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GarbMoCo: Advanced prototype for garbage monitoring and collection on solid waste

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Abstract

Improper solid waste management remains a persistent challenge in the Philippines, contributing to environmental pollution, public health risks, and inefficient collection systems. This study developed and evaluated GarbMoCo, a low-cost, web-based prototype for citizen-driven garbage reporting and monitoring. Using design and development research, the prototype was assessed by 72 senior high school class presidents selected via purposive sampling (Slovin's formula, N=87, e=0.05). Acceptability was measured with a 5-point Likert scale questionnaire across four indicators: accessibility, functionality, usability, and efficiency. Results showed a very high overall acceptability (mean = 4.48, SD = 0.617), with usability receiving the highest rating (mean = 4.78, SD = 0.41). These findings indicate that GarbMoCo is a practical, scalable tool for enhancing community participation in solid waste management. The study recommends offline capabilities, improved data security, and broader implementation in barangay-level systems.

Keywords: Solid Waste Management; Web-Based Prototype; Garbage Monitoring; Citizen Reporting; Community Participation; Philippines

1. Introduction

Improper solid waste management (SWM) continues to pose significant environmental, public health, and operational challenges worldwide, particularly in rapidly urbanizing countries like the Philippines. Key issues include irregular collection, overflowing bins, open dumping, and low citizen engagement in monitoring. The Philippines ranks among the top waste-generating nations in ASEAN, producing over 16 million tons of solid waste annually, with households contributing 50–80% of the total [1,2]. Local studies highlight persistent gaps in barangay-level implementation despite resident awareness [2,3].

Existing solutions often rely on expensive IoT sensors, smart bins, or hardware-heavy systems [6,7,8,9]. In contrast, purely web-based, citizen-driven reporting platforms remain underexplored, especially in Philippine senior high school and community contexts where students (e.g., class presidents) can serve as direct reporters. Literature shows that machine learning-enhanced reporting optimizes municipal operations [4], while community-based digital systems reduce improper dumping through technology-enabled participation [5]. Real-time web dashboards and alerts improve collection efficiency, reduce costs, and prevent overflows [8,9,10].

This study addresses the gap by developing GarbMoCo, a web-based prototype for garbage monitoring and collection. It contributes to environmental science, educational technology, and sustainable SWM by creating an accessible, low-cost tool aligned with K-12 inquiry programs. The primary objectives were to (1) develop the final version of the GarbMoCo website and (2) evaluate its acceptability in terms of accessibility, functionality, usability, and efficiency among target users.

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1.1. Objective of the Study

This study's primary purpose is to develop and evaluate GarbMoCo, an advanced web-based prototype for garbage monitoring and collecting on solid waste. Specifically, this study sought to achieve the following objectives:

- Develop the final version of the GarbMoCo website.
- Assess the website's acceptability in terms of:
- Accessibility,
- Functionality,
- Usability, and
- Efficiency.

2. Literature Review

This section reviewed all the related existing studies that supported the development of the GarbMoCo system, focusing on waste management, proper garbage disposal, and environmental solutions to poor garbage monitoring.

2.1. Defining and Describing the Product/Innovation

Rapid urbanization and increasing solid waste generation have driven the development of technology-supported solid waste management (SWM) solutions. Xia et al. demonstrated that machine learning applied to citizen-submitted garbage reports enables real-time identification of priority areas and faster municipal response, proving more effective than traditional manual systems [4]. Similarly, community-based waste management systems empower residents to report issues through digital interfaces, resulting in quicker authority action and better waste segregation practices [5].

Sustainable smart-city SWM frameworks incorporate IoT for continuous bin monitoring, proactive collection, and resource optimization [6]. Sensor-based prototypes, such as those using Time-of-Flight sensors, deliver accurate fill-level data to web dashboards, supporting timely decision-making [7]. These innovations, along with integrated IoT, GPS, and cloud systems, have shown clear operational improvements, including reduced response delays and enhanced environmental protection [11,12,13,14,15,16].

