Smart Waste Management System for Sustainable Urban Life for IoT-Based Smart City Solutions

***Abstract*—In the pursuit of establishing urban environments that are both sustainable and conducive to quality living, the optimization of waste management processes stands as a crucial imperative. In light of these considerations, the modernization of waste management systems emerges as an undeniable necessity. Traditional methodologies suffer from inherent limitations, primarily stemming from the lack of real-time oversight over waste receptacles, often subject to haphazard utilization by individuals. Addressing this issue, the integration of the Internet of Things (IoT) technology presents a transformative opportunity. This study undertakes a thorough exploration of IoT's potential and, consequently, propounds an architectural framework for a smart city waste management system grounded in IoT principles. The principal objective of this framework is to showcase the manifold applications of IoT in orchestrating efficient and adaptable waste management solutions, particularly focusing on challenges related to scalability and flexibility. Central to the proposed system architecture are ultrasonic sensors that meticulously monitor the fill levels of waste containers, engendering an intelligent responsiveness. This information is subsequently communicated to designated waste collection units via SMS messages, accompanied by precise GPS coordinates, facilitated by GSM communication channels. A symbiotic relationship between the waste truck drivers and the central server is established, wherein drivers relay information concerning waste accumulation for streamlined orchestration. Empirical validation of the proposed technology yields compelling results, affirming its efficacy. A remarkable accuracy rate of 91% in monitoring trash containers' status and an impressive 89% precision in tracking waste disposals underscores the system's proficiency in enhancing waste management practices.**

***Index Terms*—Internet of Things(IoT), Smart City, 5G, Garbage Management System, GPS Sensor(Neo-6m), Gas Sensor(MQ-7), NodeMCU, Force Sensitive Resistor, Ultrasonic Sensor(HC-SR04).**

I. Introduction

To enhance the quality of life within urban centers, the implementation of "smart municipal" initiatives has emerged as an imperative undertaking. However, the proliferation of smart city applications, encompassing domains like healthcare, intelligent transportation, retail, and firefighting, has engendered a substantial influx of data. The adept management of these voluminous and persistent data streams stands as an ongoing subject of discourse. Concurrently, the escalation of environmental perils has kept pace with the burgeoning human population. The ramifications of improper waste disposal pose dire threats to human well-being and ecological equilibrium. Waste management, an encompassing sphere spanning collection, disposal, treatment, and recycling, is pivotal in mitigating these hazards.

Remarkably, the global population annually generates a staggering 2.12 billion tons of refuse. Projections indicate that by 2050, the worldwide production of municipal solid waste is anticipated to surge by almost 70%, reaching a towering 3.88 billion metric tons. This trajectory is influenced by an amalgamation of variables, including population surges, urbanization trends, economic expansion, and evolving consumer behaviors. As the volume of waste escalates into a global predicament, the historical precedent of waste disposal—often involving rudimentary burying—stands inadequate. This historical practice, once efficacious due to lower populations, has proven insufficient amidst contemporary demographics that yield escalating waste volumes.

As the legacy waste management paradigm grapples with this modern reality, a pressing question emerges: How can a forward-looking smart waste management framework coalesce with a 5G-enabled Internet of Things (IoT) infrastructure to foster an integrated smart city model? The IoT is poised to assume a pivotal role in the genesis of a smart waste management system within the ambit of a 5G-empowered urban milieu. This research endeavor endeavors to chart the course towards a symbiotic interplay between IoT and smart city paradigms, charting a trajectory towards sustainable urban environments.

II. Literature Review

G. K. Shyam have studied a garbage collection management method based on equipping trash cans with intelligence using an (IoT) prototype with sensors. It can read, gather, and transmit huge quantities of Internet-based data. When placed in a spatiotemporal context and processed by sophisticated and optimized algorithms, such information can be used to dynamically manage trash collection processes. [1]. Using several sensor S. Kumar. developed a system that monitors the amount of garbage in waste bins. This mechanism warns authorized parties through GSM/GPRS [2] as soon as it is discovered.

A. Singh proposed a technique employing infrared sensors to collect real-time data from waste bins and the Raspberry Pi2 Development Board to transmit this data to waste management [3].

Al Mamun have presented a new framework that permits the remote, real-time monitoring of solid waste bins via ZigBee-PRO and GPRS in order to facilitate the solid waste management process [4]. The system structure was built on a wireless sensor network and had three levels: a smart bin, gateway, and control station that stored and evaluated the data

for further use.
S. Longhi built a system based on sensor nodes and employing Data Transfer Nodes (DTN) to transmit garbage bin-filling data measurements to distant servers via Data Transfer Nodes [5].

