Recycle Right and Closing the Loop Design Pitch

Praxis III
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1. Executive Summary

This design pitch document seeks to address the problem of recycling waste in Ghana, with the high level goal of increasing the amount of plastic that is recycled. We further scope the problem to only focus on the point of collection of all the waste. The current waste collection systems implemented in Ghana are unsustainable as only 5% of plastics end up being recycled. Furthermore, a large reason for waste being littered on the streets is that it ends up overflowing from waste bins.

We propose our design, Trash 'N' Track, which is a modular system that can be retrofitted to existing waste bins to let waste collectors know of the location of full bins. It contains an ultrasonic sensor which can determine the available capacity of the waste bin. This information, along with the location of the waste bin determined from an onboard GPS module, is sent to a server using a LoRa transceiver. We have also created a webapp that connects to this backend in order to provide live updates of waste bin fullness and location to waste collectors.

While creating our design, we ensured that we designed for sustainability, reliability, cost, usability, and assembly. The value this design provides is that it can prevent waste from overflowing from bins by alerting waste collectors. This data could also be useful for the government when it comes to planning the ideal location of waste bins. When waste starts to collect in urban areas, it increases the spread of diseases like malaria and cholera and so our solution also helps to mitigate their spread and creates better health conditions for residents.

We implemented our prototype using an Arduino Uno, BN-180 GPS Module, RCWL-1601 Ultrasonic sensor, HC-05 Bluetooth module, battery pack, Firebase backend, and React frontend. We used CAD to 3D print our case that protects all the electrical components. The key design decisions we made were choosing to use an Arduino board due to our team's familiarity with the firmware, using a LoRa transceiver for data transmission due to lower cost, and making our design overall more modular to increase the feasibility of integration into existing waste management infrastructure. We also delineate various future steps that should be taken in our iterative design process. Having verified that our prototype meets our objectives through verification and validation procedures, we feel confident in the recommendation of our design.

2. Introduction to Design

2.1 Opportunity and Value Proposition

In Urban slums and low-income areas of Ghana, practices such as recycling and waste sorting are not common practice for individuals [1]. Despite governmental attempts to improve waste disposal and recycling, individuals still do not have a perceived incentive to follow through with such practices [2]. Therefore, our goal as a team is to improve recycling and waste disposal by increasing waste collection as a whole without interfering with any existing practices within individual households. We will be designing for sustainability, reliability, usability, cost, and assembly since our team believes these objectives help provide the most value to our stakeholders.

2.2 Stakeholder needs

The waste management and collection issue in Ghana has grown to affect many different different groups and aspects of life. One of the key stakeholders for this project is Adwoa Coleman, who is the production engineer at a packaging facility for specialty plastics in Ghana. Improving waste collection will allow her to increase the output of the packaging facility she is in charge of. A key reason why waste collection and waste management systems have remained inefficient is due to the lack of logistics [3] available to the waste collectors to speed up this labor intensive process. Our solution is integral to the function of waste collectors since it will allow them to improve the poor waste collection and disposal practices.

Additionally, both the residents and the natural environment of Ghana have been impacted by the negative effects of land pollution. Increased overflow of waste can cause many types of diseases, such as malaria and cholera [4]. As a result, our proposed design aims to improve the existing conditions affecting Ghanian residents and the environment. Moreover, the government of Ghana is interested in improving waste collection and waste management systems in the country due to the positive externalities of lower death rates, decreased burden on health care systems, and better standards of living for residents. Lastly, as design engineers for the project, the process of developing a solution will allow us and the GSU student to develop interpersonal, cross-cultural, and engineering design skills, hence enriching both our personal and professional lives.

2.3 Framing

Current waste management in Ghana is plagued by ineffective waste collection, waste overflow, lack of bins, and illegal dumping [5]. Consequently, 95% of recyclables are not directed towards recycling facilities [5]. We will, therefore, frame our opportunity statement to increase the general collection of waste in order to maximize the collection of recyclable plastics. We choose to scope the problem to the point of collection because only 10% of all generated waste is properly disposed of on account of sub-optimal waste collection [1].

2.4 Requirements

While coming up with a final design for the solution, we identified five high-level objectives that will help guide the iterative development of our solution and provide the most value to the stakeholders. These five key objectives include sustainability, reliability, cost effectiveness, ease of assembly, and usability. Our design incorporates these values, which will be later justified in Section 3.5.1.

2.5 Description of the Design and Prototype

2.5.1 Design

Some collection sites are not visited enough by waste collectors, resulting in littering and overflow of waste in existing trash cans. This deteriorates the environment and increases health problems for residents [6]. Our design increases the collection of waste and recyclables by measuring the available capacity of the bins and notifying waste collectors of the location of full bins.

