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JOURNAL FOR THE ADVANCEMENT OF SUSTAINABLE DEVELOPMENT GOALS
Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 412-425
AN INTERNATIONAL, PEER-REVIEWED, OPEN ACCESS JOURNAL
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# ECO-SMART BIN: AN IoT-ENABLED GARBAGE SORTING SYSTEM WITH AUTOMATIC WASTE SEGREGATION FOR A PHILIPPINE HIGHER EDUCATION CAMPUS

**Jestony S. Alvarez**
IT Instructor
REH Montessori College, Inc.
Talavera, Nueva Ecija, Philippines
Email: alvarezjestony0@gmail.com

**Abstract**

This study developed and evaluated the Eco-Smart Bin, an Internet of Things (IoT)-enabled garbage sorting system designed to automate waste segregation at REH Montessori College, Philippines. Using a developmental research design guided by the Agile Model (Conception, Inception, Iteration, Release, and Maintenance), the researcher built a Raspberry Pi-based prototype that used camera-based waste detection, machine learning classification, and an automated conveyor-and-sorting mechanism to direct waste into biodegradable, recyclable, and non-recyclable bins. The system was evaluated by ten (10) IT experts using the ISO/IEC 25010 Software Product Quality Standards across eight quality characteristics, and by end-users (students, teachers, and staff) using selected ISO/IEC 25010 criteria and a researcher-made acceptability rubric, employing a four-point Likert scale. IT experts rated the system Highly Compatible (M = 4.00) to Highly Secured (M = 3.73) across all eight quality characteristics, with an overall mean in the Highly Functional-to-Highly Portable range. End-users rated the system Highly Usable (M = 4.00) and Highly Acceptable (M = 4.00) overall. The total hardware and software cost of the prototype was ₱20,755. These findings suggest that a low-cost, Raspberry Pi-based IoT waste segregation system is technically sound and well accepted by both technical evaluators and everyday users in a Philippine higher-education campus setting, and may serve as a scalable, low-cost model for other institutions.

**Keywords:** *Internet of Things; smart waste management; automated waste segregation; ISO/IEC 25010; system acceptability; Raspberry Pi; sustainable campus*

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## 1. INTRODUCTION

Rapid industrialization and urbanization have made solid waste management a growing challenge worldwide, and this challenge is increasingly visible within educational institutions. At REH Montessori College, a growing campus population generates a significant volume of waste each day, and traditional manual sorting practices remain prone to human error, inefficient recycling, and missed diversion opportunities. To address this gap, the present study designed, developed, and evaluated the Eco-Smart Bin: an IoT-Enabled Garbage Sorting System with Automatic Waste Segregation Bins. The system integrates Internet of Things (IoT) technology, sensors, and an automated sorting mechanism to classify waste into recyclable, non-recyclable, and biodegradable categories at the point of disposal, with the aim of improving sorting accuracy, reducing manual intervention, and promoting environmental awareness among students, faculty, and staff.

### *1.1 Related Literature*

A growing body of work has applied IoT to solid waste management. Qureshi et al. (2023) described IoT-enabled bins that used ultrasonic sensors for real-time fill-level monitoring and collection-schedule optimization, while Lau et al. (2020) emphasized that, despite such interventions, global plastic pollution continued to accumulate, underscoring the need for more effective segregation and recycling systems. Ali et al. (2020) linked inefficient collection systems in rapidly urbanizing areas to improper disposal and proposed an IoT-based monitoring system to address it, and Sosunova and Porras (2022) similarly highlighted sensor- and analytics-driven route optimization together with the importance of stakeholder involvement.

Several studies focused specifically on automated classification. Sheng et al. (2020) combined IoT with a TensorFlow-based deep learning model for waste detection; Nafiz et al. (2023) and Nair et al. (2024) reported high classification accuracy using deep learning and image processing, respectively; and Srivastav et al. (2023) proposed a convolutional neural network (CNN)-based classifier for urban waste streams. Sensor-based segregation hardware was explored by Megalan Leo et al. (2022) and Mangayarkarasi et al. (2024), who used ultrasonic and color sensors with bin-full alerts, and by Badotra et al. (2021), whose smart dustbin combined segregation with shredding and composting features. Gayathri et al. (2021) applied RFID-based tracking to food waste specifically, showing that real-time tracking and reward mechanisms reduced wastage.

