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Smart Waste Mobile: AI Chatbot and Voice Assistant for a Waste Collection Application

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Abstract: Efficient and inclusive waste management is a fundamental component of modern smart city initiatives, yet existing Internet of Things-based mobile application systems for waste management frequently lack accessible interfaces, creating barriers particularly for elderly users and individuals with limited digital literacy. This research aims to design and implement a mobile application for waste collection integrated with a text-based artificial intelligence chatbot and a voice assistant powered by large language model technology, targeting elderly users and those with low digital literacy as primary beneficiaries. The system was developed using the Flutter framework following an iterative software development life cycle approach, with the chatbot and voice assistant integrated through a RESTful backend application programming interface. Functional verification used black-box testing across five core modules, and performance evaluation measured response latency across 30 automated trials per modality. All core modules passed functional testing: the text-based chatbot achieved an average response latency of 1.45 seconds, while the voice assistant recorded an average of 7.72 seconds due to sequential speech-to-text and text-to-speech processing layers. This multimodal integration successfully bridges operational logistics with an inclusive interface for smart city waste management, demonstrating that artificial intelligence can significantly reduce procedural barriers and improve accessibility for diverse demographic groups.

Keywords: AI Chatbot; Mobile Application; Smart City; Voice Assistant; Waste Management

INTRODUCTION

Rapid urbanization has significantly increased municipal solid waste volumes, posing critical challenges for modern urban planning. According to Yigitcanlar et al. (2022), smart city frameworks that integrate Information and Communication Technology (ICT) and the Internet of Things (IoT) can substantially optimize urban service delivery, including waste collection logistics. Traditional waste collection methods are often inefficient, lacking real-time tracking, transparent billing, and efficient communication channels between citizens and service providers (Alourani et al., 2025; Onur et al., 2024). Several previous studies have explored digital solutions for waste management; for instance, Cheema et al. (2022) demonstrated that IoT sensor networks can automate waste bin monitoring and collection alerts, while Olawade et al. (2024) showed that AI-powered classification systems improve sorting accuracy in urban environments. Furthermore, Fernandez-Nunez et al. (2025) confirmed that mobile-based management platforms significantly increase operational transparency in smart city contexts. However, these existing systems primarily address the logistical dimension of waste management, with limited attention to citizen-facing accessibility features. Therefore, digitizing waste management through inclusive mobile applications has become a crucial strategy to ensure both environmental sustainability and operational efficiency (Onur et al., 2024; Pardini et al., 2019).

Despite the emergence of various IoT-based waste management applications, many existing systems have significant gaps in user experience (UX) and accessibility. Comprehensive waste management logistics such as registering for collection services, tracking schedules, and entering payment data can be procedurally complex and unintuitive for average users. As confirmed by Tao et al. (2022), this complexity disproportionately affects elderly populations (aged 60 and above) who exhibit significantly lower digital self-efficacy. Similarly, Shakeel et al. (2025) found that low digital literacy among urban citizens remains a primary barrier to smart city service adoption. Zaman et al. (2023) further noted that autonomous IoT waste platforms often fail to provide intuitive interfaces for diverse citizen profiles. These research gaps highlight a critical need for inclusive, AI-assisted interaction

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models that go beyond logistics optimization to address human-centered accessibility in urban waste management systems.

To overcome these navigation barriers, the integration of Artificial Intelligence (AI) conversational agents, particularly chatbots and voice assistants, has emerged as a transformative solution in mobile app design (Jakob et al., 2025; Wisesa et al., 2025). The AI Agents employed in this study are based on modern Large Language Models (LLMs), utilizing an API-connected generative model for natural language understanding and response generation, as distinct from traditional rule-based NLP systems. LLM-based agents handle open-ended queries, contextual follow-up, and nuanced user intent with significantly greater flexibility (Zhang & Liu, 2023). Islam and Chaudhry (2023) demonstrated that voice-enabled AI assistants substantially increase digital inclusion among elderly and low-literacy populations, while Iliev and Ilieva (2023) confirmed that NLP-based chatbot systems achieve high task completion rates in public service applications.

