Research Article

Design and Evaluation of a Smart Trash Bin for Automated Waste Segregation and Sustainable Management at CTU-Main Campus

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Abstract: This study explores the design, development, and evaluation of a Smart Trash Bin (STB) that automatically segregates wastes in three different categories (1. Dry, 2. Wet, 3. Metal) to address the growing issue in traditional waste disposal practices. Based on the sustainability frameworks and the need for technological innovation in waste management, this project integrates the sensor and motorized mechanisms to classify wastes into dry, wet, and metal categories. Using a quasi-experimental design, the STB prototype was made of an inductive, infrared, and moisture sensor that is connected to an Arduino-based control system, then it was tested through technical trials and user-based evaluation involving 157 respondents at Cebu Technological University-Main Campus. The results showed high sorting accuracy with weighted means of 4.43 for the dry waste, 4.39 for wet waste, and 4.21 in metal waste, all interpreted as highly effective. Compared with existing bins in the campus, the STB showed better efficiency and helps reduce human error, while respondents rated its performance, usability, and design as effective (overall mean = 4.10). Recommendations highlighted increasing bin capacity, enhancing feedback features, and putting solar power. In summary, the results indicate that the STB is a practical and scalable solution that supports sustainable waste management if it is implemented in educational and public spaces.

Keywords: smart trash bin (STB); automated waste segregation; Arduino technology; sensor-based system

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1. Introduction

The rapid advancement of technology has opened up new approaches for addressing the urgent environmental and waste management challenges. As the cities strive for sustainable urban development, the integration of smart technologies in everyday utilities are becoming increasingly important (Nyokum & Tamut, 2025). Traditional waste management methods often are insufficient, leading to significant challenges, including contamination of recyclable materials, increased landfill use, and also high environmental damage. The need for efficient waste segregation and management is established by studies that highlight inefficiencies in current practices and the incorporation of technological advancements (Pires et al., 2011). The integration of technology into waste management practices presents an opportunity to increase efficiency and effectiveness.

The design of the Smart Trash Bin (STB) reduces the probability of contamination of wastes and ensures that the recyclables are processed appropriately that aligns with the importance of performance measurement tools in optimizing waste management systems (Zaman & Lehmann, 2013). It automatically detects and classifies waste into three categories: dry, wet, and metal, using sensor technologies. Furthermore, the STB features a user-friendly interface designed to educate the public on proper waste disposal practices, as public engagement in waste management initiatives can significantly enhance the overall effectiveness and compliance with sustainable practices (Cuizon, 2025).

The inclusion of technology to address the current issues of garbage disposal presents an opportunity by making use of smart sensors to automate the waste segregation. The development of smart waste management solutions is essential to address the diverse and changing nature of waste in the environment (Elechi et al., 2021). The system is tested for its efficiency in improving waste segregation and its impact on promoting sustainable waste management practices, particularly within the context of the current waste management system at Cebu Technological University (CTU)-Main Campus, Philippines. It began by identifying the critical needs in proper waste disposal, which guide the conceptualization of the features of STB. As the management of waste is becoming more complex due to the increasing variety of materials, many of them require specific handling and processing methods, making it crucial to accurately identify and sort the wastes by hand (Hariyani et al., 2025).

Despite the promising prototypes, a gap remains in evaluating the long-term user acceptance and operational reliability of the STB, especially in busy public parks and schools where humidity can affect the sensors (Zoumpoulis et al., 2024). This study aims to address these gaps by evaluating the performance and user acceptance of a prototype STB utilised in the CTU-Main Campus for over two weeks. The objectives of this study were achieved based off from the following questions:

1. What are the technical requirements used in terms of materials and technologies for the development of STB?
2. How effective does it accurately segregate wastes into dry, wet, and metal categories during the field test?
3. How is the performance of the STB compared to the current management system at CTU-Main Campus?
4. What is the level of acceptability of the STB in terms of performance, features, usability, and aesthetics?