Broader treatments of IoT architecture and connectivity (Mouha, 2021; Laghari et al., 2022) provide the technological grounding for these applications, while several studies evaluated system quality more formally: Sigongan et al. (2023) assessed an IoT-based smart bin using ISO/IEC 25010 standards and reported high acceptability, a precedent this study follows directly.

### *1.2 Research Gap and Conceptual Framework*

Across this literature, most existing systems addressed a single aspect of waste management — monitoring, classification, or collection routing — in isolation, and comparatively few studies evaluated their systems against a standardized software-quality model or assessed real-world user acceptability. The present study addressed this gap by integrating IoT sensing, machine-learning-based classification, and automated sorting into a single platform, and by evaluating that platform against both the ISO/IEC 25010 Software Product Quality Standards and end-user acceptability criteria.

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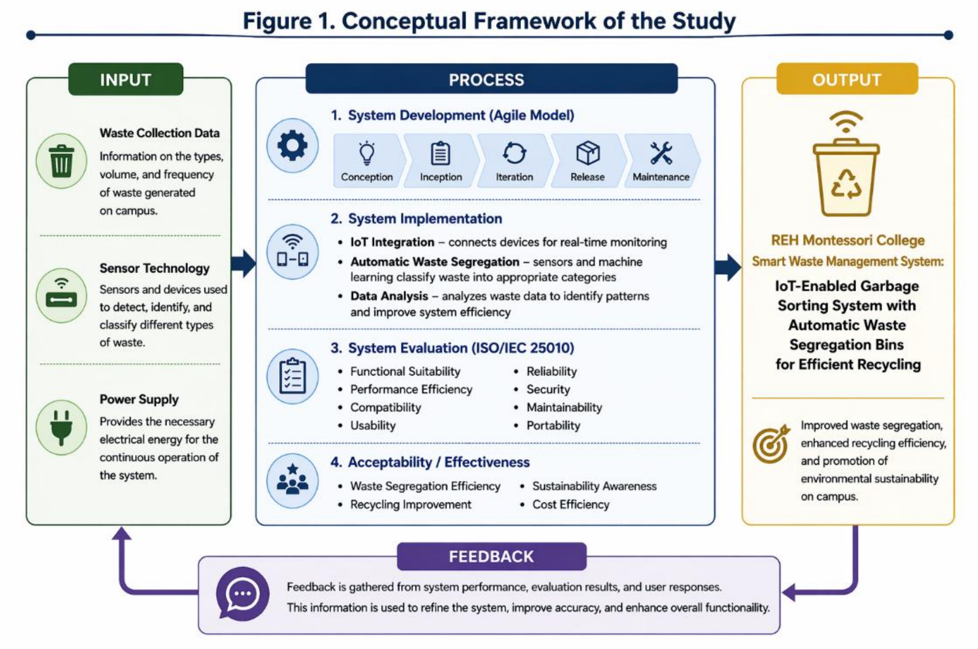


**Figure 1. Conceptual framework of the study (Input–Process–Output model with feedback).**

As shown in Figure 1, the framework followed an Input-Process-Output (IPO) model with a feedback loop. Inputs consisted of waste-collection data, sensor technology, and power supply. The process stage comprised system development (using the Agile Model), system implementation (IoT integration, automatic segregation, and data analysis), ISO/IEC 25010-based quality evaluation, and acceptability assessment. The output was the deployed Eco-Smart Bin system, with performance and user feedback looping back to refine the system.

