Value Proposition

Following performing contextual research as outlined in S2.1, an initial list of 7 Value Proposition ideas were brainstormed by team members and can be found in the Jan 23 Meeting Minutes.

To define an appropriate scope and frame, a requirements model approach was taken to refine the set of initial Value Propositions to converge out unfit Value Propositions. Objectives were constructed based on contextual listening done by referencing artifacts outlined in S2.1 and are outlined in the Value Proposition Requirements Model. Metrics were chosen in order to evaluate how well a specific Value Proposition addresses a specific objective. For each objective that the Value Proposition must address, constraints and criteria were applied.

The model was then applied to the 7 initial brainstormed ideas and this work can be found in the Value Proposition Metrics Table Document . Some key objectives that were emphasized included whether the Value Proposition aligned with team values in the Team Charter, whether the Value Proposition offered a diverse design space, if the Value Proposition was feasible within the scope of ESC204, and if the Value Proposition was socially informed. For example, it was found Value Proposition #5 - "A mechatronic device that speeds up the collecting process for the informal labor, to allow more plastic collection", was very easy to come up with multiple feasible ideas within in a short time span of 5 minutes, thus indicating it had a promising design space, however, it was found that it could potentially misalign with the team's value of responsibility in terms of being a global citizen as it could promote the same unjust social cycles associated with plastic collection such as children picking up plastic for unfair resale prices. Thus, having considered all objectives the final value proposition outlined in S2.1 was converged upon. It was found that having a mechatronic component and specifically tackling the sorting issue would address the objective of having a promising design space and being feasible in the scope of ESC204. Furthermore, through implementing an educational interface, the team's values were being included in potential designs. The updated Value Proposition now allowed for the potential to address root causes of the waste crisis issue as described by the Opportunity Champion in the Opportunity Champion Meeting Notes. This also aligned with the team's shared values of equity, social awareness, and responsibility. Using the above methods, the value proposition was chosen.

2.2.2 - Engineering Requirements

Upon deciding the Value Proposition, a set of Engineering Requirements was constructed. Iterations of the Engineering Requirements table can be found in the team's Sharepoint folder. The final copy of the engineering requirements table along with justifications can be found in the Engineering Requirements Version 2 Document.

Before defining design specific objectives, Design for X (DfX) criteria were considered based upon team values and what value the team hoped to achieve through the established Value Proposition. Emphasis on designing for social justice was placed since this aligned with team values such as equity.

Design for reliability was chosen as another DfX of interest as it was important to create a design that would be able to handle a variety of conditions and edge cases to make a constructive impact with regards to the waste crisis. If the design failed easily, it would not be of use to key stakeholders including the general Ghanaian population who would not have a place to deposit their recyclables and to formal collectors who would be additionally tasked with dealing with the failed collection/sorting device in addition to collecting the recyclables themselves.

The third DfX which was focused on was designing for reusability and repairability. Reusability ensures that components of the design do not further contribute to the waste crisis in Ghana at the end of their life cycle. Repairability of the design gives the tools and assets to the general population. It was mentioned by the Opportunity Champion that "If people are not equipped with the ability/toolset to make change nothing happens". In order to create systemic change, design solution failures must be able to be handled by members of the general population. A specific repair person should not be required to come in if the device does fail. Furthermore, in accordance with the Leydens framework for social justice in engineering [7], increasing repairability of the design allows an increase in opportunity by allowing specific community members to be trained in repairing the design while also enhancing human capabilities by providing a means of playing a central role in the design solution if a failure does occur.

Design for the environment was considered so as to not further contribute implicitly to the other issues of the waste crisis such as climate change. Furthermore, as the environment also refers to the urban environment, when an engineering design is planned to be situated in an urban setting, the policies and regulations of the geographic setting must be respected. For example, the physical space the design takes up or the amount of noise the device makes, which is of significance due to the mechatronic nature of the design, as Ghana does have strict noise pollution guidelines[8], had to be considered. Design for awareness was considered since through the meeting with the Opportunity Champion and additional research it was found that the majority of Ghana is lacking awareness about the dramatic negative effects of plastic pollution and proper recycling practices. This is one of the main causes behind the waste crisis in Ghana and thus an area the team wanted to focus on.

Finally, design for utility was considered since the design would not provide power to the general public if it were not intuitive to use. Ideally, the design should increase the incentive to recycle. This can be achieved by making the device more intuitive and thus more usable. Furthermore, the extent to which the design can distinguish recyclables adds an additional layer of robustness in the recycling process and benefits stakeholders such as formal waste collectors who can easily collect pre-sorted recyclables. The specific engineering requirements and their justifications can be found in Engineering Requirements v.2.

2.2.3 - Competing Requirements

Several requirements that fall under design for environment and design for utility compete with each other. For example, the requirement of "Should have easy repairability" can potentially compete with the requirements of "Should be capable of generating its own energy efficiently" and "Should increase opportunity." Implementing cutting-edge energy sources such as solar panels may inhibit the ability of a community member without technical expertise from partaking in the repair of the design if it does fail. This would take away opportunities from community members as external sources of assistance would be required to address repairs. Consequently, this hinders the ability of the device to address social justice issues. Leyden's social justice in engineering framework emphasizes that one of the ways an engineering design can be socially informed with human-centered design for communities is if the design enhances and accommodates culturally appropriate opportunities [7]. By incorporating components that would require a niche technical expertise to troubleshoot, power is taken away from stakeholders such as municipalities and communities and thus decreases repairability and takes away opportunity.

Another set of requirements that compete with each other include "Should have easy repairability" and "Should be effective at sorting". As will be made evident in S2.3, the team converged on using an IR spectrometer to classify and sort recyclables, however, this competes with the repairability requirement as an IR spectrometer is a sensitive piece of equipment that requires technical expertise when it comes to repairs. Thus some compromises with respect to these two requirements must be made.

A third pair of requirements that compete with one another include “Should be effective at sorting” and “Should not damage/disturb the local environment”. Also as will be seen in S2.3, the component that mechanically sorts the inputted recyclables is a mechatronic component. This module of the design can be expected to make noise and contribute to noise pollution where the design is situated. This issue is expected to arise when dealing with mechatronic components and many moving parts. Comprises must once again be made with regard to these two requirements.

Furthermore, the functional requirement of “Should promote education about the importance of recycling through IOT interface” can potentially compete with “Should incentivize recycling”. If the design enforces the spreading of information about proper recycling, this could potentially remove incentive recycling efforts as the educational aspect may discourage community members from learning about recycling since the new influx of knowledge may appear intimidating [9]. Thus it is important that the educational interface spreads information in a manner that incentives recycling practices but also does so in a digestible manner.

S2.3: Conceptual Design: Bring The Recyclables To Me Sorter (U-Sort)

There were various conceptual designs that addressed the engineering requirements our team developed (Conceptual Design Brainstorming, Unused Designs); however, through an iterative design process, we concluded on a design concept that we are proposing for our value proposition. Our [design concept] is visualized in Fig. 2 and can be categorized into 4 steps; inputting the recyclables into the machine, aligning the recyclables for sorting, sorting the recyclables based on their material composition, and finally placing them in their respective categories for collection.