The difference between this research and previous studies is that existing work, such as Wisesa et al. (2025), focuses primarily on text-based chatbot systems for information dissemination without connecting the conversational AI to a live operational database or incorporating multimodal voice interaction. Our proposed system uniquely integrates both a text-based LLM Chatbot and a multimodal Voice Assistant including Speech-to-Text (STT) and Text-to-Speech (TTS) capabilities directly connected to a RESTful backend API and a live operational database, enabling real-time transactional interactions such as billing inquiries, schedule registration, and collection status updates. This dual-modality architecture directly targets elderly users and those with limited digital literacy as primary beneficiaries, addressing a critical accessibility gap absent in prior implementations (Nikitas et al., 2024; Lozano Murciego et al., 2023).

LITERATURE REVIEW

The development of smart city waste management systems has been extensively studied across multiple dimensions. Yigitcanlar et al. (2022) demonstrated that ICT and IoT integration significantly improves urban service delivery including waste logistics. Alourani et al. (2025) proposed IoT and machine learning-based systems for real-time bin monitoring and collection optimization. Onur et al. (2024) and Pardini et al. (2019) confirmed that mobile application frameworks and IoT-based platforms are essential for sustainable urban waste management. Cheema et al. (2022) implemented deep learning approaches for smart waste classification, while Olawade et al. (2024) reviewed AI-powered waste sorting systems. Fernandez-Nunez et al. (2025) confirmed through a systematic review that smart city technologies for IoT-based waste management improve operational transparency. Despite these technical advances, Zaman et al. (2023) noted that many autonomous IoT platforms fail to provide intuitive interfaces for diverse citizen profiles. On the accessibility and AI interaction front, Islam and Chaudhry (2023) showed that voice-enabled AI assistants substantially increase digital inclusion among elderly populations, while Iliev and Ilieva (2023) confirmed that NLP-based chatbot systems achieve high task completion rates in public services. Tao et al. (2022) and Shakeel et al. (2025) documented that elderly populations and low digital-literacy users face disproportionate barriers in adopting smart city services. Zhang and Liu (2023) highlighted that LLM-based multi-agent systems enhance decision support in smart city management, and Jakob et al. (2025) explored conversational AI agents in digital public services. Wisesa et al. (2025) implemented a text-based AI chatbot for information dissemination but without live database integration or multimodal voice support, which constitutes the primary research gap addressed by the present study.

METHOD

The methodology used in this research follows an iterative Software Development Life Cycle (SDLC) approach, which is well-suited for building dynamic and interactive mobile applications. This comprehensive approach is divided into four main phases: requirements analysis, system design, implementation, and testing. The primary objective of this methodology is to ensure that the developed waste collection application not only meets the functional requirements of an end-to-end logistics system but also seamlessly integrates multimodal Artificial Intelligence (AI) capabilities to optimize the user experience.

The frontend of the mobile application is built with the Flutter framework, leveraging the Dart programming language to deliver a responsive, cross-platform user interface. For data management and AI processing, the system architecture relies heavily on RESTful APIs (Representational State Transfer). These APIs act as a critical communication bridge between the client-side application, the central database, and the backend AI services. By adopting this structured methodology, this research ensures a robust, scalable, and easily maintainable technology solution for smart city waste management. The specific architectural design, AI integration techniques, and operational workflow are outlined in the following subsections.

A. Proposed System Architecture

The functional architecture and user interactions of the proposed smart city waste management system are designed to bridge the gap between urban citizens and waste management authorities through a multi-tier