W. Reshmi et al. created a system that utilizes a biosensor sensor, a weight sensor, and a height sensor to detect the overflow of waste in the trash can and the level of pollution caused by the release of poisonous gases from the trash can [8]. In this system sensor unit was used for sensing, a microcontroller for controlling and for communicating the GSM module is utilized.

V. Catania [9] developed a method for waste collection in which bins' levels of fullness are monitored in real time by sensors installed within the containers.

S. Islam presented an integrated system that incorporated RFID, GPS, GPRS, GIS, and a web camera. The RFID reader fitted into collection vehicles would automatically retrieve a variety of customer data and bin data from RFID tags attached to each bin. GPS would provide the collection truck's location information [6].
J. Joshi [11] have developed a solution for the Smart Bin, which is a network of garbage cans that integrates the (IoT) with a Stack-Based Front-End strategy for integrating Wireless Sensor Network with a focus on software.

N. Kumar [12] have developed a smart alert system for garbage clearing by sending an alert signal to the municipal web server for immediate dustbin cleaning with proper verification based on the level of waste accumulation. They used an ultrasonic sensor, RFID, and Arduino UNO to monitor the level of rubbish in the trash can and notify the municipal web server if the bin is full. He suggested that once the system verifies that the trash cans are completely full, they should be emptied using an IR device, GSM mode, and microcontroller. Once it's it, it should be reportable to the contractor's superior authority. It decides that the environment is clean and reduces the total number of visits made by the garbage truck.

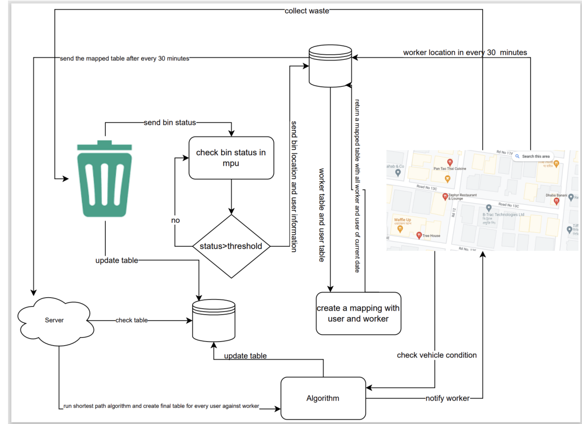

Fig. 1. Proposed Smart Waste Management System

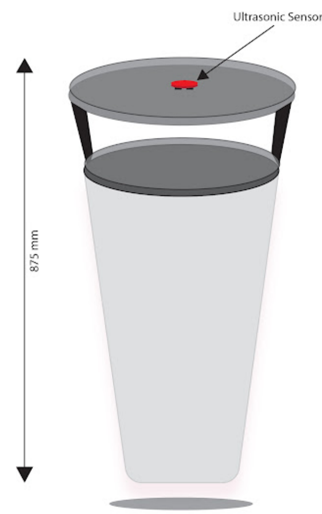

Fig. 2. E-Bin

PROPOSED MODEL

Our proposed smart waste management system that is visualized in Fig[1] can not only handle garbage more intelligently, but it can also handle a heavy load due to the high population and industry.

A. Model Design

Our system has three different sections. E-Bin shown in Fig 2, System, and Service-end. Together they complete the whole smart waste management system. Starting with the garbage collection to drop off at the dumping station is a long process.

1) E-Bin: The need for an upgraded approach to trash collection and disposal holds significance not only in Bangladesh but across global contexts. In response to this exigency, we have introduced an innovative solution termed the E-Bin shown in Figure [2]." The concept of the "E-bin" entails a paradigm shift towards fully automated waste receptacles that harness an array of advanced sensors to autonomously gauge their fill status. This real-time decision-making capability determines the appropriateness of trash collection interventions, thereby streamlining waste management processes. The core architecture of the E-Bin establishes a dynamic connection with a central server, facilitating seamless and efficient operations.

The technological realization of this automated waste management endeavor rests upon the integration of key components, including the NodeMCU microcontroller, ultrasonic sensor, and gas sensor. The NodeMCU microcontroller orchestrates the automation process, functioning as the central control unit. At regular 10-minute intervals, the microprocessor within the E-bin assesses the fill status. Once the fill level surpasses a predefined threshold, the microprocessor instantaneously updates the central database with the latest information, encompassing timestamped data to facilitate effective system administration.