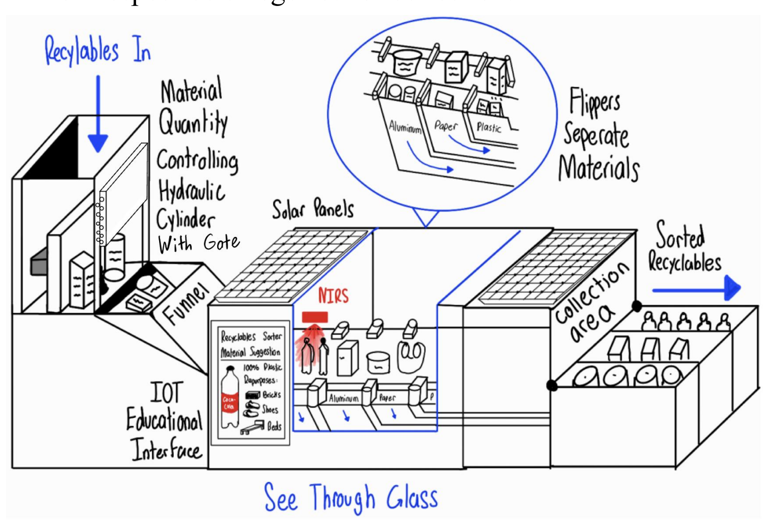


Figure 2: Detailed Sketch of Design Concept

2.3.1 - Step 1 Inputting the Recyclables

The first step of the design concept is inputting the recyclables into the machine, where our design makes use of a hydraulic cylinder system.The ideal input to the machine would be recyclable materials and we needed to decide the quantity of them being inputted. We diverged upon two design concepts through classical brainstorming; inputting recyclables one by one or in large quantities.Through the use of pugh charts, we converged to inputting recyclables in large quantities. This serves our engineering requirements more appropriately, embodying the DfX's of Design for Utility and Design for Social Justice. Additionally, value was created for stakeholders as they can now bring more recyclables to our device thus reinforcing our value proposition of incentivizing recycling. To ensure the ability to recycle in great quantities we converged to an open-top face (Fig. 2) which was inspired by reference designs of waste collection bins where users can simply dump all their waste thus increasing the number of materials that can be recycled. When being loaded, recyclables are dumped into the machine with the gate closed. Then, while the gate is open, a hydraulic single-acting cylinder pushes the materials at fixed intervals down the funnel to control the rate of trash flow (Fig. 2). The funnel itself acts as an alignment mechanism (Section 2.3.2). Single-acting cylinders found in garbage trucks are used as a reference design due to their simplistic design aligning with the previously mentioned engineering requirements [10][11]. The purpose of the hydraulic cylinder and gate system is to ensure that the machine is not overloaded with materials and that the sorting process is not affected by an inoperable amount of recyclables.

2.3.2 - Step 2 Aligning the Recyclables

The second step of the design concept is to employ a funnel system to align the recyclables for sorting and to transport them from the input into the sorter (Fig. 2). Because the inputs into the machine are recyclables at great quantities, to ensure adequate sorting of the materials in the next mechanism, the funnels attempt to align the materials into a line as the opening of the funnel constricts the flow of recyclables. Funnels are used in the industry and reference designs were consulted where waste was dumped into the funnels and transported onto the conveyor belts for sorting.

2.3.3 - Step 3 Sorting

The third step of the design concept is sorting the recyclables based on their material compositions with the use of near-infrared spectroscopy (NIRS) and a conveyor belt to carry the recyclables (Fig. 2). NIRS is a spectroscopic technique that employs the near-infrared region of the electromagnetic spectrum ranging between 760 to 2500 nm [12] to measure the absorbance and scattering of light by materials [13]. The technology works by emitting light from an incandescent light source onto a material and the diffuse reflectance of the light back to the receiver is used to identify the composition of the material [14]. In our design concept, the use case of NIRS is to analyze the recyclables in the machine and differentiate them based on their composition. Some of our primary research on NIRS comes from working with sensors in Lab 5. Evidence of this work can be seen in the Lab 5 directory. In particular, working with the PIR sensor provided some background in working with an infrared sensor and baseline framework. After significant secondary research on NIRS, we concluded it would be the optimal design choice due to its non-destructive nature ensuring the integrity of the materials, ability to analyze materials rapidly, and relative affordability compared to other identification methods at waste facilities [15]. One of the key pains of recycling our Opportunity Champion mentioned was the necessity of maintaining the structural integrity of the recyclables. If the materials are damaged during the process and their quality is hindered, primary stakeholders such as waste collection facilities and plastic traders are no longer able to reuse such materials or sell them at competitive prices. Thus, using our NIRS design concept we mitigate potential pains for our stakeholders and instead provide value.

2.3.3.1 - Functional Requirement of Sorting

Once the NIRS device analyzes the materials, our design must be able to sort them based on their composition. This sorting mechanism is one of the most crucial primary functional requirements of the design and our final design concept was rigorously compared against each of our DfX and engineering requirements. During the diverging process, we used classical brainstorming and Brainwriting 6-3-5 to diverge upon various methods of sorting. From the image, it is easy to see we utilized 2D drawings to represent our ideas more clearly and were able to mitigate biases in the design process as we commented on each other's designs as we proceeded. After diverging we arrived at 6 design options and used 6 pugh charts to compare the options for the requirements. By comparing these designs with each other and keeping one design as the reference each time, we were able to determine the advantages and disadvantages of a specific design. We finally converged on the design concept of using a conveyor belt to transport the recyclables from the input into the machine where a flipper would obstruct the path and thus push the material into its respective category (Fig. 2). Another functional requirement was that our design concept should educate its users about the importance of recycling through an IOT interface. Similar to above, we diverged upon various methods of educating our users using classical brainstorming and did not need to converge on a single method as our IOT device would be able to display various educational features to users. Our final design concept was an LED screen that would be on the machine which would educate users about the recyclables they are inputting into the machine as well as how the materials can be transformed into other items such as bricks for construction, shoes, or beds for the homeless (Fig. 2). In this case value would be provided by providing long term systemic change to stakeholders including municipalities, communities, and the general population. While a major reason behind the waste crisis in Ghana is a lack of infrastructure and policy, a large part of the crisis is also caused by most Ghanaians receiving very little education about recycling. By implementing an educational platform, the design will be directly targeting the root issue that creates the design opportunity. Additionally, by ensuring the educational interface aligns with the requirement of being intuitive to use, those who may have busy schedules and learning inaccessibilities are also benefited from our design, thus providing more value [16]

2.3.3.2 - Functional Requirement of Incentives

Incentivizing recycling was another functional requirement of our design and through a similar diverging process, employing Brainwriting 6-3-5, we arrived at two distinct methods; direct monetary incentives and cost/time effectiveness-based incentives. We converged to cost and time-effective-based incentives using a pugh chart as they aligned more appropriately with our requirements and DfXs of designing for social justice, reliability, and utility. This design is the most useful and has the most potential to spread awareness about proper recycling practices since it has an innate appeal to the general population for various reasons. This innate appeal is that our machine offers users an easy way to dispose of their recyclable materials instead of having to dispose of them via burning or dumping them into bodies of water [17]. Additionally, instead of having to pay collectors to come and collect waste, stakeholders are able to save money as they can directly dispose of their recyclables into our device [18]. The aim is to place the machine in key locations in neighborhoods so residents can conveniently deposit their waste. It would be ideal to have widespread placement for increased effectiveness in urban neighborhoods where most trash is generated where it ends up in landfills or roadsides for informal labor to collect in unsanitary conditions. Additionally, since the output is large amounts of sorted waste, transportation costs of taking unsorted waste to recycling centers is saved, manual labor is reduced and health risk due to direct interaction with garbage is curtailed.

