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An Intelligent App-based System for Waste Segregation and Collection

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Abstract

Municipal solid waste generation in India is increasing as a result of rapid urbanisation and a growing population. Due to gaps in the existing waste collection, treatment and recovery methods, large-scale unscientific disposal and lesser waste recovery have been observed. Insufficient source segregation, unorganised efforts, less awareness and indifference towards malpractice, and a lack of strict implementation were identified as the causes through literature review, surveys and interviews, Therefore, there is a need for a system of interventions, which organises efforts toward waste management and reduces the tolerance for source segregation errors. This paper aims to provide a solution that increases community participation and prevents the generation of mixed waste to ensure waste recovery. The proposed framework integrates municipal solid waste, human elements, and technology into an intelligent app-based system. This includes a smart bin that segregates waste at the source through image classification and an application for communication and data collection.

Peer-review under responsibility of the scientific committee of the International Conference on Machine Learning and Data Engineering

Keywords: Waste Management, Solid Waste, Source Segregation, Artificial Intelligence, App Development, Smart Bin

1. Introduction

Waste is any material that the producer, processor, or user no longer requires. Solid waste includes any non-liquid organic and inorganic waste produced by society after it has lost its original value [1]. Municipal solid waste refers to the heterogeneous or homogenous solid waste generated in urban and peri-urban areas [1]. The Composition of Municipal solid waste is always varying constantly. But the collected waste can be divided into the following types: c wet waste, dry waste, domestic hazardous waste, sanitary waste, construction, and demolition waste, and mixed waste [2].

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There is no waste produced in nature. Waste is a resource for creation in the next cycle of creation. But a linear view of the process produces more waste than nature can handle [3]. As a result of the country's 1.37 billion population's increased need for land, utilities, food, and other resources, India's waste production has grown significantly [4]. In 2018, the World Bank predicted that the generation of MSW would reach 3.4 billion tons by 2050 and half of India's population would be living in cities by 2050 [5]. This increase in urban population will lead to far greater amounts of waste being generated [6]. A drastic change in the lifestyles of people concerning consuming habits has already hugely impacted the generation of municipal solid waste [7]. Handling unsegregated heterogenous waste has led to drastic environmental changes through irresponsible, large-scale landfilling. In India, more than 90% of waste generated is disposed of in this manner. This untreated waste is a source of various types of pollution and causes other socio-economic problems. Unsegregated waste has a large number of organic components that release methane, carbon dioxide, and other trace gases when they decompose [1]. Processing facilitates the 3Rs (reuse, recycle, and recovery) processes which reduce the amount of waste being disposed of and thereby minimise the carbon footprints of municipal solid waste [8]. The waste that is disposed of or burnt without handling properly leads to air, water, and soil pollution [9]. This waste cannot be recovered and the potential of the other recyclable components in the mix is lost. Many developing countries, like India, find their organic waste and recyclables mixed while collecting. This reduces the waste recycling rate [8].

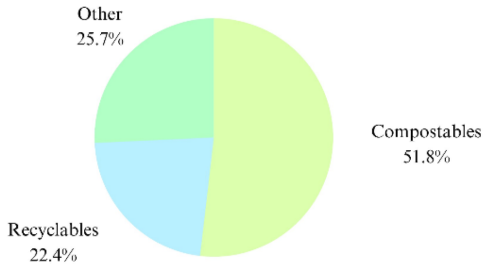

Fig. 1. Composition of waste collected in Bangalore.

The amount of waste generated in Bangalore city varies from 1700 MT/day to 2300 MT/day [10]. In a recent study conducted in 2021 in Bangalore, it was found that only 60% of the household waste is collected door to door and only 15% of the collected waste is treated due to its mixed nature [3]. 51.8% of the waste collected comprises compostable materials and 22.4% are recyclables (Figure 1). The rest of the waste is disposed of in an unscientific manner all around the city. A part of this waste is constantly recovered due to the efforts of the informal sector and other NGOs or companies working towards this goal. It was found that the informal sector recovered around 23% of waste in major cities. India, China, and Brazil are the three largest countries with major informal activities. It is estimated that there are around 1.5 million informal workers in India alone. But, there is a high chance that the actual population exceeds this number [11]. Therefore, India needs an improved system where the waste sector is organised and its resources are used to their full potential. A system that reduces the generation and collection of mixed waste and increases the amount of waste treated and recovered while also ensuring the workers involved in this sector lead a life with dignity. The need to integrate new technology has only increased with the constantly growing numbers in waste generation.

1.1 Objectives of the Research

This paper aims to understand the challenges in the waste segregation and collection processes by reviewing literature andinvestigating the attitudes and actions of residents. It aims to develop a means of enhancing stakeholder engagement and integrating technology into waste management processes to decrease the amount of mixed waste generated, facilitate maximum waste recovery and achieve an environmentally sound waste management system.