### *1.3 Objectives of the Study*

This study sought to:

1. Develop the Eco-Smart Bin: IoT-Enabled Garbage Sorting System with Automatic Waste Segregation Bins using the Agile Model, in terms of Conception, Inception, Iteration, Release, and Maintenance;

2. Evaluate the system as rated by IT experts based on the ISO/IEC 25010 Software Product Quality Standards, in terms of functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability;

3. Evaluate the system as rated by end-users (students, teachers, and staff) in terms of functional suitability, performance efficiency, and usability; and

4. Characterize the acceptability of the system and determine its overall project cost.

### *1.4 Significance of the Study*

The findings are intended to benefit REH Montessori College directly, by making waste segregation more organized, reducing improper disposal, and supporting a cleaner, more sustainable campus. Students and employees stand to gain a more convenient way to practice proper segregation and greater environmental awareness, while campus administrators and maintenance personnel gain improved monitoring and a reduced manual-sorting burden. More broadly, the study contributes reference data and a working prototype for researchers and future scholars developing IoT-based waste-management systems, and offers other schools and institutions a practical, low-cost model for adopting smart, technology-driven waste segregation.

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## 2. METHODS

### *2.1 Research Design*

This study used a developmental research design to design, develop, test, and evaluate the Eco-Smart Bin system, combined with a descriptive-evaluative component to gather stakeholder feedback. System construction followed the Agile Model — Conception, Inception, Iteration, Release, and Maintenance — allowing continuous refinement across development stages. To assess the finished system, functionality, usability, efficiency, and acceptability were evaluated through IT-expert and end-user survey instruments based on the ISO/IEC 25010 Software Product Quality Standards, and system performance and cost were assessed descriptively.

### *2.2 Research Locale*

The study was conducted at REH Montessori College, Philippines, a campus selected for its significant daily waste generation and diverse population of students, faculty, and staff, and for its institutional commitment to environmental sustainability.


**Figure 2. Locale of the study — REH Montessori College.**

### *2.3 Participants*

A stratified random sampling technique was used to ensure representation across stakeholder roles. The final sample consisted of 35 respondents: 10 IT professionals/experts (28.57%), 10 student end-users (28.57%), 10 teacher end-users (28.57%), and 5 staff end-users (14.29%).

| Respondent Group | n | % |
|---|---|---|
| IT Professionals / Experts | 10 | 28.57 |
| Students (end-users) | 10 | 28.57 |
| Teachers (end-users) | 10 | 28.57 |
| Staff (end-users) | 5 | 14.29 |

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| Respondent Group | n | % |
|---|---|---|
| Total | 35 | 100.00 |

**Table 1. Distribution of respondents.**

### *2.4 Research Instruments*

Data were gathered using survey questionnaires, evaluation forms, and rubrics anchored to the ISO/IEC 25010 System and Software Product Quality Model. The IT-expert instrument contained 26 items covering functional suitability (3 items), performance efficiency (3), compatibility (2), usability (6), reliability (4), security (5), maintainability (3), and portability — administered on a four-point Likert scale (4 = Highly Functional/Highly Acceptable to 1 = Poor). The end-user instrument contained 12 items covering functional suitability (3), performance efficiency (3), and usability (6), and a separate researcher-made acceptability rubric of 8 items (accuracy and reliability, ease of use, real-time efficiency, environmental impact, accessibility, response time, reliability, and suitability) was used to characterize overall acceptability, also on a four-point scale.

### *2.5 Validity and Reliability*

Instruments were reviewed for validity by the research adviser, an English-language critic, a statistician, and IT specialists, whose feedback informed revisions for clarity, relevance, and alignment with ISO/IEC 25010 standards. A pilot test involving 10 respondents who were not part of the actual sample was conducted; Cronbach's alpha was 0.857, interpreted as "Good" internal consistency.

### *2.6 Data Gathering Procedure*

Following instrument validation, questionnaires and evaluation forms were administered to the 10 IT experts and 25 end-users during the system's release phase, after respondents were given the opportunity to observe and use the prototype. Completed instruments were collected, encoded, and checked for completeness prior to analysis.