With these questions it underlines the importance of the study in bridging technological innovation along with the practical demands of public waste management. By exploring how the STB influences disposal behavior, manages the waste volume, and improves the sorting practices, the study sheds light on the effectiveness of automated waste systems in everyday settings. The findings gained from these are expected to support the evidence-based improvements in smart technologies and contribute to more broad efforts towards a cleaner, more organized, and sustainable community

2. Materials and Methods

The study focuses on the design, development, and evaluation of the STB, an automated waste segregation system. The STB was constructed using Arduino Uno R3 microcontroller to control the system's sensors and motors, enabling the automated segregation of waste. The sorting mechanism was powered by a servo motor to control the lid and sorting compartments, while a stepper motor rotated the sorting platform, directing waste into designated compartments. The STB employs three key sensors: an inductive proximity sensor to detect metallic waste, a raindrop sensor to identify wet waste, and an infrared sensor to detect waste presence for sorting. The system also includes plastic containers for segregating the waste into dry, wet, and metal categories. Polycarbonate sheets were used for the bin's exterior to allow visibility of the internal components. Other structural components, such as PVC pipes and fittings, directed waste into the correct compartments. Electrical connections between the sensors, motors, and Arduino board were made using wires and jumper cables, with a breadboard used during the initial testing phase. The system was powered using 3.7V rechargeable batteries, ensuring portability and efficiency.

The STB was developed through a step-by-step process. First, the housing was constructed using plywood, providing structural support, while polycarbonate sheets enabled visibility of the internal workings. The sensors were strategically placed to optimize waste detection. The inductive sensor detected metallic waste, the raindrop sensor identified wet waste, and the infrared sensor confirmed waste presence. The stepper motor rotated the sorting platform to direct waste into the appropriate bin, and the servo motor controlled the sorting lid. Electrical wiring was connected to a breadboard, ensuring proper integration of components. The system was powered by 3.7V batteries, making it portable and self-contained.

2.1. Assembly Process

The assembly procedure of the STB began by gathering all the necessary materials and equipment. The first step was cutting and aligning the wood to form the bin's housing. Once the wooden pieces were securely nailed into place, we moved on to the internal setup. We created a section in the housing to securely hold all the electronics, including the Arduino board and sensors. The wiring was connected, and motors were installed to control the sorting mechanism. The sorting platform, made of PVC pipes, was positioned to direct the waste into designated bins for dry, wet, and metal materials. Finally, we attached the polycarbonate sheet for the lid, which not only allows visibility of the components but also adds to the bin's aesthetic appeal. After securing everything in place, the STB was ready for testing and use. The compact design ensures everything is neatly organized, while the system is fully functional for waste segregation.

2.2. Electronics Configuration

Figure 1 shows circuit diagram of the STB. It proves that the electronics components play a vital role in the operation of the STB. A system layout allows the sensors and motors to function efficiently and accurately. This section discusses the overall functions of the electronic components, focusing on their placement, connection to the main board, and the wiring arrangement that supports the system's performance, effectiveness, and accuracy.

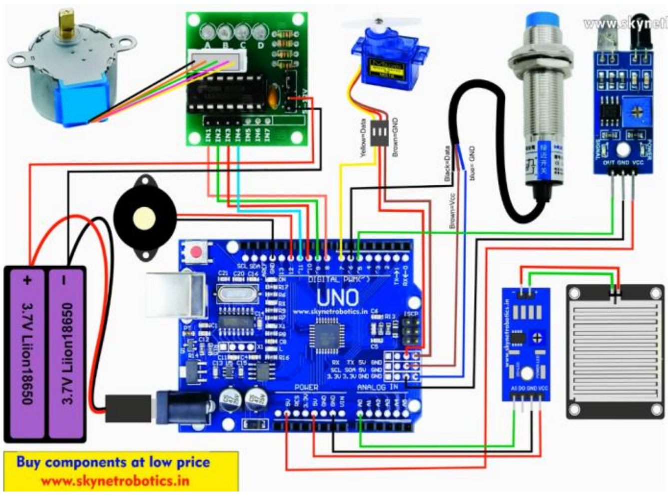

Figure 1. Circuit diagram of the STB.

