1. Problem Definition

About 20% of waste generated worldwide is not collected at all, which means that it is burned or dumped in the open with detrimental effects on the environment and human health. Merely 13.5% of the world's waste is recycled, despite the fact that 44% of it is deemed biodegradable. It is almost a shame that most of these wastes go unnoticed in our day to day lives in our own environment surroundings. This project's primary goal is to carry out one of the 17 Sustainable Development Goals- "Sustainable Cities and Communities". The problem often starts at collection and segregation of these wastes as everyone has their own priorities and no one is to blame. Instead on emphasizing more on the management of these waste, assisting humans is the whole point of innovation. Hence, the requirement for an intelligent garbage classifier bot.

I would like to quote a case where my above concern was right, Solid Waste Management: A Case Study of Jaipur City. In Jaipur, the solid waste management system has faced several challenges, particularly in waste segregation, collection, and disposal. The Jaipur Nagar Nigam (JNN) handles a large volume of municipal waste, around 1200-1400 metric tons daily, with around 55% of it being organic waste. Major problem lies in lack of segregation, collection and poor disposal practices. A particular study conducted by Central Pollution Control Board shows status of Municipal Solid Waste Collection, Treatment & Disposal in and around Jaipur City in 2007-2008. Most of the population of the city does not store the waste at source and instead disposes the waste into the garbage bins, roads, open spaces, drainage pipes, etc. The article further talks on how collection and segregation of these wastes proves to be a problem due to huge dependence on labour force. Even though decades have gone by, the situation has not become any better with almost no major initiatives taken by government.

Thus, how does our solution fit into our theme of Environmental Sustainability? Our idea has the ability to replace humans in the process of collection with its exemplary autonomous skills and solves the problem of segregation. The whole point of being sustainable in implementing step by step solutions and the contribution of our product could be one such. Our society often experiences temporary surges in awareness driven by movements and discussions that lead to short-term improvements. However, once the initial impact fades, things tend to return to their previous state. This proves to be incredibly difficult to achieve a lasting change in human principles. One waste at a time similar to the adverb of “one at a time” can be collected and segregated and thus contribute to a better green environment.

2. Validation Of The Problem Through Data Collection And Analysis

The identification of relevant customer segments was done through analysis of similar problems across all regions and solutions they came up with. We also researched more on where the problems were majorly concentrated and came to different customer segments or places where we would be of maximum utility. We identified the relevant customer segments to be: -

- City wide cleaning like sidewalks and park areas for clean cities and urban development
- Private purposes such as Large campuses, institutions or factories can use Sortify for solid waste collection
- Environment enthusiasts or NGO associations which can use our product for cleaning dense solid waste polluted areas such as beaches
- Public use such as in homes or gated communities (public amenities)
- Service sector businesses (venue management event organisers hospitals etc.)

We also wanted a view on how people of different backgrounds different occupations would think of our product. So, we conducted a survey with a few relevant questions that might help us understand and empathise from a customer point of view. The sample size for analysis we took was 25 responses of which 77% of the people belonged to the age group of 18-30 and only 11.4% were above 51 years old. This is one of the proofs where in young people are more viable and adaptable to new technological changes. And the survey was conducted on a wide range of occupations where in more than half of the responses were observed to be students and other scattered over various professional fields such as IT, healthcare, education, finance, and retail. This diverse range suggests that while Sortify should target the student population who are tomorrow's professionals. There is potential for broader adoption across various industries, where time-saving and efficient waste management is also critical.