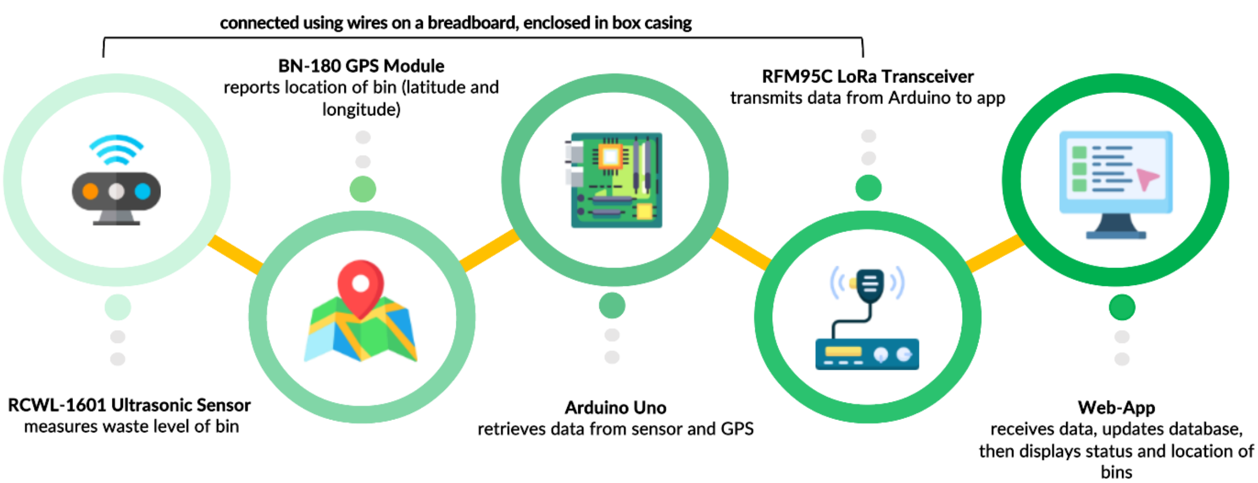
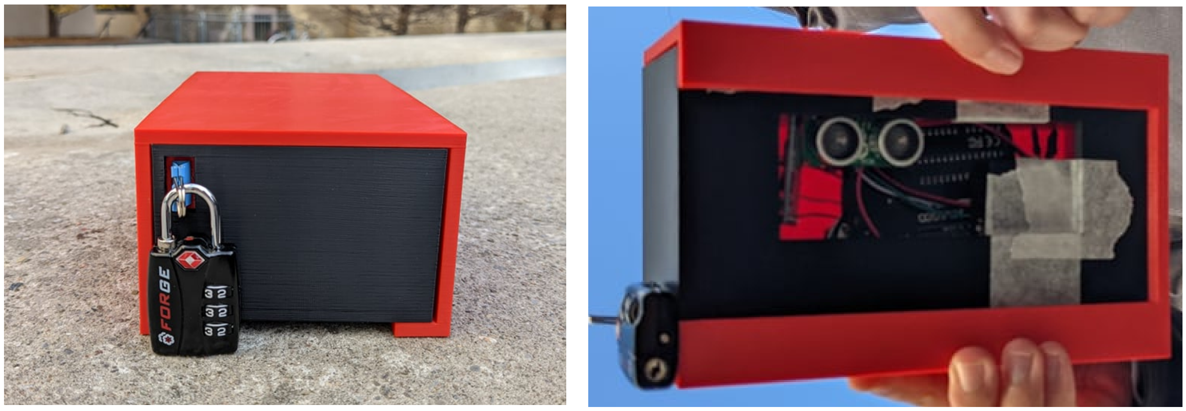


Figure 1: A visual representation of our design for Trash 'N' Track, including the specifics for each component.

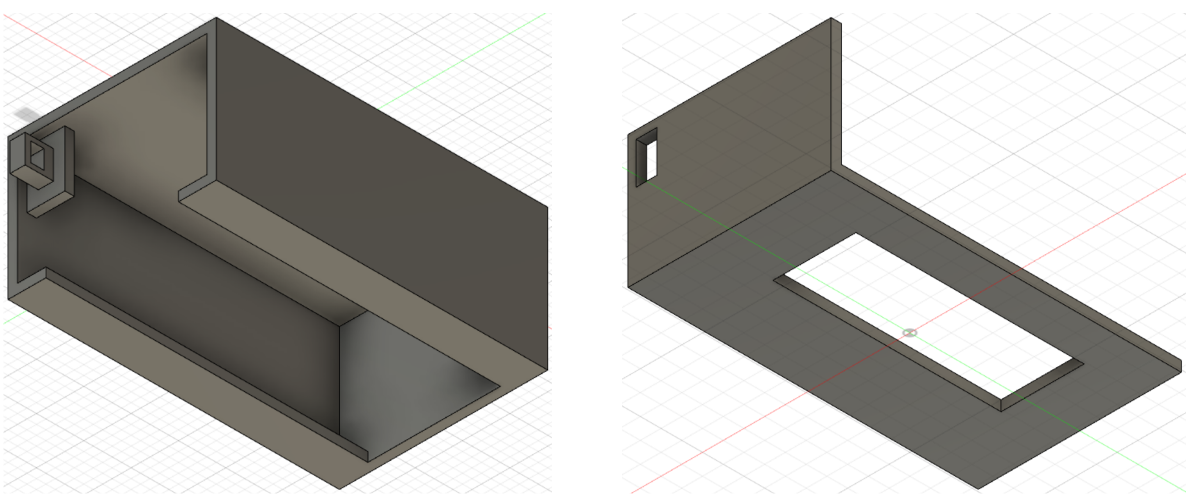
Our final design, Trash 'N' Track, is a modular device that can be attached to existing garbage cans. Using an ultrasonic sensor, it is able to read the distance between the lid and the top layer of the waste. This is analogous to the remaining capacity of our waste bin. As well, using a GPS module, our system is able to reliably emit the location of the bin. The information for each bin is sent to a real-time database using a LoRa transceiver, which is then retrieved and displayed by the virtual system. Thus, our design is able to provide real-time data to waste collectors about the location of full waste bins. By alerting waste collection authorities when waste bins are full, it mitigates waste overflow from bins, ultimately increasing the amount of waste that gets processed. This improves the throughput of recyclable materials, addressing the primary stakeholder's needs. In doing so, our design ensures sustainability. Its modular nature allows for it to be implemented with minimal disruption to existing waste infrastructure thereby allowing for deployment at scale with minimal cost. A diagram of how our design works is shown in ***Figure 1***.