2.2. Benefits of Innovation

IoT-enabled SWM systems provide multiple advantages, including improved collection efficiency, reduced operational costs, lower fuel consumption, and prevention of bin overflows through real-time alerts and community reporting [8,9]. Digitization further optimizes routing, automates scheduling, enhances stakeholder coordination, and supports data-driven decision-making [17,18,19,20,21]. Studies report reductions in labor demands by up to 40%, fewer unnecessary collections, and better handling of hazardous waste [22,23,24]. Web-based applications promote citizen participation, minimize redundant routes, and contribute to environmental conservation through efficient resource allocation and recycling support [20,21].

2.3. Existing Innovations Related to the Product

Numerous IoT-based systems have been developed for smart waste monitoring, including frameworks using ultrasonic sensors, Wi-Fi, GPS, and cloud dashboards for real-time bin status and route optimization[25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40]. Examples include smart bins with automated sorting, web applications for stakeholder-inclusive reporting, and dynamic routing platforms deployed in urban settings across Portugal, India, Hong Kong, Italy, Morocco, and other regions [26,35,37,41,42,43,44]. While most innovations rely on hardware sensors, purely web-based, citizen-driven reporting platforms remain limited, especially in resource-constrained Philippine school and barangay contexts [10].

This study addresses that gap by developing GarbMoCo as an accessible, hardware-free web prototype focused on community reporting, map integration, and administrative management. The research is anchored on the Technology Acceptance Model (TAM) [45], which explains user adoption through perceived usefulness and ease of use, and the Input-Process-Output (IPO) model for systematic prototype development and evaluation.

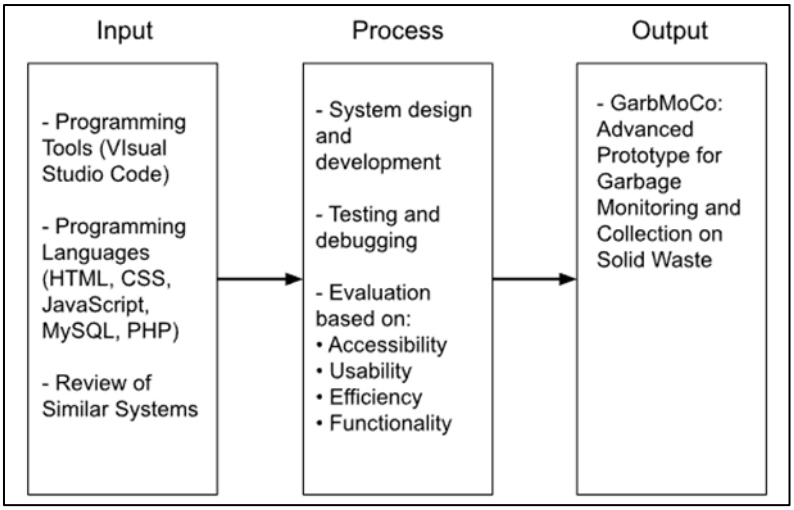

Figure 1 Conceptual Framework of the Study

2.4. Scope and Limitation

This developmental study focused on the development of GarbMoCo, which aimed to create an online, functional, and efficient website integration for SWM, specifically for garbage monitoring and waste accumulation. The study was conducted at a particular school in Tagum City during School Year 2025-2026. Class presidents from various grade levels were selected as respondents using a purposive sampling method. The study examined the important use of GarbMoCo, focusing on its accessibility, usability, efficiency, and functionality, as well as its role in addressing environmental waste concerns within the school setting.

The study was limited to selected students from one school in Tagum City, Davao del Norte, Philippines during School Year 2025-2026 and did not include other schools, students, teachers, or external waste management systems. The prototype was limited by its reliance on internet connection, lack of mobile app functionality, and operation solely as a web-based platform. The study assumed that selected participants provided valid and accurate responses and that their feedback reflected the experiences of similar educational settings, though generalizability beyond this context remained limited.