Analysing the survey responses to various questions, a number of conclusions were drawn and the analysis suggested a lot of possible ways for us to approach the problem with solutions. Some of those conclusions were:

- The waste segregation frequency was asked on the survey to determine the current status of people's mentality towards today's existing methods. The data highlights inconsistency when this was inspected. We were surprised to find that only 22.6% of the responders segregate their waste frequently and 37.1% do so occasionally, and 34.3% rarely engage in the practice. This explains the lack of priority of people to waste segregation which is the whole purpose of Sortify's existence and innovation.
- The challenges often faced by these people during segregation was also being asked and the response was as follows. The time it takes (45.7%) and the difficulty in understanding how to categorize waste properly (45.7%) and a smaller percentage (8.6%) cited a lack of initiative to participate in waste segregation. This proves our ideology of preciousness of time, priorities and the need for Sortify.
- Additionally, 85.7% of respondents had never heard of any smart waste segregation systems before, meaning there is a significant opportunity for Sortify to capture this untapped market. This group is particularly tech-savvy, environmentally conscious, and likely to advocate for the benefits of an automated solution if it proves effective.

Thus, the most significant issues people face on waste segregation includes the fact that it is too time-consuming and the confusion surrounding which items belong in which category. Specifically, plastic waste and food scraps were identified as the most difficult to sort, which aligns with challenges in waste management that are faced by many. This problem is compounded by the fact that only a small portion of respondents (28.6%) frequently segregate their waste, while the majority either do so occasionally or rarely. Additionally, most people (85.7%) have never been exposed to any form of smart waste segregation system, meaning awareness is low, but there's potential for high impact.

Furthermore, 54.7% of people think that accuracy in detecting and sorting waste is crucial, reinforcing the need for a reliable and precise solution. A simple, user-friendly machine is also preferred by 60% of respondents, indicating that Sortify should prioritize ease of use alongside functionality. Many

respondents believe that Sortify can reduce waste sorting time by up to 5-10 minutes, making it an attractive solution for both individuals and institutions.

3. Idea-Concept-Solution to address the problem

After the review of various case studies and as a by-product of our recent internships at NGOs, we were typically inspired by the work all these professionals do to keep our society intact. So, while we participated at these beach cleaning drives, waste picking etc., we noticed that the areas chosen for these activities always depended on number of people signed up for the initiative. That got us thinking, if we simply needed more workforce, why not replace them with bots capable of performing the same tasks? That's when we started working on what features should a bot have, to be capable of this. So, we went through the solution as a bot, that needs to identify an object and start moving towards it and dispose that waste. Even though it sounded as easy as it seems, we realised after some research that there are very few products in this domain. Thus, we formulated our idea as four major parts

(i) Mobility

Mobility involves an obstacle avoider bot coupled with 2d mapping facility. This mapping is done with the help of 6 axis gyroscope and ultrasonic sensors. Once enough data is accumulated through mapping, we can train a model to improve the accuracy of the map and give point to point moving instructions. The obstacle avoider avoids obstacle and turns until it gets ahead of the obstacle

(ii) Object tracking and following

This part involves OpenCV script based on trained ML model that can identify any objects on ground and can estimate the distance and starts moving towards it. This tracking works only on objects on ground and aims on deliberately moving towards it.

(iii) Object classification

Here, we multithread the tracking and classification of the type of waste whether biodegradable or non-biodegradable and segregate them accordingly. Classification involves training a model to identify the kind of waste it is. The accuracy percentage of over 1000 frames are considered and normalized before classification

(iv) Object removal

This involves a trolley like structure with separate compartments that has a servo motor equipped sweeper that can take in the object according to the classification. This part needs to be structured exactly as it is meant and it is to be 3D print with necessary materials for long lasting use and better accuracy.

An IOT (Internet of Things) to oversee all of the functions and to control alerts and SOS features is included for the user control and ease of use.

We figured out a lot of things but it was time to think through what was workable features and we decided to use the 6 De Bono Hats to think this. Seshadhri often wore the Blue and Green hat as he often led the discussions and structured our thoughts. He came up with quite a lot of creative ideas, as well for implementation and design, as he is technologically sound. Ajay wore the white hat for the most part. He was logical and bringing in the working perspective. He was very neutral to all ideas

and giving out his true thoughts about it with no biases. Kamalesh wore the yellow hat, as he always saw the positives on whatever was brought on to the table. He saw whether the solutions were logically feasible and not an overkill. Adarsh took on the Red Hat as his gut and instinct was right for the most part. He researched through a lot of existing solutions and came up with ideas instinctively that were workable. His ideas were also sometimes with no technological backing but really awesome and made us work to achieve it. Ashwin wore the black hat as he always had a good eye for weaknesses and what doesn't work. He came up with risks and even alternate ideas that can be put to use.