The paper introduces a framework involving the three main elements to be considered before designing waste management processes. The potential of existing solutions and resources are analysed. In the present study, a system of solutions is proposed. The paper also describes the stakeholders and their roles in the process of waste recovery. A discussion on implementation, limitations and future opportunities is included. The rest of the paper is organised into the following sections: — Section 2 reviews the works relevant to this study, Section 3 introduces the methodology for conducting this research; Sections 4 and 5 discuss the results and outcomes of this project; Section 6 concludes the paper by summarising the findings.

2. Related works

2.1 Literature survey

The world's energy demand has been continuously increasing and is expected to reach an oil equivalent of 17 billion tonnes by 2035. This establishes the need for finding alternate sustainable sources of energy. Energy waste is the best option but due to the multiple challenges faced due to the poor methods used for collection, segregation and disposal, the potential remains untapped. Enforcing manual waste sorting or recovery with the current state of mixed waste collected results in exposing workers to a toxic work environment [12]. Therefore the waste must be recovered before it reaches that stage. Previous studies have established that community participation is crucial in waste management because the generation and segregation of waste are directly related to people's actions [7]. Effective implementation calls for more inclusivity and higher participation in contrast to the very little involvement observed currently [6]. Some suggest economic incentives to ensure public participation in waste management processes [7].

In Bangalore, waste pickers from the Hasiru Dala, a cooperative for waste workers, recovered over 1050 tons/day of waste and saved Rs. 84 crores annually [9]. Multiple third-party organisations have had a large impact on waste recovery. However, their efforts are yet to be organised and acknowledged by the central authority, the government. A lack of accountability in the existing systems and a general lack of awareness on waste handling among citizens have already shown that sufficient effort hasn't been put into waste management. The different systems operating on waste management cannot act parallelly but need to be inclusive and cooperative. Processes and activities should be designed in such a way that effort and resources are shared between the formal and informal sectors [11]. The very little interaction between the stakeholders has decreased the trust among users and providers. This lack of communication between the administrators and stakeholders ensures that the highest potential of all the resources and the system is not reached. Integration of the informal sector with the formal sector will ensure a more efficient decentralised system. This will result in a fair and smooth division of labour and power being distributed among multiple parties instead of one [6].

Much of the research available has been conducted in developed countries due to the availability of source-segregated waste [12]. The same technology cannot be applied in India due to the heterogeneity of waste, the shortage of resources and data, and the reluctance to adopt new technologies [6][13]. The potential of collecting time and geography-specific data through solutions was reviewed and found to be useful to help understand the behavioural patterns of a community [14]. Literature was reviewed to understand the methodology in similar research (Table 1).

3. Methodology

A nine-step methodology (Figure 2) was derived and improved from the existing research reviewed. From the comparison (Table I), it was found that primary data collection is necessary for designing a product that aims to improve resident involvement in waste management processes. The frameworks reviewed citizen involvement, people-centred development and re-established the need to enhance the participation of all stakeholders. A conceptual framework for waste management was also studied. The proposed solutions ranged from smart bins to applications. They were also tested through surveys and pilot studies while AI models were tested for accuracy.

Table I. Review of existing literature.

Ref.	[15]	[16]	[6]	[17]
Data collection	Reviewing existing case studies and Online surveys	Extensive literature review but no primary data	Primary survey in the wards and selecting volunteers	Literature review and training images of waste
Framework	People-centred Development	Conceptual framework for Zero waste management	Citizen science or participatory science	No framework was considered for the study
Proposed solution	Smart bin with normative/emotional information	Conceptual framework for Zero waste Management	Public Affairs Centre Waste tracker for mapping issues in waste management	A bin equipped with sensors to sort waste with image classification
Testing	Surveys and comparison to other studies	The proposed solution was not tested	Data analysis from a pilot study conducted	The AI model used was tested for accuracy

Therefore, the design methodology (Figure 2) used in this paper is initiated by reviewing existing literature and solutions. A survey followed by interviews validated the context of the literature review. The results of these research methods were used to create a basic framework for a source segregation system. A system-based solution was built on this framework and it was conceptualised for the next step. The prototypes were tested and the final validated solution is presented in this paper.

Fig. 2. Methodology adopted for the paper.

3.1 Surveys and– Interviews

Preliminary primary research was conducted with the stakeholders to support the secondary research and validate other assumptions made about waste management processes. The stakeholders considered are: — a) Residents who generate the waste; b) BBMP workers and the informal sector workers who are in direct contact with the waste; c) Waste management companies and service providers who handle the waste; d) The Government that manages and oversees the overall process and e) Other contractors who aid the government at various stages. A survey was conducted to gain a broader understanding of the problem. Interviews, with a select few stakeholders, were conducted with a predefined set of questions. The collected secondary and primary data were analysed and a set of requirements was defined. These requirements were based on functionality, usability, reliability, safety and social context of the environment it will be used in. The framework and the ideations followed the requirement generation.

Fig. 3. Overfilled public bins at the site of the preliminary study.

3.2 Framework development and design

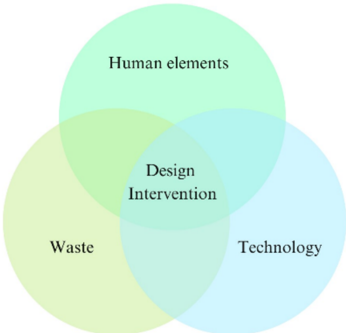

Fig. 4. System framework for designing solutions (Waste management).