### *2.7 Data Analysis*

Mean scores were used to summarize evaluations across the Agile development phases and across each ISO/IEC 25010 quality characteristic, interpreted against a four-point verbal scale (3.25–4.00 = Highly Functional/Efficient/etc.; 2.50–3.24 = Functional/Efficient/etc.; 1.75–2.49 = Needs Improvement; 1.00–1.74 = Poor). The same scale, relabeled for acceptability (3.25–4.00 = Highly Acceptable; 2.50–3.24 = Acceptable; 1.75–2.49 = Less Acceptable; 1.00–1.74 = Not Acceptable), was used to interpret the acceptability rubric, with 2.50 as the minimum acceptance threshold. As reported in Chapter 2 of the source thesis, an independent-samples t-test was planned to compare IT-expert and end-user evaluations, and Pearson correlation and regression analysis were planned to examine relationships among usability, engagement, and waste-segregation outcomes.

### *2.8 Ethical Considerations*

The study considered five ethical dimensions in the system's design and deployment: (1) privacy and security of data collected by the bins; (2) the digital divide and accessibility for users unfamiliar with IoT-based systems; (3) the environmental footprint of the IoT hardware itself, including eventual e-waste; (4) potential displacement of manual waste-sorting labor, mitigated through retraining or reassignment; and (5) system reliability and accuracy, since misclassification of hazardous or recyclable material could itself cause environmental harm.

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## 3. RESULTS

### *3.1 System Development*

The Eco-Smart Bin was developed through five Agile phases. In the Conception phase, the researcher identified core problems — improper segregation, inefficient disposal, and the absence of automated monitoring — and proposed an IoT-enabled solution. In the Inception phase, hardware requirements (Raspberry Pi, sensors, motors, conveyor mechanism, waste bins) and software requirements (Python, TensorFlow, OpenCV, Flask) were identified and prepared. During Iteration, the Raspberry Pi, camera module, sensors, conveyor mechanism, and motor drivers were integrated and repeatedly tested against different waste materials, with adjustments made to detection accuracy, conveyor movement, and system response time. In the Release phase, the completed prototype was deployed at REH Montessori College and demonstrated to IT experts, students, teachers, and staff, who used the system directly before completing the ISO/IEC 25010-based evaluation instruments. In the Maintenance phase, hardware connections, software performance, and classification accuracy were monitored and adjusted as needed to sustain reliable operation.

| Phase | Task name | Start | Finish | Duration |
|---|---|---|---|---|
| 1. Preparation | System Requirements: Software and Hardware, Development Tools | 19-Jan-26 | February 28,2026 | 5 wk |
| 2. Development | Download images, Train Machine, Convert into Camera | 26-Jan-26 | 4-Apr-26 | 9 wk |
| 3. Internal Testing | Conduct quality Assurance and Debugging | 6-Apr-26 | 17-Apr-26 | 1 wk |
| 4. Pilot Testing | Test with select users (Student, Staff and Teachers) | 20-Apr-26 | 24-Apr-26 | 0.6 wk |
| 5. Evaluation | Collect IT Experts and end-user Evaluation | 27-Apr-26 | May 01,2026 | 0.6 wk |
| 6. Orientation | Train, Conduct and Distribute Materials | 4-May-26 | 5-May-26 | 2 days |
| 7. Deployment | Full Deployment | 6-May-26 | 8-May-26 | 3 days |
| 8. Monitoring | Provide ongoing support | 11-May-26 | 15-May-26 | 1 wk |

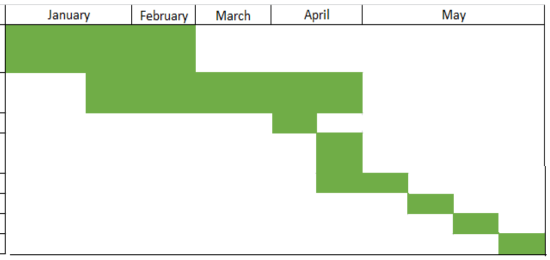


**Figure 3. Gantt chart of the study.**

### *3.2 System Design*

The system's operation is summarized by a Data Flow Diagram (Figure 4): a user places a waste item into the system; a camera or sensor captures it; an on-device model classifies it as recyclable, non-recyclable, or biodegradable; the sorting mechanism directs it to the corresponding bin; and the result is displayed to the user in real time.