The functionality of the STB relies on the proper installation and integration of its electronic components. This section presents the configuration of these components, with all components connected to the main board, which serves as the central control unit of the system. The components were put in their designated positions for easy reach maintenance, to ensure stable voltage regulation, accurate signal transmission and synchronized interaction among the sensors and motors. The wiring layout was organized to prevent tangled or overlapping circuits, avoid loose connections, and enhance overall system reliability.

The main board (Arduino Uno R3) is responsible for coordinating the operation of the sensors and motors, ensuring that each component performs its designated function accurately and efficiently. The stepper motor provides rotational alignment to properly position the trash compartment, allowing the waste to be directed into the appropriate section. The servo motor, which is also connected to the main board, controls the opening and closing of the lid through rotational movement. The inductive sensor and raindrop sensor are used to detect metallic and wet waste, respectively, enabling proper waste segregation. The infrared sensor detects the presence of waste, while the battery supplies power to the system. The mini speaker produces a beep sound whenever waste is detected, providing user feedback.

The STB is equipped with 10 electronic components in total. The configuration process takes time, especially due to the complexity of the pins and the need for wire extensions, as some wires were too short. Each component has a unique function and cannot work if other electronics are detached. The entire system operates on 7.4V using a 3.7V battery. Additionally, a breadboard is included to provide extended 5V and GND ports, ensuring better organization and preventing confusion during the wiring process.

2.3. Technology Utilized

The technology used in this project is the automated mechanism that stands as the main performer to separate the trash into different containers which are dry, wet, and metal. A set of sensors first identifies the type of waste, and then a motorized sorting platform directs the trash into the appropriate container through controlled rotational movements. Table 1 presents the main components used to operate the STB.

Table 1. Technology utilized in the STB.

Components	Function/Description	
Inductive sensor	Detects metallic objects with an approximate (0.25cm) clearance required to activate. This is used to identify metal waste.	
Raindrop sensor	Activates upon direct contact with liquid or moisture, allowing the system to detect wet waste.	
Infrared (IR) sensor	Provides object detection at around (1cm) from the sensor, confirming the presence of trash before the sorting process begins.	
Servo motor	Performs a 180° rotation to open or tilt the gate/flap, allowing the detected trash to drop onto the sorting platform.	
Stepper motor	Controls the rotational position of the sorting platform, with specific angles assigned to each waste type.	
	Dry waste	The platform remains at 0° (no rotation); the trash falls into the dry waste compartment in its default position.
	Metal waste	The platform rotates 240° clockwise toward the metal bin opening to discharge the trash, and then rotates 240° counterclockwise back to return to its original position.
	Wet waste	The platform rotates 120° clockwise toward the wet bin opening to discharge the trash, and then rotates 120° counterclockwise back to return to the starting position.

Overall, the technology utilized in the STB components demonstrates automated waste sorting systems. By combining inductive, raindrop, and infrared sensors for accurate waste identification with servo and stepper motors for controlled mechanical movement, the system effectively categorizes and separates trash into dry, wet, and metal compartments. The assigned rotation angles for each type of waste help the trash fall into the correct compartment. This reduces the need for human assistance and makes waste segregation easier. By combining sensors and motors, the STB works efficiently and helps promote proper waste management in a simple and effective way.

3. Results

The data gathered are from 157 respondents from CTU-Main Campus who tested the STB for automated waste segregation. The data includes their evaluation on the product's usability, accuracy in waste segregation, and sustainability (Table 2).

Table 2. Respondents' data.

