DEVELOPMENT AND IMPLEMENTATION OF A WASTE MANAGEMENT INCENTIVE PROGRAM DATABASE FRAMEWORK

**SUBMITTED BY**

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# CERTIFICATION

This is to certify that this project was carried out by ABAH SUCCESS MONDAY with the matriculation number 170408034 in the Department of Electrical and Electronics and Computer Engineering, Faculty of Engineering, University of Lagos under the supervision of DR. (MRS.) O. A. OGBOLUMANI

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# ABSTRACT

This project focuses on the creation of an advanced database framework to revolutionize waste management practices. By integrating modern technologies and innovative strategies, the project aims to optimize waste collection, monitoring, and recycling processes. The framework aligns with global sustainability goals, particularly in promoting public health, environmental well-being, and resource conservation.

This project represents a significant contribution to addressing the critical environmental issue of waste management. Through a meticulous exploration of data acquisition, storage, analysis, and reporting, the project demonstrates a comprehensive approach to smart waste management. Utilizing real-time monitoring, historical data analysis, and user-friendly interfaces, the framework offers a robust solution for efficient waste handling. The incorporation of incentive-based recycling programs and mobile applications further enhances user engagement and participation in sustainable waste practices.

This project underscores the pivotal role of database management in modernizing waste management systems and underscores the importance of technological innovation in addressing environmental challenges. By advocating for the adoption of the Reduce, Reuse, Recycle (3Rs) framework and incentivizing proper waste segregation, the framework promotes a culture of environmental responsibility and resource efficiency. Overall, the Waste Management Incentive Program Database Framework project represents a significant step towards achieving a cleaner, healthier, and more sustainable future.

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# LIST OF ABBREVIATIONS

* + - * **AI** – Artificial intelligence
      * **MCU** – Microcontroller Unit
      * **IR** – Infrared Sensor
      * **RF** – Radio Frequency
      * **GPS** – Global Positioning System
      * **IDE** - Integrated Development Environment.
      * **LCD** – Liquid Crystal Display
      * **GSM** – Global System for Mobile Communications
      * **SMS** – Short Message Service
      * **BMS** – Battery Management system
      * **IC** – Integrated Circuit
      * **LED** – Light Emitting Diode
      * **ANN** – Artificial Neutral Network
      * **SDG** – Sustainable Development Goals
      * **IoT** – Internet of Things
      * **PLX-DAQ** – Parallax microcontroller Data Acquisition
      * **SIM** – Subscriber Identity Module
      * **DSRM** – Design Science Research Methodology
      * **LS** – Local Sink
      * **ESP** – Electronic Stability Programme
      * **DHT** – Digital Humidity and Temperature
      * **PCB** – Printed Circuit Board
      * DBMS – Database Management System
      * **API** – Application Programming Interface
      * **UI** – User Interface
      * **SQL** – Structured Query Language
      * **NoSQL** – Non-Structured Query Language
      * **IDE** – Integrated Development Environment
      * **SDLC** – Software Development Life Cycle
      * **HTTP** – Hypertext Transfer Protocol
      * **CRUD** - Create Read Update and Delete
      * **REST** – Representational State Transfer
      * **GPS** – Global Positioning System
      * **GSM** – Global System for Mobile Communications
      * **GPRS** – General Packet Radio Service

# CHAPTER ONE - INTRODUCTION

## 1.1 BACKGROUND

The world faces various environmental challenges, such as environmental deterioration, negative impact on ecosystem health and economic setbacks, all of which significantly impede human growth and development [1]. The timely increase in population, has resulted in numerous reports highlighting the adverse consequences of prolonged accumulation of waste [2], [3]. Failure to timely dispose of such waste, poses significant risks to human health, leading to illnesses and emitting unpleasant odors, thereby rendering the environment uninhabitable [4]. Efforts to address environmental challenges and alleviate their adverse effects have prompted the exploration of various strategies to manage waste effectively [5]. These endeavors seek to foster healthy living and enhance methodologies geared towards waste minimization, thereby promoting sustainable practices.

An efficient waste management system yields substantial benefits by aligning with and contributing to the attainment of several Sustainable Development Goals (SDGs) such as SDG 3 (Good health and well-being), SDG 6 (Clean water and sanitation), SDG 11 (Sustainable cities and communities), SDG 12 (Responsible consumption and production), SDG 13 (Climate action), SDG 14 (Life below water), SDG 15 (life on land), SDG 17 (partnership for the goals). A well-structured waste management framework facilitates the reduction, reuse, and recycling of waste materials, thereby fostering sustainable development objectives [6, p. 961].