A framework was designed to visualise the different elements of the system, the relationships between the elements, and their roles in aiding the waste management process. The proposed system considers the three main spheres: — a) Waste; b) Human elements; c) Technology. Similarly, the proposed solution consists of three major components. An application for residents to use and participate in the waste management processes. It is integrated with another version designed for authorities such as the BBMP and other waste management companies to communicate with residents and oversee the functions. There is a physical addition to the app, a smart bin to facilitate accurate data collection and automated waste sorting. The two users of the integrated application will be: — a) the residents who use the app to segregate waste and earn benefits for reduced waste generation and responsible management; b) Authorities who communicate with each other and track waste from its generation to transportation to disposal, intervene as required for reusing and recycling waste to minimise the disposal.

3.3 Product development

The generated requirements were used to define the features of the product. The brainstorming stage was followed by morphological analysis. The ideation phase resulted in five concepts. Among the ideations, one final concept was chosen. The concept consisted of a system of interventions. An intelligent application for residents and authorities to use and communicate with each other and a physical smart bin for segregating waste at the source.

3.4 Prototype development

A preliminary prototype of the system was made for visualising the design and testing it. Prototypes made were for: — a) a mobile application for residents; b) a smart self-segregating bin. The application user interface was prototyped on Figma and the AI model used for the app's major function, segregation through image classification, was prototyped separately. The preliminary AI model was trained on a Teachable Machine and tested with real-life images as proof of the concept. The physical prototype was assembled using the digital 3D model made as the reference. The prototype included a circuit for actuating the main functions of the product.

3.5 Testing and Confusion Matrix

The image classification model was validated through testing and its confusion matrix. With the values in the matrix, the accuracy, precision, recall, and F1 scores were calculated to evaluate the performance of the trained model.

4. Results

4.1 Insights from Surveys and Interviews

Preliminary research is initiated by a short survey conducted with 50 residents. It consisted of thirteen questions for understanding the living conditions, waste generation and segregation habits, storage, and disposal. The survey also collected information to assess the awareness and inclination towards participating in waste management. It was found that most of the stakeholders live in apartment complexes or gated communities. Therefore, most of them are required to separate their waste into dry and wet waste bins. 42% of the participants who segregated waste inside their homes noticed that they weren't collected separately for transportation. Beyond collection, 86% had no idea how the waste collected from their homes was handled. 16% of the participants were very confident that they were aware of the SWM guidelines in Bangalore and 68% had a very basic idea about it. 16% had never thought about it before. More than half of the participants stated that they would buy products that are not environmentally sustainable even if they were informed about the risks. However, more than 84% were ready to collect recyclables separately if a recycling agency was ready to take them from them (Figure 5). 80% of them had noticed waste being disposed of illegally but only 12% of them had done something about it. 68% had no idea what to do about it. They had simply observed that the reason was an existing pile of garbage that people added to and the lack of or overfilled public bins. They also felt that there were no consequences to illegal dumping which allowed people to litter without the fear of penalties. Overall, 86% of the participants believed that information about waste management was not easily accessible. Fifteen of the participants were chosen for a second round of detailed interviews on the same topics. Four of the interviews were conducted at a public site of preliminary study for better context (Figure 3).

A set of requirements and a problem statement were devised to create a framework for the solution. The paper aims to propose a solution that ensures source-level segregation of waste and connects all stakeholders to a highly functioning system of waste management.