The ultrasonic sensor, positioned within the bin, accurately gauges fill levels by calculating distances through sound reflection and a known time frame. This height measurement informs the decision-making process based on predefined threshold parameters. Additionally, the automated system incorporates a gas sensor adept at detecting combustible or hazardous gases. This sensor employs piezoelectric materials to discern gas concentrations, enabling swift responses to potential gas leaks. The simultaneous deployment of both ultrasonic and gas sensors empowers the system to transmit pertinent data to cloud-based repositories, fostering comprehensive data-driven insights.

2) System: The system's schematic representation is depicted in the above figure, elucidating the inter connectivity and communication pathways among the distinct processes, database operations, and the waste bin entity. The primary cornerstone of this architecture is the micro-controller, endowed with Internet connectivity capabilities. To facilitate seamless data transmission to the server, we have devised an API framework, access to which is limited to authorized users and administrators. To interface with the server, MySQL has been employed for data retrieval, employing the FreeMySQL-Hosting database hosting service, wherein an administrative dashboard is established.

The administrative dashboard assumes a pivotal role, serving as the gateway for server interactions and execution of SQL operations such as insertion, deletion, selection, and data updates. Real-time geo-location visualization is empowered by the integration of the Google Maps API key, affording dynamic mapping features. Notably, this API key is leveraged within our micro-controller setup to acquire the current vehicle location, effectively capitalizing on the geo-location JavaScript function in tandem with the GPS module.

Within the system, three distinct user categories are identified:

User: Post successful registration, users are granted access to our service suite, facilitating activities such as complaint submission, feedback provision, and assistance requests, encompassing a comprehensive array of service requisitions.
Admin: A dual-interface system comprising web and app versions has been developed to empower administrators with enhanced system oversight. Administrators enjoy uninhibited access to all system components, affording functionalities like initiating calls, messaging, email communication, and location tracking for both workforce and users. This comprehensive vantage point enables effective system monitoring and management.
Worker/Vehicle: At the operational forefront, workers or field vehicles embody the beneficiaries of our service. Following a rigorous registration and assessment procedure, workers are selected based on physical fitness, aligning with our stringent workforce criterion. These workers execute garbage collection tasks at diverse residential locations, thereby contributing significantly to waste management endeavors.

3) Service-end: The demarcation of service regions stems from the data furnished during the registration process. Integral to the registration form is the collection of pertinent information, including user or employer addresses and worker identities. Augmenting this data acquisition is the integration of geo-location API, enabling the extraction of precise positional coordinates. In scenarios marked by concentrated user clusters within specific zones, resource allocation is optimized by deploying additional personnel from proximate suburbs. Tasked with the transportation of waste, workers facilitate the transfer to assigned urban receptacles or designated landfill sites. Notably, the waste management ecosystem is overseen by two distinct municipal corporations, collectively bearing the responsibility for waste segregation and management across the entirety of the urban expanse.

B. Proposed algorithm:

The algorithm's execution shown in Figure [3] entails the determination of the minimum distance, followed by the derivation of the heuristic value for A* search using Equation 1, a formulation that also furnishes insights into user-to-worker relationships.

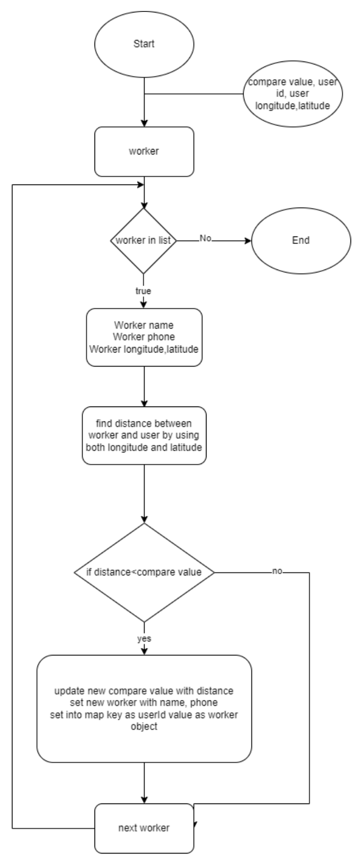

Fig. 3. Flowchart Of Proposed Algorithm.