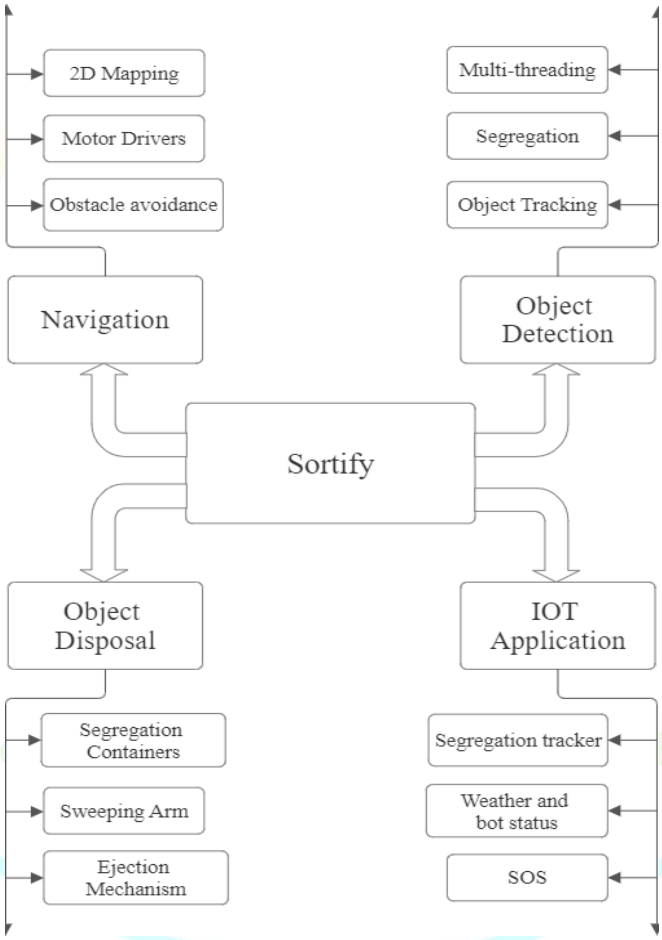
Thus, we came up with our USP (Unique Selling Proposition). Our idea is unique from others as it integrates multiple components that exists as separate entities. It does an end to end job of collection and segregation leaving no chances for external interference or dependence. It is different as a product while others exist as ideas and research prototypes. I would like to quote few of those research papers or articles, that came close but not giving an end to end solution. Artificial Intelligence-Based Robotic Technique for Reusable Waste Materials - PMC, this article suggests a stationary structure of Sortify but that is not viable and ultimately defies our problem. We are also technologically better with the use of Machine Learning algorithms and AI models that can continuously learn and be better. Trash-sorting robots inspire residents, this is just a classifier and stationary model whereas, ours can navigate different terrains and is a multi-purpose bot.

Next USP would be that, our product is trying to get people think that the technology is required for day to day life making it more of a successful innovation. Our product is a multi-purpose bot that can be customized depending on the need (homes or beaches or large campus areas). The 2D mapping would be effective for homes for futuristic uses like interior design or space planning and special mobility structure would be added for beach navigation. Things like these makes it a hit among different sections of people.

Third USP would be that, it uses comprehensive AI model that will be deployed on the later stages. It is a predictive model that can analyse data and give conclusions or even lifestyle changes. We are also implementing a database that stores what kind of waste (E-waste, sanitary waste, dry waste, wet waste) is collected and gives the user a comprehensive analysis.