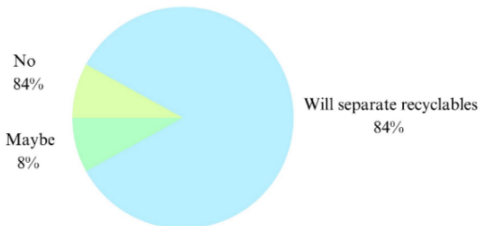

Fig. 5. Participants ready to collect recyclables separately

4.2. Framework development and design

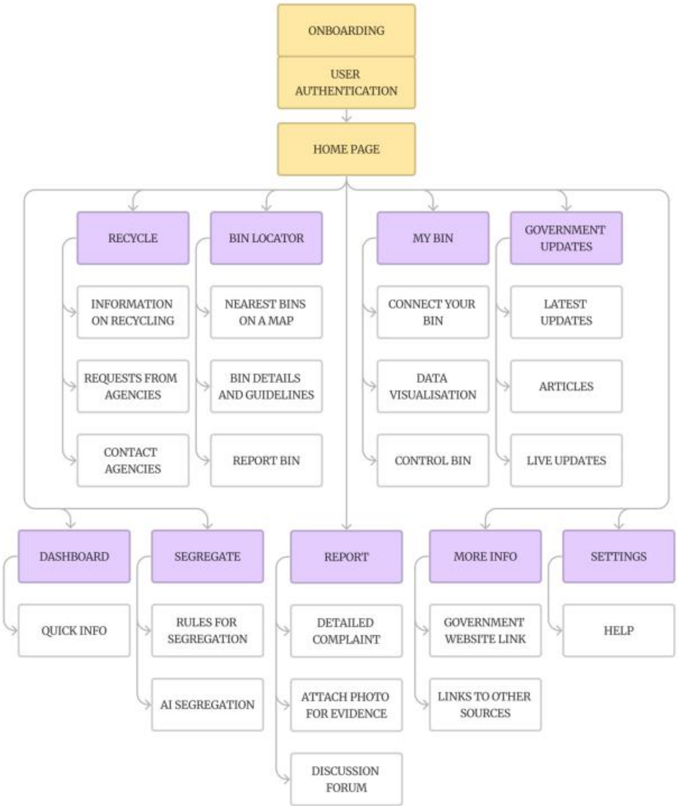

Fig. 6. Information architecture of the application.

A framework (Figure 4) of the system was laid down to comprehensively understand the elements and their functions to design more efficient interactions. The system is divided into three principal spheres: — a) Municipal solid waste; b) Humans; and c) Technology.

Municipal solid waste refers to the materials used and then discarded from sources such as houses, offices, educational institutions, hospitals, and other public spaces in urban or peri-urban areas. It can be further categorised into wet waste, dry waste, domestic hazardous waste, sanitary waste, and construction and demolition waste. In the waste cycle, waste is generated, segregated, collected, transported, treated, and recovered or disposed of. In an ideal circular system, waste is considered a resource after recovery and is a raw material for the creation of new goods. Waste is the subject of the system and variable that can be handled through design interventions. The second sphere includes all humans directly or indirectly interacting with waste. Humans are the primary creators of waste through various sources. As responsible generators, they ideally follow the rules of waste management and segregate waste at the source. Workers responsible for further segregation, collection, and transportation are considered for these functions too, due to their constant direct physical contact with waste. It is important to include the third parties and the informal sector who are also involved in the process to the same extent. Humans generating waste also bear the consequences of substandard waste management and are responsible for causing harm to other life forms and the environment. Therefore, in an ideal system, humans are responsible for designing interventions and implementing them to treat the waste they produce for recovery and if required, dispose of it responsibly with the help of the available resources and tools.

Technology is a necessary tool for constantly improving waste management processes and devising an ideal waste recovery cycle. Different stages of waste management require different tools and these tools must be frequently updated to keep up with the constantly increasing population, urbanisation, and waste generation. Humans find potential in existing technology and design innovative ways to use them as well as invest time and resources into updating them for better efficiency. Additionally, there is a significant need for inventing new methods of treating and recovering waste which has been segregated through the improved system to complete implementing the process of recovery. Therefore, integrating frequently updated technology and methodologies into design interventions allows for improved work conditions and efficiency and reduced impact on the environment.

The stakeholders and participants in the waste management processes are: - a) Waste producers- Residents; b) Principal processors and disposers- Government authorities (BBMP); c) Third party processors- Informal sector and Waste management companies. Their interactions and roles are thoroughly reviewed in a later section of this paper.

The relationship between waste and humans is defined by the processes of generation and handling. Waste and technology are related through the multiple resources and tools required for the enhancement of waste management processes. Humans and technology have a constantly evolving relationship and the lack of such a resource in human activities has caused irregularities and errors in the resulting outcomes. Therefore, the triangular relationship between the material, users, and tools must be considered before designing a solution. The gaps in their interactions have to be identified. Therefore, every solution derived from these gaps, lies within the triangle, utilising all three spheres to varying extents. The proposed solution considers the way waste is currently perceived by humans and attempts to change it. This is done by establishing waste as a resource for the next stage in a product cycle. The most important requirement to be able to treat waste is segregation. Mixed waste is much harder to treat and recover.

Therefore, source segregation ensures that all the waste produced is either treated and recovered or disposed of in the right manner. The second gap recognised is the age-old methods of waste management used without technology updates. The need to integrate new technology with waste management has only increased with the accelerated waste production in metropolitan cities. Human errors and neglect can be remedied by using technology. Segregation, which has been primarily done by humans, can be improved to a huge extent with the minimising of errors. This also decreases the amount of direct harmful contact with waste for most workers due to a lack of appropriate equipment and technology. The third gap shows multiple communities/organisations working towards the same goal without communication. By connecting them and involving the large mass of residents, a highly functioning system can be created for smooth waste management. Considering the abovementioned gaps, the solution also works as a system to tackle the multiple sides of the problem together through an integrated design intervention. It consists of both physical and digital aspects. An application is designed to connect multiple stakeholders and ensure consistency and communication. This paper chooses to elaborate on the version used by residents. This version focuses on ensuring source segregation through the smartphone's camera as well as a smart bin that can be connected to it. The other versions of the application add to the main function of source segregation and facilitate future stages of the waste management process through the authorities concerned.