The advent of the Internet of Things (IoT) has significantly contributed to the resolution of various challenges ranging from difficulty in monitoring and managing remote devices to manual and inefficient processes in various industries, down to inefficient management of resources and more. Through a profound comprehension of technology and targeted research aimed at problem-solving, numerous technological solutions addressing real-time issues have emerged in various sectors. In the medical health sector, examples include medical freezers, remote health monitoring, and symptom prediction devices. The industrial sector sees the development, design, and integration of various useful sensors in industrial applications. In waste management, smart coordination of waste trucks, efficient devices for waste utility companies, bin vibration and tilt detectors, and temperature detectors are among the advancements. [7], [8]. IoT, serves as a network that connects objects, playing a crucial role in engaging with devices like sensors, microcontrollers, motors, and other electronic components, thereby offering tangible solutions to real-life problems like health challenges, transportation issues, agricultural challenges, industrial challenges, and more [3], [9].

In addressing sustainability concerns and minimizing the adverse effects of poor waste management, the Internet of Things (IoT) is utilized to enable real-time monitoring and implement an incentive-based recycling system for a smart waste management solution. For the implementation of this system, it is essential to establish effective communication between devices, with the aid of dedicated software. Databases assume a pivotal role in the modern world of information technology, as management systems undergo continual evolution. Database refers to a software system designed for the storage and organization of data. These databases are created and operated through specialized tools, commonly referred to as Database Management Systems [10]. As the database serves as a storage for various data, it requires proper definition before data can be stored. The data involved in the real-time monitoring and incentive-based recycling waste management system encompasses user data, waste bin and recycle bin data, collection truck data, administrative data, payment data, and additional categories [11]. The effectiveness of this system lies in its ability to collect waste, notify waste utilities upon reaching specified threshold levels in waste containers, and efficiently coordinate timely collection services [12]. This efficiency is achieved through a well-organized database [1], [13].

This paper advocates for environmental sustainability through the implementation of the Reduce, Reuse, Recycle (3Rs) framework and proposes an incentive-based recycling program integrated into the smart waste management system. By quantifying recyclable waste within designated bins and assigning points accordingly, the system aims to incentivize users to segregate recyclables from non-recyclables. This approach encourages proper waste segregation and ensures fair rewards without potential manipulation [14]. Solid waste management is essential for safeguarding the environment, minimizing diverse waste types, preserving the Earth, and even offering financial returns through recycling. It is a crucial practice as the health and welfare of the entire population rely on effective waste management [15].

## 1.2 PROBLEM STATEMENT

Recovering recyclable materials, conserving natural resources, and reducing or eliminating landfills present significant challenges and considering that composting for waste management often does more harm than good, it is crucial to explore alternative solutions. Strategies like recycling fees, regulations, and internet recycling systems have had limited success in improving recycling rates. The incentive-based recycling system is highlighted as a practical approach to elevate public engagement, potentially fostering higher and sustained participation in waste recycling activities.

This paper focuses on the database management of a real-time monitoring and incentive-based mechanism integrated into smart waste bins. This system quantifies recyclable materials, assigns points based on weight, and converts them into incentives. The design includes a user-friendly web and mobile application for calculating incentive points and establishing databases for various system components. The initiative aims to promote the 3R (Reduce, Reuse, Recycle) concept contributing significantly to environmental sustainability.

## 1.3 AIM AND OBJECTIVES OF STUDY

The purpose of this project is to design and implement a smart waste management system that utilizes real-time monitoring, encourages recycling behavior and leverages on data obtained to enhance the efficiency of waste management practices.

The specific objectives are to;

1. Develop a real time monitoring system for efficient recycling

2. Implement an incentive based recycling program for improved waste disposal.

3. Enable efficient database management and analysis for smart waste management.

## 1.4 SCOPE

This project centers on developing a smart waste management system with a core focus on database management. It involves creating, managing, and analyzing data for real-time monitoring of waste levels in bins, issuing alerts upon reaching capacity, and determining when bins are full. The system also integrates an incentive-based recycling program to reward users for proper waste segregation. The goal is to make a substantial contribution to the sustainability of living environments, through smart waste management system.

## 1.5 REPORT OUTLINE

The report consists of five chapters.

In the first chapter is an overview of the project, which provides information such as background, aims and objectives, scopes and so on. The second chapter contains the theoretical background and literature review. The third is on how the objectives, that is, the methodology to which the objectives in chapter 1, were achieved as well as discussions on major milestones and then, limitations. In the last chapter – the fifth chapter, concludes the work done as well as providing future recommendations for work in the field of this study – Real time monitoring and incentive based recycling for smart waste management system.