4. Project Description and High-Level Design

Description of the product comes down to an intelligent garbage classifier bot that is mobile and segregates solid waste. The basic idea is to reduce the dependence on humans and an aim to establish autonomous bots that can cover for the mistakes us humans make. Our product, Sortify has the ability to navigate itself around and track an object (solid waste) in order to reach it and segregate it into biodegradable or non-biodegradable waste. This has the added advantage of two-dimensional mapping of the spaces it visits. This is going to be overseen by an IOT (Internet of Things) application that can keep the users updated of the bot's status and this is also going to be equipped with a clean source of energy (solar). All of the above design ideas can be realised with use of electronic components like LIDAR, Gyroscope, Ultrasonic sensors, cameras, motor modules etc. Sortify leverages the use of advanced machine learning models to assist the waste segregation process.



(i) Navigation

This involves 3 major parts of obstacle avoider mechanism, motor driver circuitry and 2D mapping with LIDAR. Obstacle avoiders can be designed with placing of ultrasonic sensors and change the pathway of the bot when met with obstacle. Motor drivers need efficient placing of motors and a driver module that instructs the motors depending on the task fed. 2D mapping can be accomplished by the use of LiDAR. This maps the pathway and created a directory of map it has visited or explored.

(ii) Object Detection

This involves tracking of an object to decide the direction in order to reach it and

multithread this process with object identification. Identification involves whether it is biodegradable or non-biodegradable to segregate the waste.

(iii) Object Disposal

This is responsible for collecting and disposing it to the respective bins of biodegradable or non-biodegradable. It has a trolley like structure that is attached to a 3D printed sweeping arm that ensures that the object is collected. It is assisted with a hydraulic structure for collection

(iv) IOT Application

This includes creation of an application that oversees the status of all these components for an easy user accessibility. This also involves an SOS alert in cases of emergencies and gives the user absolute ease of mind with all controls at their fingertips.

Some of the industry domains that will benefit by our product would be:

1. Smart cities and Urban development (Home)
2. Manufacturing sectors (industries)
3. Educational institutions
4. Public Welfare (Parks)
5. Environmental Services (Costal clean-up operations)
6. Private uses (Venue management)

Some of the advanced cutting-edge technologies used:

1. Machine Learning
2. Artificial Intelligence
3. Embedded Systems
4. Internet of Things
5. Robotics

5. Project Benefits

Major benefits that can reaped from our product would be as follows:

Environmental benefits: Sortify provides important environmental benefits by properly collecting and separating waste which helps reduce waste and garbage. This contributes to cleaner public spaces and a healthier lifestyle. The bot supports recycling by properly classifying waste. This could increase global recycling rates beyond the current rates of 13.5%. Adaptability to a variety of environments, such as homes, beaches and educational institutions.

Time saving: Robots outperform humans in tasks like waste collection, sorting, and segregation, and can work continuously without breaks, thereby increasing overall productivity and reducing dependency immensely.

Reduction in Labor Costs: The whole purpose of Sortify is to assist humans in tasks that does not need their priority. This substitutes people and makes their life easy and thus, reduces labor costs.

Safety: It minimize human involvement in hazardous waste management, minimizing exposure to harmful chemicals and sharp objects, and can be deployed in hazardous environments like industrial areas.

Some of the minimum expected benefits are as follows:

Operational Efficiency: It can offer faster waste collection and segregation due to their higher speeds and continuous operation, enhancing productivity compare to human workers

Cleaner environment: Must focus on maintaining a clean and hygienic environment and elimination of solid waste which are one of the biggest hurdles in waste management.

Recycling Accuracy: Leveraging complex technologies, Sortify has a better waste retrieval percentage and hence increases the recycling percentage and resulting in better revenue streams.