4.3 Product development

The product designed is a solar-powered smart self-segregating bin. It is designed for both indoor and outdoor use. The public bins come in varying sizes. They segregate waste through a camera from inside the bin and actuated through a motor that separates the waste into separate compartments. The AI model is trained with dataset images taken specifically for the product for better accuracy. To avoid overfilling, the bin uses ultrasonic sensors to check the level of waste collected and informs authorities concerned when it must be emptied. The bins can be tracked with their GPS module through the application. The lid of the bin also has an IR sensor to open only when approached to reduce the permeation of bad odour and spillage. The product was designed considering the environment of the product. The product was closed on all sides with an opening only on the top and high enough to prevent street animals such as dogs cats and cows from eating or spreading the garbage. The weight of the metallic body keeps the bin from toppling in harsh weather conditions. The compartments can be opened for emptying through RFID tags and only by authorised workers to avoid misuse.

The application has six major functions. The most important function is waste segregation through image classification. The application uses the phone's camera as input for the tested image classification model to decide the category of waste. The user then segregates the waste according to the app in the absence of the smart bin. The app also provides a list of rules and regulations for segregation as issued by the government. The app connects users to third parties such as recycling agencies who need segregated waste. The waste that is not collected by BBMP can be saved and given to the agencies that offer incentives for the same. It locates the nearest public bin for the user and provides details and guidelines for disposal. Communication is made much easier with the application. The government authorities can communicate changes in schedule and new rules directly. The process is made to be as transparent as possible with access to live updates of how waste management processes are handled. In return, the residents also take up more responsibility to keep malpractice in check by reporting such incidents to the government. Such a network proves to be useful to cover large areas for supervision. The application can also be connected to the user's smart bin for control and data visualisation. The information architecture of the application is shown in (Figure 6).

4.4 Prototype development

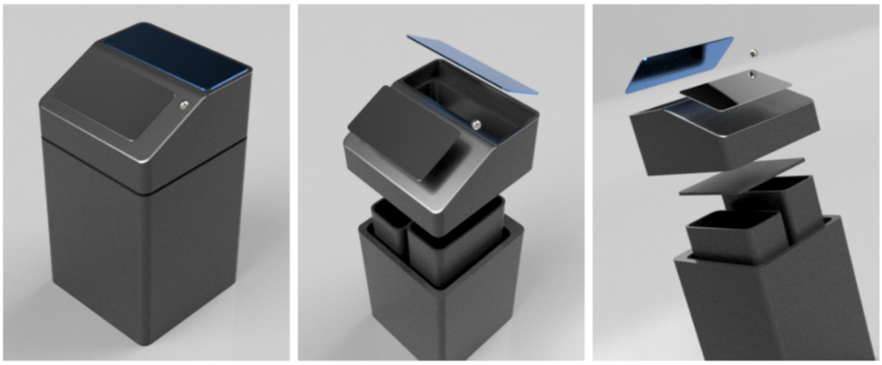

Fig. 7. Digital 3D renders of the smart bin.

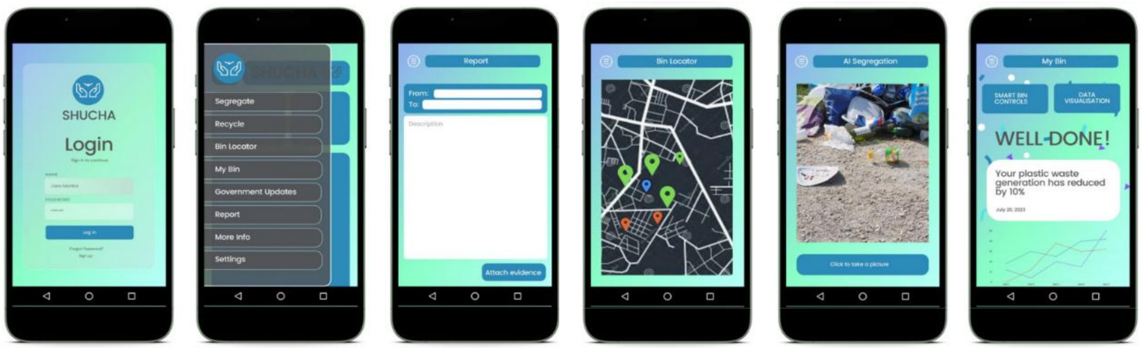

Fig. 8. User Interface of the application screens.

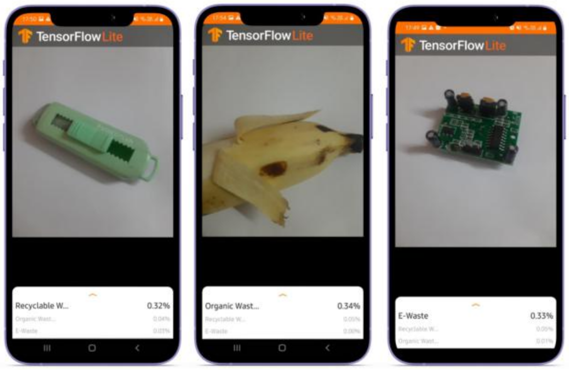

Fig. 9. TFLite Test App for Segregation.