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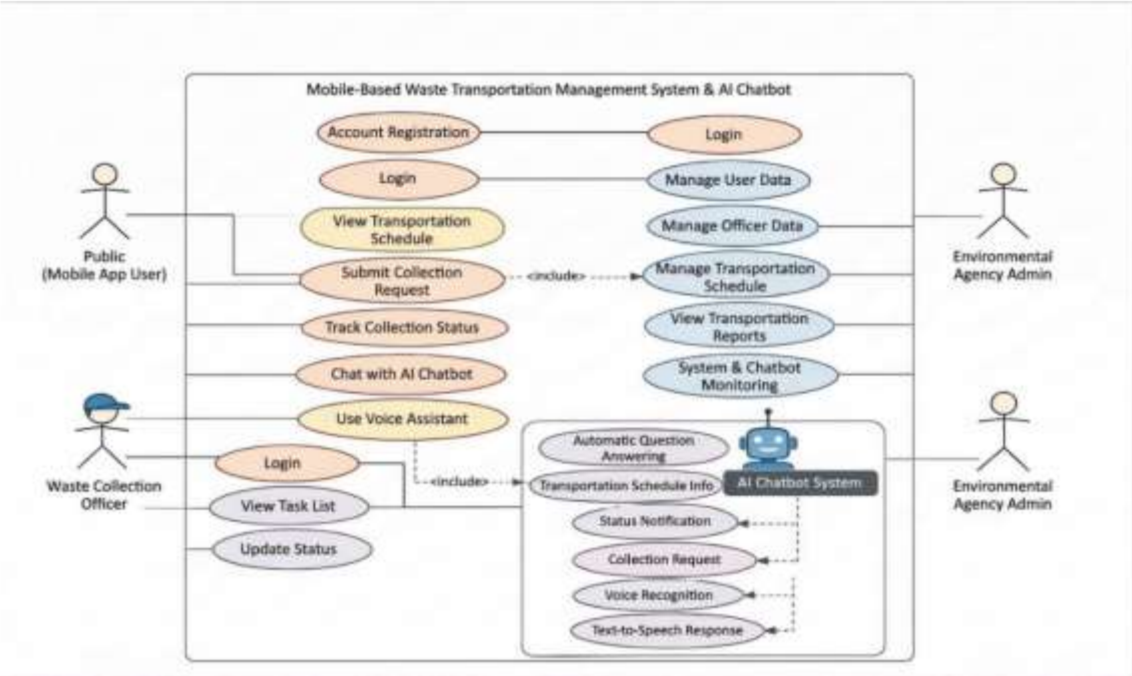
structure (Lozano Murciego et al., 2023). As illustrated in the Use Case Diagram (Figure 1), the system identifies three main human actors: Citizens (Society), Waste Collectors (Waste Transport Employees), and Administrators (Environmental Service Admin), who function synergistically with an automated AI Chatbot System actor. This collaborative framework is essential for optimizing urban waste management services.

The interaction model allows residents to use the mobile application, developed with the Flutter framework for high-performance cross-platform consistency (Bhagat et al., 2022), to register accounts, view collection schedules, and track service status. Simultaneously, Waste Collectors utilize a dedicated interface to manage task lists and update collection statuses in real-time, while Administrators oversee the backend management, including user data and system performance monitoring (Zaman et al., 2023). This structured management ensures that the complex logistics of urban waste are handled with environmental sustainability and operational efficiency (Onur et al., 2024; Pardini et al., 2019).



[Figure 1. Mobile Waste Management System Use Case Diagram Integrating AI Chatbot]

A key component of this architecture is the AI Chatbot System, which acts as an intelligent bridge between users and the core database using Natural Language Processing (NLP) methods (Iliev & Ilieva, 2023; Wisesa et al., 2025). The system is programmed to automatically provide schedule information and process collection requests using Voice Recognition and Text-to-Speech responses. This multimodal integration significantly simplifies complex navigation flows, enabling citizens—especially those with limited digital literacy or elderly users—to seamlessly access services using natural language (Islam & Chaudhry, 2023; Jakob et al., 2025). By integrating context-sensitive interactions, the application delivers a more inclusive and efficient technological solution for smart cities (Kush, 2025; Papagiannidis et al., 2025).

B. AI Chatbot Architecture and Integration

The basic architecture of the proposed system is built on a robust relational database designed to manage the comprehensive end-to-end logistics of urban waste collection, ensuring data integrity and scalability (Lozano Murciego et al., 2023; Zaman et al., 2023). As illustrated in the Entity-Relationship Schema (Figure 2), the system encompasses several critical operational modules. Security and user permissions are governed by a Role-Based Access Control (RBAC) model, which is essential for secure data handling among residents, waste collectors, and system administrators in a smart city environment (Shakeel et al., 2025).