Employing dual 2-dimensional arrays, we encapsulate essential data within the user and worker domains. The user array encompasses attributes such as user ID, geographical coordinates (longitude and latitude), as well as temporal details (date and time). Parallelly, the worker array houses pertinent data including worker name, date, time, contact details (email and phone number), and geo-location coordinates. Facilitated by the worker's phone number, proximity, and nomenclature, we establish a mapping linking users and workers.

The computation of the minimum distance between user bins and all available workers is realized via the distance measurement formula articulated in Equation 1.

$$d = \sqrt{(longitude_{user} - longitude_{worker})^2 + (latitude_{user} - latitude_{worker})^2} \quad (1)$$

C. Working Process

The schematic illustration depicted in Figure [4] elucidates the data transmission protocol to the server. The microcontroller assesses bin status, initiating a collection cycle when empty, or gauging fill levels for processing. The microprocessor iterates until the waste capacity crosses the stipulated threshold, promptly transmitting alerts to the server upon exceeding this threshold. Figure [5] delineates the backend operational dynamics. The microcontroller conveys bin-specific metadata, encompassing date, time, and location, subsequently subjected to user credential validation. Authenticated users are encompassed within the user database, wherein pertinent information like geographical coordinates, personal particulars, and registered addresses are stored. Following validation, the search vehicles module is furnished with requisite details, including location and timing.

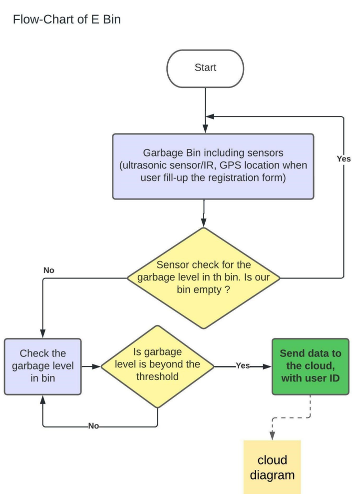

Fig. 4. Flowchart Of E-Bin.

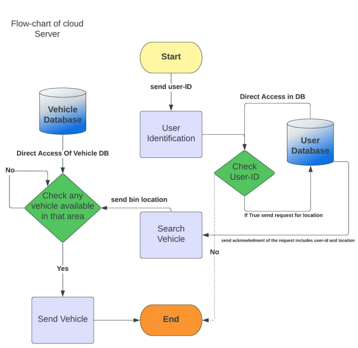

Fig. 5. Flowchart Of Cloud Server.

The microcontroller-facilitated update cycle governs the employee database, effectively correlating with real-time workforce movement. The microcontroller transmits employee location, thereby updating the worker table. Vehicle availability is determined through active searches, with proximity dictating the optimal vehicle for each task. If a nearby vehicle is detected, relevant notifications are disseminated to drivers, thereby synchronizing vehicle-bin rendezvous [6] is given below:

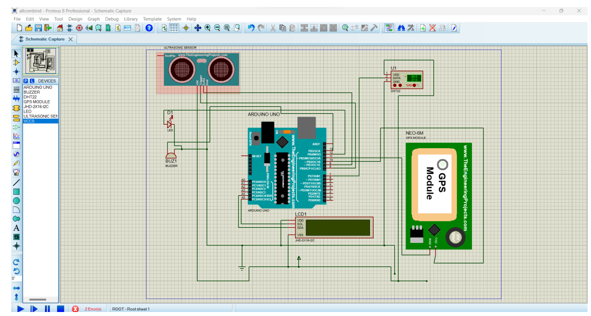

Fig. 6. Proteus Diagram for E-Bin Module

Conclusively, the system architecture culminates in a comprehensive amalgamation of operational stages. The accompanying circuit diagram shown in Figure [6] underscores the pivotal role of NodeMCU, serving as the microcontroller. This pivotal component orchestrates data flow from bin to server, leveraging its integrated Wi-Fi module for network connectivity. Our system's design is calibrated to adapt to evolving Wi-Fi infrastructure, particularly in contexts like India.

The microcontroller interfaces with a range of sensors including ultrasonic and humidity sensors, alongside LCDs, buzzers, and LEDs. By designating a 10 cm threshold from the upper limit, the microcontroller promptly signals server alerts upon container capacity attainment. Additionally, distance ranges between 10 and 20 cm indicate imminent fullness. The marriage of user registration information with bin addresses fortifies our system architecture, substantiating each acknowledgment with comprehensive data encompassing date, time, location, status, threshold, and prevailing circumstances.