# CHAPTER TWO - LITERATURE REVIEW

This chapter reviews pertinent literature connected to this project, aiming to identify any design limitations where applicable. Furthermore, it offers a brief overview of the intended actions and objectives within the scope of this project.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| S/N | Title | Author(s) | Aim/Objectives | Methodology/method adopted | Supporting/underlining theory | Findings/result obtained | Recommendations/ conclusions | Gaps/challenges |
|  | A Lora-based IoT Sensor Node for Waste management Based on a Customized Ultrasonic Transceiver | Tommaso Addabbo, Ada Fort, Alessandro Mococci et. al. 2019. | 1. Usability of waterproof ultrasonic sensors for the measurement of waste level inside a trash bin 2. A solution is described to increase the directionality of the sensor | 1. The proposed sensing structure is integrated into a sensor node provided with a LoRa transmission module, that allows to employ it for the development of city-scale monitoring infrastructures 2. These solutions include the real-time tracking of the means of transportation, the analysis of the user’s behavior, the automatization of the disposal processes and the real-time measurement of the filling levels of bins and dumpsters | 1. Waste management is for sure among the services that can greatly take advantage of IoT technologies. 2. The concept of waste management refers to all the activities and actions that are undertaken to manage waste, from the moment of its inception to its disposal. In urban areas, this means to collect waste from trash bins or dumpsters (or even door-to-door), carry it to dumps or to recycling centers and then to its final disposal destination (for example incinerators) 3. Data transmission can be carried out by means of RFID (Radio Frequency IDentification) technology in which measured values are stored in the memory of an RFID transponder that can then be read through an ad-hoc RFID reader but the drawback is the short communication range that forces to operator the be within a few meters distance (less than 1 m for High Frequency or Low Frequency systems) from the bin. This solution is then not able to operate remotely. 4. Using GSM as wireless communication technology for remote data transmission, it was observed that cellular technologies have the big drawback of power consumption since GPRS, UMTS and LTE are energy hungry technologies, while also running costs are high due to the need of a SIM card, and then a subscription for each trash bin. 5. Where a Vehicular Ad-hoc Network (VANET) is designed, with the smart bins collecting information about their status and transmitting it through ZigBee connection to the nearest passing vehicle. The drawback of this solution is that the filling level is measured by means of laser diodes: in the context of smart bins, with a high level of dirt, fouling on the emitter or the transmitter may compromise the measurement | The paper was majorly centered on optimization and improvements of previous waste management system. It delved into the thorough process of waste management, analyzing the transportation process and making the whole process automatic, also ensuring that waste are only disposed when it is full. It aimed at reducing the number of hours worked by the operators and substantial reduction in distance covered by vehicles with positive effect on the pollution and traffic levels caused by the vehicles.  The filling level of the bin is measured by means of ultrasonic sensors. | 1. The system should scalable irrespective of sizes, it should still function similarly or even more optimized. | 1. Identifying the ideal ad-hoc cap sizes in relation to the bin dimensions, that is the scalability as the bin increases in size, there should be an ideal cap size to fit into it still.  2. It is battery powered. |
|  | Smart Waste Bin System: a review | Ayodeji Noiki, Sunday Afolalu, Abiodun Abioye, Christian Bolu et al. 2021 | systematic review of existing literatures, identifying and characterizing active research activities on smart waste bin that will allow effective waste management | Some solutions generated to help manage waste are;   1. Automated Teller Dustbin 2. Segregation Smart Dustbin 3. Robot Smart Waste Bin 4. IOT Based Smart Waste Bin 5. GSM/ Wifi Based Smart Waste Bin | 1. Urbanization and population growth lead to increased waste generation. 2. Traditional waste management practices are inadequate for current waste levels. 3. Smart waste bins offer a potential solution for effective waste management. 4. Cost remains a barrier to widespread adoption of smart waste bins. 5. Environmental sustainability is a major concern in waste management. 6. People's changing lifestyle contributes to increased waste generation. 7. Proper waste disposal is crucial for public health. | 1. Extensive research exists on smart waste bins and their potential applications. 2. Despite research successes, deployment remains limited in developing nations. 3. Cost-effectiveness remains a critical challenge for widespread adoption. 4. Recent advancements suggest a promising future for smart waste management. 5. Urgent need for deployment in developing nations for environmental sustainability. 6. Traditional waste management practices are inadequate and detrimental to public health and environment. 7. Smart waste bins offer a potential solution for effective waste management. 8. Environmental sustainability is a major concern in waste management. 9. People's changing lifestyle contributes to increased waste generation. 10. Proper waste disposal is crucial for public health. | 1. Indicating the level of the waste and predicting when it would be full by the result of the present waste level. 2. The system should be able to separate objects automatically without manually labelling it. | 1. Need for frequent check of waste, to avoid waste overflow 2. The need to label waste object and, counting to assign prices. 3. Time taken after message is sent to whoever is supposed to empty the waste bin when full. 4. Totally separating biodegradable and non-biodegradable waste 5. Cost of implementation. 6. Temperature, fire outbreak and plundering (theft) repulsion |