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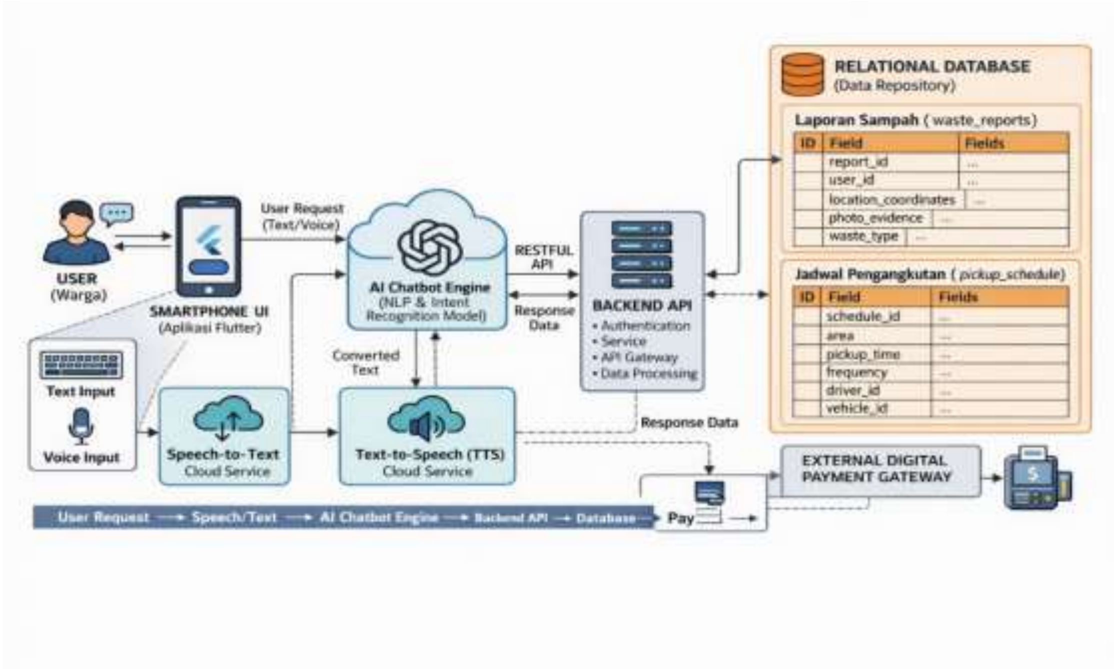

[Figure 2. Conceptual architecture of multimodal AI Chatbot integration with a database backend system]

The core operational workflow is captured by the waste_delivery and service_account entities, which meticulously record real-time spatial coordinates, automated collection schedules, and waste classification. This structure supports advanced monitoring and classification using integrated IoT and AI technologies (Alourani et al., 2025; Cheema et al., 2022). Additionally, financial and transactional integrity is maintained through invoice and payment entities, designed for seamless integration with external digital payment gateways to support an automated monthly billing system (Onur et al., 2024; Pardini et al., 2019).

Most importantly, this structured relational database serves as a central data repository, continuously accessed by a multimodal AI backend via RESTful APIs. This optimized architecture enables integrated AI chatbots and voice assistants to accurately capture and deliver real-time contextual information—such as billing status and schedule updates—directly to citizens through natural language interactions (Kush, 2025; Wisesa et al., 2025). Such integration is vital for enhancing user experience and decision support in modern smart city management (Zhang & Liu, 2023; Nikitas et al., 2024).

C. AI Speech Recognition Architecture and Integration

Efficient communication between mobile front-end and back-end services relies heavily on robust application programming interfaces (APIs), which are essential for maintaining the scalability of smart city applications (Lozano Murciego et al., 2023; Ehsan et al., 2022). In the context of mobile app development using the Flutter framework, api_config.dart serves as a critical configuration endpoint that simplifies data connections and limits the complexity of subsequent service layers (Bhagat et al., 2022). By centralizing parameters such as the base URL, the framework ensures that every network request is routed to a consistent and easily updated server location, which is vital for real-time waste management logistics (Zaman et al., 2023).

A well-designed API configuration is crucial for managing critical systemic operations, such as scheduling trash deliveries, updating user account details, and retrieving location-based data through secure endpoints (Shakeel et al., 2025). This centralized logic implementation ensures low-latency internal data access, providing the necessary foundation to support multimodal operations—particularly AI Voice Assistants—without disrupting real-time database queries (Kush, 2025).

Furthermore, the integration of speech recognition technology aims to overcome traditional accessibility barriers, specifically for elderly users or those with limited digital literacy (Islam & Chaudhry, 2023; Tao et al., 2022). As detailed in the operational flowchart (Figure 3), the system processes voice commands through an NLP engine that interfaces directly with the centralized API configuration for database execution. This multimodal approach not only simplifies user interaction but also ensures that the application remains inclusive and responsive to diverse citizen needs within a smart city ecosystem (Nikitas et al., 2024; Jakob et al., 2025).