3. Materials and Methods

This research utilized a quantitative approach that focused on the collection and analysis of numerical data to draw conclusions. According to Ghanad [46], quantitative research aims to quantify data and generalize findings through systematic collection, analysis, and interpretation. The quantitative method was adopted in this study because the evaluation of the GarbMoCo prototype relied on measurable indicators obtained through survey instruments specifically, Likert scale questionnaires, to assess respondents' perceptions and experiences regarding accessibility, usability, efficiency, and functionality.

Moreover, this study employed Design and Development Research (DDR). Richey and Klein [47] defined DDR as the systematic study of designing, developing, and evaluating instructional and non-instructional products and tools. This approach proved appropriate because the primary objective of the study was to design and develop advanced web-based garbage monitoring and collection system and to evaluate its performance based on user feedback. Through DDR, the researchers successfully aligned the creation of the prototype with identified waste-management needs and validated its effectiveness in promoting environmental responsibility and community engagement.

The respondents of this study consisted of class presidents from a particular school in Tagum City. The researchers employed purposive sampling to select participants who were most capable of evaluating the prototype. Additionally, Slovin's Formula was applied to determine the appropriate sample size. The formula, expressed as $n = N / (1 + Ne^2)$, where n represents the sample size, N the population size, and e the margin of error, was used with N = 87 and e = 0.05. This yielded a calculated sample size of 72 respondents.

Data from the prototype testing were collected using Likert scale questionnaires that measured respondents' perceptions of the system's accessibility, usability, efficiency, and functionality. The collected responses were

statistically analyzed to provide insights that guided improvements and recommendations for the GarbMoCo prototype. This approach ensured that the findings were reliable and aligned with the study's objectives.

Purposive sampling was selected because it allowed better alignment between the sample and the study's aims and objectives, thereby enhancing the rigor, trustworthiness, and credibility of the findings. As noted by Campbell [48], four key aspects of trustworthiness in qualitative and mixed-methods research credibility, transferability, dependability, and confirmability were strengthened through this deliberate sampling approach.

Table 1 Table for the Distribution of the Subjects

Grade Level	Population	Percentage	Sample Size
7	15	17%	12
8	14	16%	12
9	12	14%	10
10	12	14%	10
11	16	18%	13
12	18	21%	15
Total	87	100%	72

The process model of this DDR followed the input, process, and output to ensure the systematic flow and that the prototype addressed the identified problem effectively. Within this systematic flow, the researchers selected the iterative model, which is an aspect of the Software Development Life Cycle (SDLC) model that comprises software development progression by increment every cycle. The researchers chose this model as the process model. The prototype underwent each cycle and consistent fixing, debugging, and testing. It took inspiration from building software gradually to create finished software instead of producing software with numerous defects.

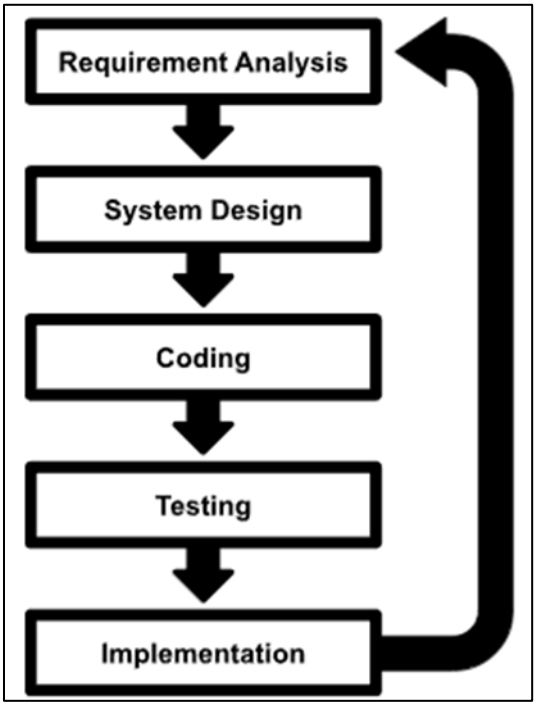

Figure 2 SDLC Iterative Model

The iterative model relied on implementing various versions of a product through small units repeatedly to achieve the proposed system. Each phase of the model consisted of requirement analysis, system design, and coding.