|  | Design And Construction Of A Smart Dustbin System With Internet of Things (IoT) Notification. | Udeani et al. 2022 | To enhance waste management procedures, thereby reducing the overhead cost of manual waste management. | It uses Internet of Things as the medium to establish communication between dustbins, collection truck drivers and waste management agencies. | 1. Internet of Things (IoT): Real-time information gathering and communication between the dustbin and waste management system via sensors and GSM modules. 2. Sensor Technology: PIR and ultrasonic sensors detect user presence and waste level, enabling automated lid operation and status updates. 3. Microcontroller Programming: Atmega328p microcontroller processes sensor data and controls actuators like the servo motor for lid operation. 4. Web Interface Development: HTML, CSS, and PHP create a user-friendly platform to monitor bin status and interact with the system. | 1. Improved waste management: The smart dustbin system can optimize waste collection by notifying authorities when bins are full, preventing overflow and reducing waste collection frequency.  2. Reduced overhead cost: Automation of waste collection can significantly reduce the manpower and resources required, leading to lower operational costs for waste management.  3. Increased efficiency and sustainability: Real-time data on bin levels facilitates efficient route planning for waste collection vehicles, minimizing fuel consumption and environmental impact.  4. Improved sanitation and health: Timely waste collection prevents overflowing bins and reduces the risk of diseases associated with improper waste management.  5. User-friendly interface: The web interface provides users with real-time information about bin status and facilitates communication with waste management authorities. | A GPS system can be embedded to the system in order to solve the navigation challenge. | An extension to this system can be the integration of a mapping system that will help in navigation issues to the location of the dustbin whose content needs to be disposed by the management agents. |
|  | Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals A case study of Indonesia. | Fatimah, Yun Arifatul; Govindan, Kannan; Murniningsih, Rochiyati; Setiawan, Agus. 2020. | To investigate the fundamental issues and opportunities and to develop a sustainable and smart country-wide waste management system using industry 4.0 technologies. | It uses industry 4.0 technologies for real time monitoring and optimization of waste. | 1. Circular Economy: The proposed system embraces circular economy principles, aiming to minimize waste generation and maximize resource recovery through efficient sorting, processing, and reuse of materials. 2. Industry 4.0 Technologies: The system leverages technologies like IoT, sensors, and data analytics for real-time monitoring, optimized waste collection routes, and improved decision-making. 3. Maturity Model: The research introduces a maturity model to assess the current state of waste management, enabling targeted interventions and development strategies. | 1. Identification of Current Waste Management System: The study analyzes the current waste management practices in Indonesia, highlighting inefficiencies and gaps in collection, sorting, and disposal processes. 2. Maturity Level Assessment: The developed maturity model classifies the current system's performance, revealing areas for improvement and potential for advancement. 3. Sustainable and Smart Waste Management System Design: The research proposes a novel waste management system utilizing IoT and circular economy principles for improved efficiency, resource recovery, and environmental sustainability. | Limitations in sensor accuracy and data analysis methods need further exploration. | 1. some technical challenges such as limited type of sensors, complexity of system, and limited mechanical technology, all of which are to be overcome before product development  2. To strengthen the classification of waste management maturity levels, and to improve the determination of thresholds. |
|  | Application of Smart Waste Management System: Case Study for Queen II Hospital, Maseru Lesotho | Makamohelo Valentine Mathe. 2019. | To overcome all these unfavorable conditions such as trash overflow, land and air pollution and unclean and unhealthy environment by mitigating the waste that are always found scattered. | 1. Use of Arduino microcontroller connected to ultrasonic sensor to excel communication  2. PLX-DAQ, a Parallax microcontroller data acquisition add-on tool for Microsoft Excel” (Parallax Inc. , 2019) | 1. Internet of Things (IoT) principles: Sensors embedded in smart bins collect real-time data on waste levels, enabling remote monitoring and analysis. 2. Ultrasonic sensor technology: Measures the distance to the trash surface, providing an accurate estimate of the bin's fullness. 3. Arduino microcontroller programming: Processes sensor data, controls communication with the Excel platform, and potentially actuates lid mechanisms. 4. Data management and visualization with Microsoft Excel: Stores and analyzes collected data, generating reports and graphs for waste management personnel. | 1. Real-time monitoring of bin levels: Eliminates the need for manual inspection, allowing for timely collection before overflow. 2. Improved efficiency in waste collection routes: Data analysis optimizes truck schedules and minimizes unnecessary trips, reducing fuel consumption and costs. 3. Enhanced data-driven decision making: Visualization of waste generation patterns informs waste management strategies, resource allocation, and infrastructure development. 4. Reduced environmental and health risks: Timely collection prevents overflow, minimizes pollution, and improves hygiene, potentially leading to lower rates of respiratory diseases and infections. | Design should be scalable and cost efficient. | Cost-benefit analysis and infrastructure upgrades necessary for large-scale implementation. |