2.5.2 Prototype



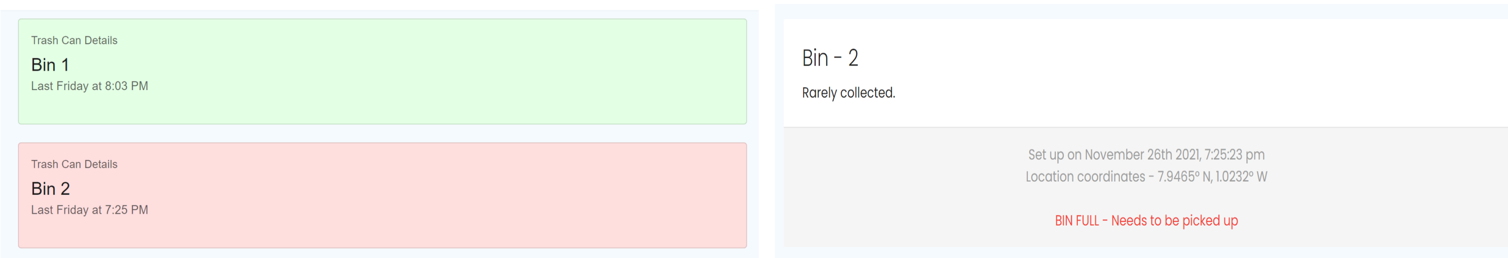
Figures 2, 3: Different perspectives of our prototype representing the physical system of our design.

In ***Figures 2 and 3***, the physical prototype of our design is presented. For our prototype, we used an RCWL-1601 Ultrasonic sensor that serves to measure the waste capacity of the bin. We also used a BN-180 GPS Module which reports the location of our bin. The data from these two components was retrieved from the Arduino Uno. Rather than using the RFM95C LoRa Transceiver mentioned in our design, we opted to use a Bluetooth module for our prototype, which transmitted the data from the Arduino Uno to Google Firebase. This database stored the information of all the existing bins and their capacity and location in real-time.



Figures 4, 5: The CAD design for the enclosed casing of our electronic system.

All of the electronics of our system are contained within the red and black box casing shown in ***Figures 2 and 3*** and designed in ***Figures 4 and 5***, which allows the unit to be attached to the underside of an arbitrary trash can lid. The red part of the box casing is attached securely to the underside of a trash can bin, allowing the black part to be easily removed for maintenance.



Figures 6, 7: Virtual platform of our prototype that displays the capacity and location of each bin.

The virtual prototype shown in ***Figures 6 and 7*** was able to retrieve the information from the database, and display it in an easy-to-use, human-readable user-interface in real-time. Here, you can observe that green corresponds to spatial availability while red indicates the lack of space. The waste collectors can easily determine which bins to collect and this allows them to improve the throughput of recyclable materials. Some of the key decision decisions we made were the choice of circuit board for prototyping, the use of LoRa, and making the design more modular. These will be elaborated upon in Section 4.1.2.

3. Select Background Details

3.1 Stakeholders

Adwoa Coleman: Adwoa manages the packaging of specialty plastics in Ghana. Finding a better solution to manage waste at the point of collection is valuable to her, as she is the production engineer where she manages waste directly. Adwoa values product safety, sustainability, and maintaining the integrity of the waste material.

Waste Collectors: The current waste collection and disposal activities undertaken in Ghana are inefficient and pose a challenge when disposing solid waste [1]. Waste collection and disposal is very labor-intensive, as there is inadequate and insufficient equipment for routine waste collection activities [6]. Moreover, many waste collection companies are not able to attract staff and personnel due to the lack of expertise and required skills in this sector [1]. This design proposal will be very valuable to waste collectors, as they can be directly affected by the outcome of generating a solution for these poor waste collection management processes. The amount of money they earn is directly related to how much waste they collect [7].

The Environment: In Ghana, there is a huge pressure on the existing environment. Every citizen has a right to a clean environment, which unfortunately cannot be fulfilled due to current waste collection strategies. It was reported that almost all local landfills fail to meet basic sanitation and technical standards [6], which present a risk to the environment.

Residents of Ghana: Many residents have a negative attitude to solid waste management, as there are insufficient public waste bins at collection points and a lot of indiscriminate disposal of waste [1]. Most residents are unaware of the risks of indecent solid waste disposal on human health and wellbeing, especially when disposed of in places such as open drains and along the streets [1]. This design proposal can affect the wellbeing of many residents, if implemented to better the current waste management strategies. As well, it offers an opportunity for residents to be employed by waste companies, which directly affects the livelihood of many residents.

Ghanian Government: Since waste collection and management systems are paid for by the government [6], the proposal holds value to them as they would be financially responsible.

Praxis Team + GSU Student: This proposal is of value to us, as the design team. It offers our team an opportunity to work collaboratively as a group, using our engineering design skills to develop a solution to a real-world challenge. It affects our personal and professional development as we learn new engineering and interpersonal skills, all while working with like-minded individuals, interacting with stakeholders as a team, and working towards a solution for the betterment of society.

3.2 Scope

Given the framing that we have outlined in Section 2.3, this section serves to provide additional context into the value proposition and our designer's limitation.