We maintained our contextual awareness in the divergence process for monetary incentives as we initially incorporated formal banking methods such as bank accounts to deposit the money for recycling, but eventually moved away from this because it posed problems for those who do not have the means of official banking services such as bank accounts.

By focusing on a design that saves users' time and money we believe the design provides great value while not disproportionately affecting certain groups.

2.3.3.3 - Functional Requirement of Education

To make an environmentally friendly design, we diverged using classical brainstorming on 2 methods; using reusable materials for the construction of the device and solar panels to provide energy. Again we did not need to converge as both methods can be utilized at the same time. In this case, value is added to the environment - another stakeholder - as our device does not need extra energy from the electricity grid in Ghana. Furthermore, plastic pollution in Ghana already significantly contributes to the environmental crises as open drains get clogged, leading to flooding risks, outbursts of diseases, open burning of plastic waste releasing hazardous toxins, and landfill sites causing air pollution and water contamination [3]. To prevent further environmental harm, the design should not add to the climate crisis and if our design is made of recyclable materials and uses solar panels for energy (Fig. 2), it would be providing sufficient value to the stakeholder at hand.

2.3.4 - Step 4 Categorizing Recyclables for Collection

The fourth step of the design concept is to place the recyclables in their respective categories for collection. With the use of NIRS, our design will now have analyzed the composition of the materials and with this differentiation, our design employs a flipper mechanism to separate the materials from the conveyor belt. Material with similar compositions identified by the NIRS device will all be directed to the same collecting area by a rotating flipper to obstruct the path of recyclables on the conveyor belt and slide into its collecting box. This collection box then gets populated with similar materials and transported out of the machine via a funnel where it can be collected.

2.3.5 - Materials and Components for Prototyping

The required materials for each part of our design to start prototyping are categorized based on their location and their purpose is explained in detail in the following section. For the outer covering, we need a transparent plastic sheet for a visual of the conveyor belt and its contents. Clear acrylic boards are available in MyFab and these will be utilized. For the other sides of the device, birch plywood is a strong material with a high-temperature limit making it the most suitable option after comparing different types of wood and acrylic boards. For the inside of the device, we are planning to use a conveyor belt to transfer waste to different places and bins, therefore, rotatable motors and soft plastic are required. Additional pipes or tubes are considered to be added between the belt and motors to increase friction.

S2.4: High-Fidelity Prototype: User-Controlled Plastic Sorting Line

2.4.1 Relationship Between Prototype and Engineering Requirements

The conceptual design mentioned above has a multifaceted approach to providing value to stakeholders and the more difficult aspects of it will be prototyped to demonstrate the designs' feasibility and to de-risk any potential hurdles in the implementation of the actual design. The sorting aspect was identified to be the most complex portion of the conceptual design in terms of design execution and engineering challenge because there are no existing solutions that carry out the entire process of sorting waste. For example, while there are currently existing solutions that are capable of implementing other specific desirable aspects of the design such as using renewable power or using sustainable materials that we could take and implement in our design, the sorting aspect would have to be one built entirely from scratch. Moreover, the sorting aspect is interfaced with the front end interface, and the circuitry. Getting these subsystems to work together presents a challenging task. Furthermore, creating a prototype that could effectively sort plastic would communicate that the entire conceptual design (outlined in Fig. 2) would be possible. This required more than one subsystem to be prototyped to adequately demonstrate that the machine is capable of sorting. Demonstrating the automatic sorting aspect of our design is integral to our solution because the current opportunity space involves strenuous manual labour, posing health and safety risks to the workers [17]. Thus our high-fidelity prototype will aim to sort recyclables using a mechatronic solution while educating people about the recycling process. Through the high-fidelity prototype, we will be able to demonstrate our DfX such as; Design for Utility, Awareness, Reusability and Repairability. The solution will satisfy the utility requirement by being intuitive to use, and the reusability and repairability requirement by employing materials that can be sourced locally. Since the incentivization is grounded more in the context of Ghanaian communities, that will not be prototyped. Additionally, since the prototype involves MYFab materials, it may not be entirely environmentally friendly. Lastly, to reduce complexity only 3 categories of materials will be accounted for while the concept design aims to accommodate more.

2.4.2 High-Level Prototype Descriptions

To model our conceptual design, the prototype will allow the user to input recyclables into the device, proxying the sorting aspect. It will be tested with custom recyclable materials sized appropriately for the prototype allowing for easier debugging and appropriate reiteration in the face of malfunctions. 3D-printed objects will be used to mimic real-world recyclables. These can be seen in the Lab Notebook under CAD Design. Three different types of recyclables will be considered to demonstrate that the design goes beyond binary sort. The four main systems mentioned in S2.3 will be utilized in addition to a software component.(Fig.3)

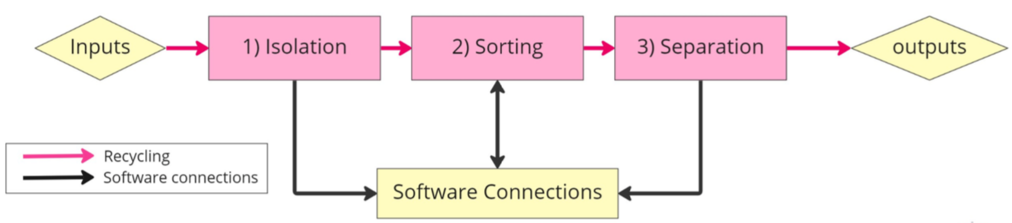


Fig. 3 Systems-level diagram of our high-fidelity prototype.

2.4.3 Conceptual Design Components to Be Prototyped

To accomplish these goals the high-fidelity prototype mimics our conceptual design but is adjusted to the physical constraints imposed by the Myhal Fabrication Facility which sets some distinctions from the design concept. An alternative separation system is explicitly employed to sort three different types of recyclables. The recyclable item is dropped on a separation base, where recycling sweepers can flip down, knocking the recyclable item into the appropriate bin. This strategy allows us to make our design smaller, thereby increasing its implementation feasibility in phase II.

Another distinction is in the isolation aspect of the design concept. Rather than using a hydraulic cylinder to push recycling into the funnel, a lid at the bottom of the funnel will be used to manually stop the recycling from falling through the tunnel. This will be controlled using Lab 2 resources (microcontrollers). Unlike a hydraulic cylinder, a lid would be easier to design for the prototype and will demonstrate the necessary sorting functions. Note that in the real world, the weight of the recycling could break the funnel lid and a hydraulic cylinder would be more appropriate. Besides these aspects, the prototype will effectively be a scaled-down version of the conceptual design. The three different steps can be found here: Isolation, Sorting, and Separation.