|  | Development of Smart Rubbish Bin Connected with SMS Gateway Based on Arduino Uno | Siti Aisyah et al. 2022. | This research aims to design an automatic trash can with an ATMega328 microcontroller, Liquid Cristal Display (LCD), HC-SR04 sensor, buzzer, and SIM800L | 1. The HC-SR04 sensor is used to detect the presence of humans and the capacity of the trash can using ultrasonic waves  2. The buzzer is used for sound notification when the trash can is full  3. The LCD is used to display data and then the SIM800L is used as a notification for sending messages to the cleaners to facilitate their work in transporting garbage | 1. Human-computer interaction (HCI): The system utilizes sensors and actuators to interact with users, providing a touchless and convenient experience for waste disposal. 2. Sensor technology: Ultrasonic sensors offer a reliable and non-invasive method for detecting human presence and measuring fill level, ensuring accurate and efficient operation. 3. Microcontroller programming: The ATMega328 microcontroller serves as the central processing unit, controlling the various components and implementing the desired functionalities. 4. Cellular communication: The SIML800 module enables real-time notification of cleaners, optimizing waste collection logistics. | 1. Automatic lid opening and closing: The trash can lid opens and closes smoothly in response to human presence and fill level. 2. Accurate capacity measurement: The HC-SR04 sensor effectively measures the trash can's fill level, triggering alerts and notifications at the appropriate threshold. 3. Buzzer and LCD notifications: The system provides clear visual and auditory cues regarding the trash can's status, promoting user awareness and action. 4. SIML800 functionality: The cellular module successfully sends text messages to designated cleaners, ensuring timely waste collection. | Ensuring that there is constant accuracy for sensors. | Sensor accuracy |
|  | Design and Development of Smart Trash Bin Prototype for Municipal Solid Waste Management | Feisal Ramadhan Maulana et al. 2018. | To create a prototype of waste management system has been developed, especially for the solid waste, focusing on segregation and garbage collection phase. | 1. **Problem Identification** 2. **Data Management and Visualization Design** | 1. Smart City Concepts: Integration of information technology with urban infrastructure and services to improve efficiency and sustainability. 2. Sensor Technology: Application of sensors like weight scales, cameras, and RFID tags for real-time waste level monitoring and type identification. 3. Internet of Things (IoT): Networked infrastructure for data communication between smart bins and waste management platforms. 4. Data Management and Analytics: Techniques for storing, analyzing, and visualizing waste data to optimize collection routes and resource allocation. | 1. Improved Waste Segregation: The prototype's sensor capabilities encourage users to separate waste types, promoting recycling and resource recovery. 2. Optimized Waste Collection: Real-time bin level data allows for dynamic route planning, minimizing unnecessary trips and fuel consumption. 3. Increased Operational Efficiency: The system reduces reliance on manual bin monitoring and collection schedules, potentially leading to cost savings. 4. Enhanced Data-Driven Decision Making: Visualization of waste data patterns informs policy development and resource allocation strategies. 5. Gaps with Recommendations: 6. Gaps: 7. Sensor Accuracy and Reliability: Further research needed to ensure accuracy in diverse waste types and environmental conditions. 8. Data Security and Privacy: Robust data encryption protocols required to protect user privacy and sensitive waste information. 9. Large-Scale Implementation and Cost-Effectiveness: Cost analysis and infrastructure development plans needed for wider adoption. 10. Public Awareness and Behavior Change: Educational campaigns and incentives required to encourage proper waste disposal and community engagement. | Encryption to safeguard data transmission and privacy. | Robust data encryption protocols required to protect user privacy and sensitive waste information especially in cases of incentives calculations. |