3.2.1 Value Proposition

Value proposition-wise, our design informs waste management agencies which areas require waste bins to be emptied, thereby preventing waste overflow from bins. The provision of useful data on waste accumulation can also be used to improve the future planning of waste bin placement in public areas. By improving waste collection, the throughput of recyclable materials will increase, effectively reducing land pollution. Since the exposure to pollutants caused by waste overflow can lead to outbreaks of diseases such as malaria and cholera [5], our design contributes to the 3rd UN Sustainability Goal of “Good Health and Well-Being”. Other goals such as the 11th and 12th of “Sustainable Cities and Communities" and “Responsible Consumption and Production” are satisfied by reducing street pollution and increasing the diversion of recyclables to recycling facilities [8]. Moreover, the design is kept relatively inexpensive to be empathetic to the financial realities of the Ghanian government, allowing it to be readily adopted into the service environment.

3.2.2 Limitations

Our team is most experienced with software engineering and electrical engineering. As such, we are more biased towards designs that involve these fields of engineering and are less inclined towards mechanical designs. Furthermore, because we are engineering students, our designer's bias leans towards engineering solutions and we are less likely to recommend any policy changes.

Also, we are limited by the fact that we cannot directly engage with our primary stakeholders and as a result, have to supplement a lot of the information gaps with extra research. Lastly, because we are students in Toronto and cannot go to Ghana, we cannot do any verification or validation in the service environment.

3.3 Service Environment

The communities where waste is generated are physically distant from the recycling centers [9], contributing to poor waste disposal. There is also a lack of public awareness and care for recycling in the service environment, as residents have no social pressure to recycle. Additionally, there is only a 52% internet penetration in Ghana [10], which suggests that it would be unreasonable to expect our solution to require a public WiFi network. Therefore, the service environment requires the amount of waste collected to increase and the responsibility of proper disposal shifted away from the general public.

3.4 Previous Solutions

The following reference designs were chosen as they fit within our scope of trying to improve the throughput of recyclables at the point of collection.

3.4.1 CleanCUBE

CleanCUBE is a solar-powered trash compactor that can store ~5 times more waste than non-compact trash bins of the same size. Overall, this solution reduces waste collection frequency by 80% [11]. This is due to sensors that detect when trash is full and notify through CleanCityNetworks if waste is ready to be picked up.

While this presents an efficient, clean solution to recycling in any context, a concern is that there is no distinction between items that are recyclable and landfill items. Moreover, the compacting of waste would cause the contamination of recyclables [12]. If we were to implement a similar solution, we would have to consider optimal placement of bins, as well as suggest a sorting mechanism (e.g., AI agent).

3.4.2 Oscar Sort

Oscar Sort uses ML and computer vision to identify what people are holding when they approach recycling bins. It uses an AI powered camera that identifies recycling from trash before you throw it in the bin and tells the user exactly which bin it belongs to [13].

One advantage of the system is that it engages users to separate their waste at the place of disposal, so it can teach the general public. However, image recognition is very difficult, images are often obscured by about 80% [13], and there are thousands of objects people could throw away.

3.5 Requirements

3.5.1 High-level Requirements

DfX	High Level Requirements
Sustainability	**Objective:** Increase collection of waste and recyclables. **Justification:** The current waste collection systems implemented in Ghana are unsustainable as only 5% of plastics end up being recycled [9]. Furthermore, a large reason for waste being littered on the streets is that it ends up overflowing from waste bins [5].
Reliability	**Objective:** Function through a wide range of operating conditions. **Justification:** The Ghanian power grid is known to be very expensive and unreliable [14]. As such, solutions that require a constant and reliable source of power may be sub-optimal given the unreliability of the power. The solution should also be functional through adverse weather conditions so that it could be functional through a wide range of operating conditions.
Cost	**Objective**: Inexpensive solution. **Justification:** Ghana is a relatively poor nation with just over 13% of the citizens of Ghana living in poverty [15]. Furthermore, the government already spends 1.6% of the annual GDP on waste disposal. Being empathetic of the financial realities in the region, any solution attempting to improve the recyclable material throughput cannot be too expensive.
Usability	**Objective**: The design is user-friendly. **Justification:** Due to the low sense of social responsibility to manage solid waste in Ghana [1], any solution must be user friendly to not further disincentivize proper waste disposal. Solutions that can accommodate a broad range of waste are more likely to be adopted by the public due to their perceived convenience. Additionally, the less time someone needs to spend disposing of waste, the greater the perceived convenience of the solution.
Assembly	**Objective:** The design should have a high ease of implementation. **Justification:** Given how serious the issue of overflowing waste bins is to sustainability and health, combined with the lack of funding, it would be desirable for any design to be easily implemented into the existing Ghanaian infrastructure.

3.5.2 Verification and Validation

In the process of refining our design, we determined several key constraints that any design must meet. Firstly, we would need designs that can report the location of waste bins to a reasonable degree of accuracy. We decided that the location of waste bins that is reported by the GPS module must be within 20 meters of the actual waste bin so that collectors do not have to spend too much time looking for where to collect the waste. Secondly, the sensor that detects the height of the waste must be reasonably accurate in its measure of waste height. This is to ensure that it does not erroneously read the bin as full and waste the collector's time emptying a waste bin that is not at capacity. Given the average height of a waste bin to be roughly 115 cm [16], we determine that the distance sensor must be accurate enough that it deviates from the true distance by no more than 10% of the bin height which equates to 11.5 cm. Our methods for verification and validation are elaborated in Section 4.2.