2.4.4 Prototype Plan

The Systems Integration Strategy was followed for designing the prototype which was gone over in the lecture. Partitioning was done first by sketching the design of each system. We could base these systems on the forethought that we had done from our conceptual design. Bringing the different systems together gave each system limitations. These limitations allowed us to converge to the final design of the prototype as the integration of the subsystems reduced their flexibility. The final prototype design converged to what is below in Fig. 4. Specific details about the materials are available in the Budget/Materials Spreadsheet.

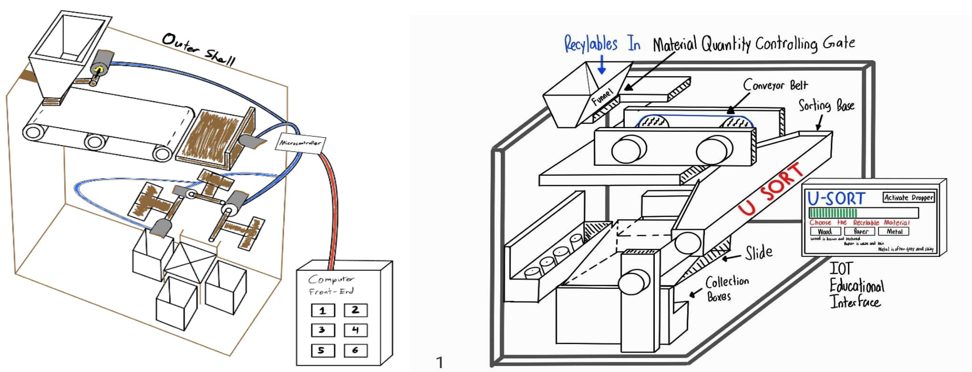


Fig. 4: Rough sketch of original and final prototype. Each gray cylinder represents a rotating DC motor, an actuator the team developed experience with from Lab 6. Brown objects are made from wood which includes the outer shell.

The first part of the prototyping plan is to create the outer shell of the design. This will involve measuring and cutting 'Birch Ply 1⁄4".' This material is chosen because it is the best value wood that can be obtained from MYFab that comes in flat planes. It also has a high Young's Modulus so it can support the rest of the prototype. The outer shell should be completed in time for the Process Review in Week 8 so that we can show our TAs the blueprint of the prototype and they can advise us on how we can continue on. Once we have created the outer shell, we can use it as scaffolding to attach other parts to it. We would create the prototype using the Waterfall Project Planning design where we would work from the top down, starting with the funnel, then the conveyor belt, then the Sorting base, then the Separating base along with the Recycling Sweepers. This plan would allow us to iteratively test the build as we go; if systems at the beginning work, we can test down the sorting chain. Most solid objects that don't move will be made out of wood because it is lightweight, cheap, and strong. Parts will attach to the outer shell by screwing it to the shell or cutting holes in the shell and fitting the objects in (depending on what option is better). This part of the design should be done by the Week 11 Process Review so that we can receive feedback from the TAs on the efficacy of what we have created. Discussions with MYFab staff have allowed us to determine other aspects of our design. For example, the conveyor belt will be made from multiple wooden dowels that rotate from a gain of 3D printed gears. Every other material is sourceable and documented in the Budget/Procurement Tracker. An example of each component's role can be found in the Detailed Block Diagram. Throughout weeks 7-11, the software/front-end will also be developed. For hardware, the MegunoLink software can be used with the Arduino which allows us to build an interactive User Interface on a computer that connects to Arduino. This will allow us to educate our User and give real-time inputs to the prototype. At this point we will interface it with our physical prototype. Weeks 11-13 will be used to ensure the integration goes smoothly and there is time to address any problems that may arise.

A high level plan can be found in the GANTT Chart. A much more detailed version of the prototype's next steps are in the Prototyping Plan.

2.4.5 Expanded: High-Fidelity Prototype: User-Controlled Plastic Sorting Line

2.4.5.1 Detailed Prototype Description

The completed prototype has seven main elements which are the exoskeleton, the funnel, the conveyor belt, the sorting base, the slide, the electrical system, and the software.

The exoskeleton itself consists of a 12x12 inch wooden base with two 12x15 panels attached such that it has a square floor with two adjacent rectangular walls, all screwed together for structural integrity. Every other element of the prototype is attached to this exoskeleton.

The funnel holds multiple pieces (recyclables) but only outputs one at a time. It is attached to the exoskeleton with hot glue and has a door operated with a stepper motor also attached to the exoskeleton.

Waste from the funnel gets dropped onto the conveyor belt made of two wooden dowels each connected to a stepper motor and free to rotate. A vinyl sheet is wrapped around the dowels such that when they turn, the vinyl sheet rotates around in tandem, creating the conveyor belt. This is constantly running so that any pieces falling on the conveyor belt are moved to the sorting base.

The sorting base consists of a plate attached to a stepper motor which is attached to the exoskeleton. When the motor turns, it tilts the sorting base to drop any objects on the sorting base onto the slide.

The slide is a wooden ramp attached to a stepper motor underneath it. When the stepper motor turns, it rotates the wooden ramp which is angled towards waste collection bins underneath. Waste from the sorting base hits the wooden ramp at the right angle and falls into the specified waste collection area chosen from the front interface. These waste collection bins are removable so that it is possible to move the waste out of the system.

To ensure each motor from the previous subsections work, there is an electrical subsystem. The wiring runs out of the back of the exoskeleton through a hole. On three breadboards, there is an A4988 driver for each motor and a total of three 12V power supplies.

Each driver is then plugged into the Arduino Uno. The software subsystem controls the electrical subsystem from these connections.

With the software subsystem, there were two crucial parts. The first is the MegunoLink interface. This contains buttons, text, and a progress bar. The buttons allow the user to interact with the prototype. For example, pressing the 'drop' button would cause waste pieces to fall out of the funnel onto the conveyor belt and pressing another button would direct the piece to the correct collection bin. This interface was custom created from MegunoLink. Important parts of the interface are the "Learn More" button that gives educational details on the different types of recyclable materials and aids user selection of materials, as well as the progress bar which demonstrates where plastic is in the system to make the program more intuitive for the user. The second part of the software subsystem is the Arduino Back-End. This is the Arduino code that reacts to the MegunoLink Front-End and is uploaded into the Arduino to run the stepper motors.

In addition, there are recordings of a full prototype demonstration and full prototype explanation. The final system architecture is also linked.

2.4.5.2 Final Prototype System Architecture Rationale

This prototype demonstrates the 'effective at sorting' Engineering requirement that drives the technical aspect of the concept design. The conveyor belt and funnel ensure that only one piece of waste is on the sorting base which allows the user to determine what category it is and tell the MegunoLink Front-End to deposit the piece in the right waste bin. This clearly communicates the conceptual design (conceptual design system architecture) where you can input all of your waste and have it sorted into different bins according to user input. It also communicates the educational aspect from the engineering requirements. The interface explains how to identify recyclables to the user while also making the U-Sort process intuitive and useful. It also educates the user on the importance of recycling which will help raise awareness of the waste issues in Ghana. These are aspects of the Conceptual Design that are most necessary to convey the feasibility of our idea in the Ghanaian landscape. The major difference is that the conceptual design is designed to handle significantly more waste of more types. The conceptual design is also powered by renewables and is much larger.