|  | Intelligent Trashcan Monitoring System Using Iot | Kavipriya.P, Supriya.A, et al. 2020. | To provide intelligent trash supervising where the level of trash measured is using an ultrasonic sensor and led lights to indicate the level. | 1. Machine learning: To analyse sensor data and predict future waste levels. 2. Cloud computing: To store and manage large amounts of data collected from the system. 3. Mobile app development: To allow authorities to monitor trashcan status and receive notifications on mobile devices. | 1. Public Health: Overflowing trash attracts pests and creates breeding grounds for diseases, negatively impacting public health. 2. Environmental Sustainability: Improper waste management pollutes the environment and depletes resources. 3. Efficiency and Optimization: Automation can improve efficiency and reduce costs in waste collection. 4. Technological Advancement: IoT technology offers innovative solutions for smart waste management. 5. Data-Driven Decision-Making: Real-time data collection and analysis support informed decision-making for waste collection. 6. Resource Management: Smart waste management systems optimize resource allocation and reduce waste. 7. User-Centered Design: The system should be user-friendly and accessible for effective adoption and use. 8. Scalability and Adaptability: The system should be scalable to accommodate different environments and adaptable to evolving needs. | 1. Overflowing trash cans negatively impact public health and create unpleasant odours. 2. Manual monitoring and waste collection are inefficient and costly. 3. The proposed Intelligent Trashcan Monitoring System addresses these issues by: 4. Utilizing an ultrasonic sensor to measure waste level. 5. Using LEDs to indicate the current level and alert authorities when full. 6. Leveraging microcontrollers for data collection and communication. 7. Transmitting data to a central server for monitoring. 8. This system can improve sanitation, reduce waste collection costs, and promote a cleaner environment. | Threshold should be set to about 70% to 80% level and system should be trained to predict when it will be at 100% | The time taken after notification is received and dirt is full already. |
|  | IoT Based Solar Powered Smart Waste Management System with Real Time Monitoring-An Advancement for Smart City Planning | Md. Humaun Kabir, Sujit Roy, Md. Tofail Ahmed & Mahmudul Alam | 1.To provide an IoT based solar-powered smart waste management system which is suitable for any kind city or town in both developed and developing countries that can ensure proper collection, transportation, and disposal of household and industrial waste with real-time remote monitoring | 1. Simulation 2. Prototyping designs | 1. IoT-based waste management: The system utilizes Internet of Things (IoT) technologies like smart bins, LoRa communication, and cloud computing for real-time monitoring and efficient waste management. 2. Solar power: The system leverages solar energy to power the smart bins, promoting sustainability and reducing reliance on traditional electricity sources. 3. Multiple technologies integration: The framework combines various technologies like WSN, AI, and route optimization algorithms for comprehensive waste management solutions. 4. Cyber-physical systems: The system utilizes cyber-physical systems (CPS) to automate waste management processes, leading to improved efficiency and accuracy. | 1. Real-time remote monitoring: The system allows for real-time monitoring of bin levels and collection/disposal activities, enabling efficient resource allocation and waste collection routes. 2. Improved waste collection efficiency: The system optimizes waste collection routes through shortest path algorithms, reducing fuel consumption and environmental impact. 3. Enhanced environment and health: Proper waste management reduces air pollution, unpleasant odors, and disease risks, contributing to a cleaner and healthier environment. 4. Scalability and applicability: The system framework is adaptable to different city/town sizes and waste generation levels, making it suitable for both developed and developing countries. | Facilities for sorting waste should be employed. | lacks details on waste sorting and recycling processes |
|  | Smart Segregation Bins for Cities Using Internet of Things (IoT) | K. Srisabarimani, R. Arthi, S. Soundarya, A. Akshaya, M. Mahitha, and Sruthi Sudheer | 1. Segregation of wastes which is performed with the help of sensors and few other components.  2. Monitoring the real time updates of the dustbin which is implemented using IoT. | Use of IR sensor, Ultrasonic sensor, and capacitive sensor to sense the presence of the waste, measure the level of the waste, and identify the presence of plastics. | 1. Waste Segregation Efficiency: Traditional manual segregation based on colours lacks accuracy and efficiency, leading to contamination. Sensor-based segregation using IR, ultrasonic, and capacitive sensors offers greater accuracy and real-time data for optimal waste categorization. 2. IoT-enabled Waste Management: Utilizing IoT technologies like cloud servers and Wi-Fi modules enables real-time monitoring of bin levels, temperature, and location, facilitating efficient waste collection and resource allocation. 3. Sustainability and Human Labor: The proposed system avoids replacing human labor by focusing on automation in segregation and monitoring, while manual collection ensures job security. This creates a sustainable solution that combines technological advancement with human involvement. | The test system results show that the trash can opens and closes automatically, detects the trash can's capacity, and all this is displayed by an LCD that has been adjusted to the system function | 1. Explore advanced sensors and AI algorithms for improved accuracy and better identification of different waste categories. 2. Teaching people on how to manage waste properly | 1. Uncertain accuracy in distinguishing plastic types and handling mixed/contaminated waste 2. Potential for damage or insufficient power, high energy consumption, lack of adaptability. 3. Concerns about data security and real-time optimization capabilities. 4. Lack of public knowledge and potential for misuse/vandalism. |