The entire development process was documented, including design improvements and system updates, to prepare the platform for the testing and evaluation stage.

To implement the website's application features, the following technologies and programming languages were used: HTML, CSS, JavaScript, PHP, MySQL, Apache, and Visual Studio Code.

Testing and Evaluation. The created prototype underwent several version iterations to ensure smooth and accurate performance. Data collected from respondents were statistically analyzed, and the analysis identified the strengths and weaknesses of the prototype. Suggestions and feedback gathered during this phase were implemented to further enhance the system.

Iterative Refinement. Based on the results of testing and the feedback received, the prototype was refined until it met the predefined standards and criteria. Identified flaws and weaknesses were systematically addressed to improve transparency and overall performance. Continuous improvements were made to optimize the prototype.

Feasibility Assessment and Implementation. In the final stage, the researchers evaluated the feasibility of implementing the prototype on a larger scale, such as within barangays. Factors including cost-effectiveness, scalability, sustainability, and resource availability were carefully considered. This assessment determined the prototype's suitability for real-world application and its potential for successful adoption in community settings.

The main research instrument used in the study of GarbMoCo, a web-based garbage monitoring and collection system, was the Likert Scale. A 5-point Likert Scale was employed to assess the system's accessibility, functionality, usability, and efficiency.

Table 2 Parameter of Limits Describing the Usability Level of GarbMoCo

Parameter Limits	Descriptive Equivalent	Interpretation
4.20 - 5.00	Very High	This indicates that the website shows excellent usability, highly accessible, easy to navigate, efficient, and fully functional—exceeding user expectations.
3.40 - 4.19	High	This indicates that the website is generally accessible and user-friendly, allowing tasks to be completed with good efficiency. Most functions work reliably, although minor improvements in design or performance could further enhance the overall usability.
2.60 - 3.39	Moderate	The website shows an average level of usability. While users can access and use the system, some difficulties in navigation, efficiency, or feature reliability may hinder the overall experience, requiring moderate improvements.
1.80 - 2.59	Low	The website demonstrates low usability. Accessibility is limited, navigation is not intuitive, efficiency is weak, and several features may not function as intended, making the system less reliable and requiring significant revisions.
1.00 - 1.79	Very Low	This indicates that the website shows very poor usability, with limited accessibility, low efficiency, and unreliable functions, indicating the need for major redevelopment.

The researchers adhered to a structured data collection process. They first obtained permission from the school administration to ensure compliance with institutional, ethical, and legal guidelines. Informed consent was secured from all student participants and, where required, from their parents or guardians; full details about the study's objectives, procedures, and potential risks were provided. Orientation sessions were conducted to familiarize participants with the purpose of GarbMoCo, its operational methods, and the expected outcomes of their participation, thereby ensuring transparency and informed engagement.

The researchers analyzed and calculated the data through statistical methods, employing measures such as mean and standard deviation. The mean, commonly known as the average, was the sum of values in a sample divided by the number of values in the sample. Since this study used a Likert scale in a questionnaire, the data were numerical and were treated as continuous.

The prototype presented was used to quantify the following indicators such as efficiency, usability, accessibility, and functionality. By calculating the mean ratings or scores provided by the respondents, the researchers determined the overall performance of the prototype. The Standard Deviation (SD) quantified the degree of data dispersion from the mean. A low standard deviation meant the responses clustered tightly around the mean, whereas a high standard deviation meant the responses were widely spread. This was used in the study to measure the variability or spread of responses regarding the prototype's efficiency, usability, accessibility, and functionality. A low standard deviation signified greater consistency, which was desirable in implementing the prototype.