4. Methods and Key Design Decisions

4.1 Path to Recommended Design

4.1.1 Project Management Plan

Our productivity was maximized through the use of the Schedule Management Plan. We assigned tasks fairly and set internal deadlines, ensuring that we worked efficiently. When prototyping, the main subsystems of our design were distributed among us so that we could work in parallel, enabling us to complete a functioning device and app on time. This entire process was supplemented by the protocols in the Communication Management Plan that guided our interactions. It made sure that we were respectful to each other and highly responsive, setting a comfortable and driven team dynamic. Also, we kept track of risks which meant that we were sufficiently prepared for deficiencies and unexpected situations. Potential wait times for ordering electrical components and 3D printing were kept in mind as we prototyped, meaning that we prioritized ordering by following the Procurement and Cost Management Plans, checked in with the Myhal and the TAs, and completed other tasks during unexpected wait times. We also fixed deficiencies in our technical abilities by researching and using more standardized systems that would contain more documentation.

4.1.2 Key Design Decisions

There were several key design decisions we made while creating our design. The first one is that we chose to use an Arduino Uno circuit board. We chose to use an Arduino board instead of the Raspberry Pico board that was given to us in Studio because our team was more experienced with development on Arduino firmware as opposed to development on CircuitPython firmware using Adafruit libraries. Initially, we were planning on using the Arduino Nano RP2040; however, upon trying to use the built-in bluetooth module and the BN-180 GPS module, we ran into issues. We could not read serial input from the GPS module without doing some form of I/O multiplexing and changing low-level pin assignments [17], [18]. Thus, we opted to use an AVR board like the Uno so that we could use the SoftwareSerial library [19] to read the GPS data.

The second key design decision we made is that we decided to use a LoRa transceiver to communicate the fullness of waste bins. We chose this because it is a low-power radio modulation technique that is used for IoT devices [20], [21]. This would be an important characteristic because we are planning on running the device off of batteries. Furthermore, LoRa supports long-range communication with a roughly 10 km range [22] in Accra, the capital of

Ghana [23], which would allow for substantial coverage over the city. Given the availability of Wifi in the service environment, it would be difficult to have all the bins transmit information via the internet. Moreover, it would make the design far more expensive as it would require either having to connect waste bins directly to internet lines or the purchase of WiFi routers and modules. Instead, using a $12 LoRa transceiver [24] would be the most economically feasible solution.

While we intend on using the LoRa radio protocol in our actual design, for the purposes of prototyping, we opted for a bluetooth module instead because it was more readily available and had better documentation. This allowed us to more easily create our prototype while still remaining functionally true to our design of using peer-to-peer radio communication without WiFi.

Lastly, upon receiving feedback from our GSU collaborator, we chose to make our design very modular so that it could be easily integrated into the existing Ghanaian waste management infrastructure. This is to comply with our high level objectives of *Design for Cost* and *Design for Assembly*. Hence, we made our design fit into a portable box that can be attached to any existing waste bin. We also ensured that it had its own internal battery pack so that there was no need for us to connect waste bins directly to the power grid which complies with *Design for Reliability*. This would allow the design to be more modular so that we could scale deployment to the waste bins that are all across Ghana.

4.2 Verification and Validation of Prototype

The purchase website for the BN-180 GPS module claims that its positional accuracy is 2 meters [25]. However, the GPS module was encased in our box with a lot of wires and so we decided to measure the accuracy ourselves to avoid potential erroneous underestimations of error. To measure the accuracy of the GPS module, we stood in front of the doors of various buildings on campus and determined the latitude and longitude of our location using Google Maps on our phones. We then used the GPS readings that were output from the sensor to determine the location on Google Maps. Using the "measure distance" function on Google Maps, we determined the deviation of the module from the true readings. Upon conducting five trials (in front of Bahen, Galbraith, Sanford Flemming, Myhall, and the Sidney Smith building), we determined the average deviation of the GPS module from the true location was 17.6 ± 1.3 meters. This is within our constraint of 20 meters and so our prototype was deemed feasible.

There was no conclusive information online about the accuracy of our RCML-1601 Ultrasonic Sensor. As such, we decided to place our sensor 15 cm away from a wall and took readings from it for 30 seconds. The average reading for the wall's distance was 15.6 ± 0.1 cm. Given that this deviation from the true value was less than 1 cm, we deemed our prototype accurate enough to measure trash depth. It is important to note that our prototype assumes that the trash will be completely level throughout the bin. This is a major limitation and can be rectified in future iterations by having multiple ultrasonic sensors placed at various locations of the waste bin in order to determine the average depth.

More broadly, we decided to test our prototype against the high-level requirements we outlined in Section 3.5.1. To power our prototype and design for reliability, we used 4 AA batteries which allows our prototype to function consistently, given that the Ghanaian power grid is known to be unreliable. We also designed for usability as the prototype is very easy to operate, since the web-app is color coded and requires little technical expertise. As well, the cost of our prototype ($80.70) is relatively inexpensive in comparison to the costs of reference designs, as the prototype is modular and makes use of existing infrastructure. The modular design also improves the assembly of the prototype, since limited resources are required in its incorporation. Finally, as our prototype aims to improve the collection of waste and recyclables, the prototype can be validated against design for sustainability.