Category	Frequency	Percentage (%)
Gender		
Male	76	48.4%
Female	73	46.5%
Age		
18-20	17	10.8%
21-25	140	89.2%

The respondent's profile presents the demographic distribution of 157 respondents who participated in the evaluation of the STB. The majority of respondents were the age of 21-25 years old (89.2%), while the 10.8% were the age of 18-20 years old. In terms of gender, 48.4% were male, 46.5% were female, and 5.1% preferred to not disclose their gender. The relatively balanced gender representation and concentration within the university age range indicated that the sample appropriately represents the campus population.

3.1. Effectiveness of the STB in Waste Segregation

The STB was evaluated by 157 respondents to determine its accuracy in segregating wastes (dry, wet, metal). The results showed high accuracy in all categories. The weighted mean in segregating the dry waste was 4.43, 4.39 for wet waste, and 4.31 for metal waste. All of the three categories were interpreted as effective (table 3).

Table 3. STB effectiveness.

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted mean	Interpretation
The STB correctly segregates dry waste.	1	0	6	74	76	4.43	Highly effective
The STB correctly segregates wet waste.	0	0	14	68	75	4.39	Highly effective
The STB correctly segregates metal waste.	0	4	24	64	65	4.21	Highly effective
The bin responds quickly when I dispose of waste.	0	0	22	102	33	4.07	Effective
The bin functions accurately in real-world use (field test).	0	3	24	91	39	4.06	Effective

The table above shows the effectiveness ratings of the STB in segregating dry, wet, and metal waste. The weighted means were 4.43 for dry waste, 4.39 for wet waste, and 4.21 for metal waste, which were all interpreted as highly effective. These findings indicated that the sensor-based detection system performed consistently during field testing.

3.2. Effectiveness of the STB in Waste Segregation

This section analyzes how the STB compares to the existing waste management practices at CTU-Main Campus (table 4). It indicates that the automated system reduced errors in waste segregation and was more effective in organizing dry, wet, and metal waste.

Table 4. STB comparison to existing waste disposal at CTU-Main Campus.

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted mean	Interpretation
The STB is more effective than the current campus bins.	0	0	30	93	34	4.01	Effective
The STB helps reduce human error in waste segregation.	0	0	21	94	42	4.13	Effective

The table shows the results of the evaluation of the STB functionality and effectiveness compared to the traditional waste disposal system at CTU-Main Campus. The respondents rated the STB as more effective than the current campus trash bins, with its weighted mean being 4.01, and its effectiveness in reducing human error at 4.13 weighted mean. The overall weighted mean of 4.07 indicated that the STB provides a more systematic and reliable waste segregation, improving the waste classification accuracy and reducing the reliance on manual sorting.

3.3. User Acceptability of the STB

Based on the results, the STB was rated as effective by respondents at CTU-Main Campus. Overall, the total weighted mean of 4.10 indicates that the STB is effective, practical, and respondents are satisfied with its performance, features, usability, and aesthetics.

Table 5. STB acceptability.

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted mean	Interpretation
Overall performance of the STB is satisfactory.	0	1	23	101	32	4.04	Effective
The features (sensors, indicators, compartments) are useful.	0	2	20	98	37	4.08	Effective
The STB is easy to understand and use.	0	0	17	92	48	4.20	Effective
The design and appearance of the STB are acceptable.	0	2	25	88	42	4.08	Effective

Table 5 presents the acceptability ratings of the STB in terms of performance, features, usability, and aesthetics. The weighted means ranged from 4.04 to 4.20, which all interpreted as effective; the response saying "ease of use" received the highest rating, being 4.20, which indicated as user-friendly and intuitive according to the respondents.

3.3. Recommendations for Future Improvements

Of the open-ended suggestions, the most common theme was increasing the bin capacity, followed by sensor and feedback features, and solar power / energy efficiency. Other respondents provided ideas on display, waterproofing, compartments, and design, while 137 respondents did not have any specific suggestions. This provided important inputs for the future development and scalability of the project

Table 6. STB respondents' suggestions.