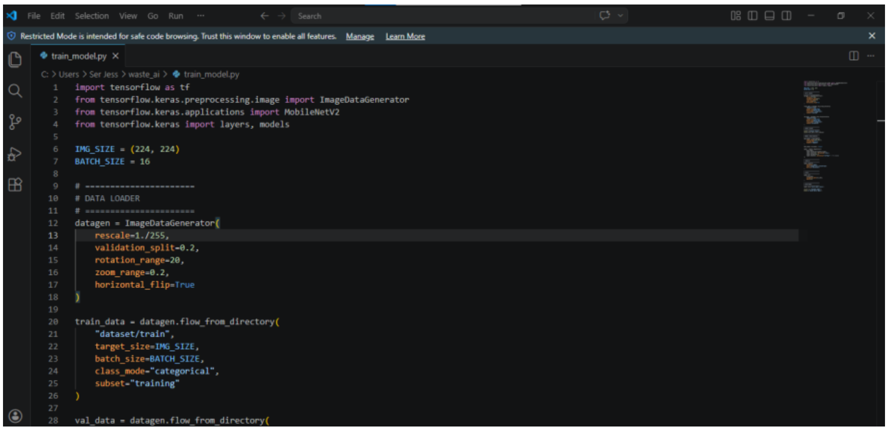


**Figure 4. Data flow diagram.**

The Entity Relationship Diagram (Figure 5) modeled the relationships among USER, WASTE, WASTE_TYPE, BIN_MAPPING, BIN, and RESULT_LOG entities to support accurate bin assignment and result tracking, and the Use-Case Diagram (Figure 6) modeled user interactions such as placing waste, initiating sorting, viewing results, and identifying bin destination.

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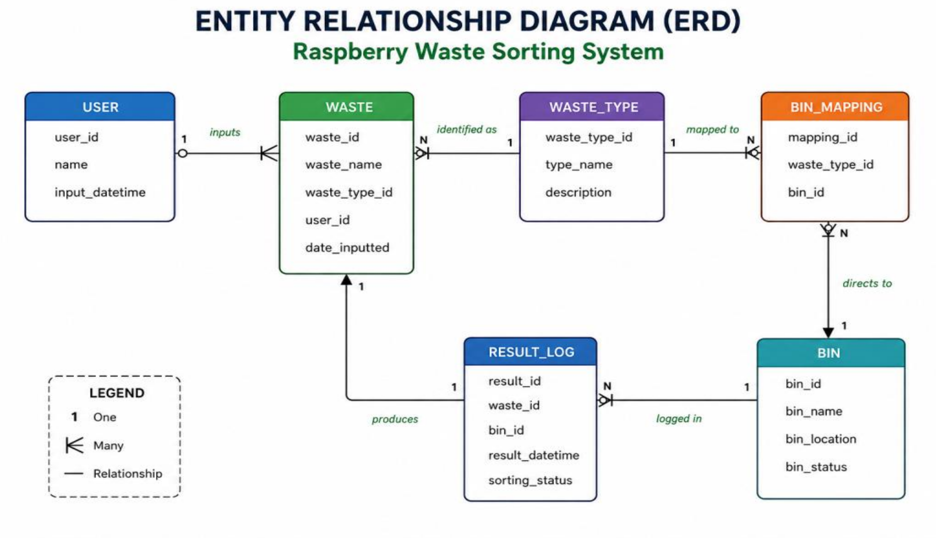