4.3 Comparison to Previous Approaches

Our design focuses on measuring the remaining capacity of a bin. While CleanCUBE does contain this function, it is also a compression system. Compacting all types of waste would actually hinder the separation of recyclables from the trash and contaminate the plastics, thereby reducing the throughput of recyclables which is counterproductive to our purpose [26]. Thus, it does not meet the *Design for Sustainability* requirement. The entire system is also integrated into a trash can, so it is expensive and requires the bins used at present to be removed, thereby going against the *Design for Assembly* requirement. In contrast, our design offers a retrofit unit that can fit onto existing waste bins. As a result, our solution is able to seamlessly integrate into and improve current communal waste collection systems while being of a lower price.

OscarSort is another design which seeks to increase the throughput of recyclables at the point of collection. However, as mentioned previously it uses a camera to detect the garbage that someone is holding and a large monitor to display information, thus only being useful indoors where it is not affected by the elements. This does not meet our *Design for Usability* requirement. In addition, it is far more expensive as it requires the implementation of a computer vision stack which is not entirely reliable given the diversity of waste items that can be thrown out. Hence, it does not meet our *Design for Reliability* requirement. Lastly, the fact that it needs a camera and large screen means that it would be excessively expensive and challenging to implement into the existing infrastructure, thereby not meeting the *Design for Cost* and *Design for Assembly* requirements.

4.4 Reflection on GSU Collaboration

The interaction with the GSU student helped us look at our design from a more holistic perspective. She mentioned "I think another thing stakeholders might find interesting is how fast these systems can be implemented and integrated within Ghana streets". This led to us adding our last High Level Objective of *Design for Assembly*. Previously, in our Design Proposal, we placed a lot of emphasis on the technological aspects of our design when creating our requirements model. After her feedback, we focused on trying to make our implementation modular which is why it can be attached to existing bins, does not need any external power source, and does not need any extra communication infrastructure (e.g. WiFi networks). The feedback we received was instrumental in understanding the broader context in which our design would be operating.

5. Discussion of the Final Outcome

Our design, Trash 'N' Track, is a modular system that notifies waste collection authorities of the locations of full bins. This is a valid solution for our main stakeholders – waste collectors and residents of Ghana – as it aims to reduce the overflow of garbage by suggesting more efficient waste collector routines. Since pollutants have adverse health effects, Trash 'N' Track improves the quality of life of the residents of Ghana because it increases the collection of waste without imposing an additional effort or time cost on the residents. Furthermore, our design makes use of existing waste infrastructure, thus minimizing additional consumption of materials and cost.

Our design is non-compatible with fully metal trash cans due to limitations of the GPS signal. The team operated under the assumption that most communal trash cans will be made of plastic based off of the pictures shown in Agorize. Additionally, Trash 'N' Track is designed for large communal bins because we recognise that households do not need data on the remaining capacity or the location of their personal trash cans. Another requirement is that regular maintenance is needed to switch out or recharge the batteries powering the system. Batteries were chosen to power the design because other alternatives, such as solar panels and wired charging, would require more maintenance, higher cost, or reduce the modularity of the design. Security of our unit presents yet another limitation. One disadvantage of a very portable and modular solution is higher probability of attempted theft being successful. A final limitation is exposure to difficult conditions; for example, if the lid is fully open and it is raining. Lastly, a key assumption that our team makes is that the waste collectors will be able and are willing to act upon the location and bin status data provided through Trash 'N' Track's app. As explained in section 3.1, this is a reasonable assumption.

Our prototype confirms that the key operations of our design are functional and can run in parallel in reality. Specifically, our prototype demonstrates that it is possible to transmit live-data from both the ultrasonic sensor and the GPS wirelessly to an app. To develop this model, our team initially identified the subsystems of our prototype: the CAD designed case, ultrasonic sensor, GPS, bluetooth module, and React app. The implementation of these components were assigned to team members based on individual expertise as described in Project Management Plan and Team Charter. Afterwards, we integrated these systems as a team, proving that our design is feasible.

6. Next Steps and Conclusion

The stakeholders have explicitly expressed a desire for solutions that would promote better waste management and increased recovery of recyclables. Our primary stakeholder, Adowa Coleman has emphasized the need to better manage waste at the point of collection to ensure quality and integrity of waste material. Trash 'N' Track is an effective way to monitor trash levels and optimally schedule pickup; directly improving waste collection and consequently diverting recyclables that normally overflow into streets to appropriate recycling facilities. In particular, the solution considers the indifference of the general public to proper waste disposal because they have no direct involvement in the physical device or the web app. This enables them to continue disposing waste as usual with the added benefit of available capacity in waste bins. The design also doesn't require WiFi, making it suitable for the operational environment. Consequently, we believe our solution addresses the main desires of our stakeholders, while maintaining true to our core design considerations (Section 4) and the UN SDGs (Section 3.2.1) that were developed to ensure validity and design translation in the service environment of Ghana.

Our prototype supports the validity of our design by clearly demonstrating the critical components of our design. Specifically, our design depends on the ability to accurately detect fullness of arbitrary trash cans, and reliably provide location data, which we demonstrate with the use of an ultrasonic sensor and GPS module, respectively. The prototype also demonstrates that we can effectively connect the information from sensors to a web-based application, creating a functional product. Finally, we have demonstrated the modularity of our design by creating a retrofit unit meant to attach to existing garbage cans, with almost no interference with existing communal practices.