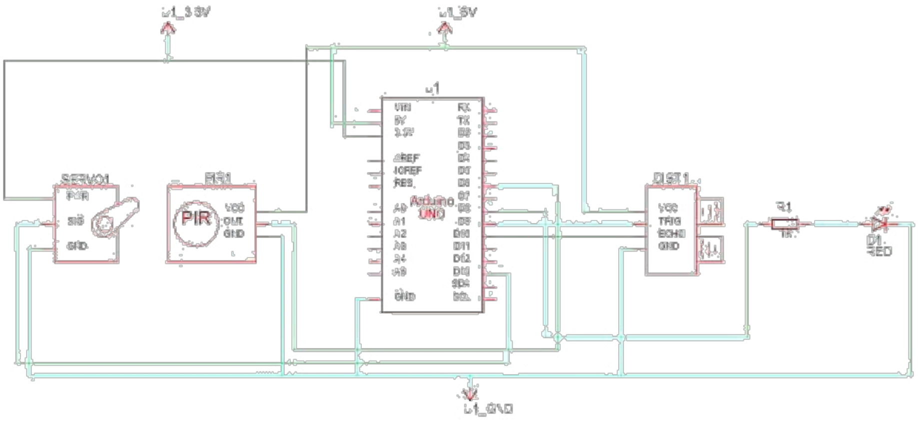

Fig. 10 Circuit used in the prototype

The application used by the residents can be uploaded on a smartphone for easy access to information and help related to waste segregation. The prototype of the application was made on Figma. The six main screens are shown in (Figure 8). The application uses the phone's camera for its image classification model and the built-in GPS module for mapping nearby bins for easy disposal. The image classification function of the application is prototyped separately through a TFLite test app. A preliminary AI model was trained on Teachable Machine using multiple datasets for three classes - Recyclable Waste, Organic Waste, and E-Waste. The model was validated through testing and its accuracy, precision, recall, and F1 scores. The validated model was used in the test application. The screens are shown in (Figure 9). A model of the product was made on 3D modelling software (Figure 7) before making the physical prototype. The prototype was also made physically and attached to the circuit to show four of its basic functions. This included the automatic opening of the lid, sensing the level of waste collected, informing when the capacity is nearly reached, and a motor for segregating into the right bin. The circuit has been included in (Figure 10).

4.5 Testing and Confusion Matrix

The trained image classification model was validated through testing. Random pictures outside the training dataset were used for this. The results are shown in (Figure 11). It was also validated through its confusion matrix (Figure 10) and by calculating the accuracy (1), precision (2), recall (3), and F-score (4) for each class (Table II).

The abovementioned values were calculated for the confusion matrix (Figure 12) obtained through Teachable Machine. The high values of average accuracy of 97.22% for the three classes and average precision of 95.8% validate the effectiveness of the image classification model. Therefore, a more specific dataset collected for the smart bin will produce results with higher accuracy and precision.

$$Accuracy = \frac{True\ Positives + True\ Negatives}{Total} \quad (1)$$

$$Precision = \frac{True\ Positives}{True\ Positives + False\ Positives} \quad (2)$$

$$Recall = \frac{True\ Positives}{True\ Positives + False\ Negatives} \quad (3)$$

$$F1\ Score = \frac{2 * Recall * Precision}{Recall + Precision} \quad (4)$$

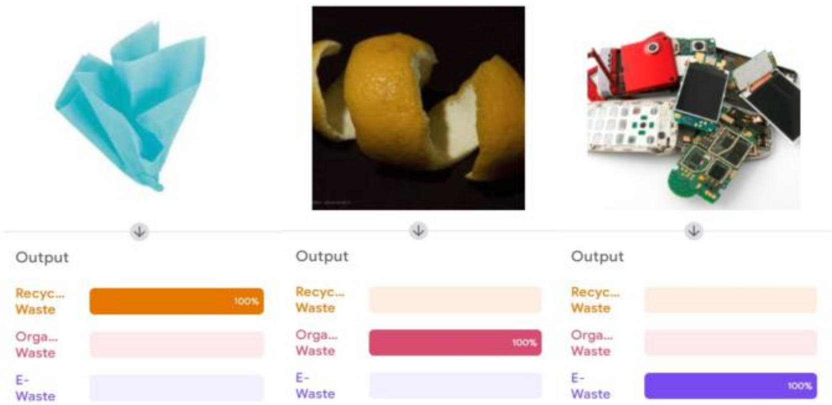

Fig. 11. Testing the image classification model.

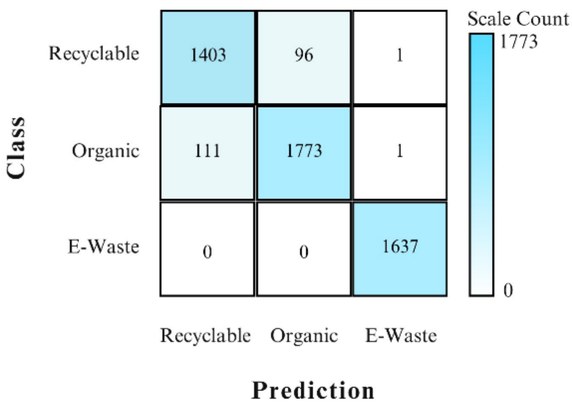

Fig. 12. Confusion matrix of the image classification model.