Return on investment is a very futuristic thought process required to assess the product's actual profitability. Actual returns cannot be calculated at a very early stage hence we will list down return opportunities that we have to grab:

- Identifying target markets
- Creation of revenue model
    - This involves planning pre-defined units of production and try to get huge orders for maximizing profits
    - Involves outsourcing or offering in house post-sales maintenance contracts that can provide steady income stream
    - Constant improvements and patch updates to keep the user satisfied in order to maintain reputation can help in long term sales
- ROI upside (customer perspective)
    - Proves to be very useful when comes to labor cost saving calculations. A cost of ₹15,000 to ₹20,000 per month can be saved on an average per person.
    - Return from better recycling percentages of waste can also be accounted to the use of Sortify
- ROI downside (customer perspective)
    - Maintenance costs of ₹10,000/ year can be foreseen and an installation cost of ₹1000.
    - One-time investment of capital for purchasing these bots and electricity charges for charging batteries.

6. Market Assessment and Readiness

Know your customer is how we know our product. if a product is designed without empathising and prioritising users' needs, it might as well be an invention not an innovation.
What we think as our primary customer segment is large institution and industries that struggles with problems like mentioned above. Most of these spaces have a large numbers of people visitations with frequent spikes and often unmanageable. Also, in reference to the survey we conducted, majority of the respondents were students, initiatives like these would be encouraged and welcomed among student campuses. Factories that have large amounts of solid waste emissions would be an ideal choice of customers tailored for our product. Thus, subsections of our primary customer would be

1. Schools and Colleges
2. Gated communities
3. Industrial parks
4. Exhibition Halls and convention centres

Our secondary customers would be environmentalists. As much as these people care for their environment they also need assistance to manage these wastes. Often manpower shortage becomes a problem where our product can act as substitution and assist the people better. Large operations can be done with ease if our product is deployed, as more ground area can be covered at a lesser possible time. Subsections of this segment would be:

1. NGOs (Non-Government Organisations)

2. CSR (Corporate Social Responsibility)
3. Tourist Spot Managements
4. Cleaning service professionals

Some of our unique value propositions would be as follows:

- End to end automation
- Wide range of customer market
- IOT integrations for remote access
- AI driven new age solutions

Our product is ready at a research perspective. It is through the first three levels of Basic principles observed, Technological concept formulated, Experimental proof of concept. Our proof of concept might not be for the entire product but for some parts at a foundational level. We are able to classify objects with the help of machine learning and OpenCV powered camera. Experimental proof is included with the submission.

Our risking zone would be that our competitors have an established brand and supply chain. In order to be better, we have to advertise better on what our brand focuses on and improve our product's reliability

Our losing zone would be the need for simplicity, our product is a bit complex on its molecular level and integrating all of these technologies to work seamlessly would be difficult. Appealing to the customers that the user perspective is pretty simple and actually making it simple with the help of our IOT application.

7. Other Aspects

Some of the other aspects would involve environmental impact and mitigation. Some of the foreseen impacts and mitigation steps are as follows:

Energy: The energy source used to charge the batteries are from our current power stations which increases the load on existent systems. As most of these are generated from natural resources such as coal etc. which are getting depleted. The mitigation steps would be switching to greener sources such as solar. We have planned to make some part of the charging at the least through solar.

Emissions: Mass production of our product also releases considerable amount of carbon footprint. It is impossible to make it zero, but can be reduced. Mitigation of this would be through usage of more of recyclable materials in manufacturing and sourcing materials from recycled by-products.

Battery: Lithium ion battery have an impact that leads to mining and production of more lithium, cobalt and nickel. This results in the release of more Carbon Di-Oxide thus, leading to global warming. Mitigation would be to reduce unwanted charging and improved charging cycles for better battery life.

Electronic components: It poses a harm due to hazardous substance like lead, mercury and cadmium if not disposed properly. Usage of these resources in the first place are a stress on the natural resources. Mitigation would be to increase the efficiency of these components to reduce its usage.

Plastics: Incineration of plastics releases 450 kg of CO_2, contributes to climate change, and can cause soil and water contamination, microplastic formation, health risks, and loss of resource value. Mitigating plastic is an impossible task but reduction of usage can be attempted.