2.4.5.3 Iteration, Integration, and Debugging

The team employed iterative strategies all through building, integrating and debugging the system, as can be seen in the Iteration History. This was done for each subsystem individually, and then in the integration process, which led to the final prototype. According to the prototyping plan, the first subsystem created was the exoskeleton. An initial issue was the use of incorrect screws that protruded out and made the exoskeleton unstable. Additionally, the vertical height of the 12 x 12 walls was too small to accommodate the waterfall design. Therefore, both back pieces were upsized to 12 x 15 inches, with the correct flathead screws. (see Iteration History document, iterations 1 to 2) .

For the funnel, the plan was to have a solenoid operating the door, however, it was discovered that MyFab solenoids were not powerful enough to open and close the distance of the gap. After multiple iterations, the final design was a rotating door powered by a stepper motor which could open and close rapidly. When testing the door and funnel initially, it was discovered that sometimes the funnel door would kick the plastic out of the prototype. Thus, code was changed to make the funnel door stay open for a longer time and rotate further downwards to ensure the plastic fell out completely. These changes are reflected in the Iteration History document from iterations 1 to 6.

The next subsystem iterated was the conveyor belt. Once the dowels were set into the conveyor belt frame, it was a challenge to figure out how the belt could be attached to the dowels with enough friction to allow rotation. Tightening the vinyl around the dowels for friction would create force on the dowels, pushing them into their frame. This increased friction at the rotating points which the 6V DC motor was unable to handle. It was then replaced with a stepper motor which is stronger (see Iteration History). While this allowed the dowel to rotate, there was not enough friction between the dowel and the vinyl sheet. MyFab staff recommended using foam as a belt, however, this did not work either. The team reverted to the original vinyl belt, with the addition of a stepper motor on the other dowel. This improved the belt but for consistent rotation, MyFab staff recommended putting hot glue on the dowels and letting it dry to create more friction (see Iteration History). This was a success and finally allowed the conveyor belt to run consistently with two both stepper motors.

In terms of the electrical subsystem, there was iteration of components and wiring. When initially testing the stepper mechanisms, the L298N driver was used. However, the drivers and the stepper motors were incompatible, resulting in overheating. From MyFab staff's input, the driver was changed to the A4988. For overall compatibility, changes had to be made to the code after the new drivers were implemented. Once all of this was changed, there was opportunity to customize motor functions for integration with the front-end. A complete history of iterations of circuit layouts can be found in the Lab Notebook.

Further the backboard of the sorting base was iterated. Sometimes, as an edge case, waste pieces would fall off of the back of the sorting base (see Iteration History). To solve this, a backboard was hot glued to the back to stop the pieces from falling off (see Sorting Base label). Another minor iteration was the addition of guardrails on the slide of the dropper. This is reflected in iteration 6 and 4 in the Iteration History. As another edge case, some waste pieces in unique shapes would slide incorrectly. This was solved with the addition of guardrails hot glued onto the slide (see slide).

Also, there was exhaustive debugging of code. The MegunoLink interface often needed to be tested and played with so that the team had an understanding of the new software. Coding errors like typos, mislabeled functions, forgotten semicolons, and uploading errors were dealt with. Additionally, the system was initially moving in disunion which required troubleshooting and compartmentalisation of subsystems to establish coherent motion through the design. The switch from the Arduino nano to the UNO was also made for Megunolink compatibility. Examples of this segment of iteration can be found in the Lab Notebook under Computational System Failures.

2.4.5.4 Design Testing

The High-Fidelity Prototype is an attempt at modelling the result of the conceptual design. Key requirements that were kept in mind of testing when designing the physical prototype, leading to an improved understanding of the conceptual design, included addressing the Functional Requirements of sorting and promoting education about the importance of recycling through an IOT interface. Another key requirement kept in mind included addressing utility concerns such as having the capacity to hold sorted waste. The High-Fidelity Prototype contributes to the understanding of the Design Concept as it allows us to gain insightful information about the performance of the above requirements such as whether or not it is possible to sort waste into categories while simultaneously providing an educational platform.

The High-Fidelity prototype was able to accurately sort differently labelled materials while another user was testing. Tests were conducted that tested the entire prototype at once as well as testing separate subsystems. Results of these tests are represented in table 2.4.5.1 and explained below.

The first test conducted was slide accuracy. This is done to ensure the feasibility of the sorting requirement. In this test, a plastic piece was placed on the sorting base, and a waste collection area was picked on MegunoLink so that the piece would fall into the waste collection area. This process was repeated with the remaining waste collection areas. It was recorded that 8/10 times, the piece ended up in the specified waste bin. The errors that often occurred were when the slide would not turn the entire way. This was unexpected as the code specified the number of turns. Leading hypothesis for the cause of error is that when running the motors for a long time, they tend to produce errors. The two faults occurred at the end of the testing period rather than the beginning.

It was also measured that the conveyor belt moved a piece of plastic across it in 14.77 seconds with two motors running and 39.97 seconds with one motor running. The double motor time was deemed acceptable for the prototype as it gives the user around 15 seconds to make a decision which is sufficient as can be seen in Control Person Tests. This test was performed to test the feasibility of implementing an educational interface alongside the sorting mechanism.

Another test was the Single Plastic Funnel Dropper test where a single piece of plastic was put in the funnel, and the number of times the plastic fell out vs. the number of "drop" commands to the dropper was sent. The accuracy was 7/10. Usually the dropper failed because the test plastic was in a unideal configuration. If the test plastic was smaller, the dropper would be much more accurate as it would always fall. We could calculate the single piece success rate based on the slide accuracy times the dropper accuracy which was 56% (8/10 times 7/10). With different test piece configurations, we may be able to increase accuracy.

Table 2.4.5.1: Results of different tests of the prototype.

Test	Slide Accuracy	Conveyor Belt Speed with two motors running	Single Plastic Dropper Accuracy	Prototype Accuracy
Result	8/10	14.77 seconds	7/10	56%

Additionally, two real-world simulations were carried out to test the MegunoLink Front-End and User sorting concept. The first simulation involved a control person, who was selected from another Praxis group and given brief instructions on using the device. They were recorded while sorting plastic and were able to do so successfully, which indicated the feasibility and usefulness of the sorting concept alongside education.

The second simulation was a dropper test with multiple plastic pieces. Ideally, only one plastic piece should drop every time the user instructs the dropper to move. However, this was not always the case, as sometimes no plastic pieces would drop or multiple pieces would drop. Nevertheless, from multiple tests, it was observed that about one-third of the time, only one plastic piece would drop. Changing the plastic pieces might improve this result. The prototype shows that it is possible to separate plastic pieces using this method, but further improvements are necessary.

2.4.5.5 Future Improvements

Variables such as speed, rotation angle, and delay of each motor's rotation can be adjusted through the arduino. Optimizing these variables for most types of waste piece configurations would improve accuracy of results overall. It would also be beneficial to improve the funnel such that it works more generally for different sizes and shapes. This involves testing for more edge cases with very different types of materials, sizes, and shapes. Furthermore, more testing with different shapes would expose errors that can be fixed through the code/design to account for edge cases, or consistent errors when the system is running for a while. These changes would allow the prototype to demonstrate the effectiveness of the Design Concept more accurately.