Table II. Performance of image classification mode.

Class	Accuracy	Precision	Recall	F1 Score
Recyclable Waste	0.95857	0.92668	0.93533	0.93099
Organic Waste	0.95858	0.94864	0.94058	0.95129
E-Waste	0.99960	0.99878	1.00000	0.99939

5. Discussion

5.1 Stakeholder analysis

The three main stakeholders and participants in the waste management processes are: — a) Waste producers-residents/owners; b) Main processors and disposers-Government authorities (BBMP); c) Third party processors-Informal sector and Waste management companies. The ideal relationships between these stakeholders were visualised through a diagram and their main functions were included.

The producers include all the residents of an area and every community they are a part of and produce waste through. The major functions include producing waste, following the right waste management processes, forming a database by constantly tracking illegal waste practices around them, communicating the same with authorities involved, receiving information from the authorities, communicating with third parties for recycling as required, and earning benefits/receiving incentives for extra efforts towards sustainable waste management. The Government authorities i.e. BBMP include officials working in the waste management sector and especially the workers involved in the collection and transportation of waste. Their major functions include communicating information directly to residents and updating data on website/applications, receiving information on illegal practices from residents and taking action, ensuring smooth and regular collection and segregation at source, avoiding overfilling of bins and trucks, communicating with third parties, acknowledging and organising the informal sector, providing incentives and benefits for extra efforts and allowing for proper recycling and recovery practices through third parties and development of technology for the existing plants. The third parties and the informal sector function in between the other two stakeholders. They communicate with the government authorities and provide an alternative to disposing of the waste directly without recovery, provide a helping hand to the understaffed BBMP sector that collects and clears waste from the city, receive compensation for the work, provide services to residents willing to aid the collection of recyclable materials and compensate them and give a new life to the recycled materials and receive a steady source of income through them. These measures prove effective in reducing the burden on the BBMP waste sector workers. They will be aided by residents, informal sector workers, and organisations with similar goals. This ensures employment to a large group of people and successfully improves the efficiency with which waste is handled and converts it into a resource to be sought after.

5.2 Implementation

The implementation of the proposed waste management solution should first be conducted in a controlled, smaller-scale environment initially. This allows for thorough testing and optimisation before full-scale deployment. Utilising artificial intelligence, areas with the highest necessity for these bins can be identified. Such an approach can be presented to the BBMP, providing them access to comprehensive data for efficient waste management, waste-to-energy initiatives, and reduced waste disposal. The application is then introduced to multiple waste management organisations, for collaborating and collecting specific waste types directly from the bins for treatment and recovery. This creates a way for residents to interact with public bins and receive vital information from authorities, like the BBMP.

5.3 Costing and Specifications

The cost of the product is calculated through the prototype. The cost for preliminary implementation was calculated from the individual prices of the components used in the prototype (Table 3). The product cost is estimated to be one-third the cost of the prototype. The total amounts to $12.45, that is, ₹1035.56 in Indian Rupee.

Table 3. Components, specifications and cost.

S.No.	Component	Specification	Cost
1.	Arduino UNO	ATmega328P	$2.68
2.	Solar Panel	5V	$2.68
3.	DFRobot Solar Power Manager	5V	$7.93
4.	Lithium Battery	3.7V	$2.80
5.	Ultrasonic Sensor	US-100	$2.44
6.	AC-DC power adapter	6-12 volt, >600mA	$4.88
7.	TFT display	Unique TFT shield	$4.88
8.	Camera	OV7670	$3.90
9.	Bluetooth module	HC-06	$2.44
10.	IR Sensor	2-10cm	$0.28
11.	Servo Motor (x2)	SG90	$1.10
12.	RFID Module	RC522	$1.34
14.	TOTAL	Prototype	$37.35
15.	TOTAL	Product(approx.)	$12.45

5.4 Business model

A hybrid business model, which allows for several revenue streams and varied tactics, is chosen for the product. Awareness about the product is increased through usage in public spaces. The application is introduced to users who find an easier way to communicate with authorities and regulate their own waste generation and segregation habits. The revenue stream will be balanced for the costs incurred through sales of the product, smart bin, to house owners, educational institutions, businesses, hospitals and other spaces. The data collected by the products all over the city can be monetised and shared with third parties working towards waste management. Partnerships with third parties and contractors allow for a joint effort for waste management and also share revenue.

5.5 Opportunities for growth

The framework includes the entire population of a metropolitan city and considers huge bodies such as the government, multiple organisations, and communities of workers as major stakeholders. Achieving this goal, after small-scale implementation, leads to expanding the project to a nationwide scale. With more resources, the products can be improved to reduce the cost of manufacture and make them more accessible. India needs resources and technical expertise to deal with the MSW. The newly organised system provides for a large number of individuals by ensuring employment and safe working conditions. Acknowledging the informal sector encourages the creation of start-ups and highly driven individuals to increase the percentage of waste recovered through innovative methods. However, it is important to acknowledge the limitations. The success of the system depends on active participation and cooperation from residents and waste management organisations. Adoption rates and the willingness of residents to segregate waste must be carefully monitored. Additionally, the smart bins need to undergo rigorous testing to evaluate their performance in various conditions, such as different waste types, and weather conditions.

