Strategies for Enhancing Interoperability between Mobile Apps and Waste Systems

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ABSTRACT

This study aimed to investigate how IoT-enabled smart waste management systems, specifically connected waste bins and mobile applications, can enhance user engagement, optimize waste-disposal behaviors, and support upcycling practices. A mixed-methods approach was employed. Following a literature review and pilot testing, a survey was developed that included demographic items, multiple-choice questions, and open-ended prompts. Qualitative data were also collected through in-depth, one-on-one interviews and online surveys with 48 male participants, with an average age of 20. Each interview lasted approximately 10 minutes, and online surveys required about 5–10 minutes to complete. The survey responses were analyzed using Qualtrics and qualitative content analysis. Findings provide insights into user-centered design considerations, behavioral incentives, and the technical and experiential factors needed to develop a cohesive, scalable, and user-friendly smart waste system. These results offer implications for universities, municipalities, and developers seeking to improve recycling efficiency through IoT-driven solutions.

INTRODUCTION

- Global waste generation has increased significantly in recent decades, exceeding 2.24 billion tons annually, and is projected to rise by nearly 70% by 2050 (UNEP, 2024).
- Rapid urbanization, population growth, and shifting consumption patterns continue to place substantial pressure on municipal waste management systems (World Bank, 2025).
- Many systems still rely on manual collection processes and limited data monitoring, which restrict operational efficiency and make it difficult to respond to changing waste-disposal patterns.
- These limitations hinder cities' and institutions' ability to manage waste sustainably at scale (Nesmachnow et al., 2025).
- Current waste management models prioritize logistical operations rather than user motivation. The absence of interactive tools (gamified apps, reward systems, etc.) further limits user participation, particularly among college students (Venturi et al., 2025)
- Internet of Things (IoT) technologies, including sensor-equipped smart bins and real-time monitoring systems, present promising opportunities to improve collection efficiency and support circular-economy practices such as recycling and waste reduction (Addas et al., 2024; Komane & Mathonsi, 2023).
- However, the effectiveness of these technologies depends heavily on user engagement and consistent waste-sorting behaviors, which remain inconsistent among college populations (Ibokette et al., 2024).
- Because many existing systems prioritize operational efficiency over user experience, they often lack meaningful interaction features that could encourage correct waste-disposal behaviors (Venturi et al., 2025; Shan, 2020).
- These challenges highlight the need to better understand how mobile interfaces, behavioral incentives, and integrated IoT ecosystems can motivate individuals to dispose of waste properly and contribute to circular-economy outcomes.

RESEARCH PUROPSE & QUESTIONS

The purpose of this study was to determine how IoT-enabled smart waste management systems and the integration of mobile apps with connected bins will enhance user engagement while optimizing waste disposal and to find how this supports upcycling through effective design, behavioral incentives, and the use of real-time data.

- ***RQ1.*** How does a mobile app interface influence college students' engagement in waste segregation and disposal?
- ***RQ2.*** What behavioral incentives (e.g., rewards, gamification, notifications) effectively encourage proper waste disposal?
- ***RQ3.*** How can interoperability between Internet of Things (IoT) devices, mobile apps, and municipal waste systems be improved?

METHODS

- The primary method of data collection in this study was surveys administered in both interview and online formats.
- Each interview lasted approximately 5–10 minutes and included 31 questions divided into three subsections: (1) demographic information, (2) shared questions assessing participants' general opinions on recycling and current recycling methods, and (3) the project's research questions, and evaluated how useful the proposed recycling-support solution would be for individuals at FSU.
- The survey received 48 responses, primarily from sophomores and juniors with limited prior recycling experience.
- Most respondents were sophomores (43.8%) or juniors (43.8%), with 6.3% identifying as freshmen and 6.3% as seniors.
- All participants were male, 77% identified as Caucasian, and 65% had not previously participated in any recycling initiative.

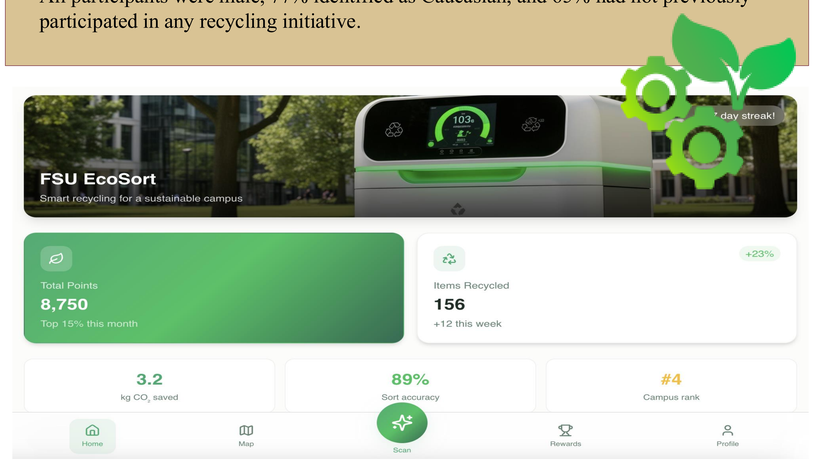

Figure 1. Develop a smart waste app using Lovable mock.

Figure 2. Develop a smart waste bin system.

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RESULTS

- Many participants expressed interest in receiving notifications or reminders related to recycling behaviors, suggesting that behavioral prompts may reinforce more sustainable habits.
- Participants reported inconsistent engagement in sustainability practices.
- Respondents liked the idea of tracking their recycling progress through statistics, noting that this feature could increase their participation.
- Survey responses indicated that ease of use is extremely important; approximately 98% of respondents stated they would not use an app that is difficult to navigate or poorly designed, emphasizing the need for a strong user interface.
- Despite this, only 19% said they would definitely use the app, 42% expressed interest, and 39% reported they would not use it at all.
- A large majority of participants (around 85%) indicated that a points-based reward system would motivate them to recycle more often, suggesting that embedded rewards could positively influence sustainable behavior.
- Participants also showed strong interest in gamification features such as challenges, leaderboards, and team competitions, indicating that competitive elements may encourage greater app engagement.
- Many respondents preferred individual rewards for recycling efforts, suggesting that personal incentives (redeemable points or recognition) may be particularly motivating.
- A high level of trust in smart waste technologies, with approximately 82% of participants considering smart bins to be trustworthy.
- Respondents emphasized the importance of interoperability among smart bins, mobile apps, and campus systems, indicating expectations for seamless integration within a larger waste-management ecosystem.
- Many participants noted that real-time feedback, strong system connectivity, and transparent data tracking would increase their confidence in smart waste infrastructure.

DISCUSSION & CONCLUSION

- Students view waste sorting as important but not urgent; many were open to technological or reward-based solutions, and a smaller subgroup still expressed confusion about recycling, indicating a need for clearer guidance.
- The mobile-app interface section showed that the app must be intuitive, visually clear, and capable of providing real-time feedback, demonstrating a strong preference for usability and well-designed features.
- Incentives were also found to be effective motivators for individuals who are not already inclined to recycle.
- Participants preferred individualized rewards over group rewards and expressed interest in seeing the broader impact of their recycling efforts.
- Finally, the section on interoperability among IoT systems, mobile apps, and waste-management infrastructure indicated that participants are open to trusting automated sorting technologies. Seamless integration increases perceived legitimacy, and interoperability enhances the overall credibility of the system.

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