III. Result

The E-Bin system offers the capability to generate trash status reports and employ model-based mapping. To validate the system's efficacy, we conducted a comparative analysis between system-generated report data and real-world test data. Actual bin heights were measured using a scale to provide empirical insights. We subsequently constructed a data table within the system, and compared it with the acquired test data.

A. Test Case:

Initially, data was extracted from trash bins, as shown in Table [I]. This information was manually derived through bin inspection involving three randomly selected consumers. The table illustrates that User ID 12 exhibits 10 cm of open space

TABLE I
TAST CASES AND RESULTS:

User ID	Test Case Bin Status	Test Data	Expected Result	Output	Bin Status	Result
12	The dustbin is filled completely	Less than 10cm	Filled	Filled	Full filled	Pass
12	Dustbin is almost full	12cm	Almost Full	Almost Full	Almost Full	Pass
34	Dustbin is half filled	23cm	Not fully filled	Half filled	Half filled	Pass
27	Dustbin is half empty	53cm	Empty	Empty	Empty	Pass

atop the bin, breaching the bin capacity threshold and necessitating collection. User ID 34 displays 23 cm of clearance above the trash, classifying it as a half-filled bin (15–30 cm). Consequently, prompt collection is not imperative. For User ID 27, 53 cm of unoccupied space is observed, falling beneath any threshold limit, yet the bin remains empty. An additional test case for User ID 12 yielded a measurement of 12 cm, implying near-fullness since the threshold limit indicates nearly full at 11–15 cm. Table [II], a system-generated report garnered from the server, is anchored on data supplied by the E-Bin module. Ultrasonic sensor readings were employed in this instance to ascertain bin status. The system employs a multi-tiered threshold approach: the first being less than or equal to 10 cm indicating fullness, the second indicating near-fullness, established between 11 and 15 cm, and ceasing communication with servers beyond 15 cm.

Cross-referencing the server database Table [II], we infer that User ID 12's bin status is nearly full. This aligns with Table I, wherein the last received data corresponded to a 12 cm status, signifying near-fullness. Notably, the system database incorporates an additional entry for User ID 12, reflecting the previous full status. However, as the server's data is the most recent, it prevails based on the current date and time. A comparison of both tables validates the congruence of test and system data. For User ID 34, the system denotes half full, consistent with the test case database, thereby passing validation. Notably, User ID 27 lacks data in the system database, given that data transmission only transpires when the threshold deems the bin nearly full or empty.

Moreover, Table [II] includes supplementary worker information such as IDs and locations. The algorithm utilizes this data to facilitate mapping and further refines it, culminating in Table [III]. In the initial assessment scenario, focusing on the process of bin state verification, we achieved an accuracy level of up to 92%. Notably, while the server's recorded status for User ID 12 was set at 12 cm, our physical measurement yielded a value of 11.7 cm. However, in other instances, our test data exhibited congruence with manual testing outcomes. Similarly, during worker position acquisition, our GPS module demonstrated an impressive 98% accuracy rate. However, it's pertinent to note that there was a marginal delay in obtaining the location data from the GPS module.

The GPS module operates on the NMEA data format, facilitating its compatibility across a spectrum of GPS devices and enabling developers to harness this data for their GPS applications. Notably, this geolocation approach exhibits a minor 10–15% discrepancy, potentially leading to positional deviations of up to 10–15 meters. Nevertheless, our trash can monitoring system maintains a commendable 91% accuracy rate.

B. Discussion

The furnished table encapsulates comprehensive data pertinent to individual user requests for waste collection, intricately linked to designated workers via unique IDs. Our microcontroller initiates data transmission to the server under conditions where the trash can capacity exceeds 85%, with over 70% capacity deemed as nearing fullness. Evidently showcased in the table, data is relayed at 30-minute intervals, superseding prior entries and thereby ensuring storage efficiency. The server autonomously generates this tabular representation, which subsequently serves as the substrate for our algorithmic traversal according to a tree structure. This traversal facilitates the establishment of user-to-worker mappings, ultimately culminating in the formation of Table [III].

By virtue of this table, the delineation of allocated tasks for waste collection, intertwined with user-specific details, is vividly elucidated. User identification within this table equips us to access user particulars, thus enabling real-time tracking of both workers and users. Further optimization is realized through the deployment of an application designed to enhance system efficiency.