Further adjustments need to be made with the circuit wiring. Many motors (specifically in the conveyor belt) were prone to overheating and could often act irrationally. Additionally, sometimes motors would not rotate back to their original positions which was especially a problem when it came to the slide motor. It would be necessary to debug this issue by perhaps switching to another model of the NEMA stepper or finding a different solution.

A plexiglass shield around the sides and a wooden roof would improve the prototype's structural integrity while maintaining visibility, similar to the Conceptual Design's looking glass.

Another improvement that could be done is to increase the categories of recyclables it can sort and accommodate. This would be done by creating more bins at the bottom of the prototype and code that allows the motor to stop at each new bin. This would make the prototype resemble the conceptual design more as the conceptual design can sort more than three categories.

S3: Statement of Collaboration

3.1 - Team Identity

In the first session, we shared our individual values that mattered to us as engineering designers. These were drawn from personal beliefs and past praxis experiences that had left the members with an idea of dos and don'ts. In TC version 1, we all had the shared *team* values of honesty, timely communication, responsibility, assistive behavior (helping each other) and accountability. This was integral to ensure everyone was on the same page about what we valued, and expected from each other in team interactions. For our *design* values, we unanimously agreed upon social awareness since we all wanted to practice engineering design with an overarching sense of intentionality and regard for the community that we would be working with. Over the first 2 weeks, we realized that we needed a value that would bring our *design* and *team* values together. 'Equity' acted as the all-encompassing term that coalesced both dimensions of our identity. Essentially, we wanted to create not only a team environment that would be equitable, but also a design that would not achieve social justice by drawing from an equitable framing of the design space. Additionally, we also agreed that we wanted to have fun along the way, hence the idea of having fun was formally added to our team identity. In the revised version, we also added definitions of all the shared values to ensure we interpreted our expectations from each other in a similar manner.

With these values we were able to unify everyone's unique strengths to fill in the gaps of individual shortcomings. For instance, Solomon has past experience with Robotics and Arduino, Zack has Mission Operations Experience from the University of Toronto Aerospace Team, Mithun takes interest in Engineering Physics and has a lot of knowledge in the field. Alina has good research skills and Minahil enjoys creative and organizational tasks. Having a section on interaction protocol focusing on inclusive interaction pulled these strengths together, creating a teamwork culture of building each other up. Furthermore, a solidified team identity helped shape our approach to the opportunity provided e.g., we knew we wanted a design that drew from heavy contextual listening, owing to our values of social justice. This allowed the team to listen to Minahil who had seen garbage picking issues in real time in her home country. Solomon filled in with mechatronics experience and Zack with operations experience from UTAT which then guided the team's design thinking. Acknowledgment of the unique strengths and shared values guided the framing stage, and helped responsibility division in team organization.

In phase 2, the team realized that the time constraints were a lot stricter and work had to be done quickly. This meant meeting time had to be utilized smartly, without going over time because academic load across other courses had also significantly increased between phase 1 and 2. Hence, team values were updated to add time efficiency as can be seen in TC version 3. This was a necessary addition following the team process review after phase 1 where members expressed that having shorter, crisper and all-hands-on deck style meetings would speed things up and prevent the team from hitting productivity plateaus. While prioritizing efficiency, the team acknowledged that the quality of the work was not aesthetically impressive, however this did not majorly impact team identity or values, rather it allowed the team to focus more on the functional aspects of the engineering challenge.

3.2 - Team Organization

For team organization, a communication and organization protocol was set up. All meeting agendas were laid out 3 days before a meeting to ensure members came prepared, especially in the earlier stages where extensive contextual research was required to have discussions about the socio-political landscape in Ghana and in the diverging stage where research-grounded knowledge of the design space helped team creativity. Meeting Minutes were recorded for each meeting and a list of action items was devised to keep the design process moving. This allowed the team to always think ahead and make progress outside studios and meetings, on an individual basis. For this, we also had a Responsibility Tracker to keep track of tasks, deadlines, responsible members, and progress status. This also helped push the team forward by directing focus towards things that needed doing, and allowing transparency in responsibility division by making the task assignment clear. Moreover, we also laid out conflict management strategies earlier in the term for timely conflict resolution, instead of waiting until we ran into a conflict to devise a management strategy. A democratic solution was one of the strategies proposed which the team utilized multiple times to remain on track under time constraints when conflict would be likely to slow the team down. Evidence can be seen in the meeting audio recording for Jan 30th with an explanation in the audio comments.

To remain organized, we also had work sessions in the later half of phase 1 (Video recording) where the team worked together and provided input to each other on the go. Here, we had some team building exercises like fun selfies, a dinner run, and a boba session (Images found here) to make work sessions enjoyable. However, we realized our meetings were hitting productivity plateaus. This reflection helped us revise and update our interaction strategy to include an online joining option to accommodate different learning styles as some team members felt like they could be productive for longer while working from home, but also wanted to benefit from an input on-the-go model that our work sessions provided. This revision was noted in the Team Charter.

This change was further implemented in phase 2 where an increased sense of accountability and trust allowed the team to have more fluid meeting structures where members could join and leave when they wished, so long as they put in fair effort and upheld equitable work division. Having effective communication channels and responsibility tracking helped maintain team cohesion with this new structure. This change in team organization is further reflected in the decrease in the level of detail from Phase 1 Meeting Minutes to Phase 2 Meeting Minutes. This is also because the team found Meeting minutes not as useful in Phase 2 due to its hands-on nature. Instead, the team decided to focus on high-fidelity prototyping and preferred lab notebook upkeep, iteration documentation, and visual proof collection as more useful artifacts to stay organized and on track. This documentation helped members stay informed, and provided useful evidence for comparing across iterations.

3.3 - Summary of Contribution (Detailed breakdown found in Responsibility Tracker)

Zack contributed to the value proposition selection process where he proposed a requirements table to compare our multiple value propositions fairly. The team used this as a selection criteria to converge on a value proposition. He also wrote section 2.4, worked on the Prototyping Plan, project timeline, the computational subsystem with the front end interface, and the wood work in phase 2.

Solomon understood the design space quite well by reflecting on the annotated bibliography research, and team members' perspectives. He then added the mechatronics expertise to help devise a working solution. Additionally, he drew the preliminary sketches to help bring the team's vision together and wrote section 2.3. In phase 2, he was involved in making the structural subsystem and assisted with the electrical subsystem. He contributed to the visual abstract, and the systems architecture representations since he best understood functionalities of the different subsystems with respect to one another because he had worked across the board on almost every aspect of the prototype.

Mithun organized Meeting Minutes and Agendas throughout phase 1 and 2, also keeping track of folder organization in sharepoint. We were also able to benefit from his Engineering Physics expertise and understanding of IR spectroscopy. S2.1, S2.2 and S3 were written by Mithun since he actively participated in the framing process, understood the nuances of value proposition selection and kept track of team contribution through the semester. He was also involved in the structural subsystem and helped upkeep the general logistics in phase 2 by collecting and organizing project management artifacts such as iteration history and lab notebook.