Category	Responses	Frequency
Increase bin size / Capacity	"Bigger bins" / "Much larger trash bin" / "Trash bins inside should be bigger" / "Make the trash bin bigger"	7
Solar power / Energy	"Solar powered smart bin" / "Could use solar panels" / "solar"	3
Sensors & feedback / Lights	"Use lights for each waste category" / "Add color lights for each waste" / "Include a voice that says 'Thank you for recycling!'"	4
Display / Information	"Add small screen to show total weight of trash" / "Should show remaining battery level"	2
Additional compartments / Materials	"Have another bin for glass"	1
Waterproof / Durability	"The smart trash bin should be waterproof"	1
Design / Aesthetics	"Design the trash bin with rounder corners" / "Put pictures or writings of what not to throw in the trash bin"	2
No suggestions	"None" / "nothing" / "No comment"	137

Table 6 summarized the respondent's suggestions for improvement. The most frequent recommendation was to increase the bin capacity (7 total responses), followed by enhancements in its sensors and feedback mechanisms (4 total responses), and the integration of solar power (3 total responses). Other suggestions included improved display systems, waterproofing, and additional compartments.

In the recommendation rating, most respondents recommended installing the STB at CTU-Main Campus, which received a weighted mean of 4.51. This confirms that the feedback on using the automated bin to make the campus cleaner and more organized was positive.

Table 7. Respondents' recommendation.

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted mean	Interpretation
I recommend that CTU installs STB on campus	0	2	14	43	98	4.51	Highly effective

Table 7 presents the results of the overall evaluation of the STB, where the respondents strongly recommend the installation of the STB on campus which is interpreted as highly effective.

4. Discussion and Conclusions

The present study found that the STB improved the waste disposal efficiency and reduced direct contact with the garbage bin surface. This finding is consistent with the previous research on smart waste management systems. The sensor-based trash bins significantly enhance operational efficiency by reducing the overflow of waste and improving the monitoring (Vishnu et al., 2022). Similarly, the smart waste systems increased the reliability and promoted systematic waste handling (Abdullahi et al., 2024). The similarity between these findings and the present study may be attributed to the integration of motion sensors and automated lid mechanisms, which streamline the disposal process. By eliminating manual lifting of lids and reducing unnecessary contact, smart bins create a more efficient and user-friendly experience. While many previous studies focused on large-scale municipal systems, the present study contributes localized evidence demonstrating that similar benefits can also be observed within a campus-based setting.

The high acceptability ratings observed in this study align with established theories of technology adoption, particularly the Technology Acceptance Model, which emphasizes perceived usefulness and perceived ease of use as key determinants of user acceptance. Previous studies similarly found that smart devices are more readily adopted when users perceive them as convenient and beneficial (Longo et al., 2021). In the present study, respondents rated the STB highly in terms of usability and convenience, suggesting that the system successfully met both functional and psychological acceptance factors. These findings are consistent which demonstrated that intuitive design significantly increases user satisfaction in smart campus technologies. Furthermore, automated public systems tend to receive higher approval ratings in environments where users are already familiar with digital technologies, such as educational institutions.

The strong positive ratings regarding sanitation and hygiene indicate that respondents perceived the STB as contributing to a cleaner and safer campus environment. This finding emphasized that touchless waste disposal systems reduce contamination risks and promote hygienic practices in public spaces. Automated lid mechanisms eliminate the need for direct contact, thereby reducing potential transmission of bacteria and viruses. Sensor-based waste bins significantly improve public hygiene standards, particularly in high-traffic environments (Ajwang et al., 2020). The present study reinforces these findings within the context of an academic institution, suggesting that smart waste technologies may serve as supportive tools in maintaining sanitation compliance.