3.1. Ethical Considerations

Guided by the principles of integrity and responsible conduct [53], this study prioritized the protection of participants' rights through several core ethical practices. The research team established trust by ensuring privacy and confidentiality, modifying all data to remove identifying details [54]. Informed consent was secured by providing participants with full transparency regarding the study's purpose and scope before obtaining signed agreements [52]. Throughout the process, the team-maintained safety and security as a top priority to minimizing risks [55] while treating participants' opinions with **respect** and dignity [56]. Finally, to ensure data interpretation remained rigorous and transparent, participants were given the opportunity to verify their information, preventing any manipulation or misrepresentation of their contributions [57].

4. Results

In this chapter, the results of the developmental study are presented in a textual, tabular, and statistical answer to the research objectives of the study.

4.1. Development of the Final Version of the GarbMoCo Website

This section illustrates the GarbMoCo prototype through clear text instructions, regulations, and a snapshot to present a guide on using the website. The visuals will include the following: log-in and sign-up form, homepage, reported log database, reporting interface, about page, and a portion of the Short Message Service (SMS) and email notification.

Figure 3 GarbMoCo Log-in Form

To access the website, users are required to input information such as username and password. The Log-in Form serves as an entry point to the website. Once the user submits the valid credentials and notifies in case of invalidity, it will direct them into the Homepage. Alternatively, if the user is identified as an Administrator, access is directed to the Administrator Homepage.

Figure 4 GarbMoCo Sign-up Form

This allows users to create an account by submitting the required information. This feature supports first-time users by providing a structured account creation. Basic credentials are required such as valid identification card, username, and password. In addition to basic credentials, users are required to provide a phone number while administrator accounts require an email address instead. Upon successful registration, the system stores the submitted information in the database, with passwords secured through a hashing mechanism to ensure data protection and avoid breaches. This will enable future login and full access to the website functionalities.

Figure 5 GarbMoCo Homepage

The interface acts as the central navigation, ensuring a smooth and organized user experience. A separate homepage is exclusively designed for Administrators.

Figure 6 Reported Log Database

It can be varied by date or search by the case ID. The interface allows users to view, and track submitted garbage reports in an organized chronological order. The filtering and search functions help users efficiently locate specific cases, monitor report statuses, and review relevant case details, supporting effective case management within the system.

Figure 7 Reporting Interface

This allows users to submit garbage reports efficiently and systematically. The interface requires users to provide essential information about the garbage case, including the type and status of the garbage, a detailed description, a textual location, and any supporting attachments or screenshots. The location can be determined automatically by clicking the "Locate Me" button or manually selected on the map.

Figure 8 About Page

This provides an overview of the website and its purpose. The interface highlights the goals and objectives of the project and lists the members or researchers involved, including their respective roles and contributions.

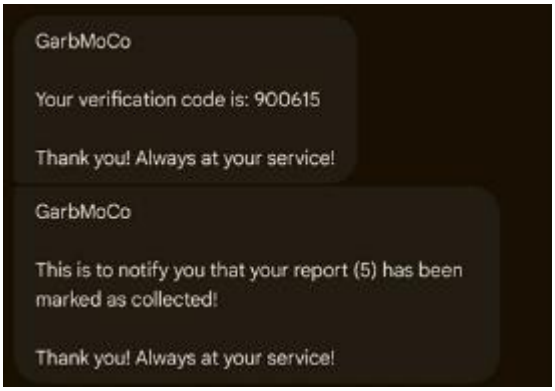

Figure 9 SMS Notification

This shows the system securely sends a verification code via SMS to authenticate user identity during reporting. It highlights the process of generating, transmitting, and validating the OTP, ensuring that only authorized users gain access.

Figure 10 Administrator Sign-up Form

This is designed for registering and managing new administrator accounts. It allows authorized personnel to input necessary details such as username, contact number, and password to create admin profiles.

Figure 11 Administrator Homepage

This displays the interface, management, and administrative metrics. It provides administrators with a centralized view of report activity and indicators.

Figure 12 Administrator Log Database

This records and monitors administrative activities within the system. It tracks actions performed by administrators, providing a detailed history for accountability.

Figure 13 Email Notification for Administrators

This delivers detailed reports and additional relevant information. It enables timely communication of alerts directly to administrators.