Alina was responsible for the Materials Research for the prototyping plan since decisions about material choices for the prototyping stage were dependent on availability and cost at MyFab. She helped put together the Prototyping Plan, the Budget Sheet, and material order. She also wrote section 2.4 of the summary document, updated S4 and organized S.5 Citations.

Minahil handled team organization, updating the responsibility tracker, gantt chart, Annotated Bibliography, and team charter. She also assisted with conflict resolution, task delegation and collaborated with everyone's tasks. Additionally, she contributed to S0, S1 and S3 for the summary document. She was heavily involved in the electrical subsystem and contributed to the computational subsystem including the front end interface.

Alina, Minahil and Mithun worked together on putting the requirements table together by coalescing input from the rest of the team. The extensive research and citations were a group work carried out by these 3 members since the task was massive and equitable distribution of labour was important. They also worked on building and documenting the sensors.

Zack and Solomon worked on the actuators and while the entire team was an active part of the diverging and converging process for the concept design, Solomon and Zack bore most of that responsibility. All team members also contributed to the annotated bibliography and photo/video proof collection.

3.4 - Planned vs Estimated Timeline Deviations

During Assessment Point #1, our team created a planned timeline that included various milestones for completing the project that is reflected in the GANTT Chart. However, during Phase 2 of the course, we realized that we had to make some adjustments to our timeline due to unexpected factors which can be reflected in the yellow bars in the chart.

One of the key drivers of the differences in our timeline was the unexpected delay in the delivery of our materials. We had planned to start building our high-fidelity prototype in the first few weeks of Phase 2, but we were unable to start until 1 week later due to delays in material delivery.

Additionally, we encountered issues during the building phase that required us to revisit and revise certain parts of our design. For instance, during the prototyping phase, we faced several challenges while creating the high-fidelity prototypes. The Exoskeleton, Funnel, Conveyer Belt, and Sorting Base subsystems all took longer to complete than expected. The exoskeleton took longer than expected due to increasing the size of the structure to accommodate the spatial concerns of the other subsystems. This change is reflected in the transition between iteration 1 and 2 of the exoskeleton in the Iteration History document. The Funnel took longer than expected due to unforeseen roadblocks such as pivoting from a solenoid to a dc motor, then to a mechanical solution, then to one stepper motor, and then finally to using two stepper motors (iterations are reflected in the Iteration History document). In the future, design specific component specifications should be better researched beforehand to see if there are any issues in components working together. For example, had the team researched the maximum torque a DC motor could provide, a pivot to using stepper motors and the time delay in receiving the stepper motor would not have occurred. However, the team understands that there are some delays that are unavoidable. For example, when working with the conveyor belt, there would be no way to tell beforehand that the vinyl sheets alone would not provide enough friction for rotation without physically testing the component – a inevitably time consuming task. The inherent unforeseeable nature of prototyping, even with the most meticulous planning, is the driver behind the fall behind timeline.

Subsystems that stayed on timeline included the sorting base and the ramp as these two components had clearer and easier to implement designs as outlined in the Prototyping Plan. Furthermore, these two subsystems were more independent of other subsystems, allowing them to stay on track even if other subsystems were experiencing delays.

Nevertheless, the transition from taking meticulous meeting minutes and having highly structured meetings allowed the team to compensate for setbacks in timeline. As we were more hands and thinking on our feet and not restricted to a rigid meeting agenda, we were able to make quick decisions that allowed significant progress to be made on the prototype.

Overall, it is important to note that prototyping projects are complex and unpredictable, and it is not always possible to stay on schedule for all subsystems. Factors such as unexpected challenges, delays in material delivery, and the need for iteration can all contribute to deviations from the planned timeline.

3.5 - Reflection

In Phase 1, our team organization methods have been useful for advancing our design process. Team building exercises created synchrony in Engineering design, and using Discord for communication has helped us stay connected. However, additional channels for separate topics are needed to keep information organized and were implemented for Phase II. Time caps on meetings were also implemented for Phase II to prevent spillovers and burnout in the face of the time-consuming nature of Engineering Design. Furthemore, the ability to work on everyone's own time greatly increased productivity as team members were not pressured to attend meetings when they had other priorities and responsibilities. In the future, the team hopes to implement regular check-ins with team members to discuss progress, identify any issues, and ensure that everyone is on the same page. This can help to prevent misunderstandings and ensure that everyone is working towards the same goal. As team members were working on subteams, it would be beneficial to have a means of staying up to date on smaller projects in an organized fashion.

S4: Annotated List of Supporting Artifacts

Design Artifacts

Engineering Requirements - PHASE 2/ Design Dossier 2 Content / Design Artifacts / Engineering Requirements

This document outlines all of our engineering requirements that we have created. It is v.2 because it is the second edition (the first edition is in the same folder). This was later used to diverge and converge our ideas. This was also used as a way to get research about our opportunity itself and determine what would be needed to work on the opportunity.

Opportunity Champion Meeting Notes - PHASE 2/ Design Dossier 2 Content / Design Artifacts/ Design Process / Opportunity Champion Meeting Notes

These were notes that we used when the Opportunity Champion was giving a talk about the Opportunity. We used them to get a first-hand account of the plastic recycling opportunity in Ghana. We referenced these notes numerous times in our design process.

Reference Designs - PHASE 2/ Design Dossier 2 Content / Design Artifacts/ Design Process / Conceptual Design / Reference Designs

We were inspired by certain real-world designs when designing our conceptual design. We have put those reference designs together in a folder for ease of access. They correspond to specific parts of our conceptual design.

Research on Near-Infrared Spectroscopy - PHASE 2/ Design Dossier 2 Content / Design Artifacts/ Design Process / Conceptual Design / Research on Near-Infrared Spectroscopy

We conducted this research to determine if there were automatic ways to determine the type of plastic an object was made from. This research informed us that it is possible to use NIR for the project which is something that we converged on.

Preliminary Design Concept - PHASE 2/ Design Dossier 2 Content / Design Artifacts/ Design Process / Conceptual Design / Preliminary Design Concept
This was our best draft of what the Conceptual Design should look like in Ghana. This was created once we had diverged and converged on multiple aspects of the design. We have used this conceptual design to help with the creation of the prototype. This is an important image in our design process as it is the culmination of all other design processes.

Conceptual Design Converging and Diverging - PHASE 2/ Design Dossier 2 Content / Design Artifacts / Design Process / Conceptual Design / Conceptual Design Converging and Diverging
We performed Diverging and Converging for different aspects of this design. We created multiple documents where we had Diverging for one aspect of the design where we then converged in the same document to clearly demonstrate our Design Process. We have used these documents to drive our final design decisions as a result.

Lab Notebook - PHASE 2/ Design Dossier 2 Content / Design Artifacts / Lab Notebook
This document includes important images during our labs with explanations. It contains flowcharts and diagrams that show the overall system functionality. For the electrical subsystem, it has the sketches of the circuits with several iterations, they help us to connect the wires and motors together. Additionally, the structural subsystem has draft sketchings indicating the size of each piece of wood, and some failure experiences during the process of building the structural subsystem. It also has images of CAD designs. Lastly, the computational subsystem has several failures and successes experiences with the prototype.