In accordance with references such as [**?**], the incorporation of RFID technology has been proposed to facilitate bin tracking. However, the economic constraints of regions like Bangladesh underscore the infeasibility of this approach, given the relatively high cost associated with providing unique identifiers for each container through RFID sensors. To address this challenge, we ingeniously devised a user registration framework wherein database entries automatically generate distinct identifiers for individual users, authenticated through user logins. Unlike alternate systems such as the one outlined in [6][5], which resort to GPS modules for trash can positioning, our approach diverges due to standard GPS modules' inoperability within confined spaces and their protracted satellite connection establishment time. With minimum GPS module prices hovering around 800-900 TK, their adoption is ill-suited for a developing nation like Bangladesh. Our innovative solution pivots on the utilization of geo-location APIs during user system registration. By leveraging the geo-location API, user positions are swiftly determined, thereby furnishing them accessibility through a gamut of devices, including mobiles and PCs. This pragmatic approach, founded on user consent, embodies cost-effectiveness and rapidity as its hallmark attributes.

The research paper [**?**] elucidates the development of a smart bin embedded with sensors including a hall effect sensor, accelerometer, and ultrasonic sensor. However, their focus remains devoid of a comprehensive method for garbage collection or disposal. The utilization of an accelerometer and hall effect sensor to determine the bin's status was a notable aspect of their approach. In contrast, our model offers

TABLE II
BIN STATUS DATA FROM SERVER

Date	Time	UserID	Email	Longitude	Latitude	Situation	Time	Worker ID	Phone Number	Vehicle Longitude	Vehicle Latitude	Status height
2022-01-12	2:12 PM	12	rimon@gmail.com	98.7861884255	23.653329078	Almost Full	1:56 PM	56	01736686396	98.7852309238	23.65145097163	Empty height
2022-01-12	2:37 PM	34	semon@gmail.com	98.7709561256	23.673409234	Half Full	2:04 PM	67	01945163820	98.7830967135	23.65004867135	Empty height
2022-01-12	2:51 PM	21	rim2@gmail.com	98.7702394538	23.6718734235	Full	2:25 PM	31	01817470168	98.7953347613	23.67243993415	Empty height

TABLE III
ASSIGNED WORKER TABLE

Date	Time	UserID	Worker	WorkerID	Longitude	Latitude	Time	Phone	Staus
2022-01-12	2:12 PM	12	Jamal	56	98.785230923	23.6514509716	1:56 PM	01736686396	Assigned
2022-01-12	2:37 PM	34	Kamrul	**67**	98.7830967135	23.65004867135	2:04 PM	01945163820	Assigned
2022-01-12	2:51 PM	27	Samim	31	98.7953347613	23.67243993415	2:25 PM	01817470168	Assigned

a more comprehensive solution, encompassing waste disposal, garbage collection, and bin status monitoring. Furthermore, the approach detailed in [**?**] incorporates RFID for data storage with unique identifiers and employs a GPS sensor within the container. Conversely, our model introduces a cost-effective alternative, substituting these expensive modules with a simplified user registration mechanism empowered by geolocation technology, which outperforms GPS within indoor environments. It's crucial to highlight that [**?**] presents test cases with undefined bin volume values, a limitation absent in our model which accurately detects bin status and transmits data to the server.

IV. CONCLUSION

In conclusion, the potential of the Internet of Things (IoT) is boundless. By leveraging large-scale implementation, strategic deployment, and meticulous management, IoT, urban data platforms, big data, and artificial intelligence have the transformative capacity to render our urban centers intelligent, sustainable, and highly efficient. This paper has elucidated the conception and implementation of an integrated waste management system driven by the Internet of Things, marked by automation and streamlined information sharing.

As our global population surges, coupled with rapid industrialization and urban expansion, the ecological balance faces mounting threats. The inadequacies of traditional waste management methods are becoming more apparent, necessitating innovative approaches. The collaboration between municipalities and waste management entities is paramount to ensure the realization of a circular economy while safeguarding citizen well-being and quality of life. Looking ahead, the trajectory of research and development should encompass the automation of both domestic and industrial waste collection, coupled with enhanced dump station processes capable of sorting and dispatching waste by category. By orchestrating a holistic approach from waste generation to disposal and recycling, our vision for a harmonious synergy between ecological sustainability and smart city evolution will come to fruition.

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