Our next steps serve to address our assumptions and limitations, outlined in section 5. To improve flexibility of our design, we plan on exploring different case attachment mechanisms, for example, mechanical fasteners, magnets, adhesives, or clasping methods. Continuing, we wish to conduct research on waste bins in Ghana to select the optimal distance for detecting fullness of different classes of containers. Regarding the system itself, we want to explore ways to avoid problems introduced by enclosing the GPS in a metal container; though existing bins shown by stakeholders are plastic bins, if we were to scale up our design to different spaces, we should consider alternatives like a GPS antenna, which would protrude outside the bin and therefore be less disturbed. Finally, we value security to ensure a design we can deploy. Currently, it would be very hard for residents to compromise our unit because openings into the internal components would be the smallest size possible to allow the ultrasonic sensor to emit and receive waves. However, a better way to safeguard the internal components from unexpected conditions will also lengthen the expected service time of the product. For example, covering internal components with a waterproof cover and using laser waves instead of ultrasonic would address certain weather conditions.

7. Appendix

7.1 Team Values Statement:
Our team prioritizes constant communication between team members, accountability for individual work, consciously practicing design empathy, and psychological safety. This behavioral consensus results in a strong and flexible team dynamic and a baseline assurance to rely on each other in projects and discussion.

In design, our team identifies usability, cost, reliability, and sustainability to be our most significant values. We believe that a meaningful solution to the recycling problem in a low-income, developing country should be intuitive to use, inexpensive, and mechanically robust. Moreover, the solution should align with UN sustainable development goals whilst not interfering with existing culture and practices unrelated to recycling. Motivated by designer's empathy, we conduct rigorous research to better understand stakeholder needs. With these motivations as guidance, we strongly believe that our final solution to improving current recycling practices in Ghana will best satisfy the needs of and empower the stakeholders.

7.2 Individual Descriptions
Fatima: Fatima is the *Risk Coordinator* and *Project Coordinator*. Her tasks involve working on overarching long-term project goals and helping combine different roles within our team for overall project success. Here, she is especially focused on ensuring that our team is on the same page, working towards the same goals, all while maintaining good physical and mental wellbeing. As well, Fatima is the software engineer of the group, which means she focused on making sure the hardware and electrical components of the design would be integrated with the software needed.

In her experience as a Co-Founder for FeminSTEM, she has always been aware of the shared long-term objectives of the company. As well, she would analyze the risks of investing with different stakeholders to ensure that everything was managed and accounted for; skills that are transferable in her roles as a Risk Coordinator and Project Coordinator for our praxis team. Moreover, with her work as a Blockchain Developer at dApp Technology Inc., Fatima is well-versed with building and deploying an app with an external database, which ultimately was a huge component in the final design.

Most importantly, Fatima values exercising Designer's Empathy. This means that she recognizes that designing a solution must cater to stakeholders' needs. She believes that

Jasmine: Within the team, Jasmine has volunteered to be the *Facilitator* and *Project Planner*. This includes creating the meeting agenda and guiding the discussion accordingly. Additionally, she is responsible for project planning. Tasks involved with this include creating a shared timeline of internal deadlines, breakdowns of tasks that need to be completed, and making sure everyone is on the same page about what they are responsible for.

Above all else in a team, she values creating a psychologically safe environment where team members can communicate openly and share any concerns without hesitation. This is something that she has practiced in all her past teams. Additionally, she recognizes how valuable accountability and perseverance is throughout the project. Accountability creates a sense of fairness, which is important for maintaining a positive team dynamic. Within the design itself, she also recognizes the importance of always consciously practicing design empathy in order to produce results that stakeholders want. She has done this throughout the Praxis courses and with each project, see's improvements in how well she practices design empathy.

Within the project management plan, her specific roles are to Facilitator and Project Planner. She has experience and transferable skills relevant to these two roles. Within the Ethical Principles in AI Team (a UofT-affiliated club), she does a lot of work organizing goals and timelines and assigning tasks appropriately so that internal deadlines are met. Regarding her shared roles, she has done research, edited documents, and presented design proposals for past Praxis courses. Additionally, she is able and willing to learn tasks required of the systems and design engineer.

Yawar: Yawar is a *Facilitator* and *Issues Coordinator*. He will coordinate with Jasmine by guiding meetings and recording issues, which he keeps in the issues log under our team's SharePoint. Yawar is also responsible for researching and defining clear requirements that our solution must meet on a high level as well as what metrics the specific solutions should be measured against. Defining clear requirements is imperative to properly guide our design process to make sure everybody is on the same page about what is expected of the final design.

In his past and current experience as a Simulation and Systems Software Engineer for the self-driving car design team AUtoronto, Yawar has always been an advocate of defining why a specific feature should be implemented and why a specific alternative fits better with the goals of the project over other alternatives. This directly applies to his verification and validation role in the Praxis team and helps him communicate his ideas and guide brainstorming sessions towards the expectations of the final solution.

Throughout my past experiences I have always valued a healthy and helpful team culture. I have found it to be a critical component in determining how productive the team is and how rewarding all team members found the work to be. I have tried to embody and create an atmosphere of empathy within our Praxis team, which extends to our team members and final stakeholders alike.

Sophie: In the team, Sophie is the Cost Coordinator, Global Team Peer Liaison, and Timekeeper. She is in charge of managing the financial aspects of the project, communicating with global team peers, and keeping track of time during meetings. Having previously been the Head of Finance at Jakarta Street Kids Global Concern, a global nonprofit organization, she is familiar with the responsibility of managing funds. Furthermore, she has experience guiding meetings that involve communication with global nonprofit and social service organizations. This qualifies her to take on a global outreach role and be in charge of time in meetings.

She also has built her technical and problem solving skills through her education program as well as hackathons. She is, therefore, able to use an iterative engineering design process to rigorously apply theory and produce solutions. This will guide her in the team-wide roles in scope and project integration management. Moreover, she values teamwork because she acknowledges that each individual in a team has their own expertise, and a harmonious cumulation of such individual skills would lead to maximal success.