**Figure 5. Entity relationship diagram.**

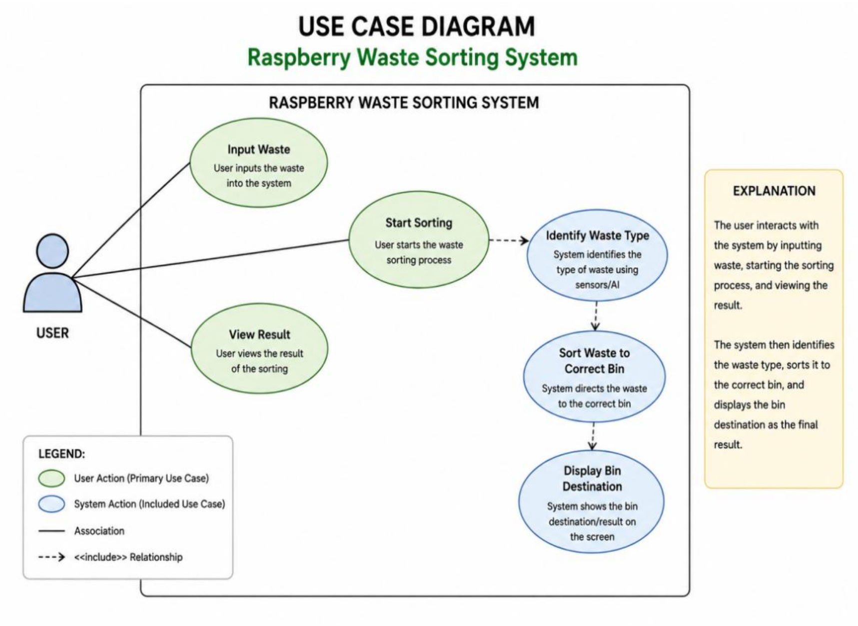


**Figure 6. Use-case diagram.**

The system's software (Figure 7) was built with Python, TensorFlow, and OpenCV for waste detection and classification, and Flask served the HTML/CSS/JavaScript-based monitoring dashboard (Figure 8), which displayed a live camera feed alongside real-time counters for biodegradable, recyclable, and non-biodegradable waste, updated via API calls to the Flask backend. The physical prototype (Figure 9) integrated a conveyor platform, sorting mechanism, Raspberry Pi and motor-driver electronics, and separate waste bins within a single enclosure.

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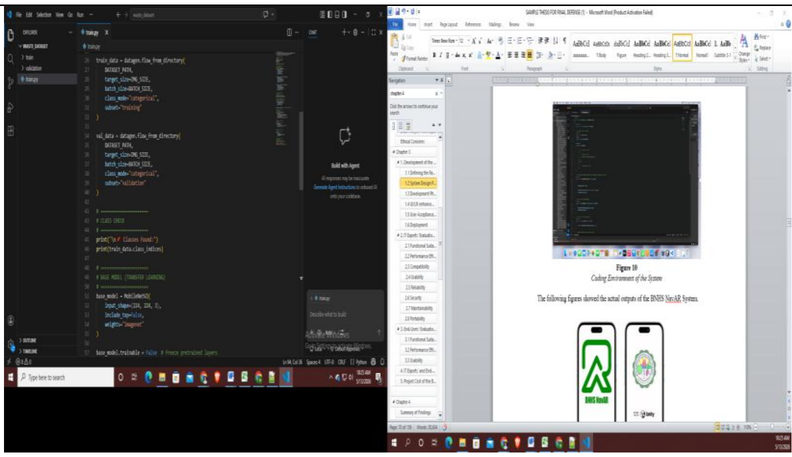