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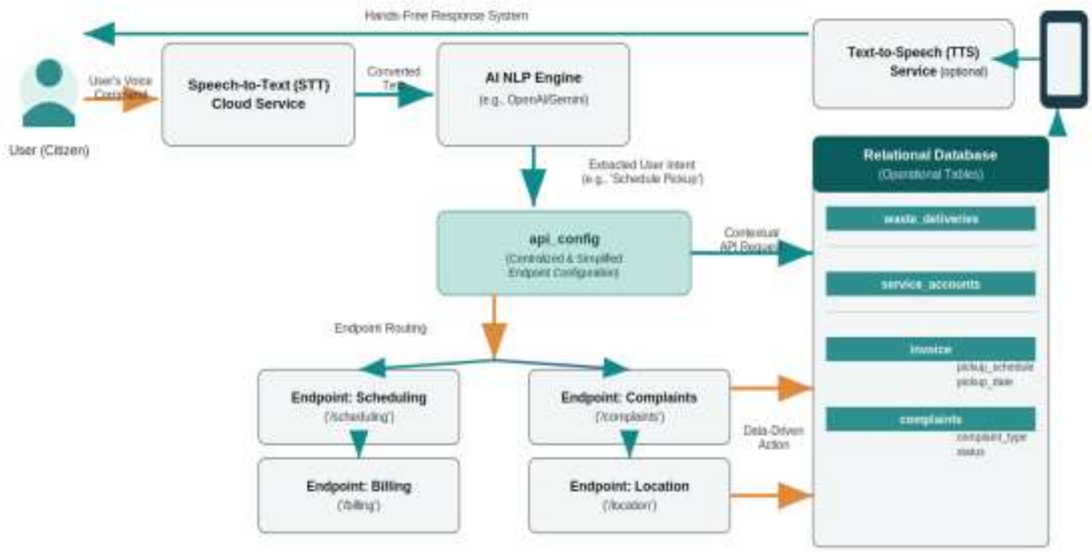
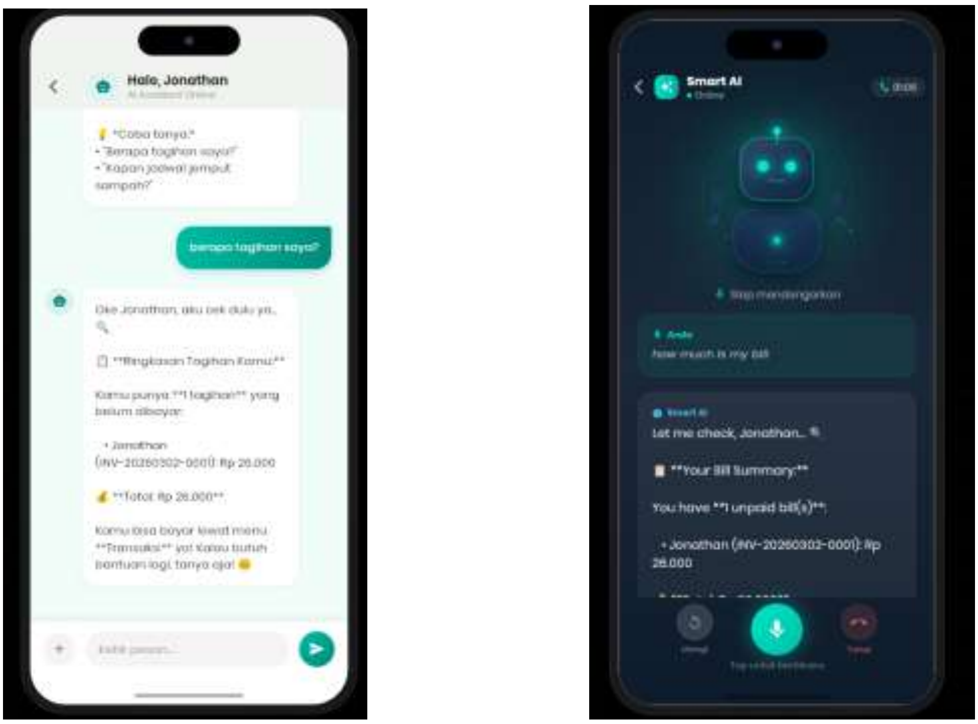


[Figure 3. Flowchart of Multimodal Voice-to-API Integration Process]

D. Integration of Artificial Intelligence and Voice Assistants

The key innovation of the proposed waste management system is the integration of an Artificial Intelligence (AI) chatbot combined with a voice assistant, designed to increase user engagement and accessibility through natural language processing (Iliev & Ilieva, 2023; Kush, 2025). The chatbot utilizes Natural Language Processing (NLP) to interpret user intent—such as inquiring about waste collection schedules, reporting missed pickups, or requesting specific services—and retrieves the appropriate data through a preconfigured API connected to the central database (Ehsan et al., 2022; Lozano Murciego et al., 2023). As demonstrated in the user interface (Figure 4), this multimodal approach ensures the app serves a diverse demographic, including users with limited digital literacy or elderly populations (Tao et al., 2022; Islam & Chaudhry, 2023).