4.2. Assessment of the Website's Acceptability in Terms of Accessibility, Functionality, Usability, and Efficiency

Table 3 Level of Acceptability of GarbMoCo in Terms of Accessibility

Benefits	Mean	SD	Description
The prototype was easy to navigate through.	4.35	0.67	Very High
The navigational elements were clearly labeled and easy to understand.	4.33	0.65	Very High
It was easy to go back and forth between pages on the website.	4.38	0.68	Very High
Users in different age groups (teenagers, adults, senior citizens) can use it without issues in accessing information.	4.42	0.64	Very High
The system was accessible and usable across different devices.	4.38	0.68	Very High
Categorical Mean	4.37	0.67	Very High

The formulated results indicated that the accessibility of the GarbMoCo prototype is appropriate to users, regardless of device or age groups. The consistent high means suggest that users find the interface easy to navigate. According to Angelis [49], intuitive navigation, ease of clear labeling, and simple user experiences tend to improve user acceptance

of digital systems. This supports the study's objective of developing a prototype where users can easily navigate to access waste monitoring information. Certain limitations were determined such that the sample may not fully represent users with disabilities, who may have different accessibility needs and browsers of the respondent's device were required to be restarted for a cleaner process. Nevertheless, the result makes the system suitable for community use, allowing residents to check waste-monitoring data.

Table 4 Level of Acceptability of GarbMoCo in Terms of Functionality

Benefits	**Mean**	**SD**	**Description**
The interactive elements (buttons, text fields, links, etc.) of the prototype were easy to use.	4.40	0.64	Very High
It was clear what the user needed to do for the trash collection schedule.	4.49	0.63	Very High
Navigating through the prototype to access different features was intuitive.	4.26	0.67	Very High
I could easily correct mistakes or undo actions while using the prototype.	4.24	0.74	Very High
The system responded quickly when I performed actions, such as updating schedules or submitting reports.	4.19	0.74	High
Categorical Mean	**4.32**	**0.69**	**Very High**

The formulated results indicated that the functionality of the GarbMoCo prototype is accepted by the users, with user-friendly and interactive interfaces. The consistent very high mean suggests that users found the system easy for information display and input. A website designed with adequate functionality results to smooth processed tasks and user satisfaction [50]. It further supports the study by developing a functional prototype where users can interact with tasks such as filing, reporting, and viewing. However, a crucial limitation was found such as the website responding incorrectly and an extensive response time due to the varied connection. Nevertheless, the results imply that it is suitable for community use, allowing residents to report and check waste-monitoring data.

Table 5 Level of Acceptability of GarbMoCo in Terms of Usability

Benefits	**Mean**	**SD**	**Description**
I found the system simple to use.	4.82	0.39	Very High
I thought the system was easy to navigate.	4.69	0.46	Very High
I found the system consistent and well-organized.	4.82	0.39	Very High
I found the system very user-friendly.	4.72	0.45	Very High
I believe I can use this system confidently without needing technical support.	4.86	0.35	Very High
Categorical Mean	4.78	0.41	Very High

The usability results indicate that respondents evaluated the GarbMoCo prototype with very high acceptance. These result values suggest that elements of the User Interface (UI) emphasize clarity, ease of operation, and overall user interaction. Moreover, this outcome influences the prototype's ease of use in its current stage of development. The composite mean of 4.78 reflects a generally acceptable usability level. In addition, this high acceptance is supported by Arora et al. [51], their study indicates a similar threshold with mean scores around 4.78, this indicates a strong agreement and high acceptance across different technological usability.