**Figure 7. Coding environment.**

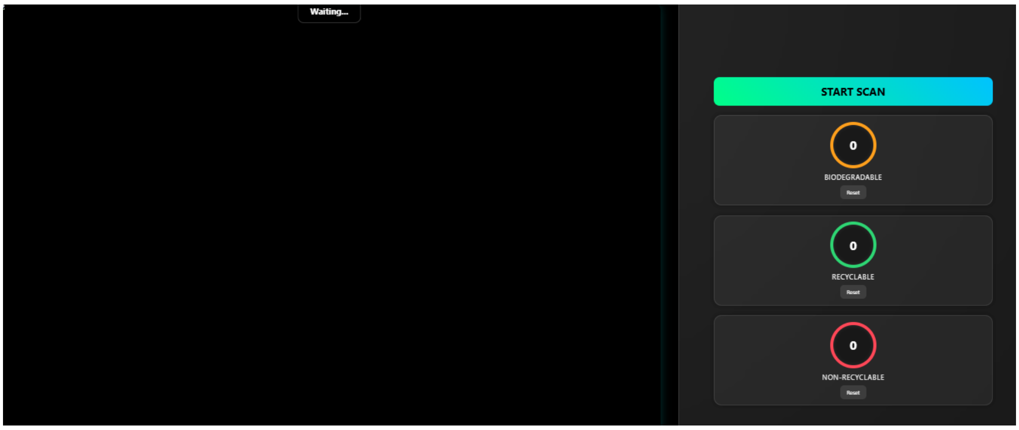


**Figure 8. Real-time monitoring dashboard.**

**Figure 9. Hardware prototype.**

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### *3.3 IT Experts' Evaluation (ISO/IEC 25010)*

| ISO/IEC 25010 Characteristic | Mean | Verbal Description |
|---|---|---|
| Functional Suitability | 3.83 | Highly Functional |
| Performance Efficiency | 3.90 | Highly Efficient |
| Compatibility | 4.00 | Highly Compatible |
| Usability | 3.93 | Highly Usable |
| Reliability | 3.93 | Highly Reliable |
| Security | 3.73 | Highly Secured |
| Maintainability | 3.83 | Highly Maintainable |
| Portability | 3.96 | Highly Portable |

**Table 2. IT experts' evaluation of the Eco-Smart Bin, by ISO/IEC 25010 characteristic (n = 10).**

Across all eight characteristics, IT experts' ratings clustered tightly in the "Highly—" band, ranging from 3.73 (Security) to 4.00 (Compatibility). Compatibility with the Raspberry Pi hardware, Python/TensorFlow/OpenCV software stack, and external devices was rated highest and most uniformly (all three indicators at 4.00). The lowest-rated characteristic, Security, still exceeded the 2.50 acceptance threshold by a wide margin, though its lowest single indicator — confidentiality/access control to system settings (3.50) — points to a specific area for hardening in future iterations.

### *3.4 End-Users' Evaluation and Acceptability*

| Criterion | Mean | Interpretation |
|---|---|---|
| Functional Suitability | 3.91 | Highly Functional |
| Performance Efficiency | 3.91 | Highly Efficient |
| Usability | 4.00 | Highly Usable |
| Overall Acceptability (8-item rubric) | 4.00 | Highly Acceptable |

**Table 3. End-users' evaluation and acceptability ratings (n = 25).**

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End-users rated the system consistently in the Highly Functional-to-Highly Usable range, with usability itself rated uniformly at 4.00 across all six sub-indicators (recognizability, learnability, operability, error protection, interface aesthetics, and accessibility). On the separate acceptability rubric, all eight items — accuracy and reliability, ease of use, real-time efficiency, environmental impact, accessibility, response time, reliability, and suitability for campus implementation — were rated 4.00, yielding a uniform overall acceptability mean of 4.00 (Highly Acceptable), against a 2.50 minimum threshold.

### *3.5 Project Cost*

| Item | Description | Cost (₱) |
|---|---|---|
| Raspberry Pi 4 | Single-board computer | 10,000 |
| Power converter | For conveyor | 950 |
| Conveyor | For spinning waste | 1,942 |
| PC monitor | For Raspberry Pi | 1,520 |
| Double BTS7960 | Stepper motor driver module | 271 |
| L298N | Stepper motor control | 100 |
| TT motors (2 pcs) | Wheels | 72 |
| Plywood and other parts | Project body | 5,000 |
| Bin | Waste bin | 600 |
| Power adaptor | For PC monitor | 300 |
| Python 3.10.2 | Software (free) | 0 |
| Visual Studio Community Edition | Software (free for academic use) | 0 |
| Total | | 20,755 |

**Table 4. Project cost breakdown (hardware and software).**

The completed prototype cost ₱20,755 in total, most of which (about 48%) was the Raspberry Pi 4 itself; all software used was free for academic purposes, keeping the overall cost relatively low for a full sensing-plus-classification waste-segregation prototype.