System Architecture Representation - PHASE 2/ Design Dossier 2 Content / Design Artifacts Representations of system architecture
The folder contains three images of system architecture representations. One is overall system architecture, and the others are related to the high-fidelity prototype. They are created during studio 8B, they are reviewed and updated regularly as Phase 2 proceeds.

Build Artifacts

Detailed Prototype Diagrams - PHASE 2 / Design Dossier 2 Content / Build Artifacts / Detailed Prototype Diagrams
These diagrams represent important parts of the prototype model. These models everything from the system view to specific tasks. They go in-depth to reveal the relationship between different systems. This was created when we were putting together our System Prototyping Plan. They all have descriptive names. As well, there are some brief notes that were involved to create the diagrams which are also included in the folder.

Materials Spreadsheet - PHASE 2 / Design Dossier 2 Content / Build Artifacts / Materials Spreadsheet

This Materials Spreadsheet was being created at the same time our Prototyping Plan was being developed. This document outlines our material research conducted to give us an idea of what we could use for the prototype. It contains useful information like price, size, strength, and so on.

Procurement & Budget Tracker - PHASE 2 / Design Dossier 2 Content / Build Artifacts / Procurement & Budget Tracker
The budget was created by combining the Prototyping Plan and the Materials Spreadsheet. It contains details on the planned parts that will be used for the prototype while also calculating the cost of the items to manage our project budget. This will serve as an important record-keeping tool to ensure we keep our finances in check.

Video or photograph(s) of each subsystem - PHASE 2 / Design Dossier 2 Content / Build Artifacts / Organizing pics&videos
This folder contains the pictures from the electrical, structural and computational subsystems of our prototypes. It also contains a folder that has videos of each subsystem moving and the ways the subsystems interact with each other. These are important recordings for the process of creating the prototype and served as the visual evidence for the systems described in this integrated summary.

Iteration History - PHASE 2 / Design Dossier 2 Content / Build Artifacts / Interaction History
The details of our prototype have been adjusted multiple times during Phase 2. We have recorded and organized them in this document, with a brief explanation and some images. Therefore, we can constantly go back and learn from these previous failures. The interactions include the changing of the prototype's structural and electrical subsystems, almost every part of the prototype has several versions.

Demonstration of the prototype's final functionality - PHASE 2 / Design Dossier 2 Content / Build Artifacts/Demonstration of functionality
The video shows a complete process of how U-Sort sorts waste into categories based on their material type (paper/wood/metal). And there is a brief description of the demonstration video in the same folder. It also includes the Arduino code used and the associated MegunoLink graphical user interface that can be used to demonstrate the functionality.

Prototyping Plan_Project Management - PHASE 2 / Design Dossier 2 Content / Build Artifacts / Prototyping Plan_Project Management
This document was created during one of the final team meetings during Phase 1 to get a plan ready to build the prototype. It is designed to outline our plan and thought process for developing the prototype. It has justifications as well as sketches and instructions. This will serve as our guide to building the prototype. And the deadlines in the documents serve as our timeline for the prototype development.

Evidence & Result of Testing - PHASE 2 / Design Dossier 2 Content / Build Artifacts/ Testing
This folder contains videos that serve as evidence of tests. We have designed various tests that are based on our requirement model, to test if our prototype meets the requirements. We tested if the prototype can sort wastes correctly, we also invited users from other groups to test if the prototype is intuitive to use and if it satisfies our education purposes etc.

Teamwork Artifacts

Responsibility Tracker - PHASE 2 / Design Dossier 2 Content / Teamwork Artifacts / Responsibility Tracker

A document created as per Studio 6A instructions worksheet. The document summarizes the duties and responsibilities undertaken by team members so far in the course. We have been using it to ensure that everything is complete for the Design Dossier. We have also been reflecting on it to determine which team members have done what. It has allowed us to optimize our work to everybody's strengths.

Team Charter - PHASE 2 / Design Dossier 2 Content / Teamwork Artifacts / Team Charter

A document created in-studio that contains each team member's values, the team's shared values, strengths of each team member, as well as discussions on how to contact each other and handle issues. The document was contracted in accordance with studio instructions in the very first team studio. We have been updating it since v.3. We have followed it numerous times and it still stands as an important document in our team for resolving conflicts.

Value Proposition Metrics Table - PHASE 2 / Design Dossier 2 Content / Teamwork Artifacts / Value Proposition Metrics Table

We had trouble coming up with a Value Proposition initially so we created this table to allow us to diverge and converge on a Value proposition. This table was the result and we were able to converge on our Value Proposition. We thought this rigorous approach would be the best way of going about determining our Value Proposition.

Project Timeline GANTT - PHASE 2 / Design Dossier 2 Content / Teamwork Artifacts / Project Timeline GANTT

We used this Project Planner to demonstrate to us how we have been accomplishing our goals. We created it after it was recommended to us in the studio. It has been an effective management practice. We also use it to plan for the future so that we know how every task connects. We have weeks booked in the future so we will continue to use it.

Team Process Review - PHASE 2 / Design Dossier 2 Content / Teamwork Artifacts / Team Process Review

We created the Team Process Review to ensure that everything was going according to plan with our teamwork and designing. Here we answered a lot of questions regarding the work that we have done as a team in phase 1. This was very useful in giving us the next steps on how we can improve as a team and let us know what work was done well and not so well. We have been reflecting on this document since writing it to improve our team.

Team Selfies! - PHASE 2 /Design Dossier 2 Content / Teamwork Artifacts / Team Selfies!

We have a selfie collection that we created throughout our meetings and work periods. As well, this folder documents the team bonding we have had where we all got pasta together and ate it really late at Myhal. These selfies were often taken during meetings or studios (whenever we remembered).

Meeting Recordings + Video - PHASE 2 / Phase 2 Team Work Artifacts / Meeting Recordings + Video

In the Meeting Recordings folder, there contains a number of meeting recorders that occurred throughout the past few weeks. Each recording covers a substantial part of the meeting. We want to keep the meetings for posterity as well as to be able to reflect on our team process. We often found ourselves going back to try to remember specific points we made. We also have the video of our team meeting in this folder. This meeting has been very valuable in showing our team dynamics. We have used it to learn about how we improve our team.

Meeting Minutes - PHASE 2/ Design Dossier 2 Content / Teamwork Artifacts / Meetings / [Within each of "Week [3-13] Meetings"]
These Meeting Minutes were created during the date listed in the name of each document. They were used to record useful things and ideas that occurred during every meeting. These served as useful markers of our design work and idea generation. They were also looked back on after meetings so we could understand our To-Do tasks. Each document varies in complexity depending on the length and importance of the meeting.

Research

Lab 5-6 Documents - Design Dossier Content / Research / Lab 5-6 Documents
These are a collection of the information we gathered from performing Lab 5 and 6. These include pictures and videos that demonstrate we have completed the necessary parts of the lab. This was all done in Studio 6B.

Annotated Bibliography v.2 - Phase 1/ Design Dossier Content / Research / Annotated Bibliography / Annotated Bibliography v.2
We created our Annotated Bibliography to have all the sources that we used. We have been able to annotate 2N (10) of the sources. We created this once we had all finished our own personal Annotated Bibliographies. Our annotations have been useful in determining how Current, Relevant, Authority, Accurate, and Purpose are involved with the article. We cite a variety of different sources.

S5: Works Cited

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