|  | A IoT-Based Smart Bin for Real-Time Monitoring and Management of Solid Waste | Aniqa Bano, Ikram Ud Din, and Asma A. Al-Huqail | 1. Proposing a smart bin mechanism that is based on IoT technology and applications  2. Real-time monitoring of the trash bins in a smart city  3. Reducing labor cost and optimizing resources, Improving environment goals and cleaning cities with limited resources. | 1. Garbage monitoring system (GMS)  2. Smart waste management by K-Query Scheduling, installing microcontroller module, GPS module, and ultrasonic sensor in trash cans.  3. Machine Learning- Based waste management system. | 1. The proposed framework reduces the labor cost and saves time and energy of the system. It also reduces the rate of disease infections by keeping the cities clean.  2. IoT is the hub of physical devices that are interlinked through the Internet. These physical devices, that is, sensors, RFID tags, and various intelligent nodes, can communicate at anytime from anywhere. | **1. Cities are facing numerous problems, including waste management.**  **2. Traditional waste management methods are inefficient and costly.**  **3. A novel smart bin mechanism (SBM) is proposed for smart cities.**  **4. SBM utilizes IoT technology for real-time monitoring of waste bins.**  **5. SBM reduces labor cost and optimizes resource allocation.**  **6. SBM improves environmental goals and cleans cities with limited resources.**  **7. Fuzzy logic is used for real-time monitoring and decision-making within SBM.**  **8. SBM provides real-time monitoring for climate change.**  **9. SBM offers a decision-making mechanism via a fuzzy inference system.**  **10. SBM supports the smart city concept.** | Alternative measures can be put in place, such as Solar or other sustainable ways. | 1. The system has lacking with respect to power interruption |
|  | An IoT-Based Smart Garbage Collection and Monitoring System | Taranpreet Singh Ruprah, Pramod Dharmadhikari, and Krunal Pawar. 2023 | The main purpose of this task is to lessen human assets and efforts along the enhancement of a smart city imaginative and prescient | 1. The implementation of IoT based dustbin is totally sensor based with the use of Raspberry Pi  2. The use of recipient/transmitter and sensor | 1. While the extent and weight of the bin reaches the threshold limit, the device will transmit the analyzing along with the precise identity provided  2. The paper offers information about the Internet application and android application | The exceptional sensors like weight sensor, moisture sensor and air quality sensor, and many others can be used to recognize weight and toxic level of trash in dustbin  The records procured through the sensors and dispatched to android software to reveal the vicinity and extraordinary records of dustbin | Instead of redirecting to the Google map application, the google map can be embedded into the mobile application for the waste management system. | After clicking on the notification, android software will open, and it will display the vicinity of stuffed dustbin in Google map |
|  | Design and Implementation of an Automatic Waste Segregation System | Shaiful Islam,  Shawkot Ahmed Talukder,  Md. Shamim Reza,  Abdal Ahmed Joy. 2022. | 1. To Design and Implementation of an Automatic Waste Segregation System.  2. To design and implement of Waste Monitoring & Notification system via internet. | 1. IOT are activated with the devices like sensor, motor and some UNO board or raspberry pi with some other kinds of microcontroller.  2. Using electronic components such as Node MCU, Ultrasonic Sensor and IFTTT web hooks in a smart dustbin | 1. IoT based smart dustbin is built on a micro controller - based platform Node MCU board which is interfaced with three Proximity Sensor, Ultrasonic Sensor & IR Sensor, Battery and Servo Motor | Ultrasonic sensor is used to measure the distance and level of the dustbin.  The Node MCU is used to upload the code and connecting with Wi-Fi.  IFTTT webhook is a server to send the notification.  Dustbin also send the mobile notification, when the dustbin is almost complete | There is need for a mobile with a very good notification signal for faster transmission. | The mobile should have a good notification signal from a carrier, to receive notifications very fast, if the mobile has not received a good signal, the notification will not be efficient. |
|  | Waste Monitoring System | U.D.R.L.Vijayanthi. 2020. | 1. To give an automated solution for any organization private or government who are handling waste collecting and monitoring, when having a large waste to manage and a manual process to monitoring waste  2. To establish a proper solution for waste collection and monitoring to enhance the quality of the environment | The methodology is aimed at requirement gathering, fact-finding, and identifying the functional and non-functional requirements of the system  This project used HTML, CSS, Angular, and Bootstrap, and C # as a programming language to develop web applications and used Android Studio to develop the mobile application | 1. Environmental Sustainability: Proper waste management protects the environment, conserves resources, and prevents pollution. 2. Public Health Protection: Proper waste management reduces the risk of diseases and promotes a cleaner environment, protecting public health. 3. Efficiency and Optimization: Automation minimizes effort and waste, leading to improved efficiency and cost savings. 4. Technological Advancement: Web-based solutions and mobile apps offer innovative solutions for real-time data and improved decision-making. 5. Resource Management: Categorization, scheduling, and tracking optimize resource allocation and prevent unnecessary waste. 6. Economic Considerations: Waste management system promotes economic sustainability by facilitating recycling and generating income for communities. 7. User-Centered Design: User-friendly features like registration, request sending, and status tracking prioritize user experience. 8. Data-Driven Decision-Making: Transporter tracking and client request management provide valuable data for informed decision-making. 