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## 4. DISCUSSION

The Eco-Smart Bin was rated "Highly—" across every ISO/IEC 25010 characteristic examined by IT experts and every criterion examined by end-users, and it exceeded the acceptability threshold with the maximum possible rating (M = 4.00). Together with a relatively low total build cost (₱20,755), these results are broadly consistent with prior IoT-based segregation systems that combined sensor-based detection with software-quality or acceptability evaluation, such as the ISO/IEC 25010-evaluated smart bin of Sigongan et al. (2023) and the sensor-plus-CNN systems of Megalan Leo et al. (2022) and Srivastav et al. (2023), and extend that line of work to a Philippine higher-education campus context that, per the review of related literature, has been comparatively underrepresented in prior IoT waste-management studies.

The one characteristic with a comparatively lower — though still "Highly—" rated — score was Security (M = 3.73), driven by a confidentiality/access-control indicator (M = 3.50). This is consistent with the ethical considerations raised in the Methods section regarding data privacy, and suggests that access controls over system configuration are the most immediate area for hardening before wider deployment.

These findings should be interpreted with several limitations in mind. First, the evaluation drew on a single-site, comparatively small sample (10 IT experts and 25 end-users), and the discrepancy between the Slovin's-Formula sample-size computation (n = 50) and the actual sample used (n = 35) noted in the Methods section should be resolved in any future replication. Second, the study's own analysis plan called for inferential tests — an independent-samples t-test comparing expert and end-user ratings, and Pearson correlation and regression analysis relating usability, engagement, and segregation outcomes — that were not ultimately reported; the ratings above are therefore descriptive rather than inferential, and claims of statistically significant differences or relationships cannot be made from the data as presented. Third, the acceptability rubric returned a uniform 4.00 across all eight items for all end-user respondents, a ceiling effect that may reflect genuinely strong performance but that also limits the instrument's ability to discriminate between stronger and weaker aspects of the system from the end-user perspective; a rubric or scale with greater range, or a larger and more heterogeneous end-user sample, may reveal more texture in future work.

## 5. CONCLUSION AND RECOMMENDATIONS

The Eco-Smart Bin: IoT-Enabled Garbage Sorting System with Automatic Waste Segregation Bins was successfully developed through the Agile Model and integrates IoT sensing, Raspberry Pi-based processing, machine-learning classification, and automated sorting to segregate campus waste into biodegradable, recyclable, and non-biodegradable categories. IT experts rated the system Highly Functional to Highly Compatible across all eight ISO/IEC 25010 characteristics, and end-users rated it Highly Functional, Highly Efficient, and Highly Usable, with a uniform Highly Acceptable rating on the acceptability rubric. At a total cost of ₱20,755, the system represents a technically sound and well-accepted, low-cost model for IoT-based waste segregation in a Philippine higher-education setting.

Based on these findings, the following are recommended:

1. REH Montessori College may adopt and deploy the Eco-Smart Bin in additional campus areas to further support environmental sustainability initiatives.
2. Future researchers may extend the system with real-time analytics, cloud-based monitoring, mobile application support, and enhanced machine-learning capabilities.
3. A reward-based feature that converts correctly classified waste into points or incentives may be added to encourage active student participation.

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4. The conveyor/sorting mechanism and auditory feedback may be refined to improve sorting speed and user feedback clarity.

5. Future studies should employ a larger, multi-site sample and should report the inferential analyses (t-test, correlation, regression) originally planned, to test for significant differences and relationships rather than relying on descriptive statistics alone.

6. Future iterations should specifically address the confidentiality/access-control gap identified under Security, and expand system coverage to hazardous and electronic waste categories, which the current prototype excludes.

7. Regular maintenance, monitoring, and software updates are recommended to sustain performance, reliability, and security over time.

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Advancing Knowledge. Inspiring Innovation. Achieving the SDGs.
Volume 1 Issue 3 Pages 412-425



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