Growing up, Sophie has been an active member of charitable organizations, targeting the improvement of environmental and social conditions for underprivileged children in Jakarta. She has come to truly value stakeholder input because she recognises that a successful solution cannot be separate from the community it is implemented in, especially when keeping long term sustainability in consideration. She hopes to bring such considerations into the project designs.

Hshmat: Hshmat is the Note-taker and Global Client Liaison for Team 106C. As note taker, he will store meeting minutes in the appropriate SharePoint folder, and will inform members of progress in meetings if they are unable to make group meetings. As Global Client Liaison, he is responsible for thoroughly reading stakeholder opportunity presentations on the Agorize platform and relaying any new information to the team. He is also responsible for compiling any questions the team has to stakeholders, and submitting them to FaCT by the deadline. His experience presenting to external teams in his previous internships, as well as note taking in all his classes give him experience to manage global interactions and record meeting minutes.

Hshmat values designing for accessibility and usability, aligning with the team's overall goal of meeting certain UN sustainable development goals. In Praxis 2, he led his team in designing a retrofit kit to be attached to existing can openers, instead of developing a new machine. That way, design is about assisting primary stakeholders but not degrading their self-worth. He hopes to transfer the benefits of a retrofit and modular design to this project. Furthermore, he has experience controlling interactions with stakeholders outside the design team. In his previous internship, he was responsible for presenting the team's progress to the software team at Bangalore, India (prepared slides and oversaw codebase on Perforce).

Hshmat prioritizes actively practicing empathy in design. He has held multiple volunteer roles; e.g. at South Asian Diabetes Prevention Program and Retirement Center; that involved deep understanding of stakeholders and their problems to improve their day-to-day physical and mental health. He is confident this experience will allow him to think of the best design for residents in Ghana, rather than biasing solutions to what is “the coolest”.

Finally, Hshmat values transparency within the team. Members should be able to voice concerns immediately, without fearing criticism, but instead expecting constructive feedback.

Ritvik: Ritvik oversees *Procurement Management*. His main roles will be component tracking, acquisition, distribution, and tracking the 3D printing of parts. He will work closely with Jasmine, who has expertise in CAD, to ensure progress with the prototype meets internal deadlines. In writing, his main responsibility is involved with specifying the requirements model. Engineering requirements are important in determining the feasibility of any candidate solution. Having metrics that are measurable but also accurately reflect the requirements provides an object measure of achievement for each solution. His technical role will be as a systems/design engineer. This means that he will not only focus on design at all levels of the technical stack, such as mechanical, electrical, and software, but also on integrating these into one large system.

Ritvik’s past experiences have primarily been working in the capacity of software engineering and electronics. Throughout these experiences, he has worked in these fields in an isolated manner as opposed to integrating the various technical areas together. Furthermore, he has not had any mechanical engineering experience. Through this engineering design opportunity, he seeks to learn more about mechanical design and building electromechanical systems that integrate across the entire technical stack.

Ritvik believes that engineering solutions should serve to benefit humanity. To this end, he makes empathy a key aspect of his design process. Empathy and engineering design go hand in hand as empathy can help elucidate some of the more latent engineering requirements which ultimately determine how useful the design is for the stakeholder.

7.3 Bill of Materials

Item	Quantity	Price	Rationale
Arduino Uno	1	$6.68	Refer to key design decisions
Full Size Breadboard	1	$11.90	Sensor and GPS module wiring must be connected to the breadboard.

RCWL-1601 Ultrasonic Sensor	1	$5.80	Measure distance
BN-180 GPS Module	1	$21.99	Provide location data
HC-05 Bluetooth Module	1	$9.50	Information transmission between sensors and app
2478CN AA Battery Case Holder	1	$0.79	Hold batteries
AA Batteries	4	$8.35	Provide power to operate design
Jumper Wires	14	$6.83	Allow flexibility in sensor placement relative to pins in breadboard
3D Printed Case	1	$8.86	Serves as casing to safeguard internal components and protect from theft or unprecedented weather conditions

Product Links:

Arduino: https://www.digikey.ca/en/products/detail/arduino/A000073/3476357

Breadboard: https://www.digikey.ca/en/products/detail/bud-industries/BB-32656/8602381
RCWL-1601 Ultrasonic Sensor:https://www.digikey.ca/en/products/detail/adafruit-industries-llc/4007/9857020

BN-180 GPS Module:
https://www.amazon.ca/BEITIAN-Module-GLONASS-9600bps-Built/dp/B09MS65NXH/ref=sr_1_6?keywords=bn180&qid=1639002201&sr=8-6

HC-05 Bluetooth Module:
https://www.creatroninc.com/product/hc-05-bluetooth-module/

2478CN AA Battery Case Holder
https://www.digikey.ca/en/products/detail/keystone-electronics/2478CN/7385278?s=N4IgTCBcDa4CwHYAcBhAciAugXyA

Jumper Wires:
https://www.digikey.ca/en/products/detail/adafruit-industries-llc/153/7241430

AA Wires:
https://www.amazon.ca/Duracell-CopperTop-Batteries-all-purpose-household/dp/B00000JHQ6/ref=asc_df_B00000JHQ6/?tag=googleshopc0c-20&linkCode=df0&hvadid=459879884531&hvpos=&hvnetw=g&hvrand=5746528799160248806&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9061009&hvtargid=pla-637193815171&psc=1

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