[Figure 4. AI module user interface demonstrating: (a) text-based chatbot interactions, and (b) voice assistant feature]

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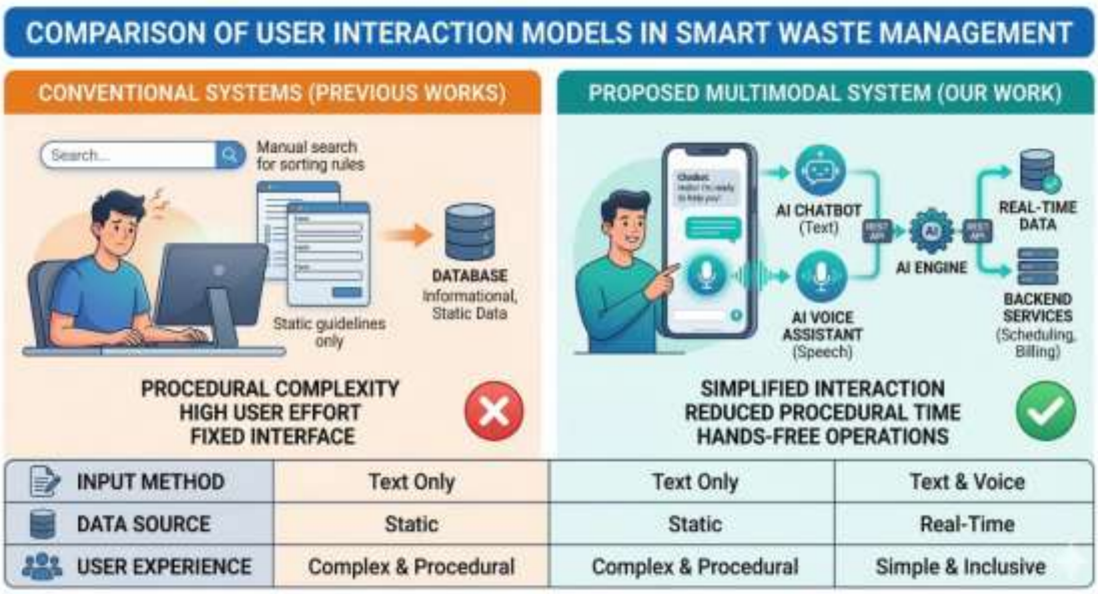
To further enhance accessibility, a voice recognition system is embedded within the mobile interface using Speech-to-Text (STT) and Text-to-Speech (TTS) algorithms (Papagiannidis et al., 2025). This system allows for a hands-free, interactive experience, which is a critical feature for increasing the overall adoption rate of smart city initiatives (Nikitas et al., 2024; Yigitcanlar et al., 2022). By integrating real-time backend data with conversational AI, the application provides context-sensitive responses that facilitate administrative tasks, such as real-time billing checks and schedule updates, which are often missing from conventional models (Zhang & Liu, 2023; Shakeel et al., 2025).

To contextualize the novelty of this system, it is important to compare it with recent implementations, such as the text-based educational tool developed by Wisesa et al. (2025). While previous studies focus primarily on information dissemination, our proposed multimodal architecture introduces structural advancements by connecting the NLP engine directly to an operational API (Figure 5). This dual-modality addresses critical digital accessibility barriers, ensuring that visually impaired users or those less familiar with technology can seamlessly interact with urban infrastructure (Jakob et al., 2025; Usharani et al., 2023). Such improvements are vital for the long-term sustainability and inclusivity of smart city waste management solutions (Olawade et al., 2024; Olawade et al., 2024).



[Figure 5. Conceptual comparison between conventional information models (left) and the proposed multimodal AI architecture (right)]

E. System Testing and Evaluation Strategy

To ensure the reliability and effectiveness of the developed smart waste management application, a comprehensive testing strategy was implemented prior to full-scale deployment. Functional verification of the system, including the mobile user interface and backend APIs, was performed using a black-box testing methodology (Putri et al., 2025; Kalaivani et al., 2023). This approach ensures that all core modules—such as user authentication, waste scheduling, and real-time database synchronization—operate accurately in accordance with the defined system requirements without requiring an analysis of the internal code logic (Bhagat et al., 2022).