6. Conclusion

The proposed intelligent waste management system, which consists of smart self-segregating bins and an integrated application, provides a holistic solution to addressing waste segregation and collection problems. The research highlights the critical need for efficient waste recovery and sustainable waste management in the context of unsegregated waste and disorganised efforts. The system bridges the gap between citizens, waste management agencies, and the informal sector. A more inclusive and cooperative waste management system is established by encouraging community participation and utilising technology. The successful implementation of this solution has the potential to revolutionise waste management practices, minimise waste generation, and harness waste as a valuable resource, opening new avenues for employment, sustainability, and cleaner, more energy-efficient cities. To ensure its success, rigorous testing, continuous monitoring, and collaboration with key stakeholders are essential.

References

[1] Ramachandra, T. V., H. A. Bharath, Gouri Kulkarni, and Sun Sheng Han. (2018) "Municipal solid waste: Generation, composition and GHG emissions in Bangalore, India." *Renewable and Sustainable Energy Reviews* **82**: 1122-1136.

[2] Bruhat Bengaluru Mahanagara Palike (2022) "Types of Waste" https://site.bbmp.gov.in/departmentwebsites/swm/ : (accessed October 2023)

[3] Naveen, B. P. (2021) "Scenarios of waste management nexus in Bangalore." *Energy Nexus* **1**: 100004.

[4] Ganesan, Srividhya, Akuluru Sai Lohith, and Shashank Poola Ashok. (2022) "Stratification Of Garbage Using Deep Learning." *Journal of Pharmaceutical Negative Results*: 1763-1766.

[5] Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. (2018) *What a waste 2.0: a global snapshot of solid waste management to 2050*. World Bank Publications.

[6] Nagendra, Bhargavi, Arvind Lakshmisha, and Priyanka Agarwal. (2019) "Mobile application in municipal waste tracking: a pilot study of "PAC waste tracker" in Bangalore city, India." *Journal of Material Cycles and Waste Management* **21(3)**: 705-712.

[7] Izquierdo-Horna, Luis, Miker Damazo, and Deyvis Yanayaco. (2022) "Identification of urban sectors prone to solid waste accumulation: A machine learning approach based on social indicators." *Computers, Environment and Urban Systems* **96**: 101834.

[8] Ye, Qing, Qasim Umer, Rongting Zhou, Amna Asmi, and Fahad Asmi. (2023) "How publications and patents are contributing to the development of municipal solid waste management: Viewing the UN Sustainable Development Goals as ground zero." *Journal of Environmental Management* **325**: 116496.

[9] Kumar, Akhilesh, and Avlokita Agrawal. (2020) "Recent trends in solid waste management status, challenges, and potential for the future Indian cities–A review." *Current Research in Environmental Sustainability* **2**: 100011.

[10] Ramachandra, T. V., and Shruthi Bachamanda. (2007) "Environmental audit of municipal solid waste management." *International Journal of Environmental Technology and Management* **7(3-4)**: 369-391.

[11] Linzner, Roland, and Ulrike Lange. "Role and size of informal sector in waste management–a review." In *Proceedings of the Institution of Civil Engineers-waste and resource management*, vol. 166, no. 2, pp. 69-83. ICE Publishing, 2013.

[12] Gundupalli, Sathish Paulraj, Subrata Hait, and Atul Thakur. (2017) "A review on automated sorting of source-separated municipal solid waste for recycling." *Waste management* **60**: 56-74.

[13] Malav, Lal Chand, Krishna Kumar Yadav, Neha Gupta, Sandeep Kumar, Gulshan Kumar Sharma, Santhana Krishnan, Shahabaldin Rezania et al. (2020) "A review on municipal solid waste as a renewable source for waste-to-energy project in India: Current practices, challenges, and future opportunities." *Journal of Cleaner Production* **277**: 123227.

[14] Esmaeilian, Behzad, Ben Wang, Kemper Lewis, Fabio Duarte, Carlo Ratti, and Sara Behdad. (2018) "The future of waste management in smart and sustainable cities: A review and concept paper." *Waste management* **81**: 177-195.

[15] Guna, Jože, Katarina Polajnar Horvat, and Dan Podjed. (2022) "People-centred development of a smart waste bin." *Sensors* **22(3)**: 1288.

[16] Ahmed, F., S. Hasan, M. S. Rana, and N. Sharmin. (2023) "A conceptual framework for zero waste management in Bangladesh." *International Journal of Environmental Science and Technology* **20(2)**: 1887-1904.

[17] Pamintuan, Miko, Shiela Mae Mantiquilla, Hillary Reyes, and Mary Jane Samonte. (2019) "i-BIN: An intelligent trash bin for automatic waste segregation and monitoring system." In *2019 IEEE 11th international conference on humanoid, nanotechnology, information technology, communication and control, environment, and management (HNICEM)*: 1-5.