Table 6 Level of Acceptability of GarbMoCo in Terms of Efficiency

Benefits	Mean	SD	Description
I can quickly report improper garbage disposal using this garbage monitoring and collection website.	4.51	0.60	Very High
This garbage monitoring and collection website starts processing reports quickly.	4.42	0.71	Very High
This garbage monitoring and collection website completes verification of reports quickly.	4.39	0.74	Very High
I can quickly receive confirmation after submitting a report through this website.	4.38	0.74	Very High
The garbage monitoring and collection website responds quickly to user actions.	4.49	0.63	Very High
Categorical Mean	4.44	0.68	Very High

This result supports the study's objective of acceptability in terms of Efficiency. Respondents perceive the GarbMoCo prototype as highly efficient, as reflected in the consistently strong mean scores. This suggests that users find the system capable of performing tasks with minimal complexity. Although the evaluation focused only on students, the consistent efficiency scores defining the prototype supports practical use and can be further enhanced for wider community application. Furthermore, Xu et al. [52] stated that findings are connected to external research across different technological domains, where a similar mean score above 4.40 on a 5 rating Likert scale.

Table 7 General Level of Acceptability of GarbMoCo

Indicators	Mean	SD	Description
Accessibility	4.37	0.67	Very High
Functionality	4.32	0.69	Very High
Usability	4.78	0.41	Very High
Efficiency	4.44	0.68	Very High
Categorical Mean	4.48	0.617	Very High

Detailed items meant consistently high. For accessibility, "Users in different age groups can use it without issues" scored 4.42. For functionality, "It was clear what the user needed to do for the trash collection schedule" scored 4.49. Usability items ranged from 4.69 to 4.86, reflecting strong agreement on simplicity and user-friendliness. Efficiency items averaged 4.38–4.51, indicating quick reporting and processing.

5. Discussion

The very high overall acceptability (M=4.48) demonstrates that GarbMoCo successfully meets user needs as a web-based tool for garbage monitoring and collection. High usability (M=4.78) aligns with studies showing intuitive interfaces drive technology to adoption in environmental platforms [49,51]. Strong accessibility and efficiency ratings support its potential in diverse Philippine community settings, consistent with findings that citizen-reporting systems improve response times and reduce improper disposal [4,5,20,21].

Compared to sensor-heavy IoT systems [6,7,8,25–44], GarbMoCo offers a low-cost, hardware-free alternative emphasizing community participation — a key advantage for schools and barangays with limited budgets. The iterative development process effectively incorporated feedback, addressing initial navigation and response-time concerns.

Limitations include the single-school sample (reducing generalizability), reliance on internet connectivity, and lack of a mobile app or offline mode. The student-focused respondents may not fully represent adult or barangay users. Future versions should integrate 360-degree mapping, data encryption enhancements, offline functionality, and broader multi-stakeholder testing.

6. Conclusion

In conclusion, the development and evaluation of the GarbMoCo prototype demonstrated its strong potential as a web-based platform for improving community involvement in reporting improper waste disposal. The system enabled users to easily pinpoint waste locations, supporting a more organized and responsive approach to monitoring environmental concerns. Its features showed how technology can contribute to cleaner surroundings by strengthening communication between users and waste management authorities. The limitations of the study such as its focus on a single school community and the absence of a sensor-based version suggest opportunities for further enhancement and wider application.

Furthermore, the assessment of GarbMoCo revealed that the system was acceptable to users in terms of accessibility, functionality, usability, and efficiency, highlighting its practicality for real world use. The positive evaluation results indicated that the system's acceptability was significantly favorable. Insights gathered from the evaluation guided the development of the final version of the website, which addressed user needs and supported responsible waste practices.

Compliance with ethical standards

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Disclosure of conflict of interest

We, Carlos Anthony U. Pepito, Roy Niño R. Salas, Godwin M. Solis, Khiara Ashley L. Barut, Dindo G. Lañas Jr., Rose Ann B. Rimando, Alex Kate E. Yecyec, and Noemi O. Lorenzana, declare that we have no conflicts of interest or competing interests to disclose regarding the publication of this manuscript or any institution, product, or entity mentioned therein. Furthermore, we have no affiliations or financial interests in any products or organizations that could influence the study outcomes presented or compete with those discussed in the manuscript.

Statement of ethical approval

All ethical standards were strictly followed in the conduct of this study, including the use of the PRISMA framework. All sources and authors referenced in the manuscript were properly cited in accordance with academic and ethical guidelines

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