The licences and permissions to use this product are very less as it is very environment friendly. Some of them are registering an idea and a product patent for the product. Use of third-party software tools for building the product might be required. Use of cloud platforms for comprehensive and fast data transfers and accessibility might be required.

The estimated cost for different components of the project currently are as follows:

Components	Cost
1. Microcontroller/Processing Unit (e.g., Raspberry Pi/ESP32)	- ₹6,000 to ₹8,000
2. Sensors (LIDAR, Ultrasonic, Infrared)	- ₹10,000
3.Cameras (RGB and/or Depth Sensing)	- ₹4,000
4. Conveyor Moving mechanism	- ₹4,000
5. Motors and Wheels (DC Motors, Stepper Motors)	- ₹1,600 to ₹8,000
6. Robotic Arm (for waste picking)	- ₹3,000
7. WiFi/Bluetooth Module	- ₹400 to ₹1,600
8. GPS Module (optional, for outdoor navigation)	- ₹1,500 to ₹2,000
9. Lithium-Ion Batteries/Power Bank	- ₹3,000 to ₹6,000
10. Chassis and Frame (Custom/3D Printed)	- ₹4,000
11. Miscellaneous Components (Wires, Mounts, Fasteners, etc.)	- ₹2,400 to ₹5,600

The rough estimated cost at a lower range is - ₹35,000 and at a higher range is - ₹50,000
The above cost also includes research and development and it is a very rough estimate considering all possible expenses cost could either go down or up.
This model can very well be mass produced the major challenges are as follows:

- Quality control
- Software support (App maintenance)
- Server side and cloud maintenance
- PCB boards mass manufacturing
- IP68 rating maintenance
- AI Model deployment feasibility issues.

8. Other Information

- The information provided under the design is a very high level, on macro level we are trying to implement some additional features like:
    - Waste compression after collection to reduce space
    - Weather conditions display
    - Track of collected waste (E-waste, sanitary waste, dry waste, wet waste)
    - Green energy sources (solar)
    - Docking charger
- Some of the information provided for return on investment and cost analysis is a very optimistic analysis for the foreseeable future. Changes will be made to those sections as the projects progress.
- Embedded links are just websites and not additional documents. They are included for the reader's reference despite the caution of no additional links.
- Experimental proof of concept will be added in the evidences folder and reference research documents that open from links will not be included in this document but to be entered as separate folder in the link provided

9. Appendices

List of research papers and article that were analysed for the problem statement and competition analysis

- Artificial Intelligence-Based Robotic Technique for Reusable Waste Materials - PMC
- A Garbage Classification Method Based on a Small Convolution Neural Network
- A Garbage Detection and Classification Method Based on VisualScene Understanding in the Home Environment
- Research on Service Design of Garbage Classification Driven by Artificial Intelligence
- AI-powered robotic system operational at Zanker Recycling
- Trash-sorting robots inspire residents, promote garbage classification - SHINE News
- Design of a Garbage Collection Robot
- Gar-Bot: Garbage Collecting and Segregating Robot

10. Appendix-A

Technological readiness level is at level 3- experimental proof of concept

Level1: Basic Principle Observed: - We have observed it throughout sections 1 and 2
Level2: Technology Concept Formulated: - Observed throughout sections 3 and 4
Level3: Experimental Proof of Concept: - Added with the files as proof

11. Appendix-B

2D Mapping/Object Tracking
Machine Learning (ML)/ Object Classification
Autonomous Navigation/Robotics and Actuation
Internet of Things (IoT)/ Artificial Intelligence (AI)
Real-time Data Processing/Multithreading for Performance
Obstacle Avoidance/Environmental Adaptability
Electric Vehicle /Energy / Power
Waste Management/Power Electronics
Garbage Classification/Water Resistant

CAUTION: The links embedded inside are websites for your reference not additional documents.