This research was conducted in fulfillment of the academic requirements for the Bachelor of Science in Technology Management program at CTU-Main Campus. All the research and findings provided are objective and just. No personal or financial influences were involved, this means that the study was carried out in accordance with ethical standards and academic integrity, and the conclusion is trusted to be exact and clean data.

The findings of this study have both theoretical and practical implications. Theoretically, the results support technology adoption frameworks by demonstrating that perceived usefulness, hygiene benefits, and ease of use significantly influence acceptance of smart waste management systems. The positive evaluation strengthens existing literature on IoT-based public facility innovations. Practically, the study suggests that campus administrators and institutional planners may consider integrating STB as part of sanitation improvement and sustainability initiatives. Given the favorable user feedback, implementation in similar academic environments may be feasible and beneficial. The system's relatively simple design further indicates potential scalability for broader institutional deployment.

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Conflicts of Interest: In conducting this study, the researchers declare that there are no conflicts of interest.

References

Abdullahi, A., Mohammed, A., Bonet, M. U., El-Suleiman, A., Ahmad, R. B., & Chollom, T. D. (2024). Development of a Smart Waste Management System with Automatic Bin Lid Control for Smart City Environment. *EAI Endorsed Transactions on Smart Cities, 7*(3). https://doi.org/10.4108/eetsc.4385

Ajwang, S., Abila, J., & Tejero-Dakay, I. (2020). Adoption Conceptual Model for Intelligent Waste Management in Smart Cities: Theoretical Review. *International Journal Of Computing Sciences Research, 5*, 426-440. DOI: 10.25147/ijcsr.2017.001.1.50

Cuizon, C. B. D. (2025). *Pathways for Waste Management Sustainability: The Case of Cebu City.* Center for Integrative and Development Studies, University of the Philippines.

Elechi, P., Orike, S., & Ogonda Igbudu, A. (2021). Development of an Improved Solid Waste Collection System using Smart Sensors. *World Journal of Electrical and Electronic Engineering, 1*(1), 51-65. https://doi.org/10.31586/wjeee.2021.151

Hariyani, D., Hariyani, P., Mishra, S., & Sharma, M. K. (2025). A literature review on waste management treatment and control techniques. *Sustainable Futures, 9*, 100728. https://doi.org/10.1016/j.sftr.2025.100728

Longo, E., Sahin, F. A., Redondi, A. E. C., Bolzan, P., Bianchini, M., & Maffei, S. (2021). A 5G-Enabled Smart Waste Management System for University Campus. *Sensors, 21*(24), 8278. https://doi.org/10.3390/s21248278

Nyokum, T., & Tamut, Y. (2025). Sustainable Urban Infrastructure Development: Integrating Smart Technologies for Resilient and Green Cities. *SSRG International Journal of Civil Engineering, 12*(4), 18-36. https://doi.org/10.14445/23488352/IJCE-V12I4P103

Pires, A., Martinho, G., & Chang, N. (2011). Solid waste management in European countries: A review of systems analysis techniques. *Journal of Environmental Management, 92*(4), 1033-1050. https://doi.org/10.1016/j.jenvman.2010.11.024

Vishnu, S., Ramson, S. R. J., Rukmini, M. S. S., & Abu-Mahfouz, A. M. (2022). Sensor-Based Solid Waste Handling Systems: A Survey. *Sensors, 22*(6), 2340. https://doi.org/10.3390/s22062340

Zaman, A. U., & Lehmann, S. (2013). The zero waste index: A performance measurement tool for waste management systems in a 'zero waste city'. *Journal of Cleaner Production, 50*, 123-132. https://doi.org/10.1016/j.jclepro.2012.11.041

Zoumpoulis, P., Konstantinidis, F. K., Tsimiklis, G., & Amditis, A. (2024). Smart bins for enhanced resource recovery and sustainable urban waste practices in smart cities: A systematic literature review. *Cities, 152*, 105150. https://doi.org/10.1016/j.cities.2024.105150