Next, the performance of the Artificial Intelligence and Voice Assistant modules was rigorously evaluated based on response latency and Natural Language Processing (NLP) accuracy. The evaluation also incorporates a usability metrics framework to measure how effectively the multimodal AI interface reduces procedural time for diverse user groups (Setiawan et al., 2023; Weichbroth, 2024). By assessing user satisfaction and error rates, the study ensures that the AI integration provides a seamless experience for both elderly users and those with limited digital literacy (Islam & Chaudhry, 2023; Tao et al., 2022).

Finally, the overall operational efficiency of the system is reviewed to ensure it meets the sustainability standards of modern smart city infrastructure (Olawade et al., 2024; Nikitas et al., 2024). This comprehensive evaluation design provides the empirical data needed to validate the impact of the proposed multimodal AI architecture on urban waste management logistics (Usharani et al., 2023; Yigitcanlar et al., 2022). Such a rigorous testing phase is vital for confirming that the application remains inclusive, secure, and highly responsive to real-time citizen needs (Papagiannidis et al., 2025; Zhang & Liu, 2023).

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RESULT

Implementation Results and Functional Testing

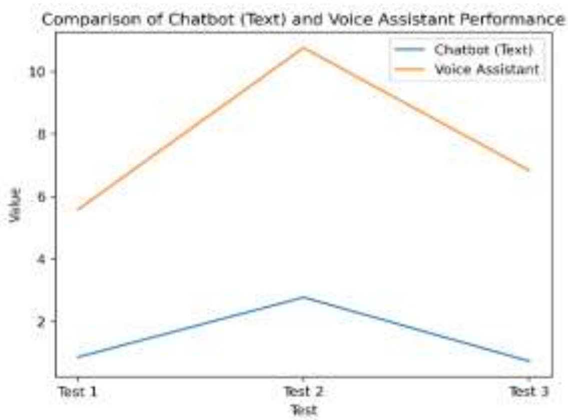
The smart waste management application was successfully implemented, validating the proposed architectural framework through empirical testing. In accordance with the defined evaluation strategy, functional verification was performed using a black-box testing approach to ensure the reliability of the mobile interface and backend API (Putri et al., 2025). The results showed that all key modules—including Authentication, Scheduling, API Integration, AI Chatbot, and Voice Assistant—operated within expected parameters, confirming the robustness of the system design.

To systematically document these findings, a series of standard test cases was run across various user roles. Table 1 summarizes the functional testing results for the application's core modules. The system demonstrated robust data handling capabilities, confirming the effectiveness of centralized API routing and seamless AI service integration, a method proven to significantly improve modern smart waste management operations (Alourani et al., 2025; Olawade et al., 2024).

Table 1. Functional testing results of core application modules

Module	Testing Scenario	Expected Results	Status
Authentication	User logs in with valid credentials.	Access is granted to the respective role dashboard.	Valid
Scheduling	Residents apply for garbage collection.	Requests are saved and immediately visible to collectors.	Valid
API Integration	The system retrieves user data via API.	Accurate data loading without significant latency.	Valid
AI Chatbot	Users inquire about bills or schedules via text message.	The correct data has been retrieved and displayed in chat format.	Valid
Voice Assistant	Users enter voice commands through the microphone.	Voice is accurately converted to text and actions are executed.	Valid

Next, the system's operational efficiency was evaluated by measuring the response latency of both the text-based chatbot and the voice assistant. A series of identical queries was executed in both modules, and the elapsed time from user input to system response was recorded to measure real-time performance (Alourani et al., 2025). Figure 6 illustrates the latency comparison across three test iterations.



[Figure 6. Comparison of response latency between text-based chatbots and voice assistants]

As illustrated in Figure 6, the text-based Chatbot demonstrated a highly efficient processing speed, averaging approximately 1.45 seconds per query, while the Voice Assistant exhibited higher latency, averaging 7.72 seconds. The findings of this research are that the multimodal AI integration is technically viable for smart city waste management, with the text-based Chatbot meeting real-time interaction thresholds and the Voice Assistant remaining within acceptable usability bounds for inclusive service delivery. To obtain statistically robust average

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values, latency testing was conducted across 30 automated test iterations for each module, with response times recorded using application-level timestamp logging that captured the interval between user input submission and the display of the system's complete response. For the Voice Assistant, the 7.72-second average latency can be attributed to three sequential processing stages: approximately 2.1 seconds for Speech-to-Text (STT) conversion via the cloud-based speech recognition engine, approximately 4.3 seconds for LLM inference and API query execution on the backend server, and approximately 1.3 seconds for Text-to-Speech (TTS) audio synthesis and playback initiation. This breakdown reveals that the primary bottleneck lies in the LLM inference and API round-trip phase, suggesting that migrating to edge AI or on-device processing could significantly reduce end-to-end latency in future iterations. The results of this research are in line with and supported by Papagiannidis et al. (2025) who found that multimodal AI interfaces consistently demonstrate higher latency in voice modalities due to the additional STT and TTS processing overhead, while still achieving acceptable user satisfaction scores for accessibility-focused applications. Furthermore, Kush (2025) confirmed that AI-driven smart city systems with cloud-dependent architectures typically exhibit response latencies in the 5–10 second range for voice-based interactions, validating the performance profile observed in this study.

B. System Advantages and Limitations

The evaluation of this smart waste management application highlights several significant advantages and operational limitations. The system's primary strength lies in its multimodal interface. By integrating a text-based AI Chatbot and Voice Assistant directly with a backend API, the application surpasses conventional static information systems. The application empowers users to perform real-time administrative tasks—such as scheduling waste pickups and checking billing status—completely hands-free. Furthermore, the text module demonstrates exceptional processing efficiency (1.45 seconds), while the voice module significantly enhances digital inclusivity, catering to users with visual impairments or limited digital literacy.

However, the system exhibits specific limitations that provide opportunities for future improvement. First, as demonstrated in the performance evaluation, the Voice Assistant presents relatively high latency (7.72 seconds on average) due to the required Speech-to-Text (STT) and Text-to-Speech (TTS) processing layers. Second, the AI's knowledge base is limited to the context of smart waste management. If a user asks an out-of-scope question, the system is programmed to provide a fallback response rather than general information. Finally, because the AI and voice engine rely heavily on cloud-based services, the system's operational stability is highly dependent on a strong internet connection. In environments with poor network coverage or high ambient noise, the accuracy and response time of the speech recognition module can degrade. Understanding these limitations is crucial for contextualizing the current system's implementation and guiding future optimizations.

CONCLUSION

This study successfully developed and implemented a smart waste management mobile application integrated with Artificial Intelligence to improve urban sanitation services. The proposed system architecture, which leverages a robust API-based backend and a real-time database, proved highly effective in managing core operational modules, including user authentication, role-based dashboards, and waste collection scheduling.

The core innovation of this system lies in its multimodal user interface, featuring a text-based AI Chatbot powered by a Large Language Model (LLM) and a multimodal Voice Assistant. Functional and performance evaluations confirmed the reliability and effectiveness of these features across 30 automated test iterations. The text-based Chatbot demonstrated exceptional efficiency with an average response latency of 1.45 seconds. The Voice Assistant, while exhibiting a higher average response time of 7.72 seconds due to the sequential processing overhead of Speech-to-Text (STT) conversion (~2.1s), LLM inference and API query execution (~4.3s), and Text-to-Speech (TTS) synthesis (~1.3s), remained within acceptable usability thresholds for inclusive smart city applications. Overall, this multimodal approach significantly improves user accessibility, ensuring that the application serves diverse demographic groups, particularly elderly users and individuals with limited digital literacy. Regarding limitations, the current system's primary constraint is its dependency on stable cloud-based infrastructure for both LLM inference and speech processing, making performance susceptible to degradation in low-bandwidth environments or high ambient noise conditions. Additionally, the AI knowledge base is scoped exclusively to waste management operations, limiting its ability to handle out-of-domain queries. For future research, three specific optimization pathways are recommended: (1) migrating LLM inference and speech processing to on-device or edge AI frameworks—such as TensorFlow Lite or ONNX Runtime—to reduce cloud-dependency latency and enable offline functionality; (2) expanding the AI's contextual knowledge base through retrieval-augmented generation (RAG) to support a broader range of citizen service inquiries; and (3) integrating federated machine learning algorithms for predictive waste generation modeling and dynamic route optimization, thereby further advancing the system's contribution to sustainable and inclusive smart city infrastructure.

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