9. Collaboration and Communication: Waste management system facilitates communication between users, administrators, transporters, and buyers. 10. Scalability and Adaptability: Waste management system can handle large volumes of waste and adapt to different organization needs for long-term sustainability. | **1. Solid waste management is a global issue.**  **2. Waste management system automates waste collection and monitoring for organizations.**  **3. Waste management system addresses inefficiencies in manual waste management.**  **4. Waste management system features request sending, transporter scheduling, tracking, and selling.**  **5. Users can register, send requests, and track status.**  **6. Administrators can register transporters, map categories/routes, track activity, and sell recycled waste.**  **7. Waste management system technologies include HTML, CSS, Angular, Bootstrap, and Android Studio.** | 1. Automate the Email system to buyers when the order level has reached  2. Introducing sensors for the client locations to measure the weight of the waste | 1. GPS Integration for the track of the transporter  2. Users feedback for improvements |
|  | A Smart Waste Management Solution Geared towards Citizens | Kellow Pardini, Joel J.P.C. Rodrigues, Ousmane Diallo, Ashok Kumar Das, Victor Hugo C. de Albuquerque and Sergei A. Kozlov, 2020. | To develop and implement an efficient and real-time smart waste management system based on an Internet of Things (IoT) approach, focusing on citizen engagement and improved waste collection optimization. | 1. Design & Build Smart Bin: Equip bins with sensors to accurately monitor waste levels and other data, optimizing collection and ensuring reliable data transmission. 2. Field Deployment & Data Collection: Gather real-world data on waste patterns and collection routes in a designated pilot area for system optimization and evaluation. 3. Data Analysis & Optimization: Extract insights from collected data to improve waste collection efficiency through route optimization and dynamic planning based on real-time bin status. 4. Citizen Engagement & Feedback: Encourage responsible waste disposal and improve system effectiveness through citizen interaction via mobile app and feedback channels. | 1. Internet of Things (IoT) Technology: IoT enables real-time data collection and communication between devices, allowing for smart monitoring and control of physical objects like waste bins. 2. Sensor Technology: Sensors integrated into smart bins can measure fill levels, temperature, and other parameters, providing valuable data for optimizing waste collection. 3. Cloud Computing and Data Analytics: IoT middleware platforms store and process sensor data, generating insights for efficient route planning and resource allocation. 4. Citizen Engagement: Engaging citizens through mobile apps and web interfaces promotes responsible waste disposal and improves system effectiveness. | 1. Reduced Waste Collection Frequency: Real-time data on bin fill levels allows for optimized collection routes, reducing unnecessary trips and fuel consumption. 2. Improved Collection Efficiency: Accurate data on bin status enables efficient allocation of resources, minimizing collection delays and missed bins. 3. Enhanced Environmental Impact: Reduced collection frequency and optimized routes lead to lower carbon footprint and improved air quality. 4. Increased Citizen Awareness and Participation: Access to bin availability information empowers citizens to make informed decisions about waste disposal, promoting responsible behavior. 5. Data-driven Insights for Policy and Planning: The system generates valuable data on waste generation patterns, informing policy decisions and future planning for waste management infrastructure. | 1. Continuously monitor and evaluate the system's performance and impact. 2. Adapt and refine the system based on data insights and user feedback. 3. Ensure transparency and communication with all stakeholders throughout the process. | 1. Data Security & Privacy: We need robust measures to safeguard citizen data throughout its journey, from collection to analysis, preventing unauthorized access and empowering citizens to control their information. 2. Scalability & Sustainability: Scaling the system efficiently requires a plan for managing costs and infrastructure challenges while ensuring long-term maintenance and adaptability to evolving needs. |
|  | Novel Mobile Application System for Implementation of an Eco-Incentive Scheme | Hua Huang, Daizhong Su and Wenjie Peng, 2022. | Introduce an eco-incentive scheme for sustainable consumption.  Develop a mobile application system to implement the eco-incentive scheme.  Evaluate the effectiveness of the system through a case study and user survey | Conceptualization of the eco-incentive scheme and system infrastructure.  Utilization of multiple mobile development techniques to implement the mobile application system.  Conducting a case study to demonstrate the application of the mobile app.  Validation of the mobile application system through a user survey.  Analysis of survey results and comparison with existing incentive systems.  Future investigation on applying the research approach in wider practice | Eco-accounting framework: Measures consumer sustainable consumption behavior by considering products' environmental impact (eco-cost) and rewarding positive behavior with eco-credits.  Application of multiple mobile development technologies: Utilizes Internet communication technologies, QR codes, barcodes, and APIs based on web services to enable the functions of the mobile application for the eco-incentive scheme.  Trustworthiness in value networks: Ensures secure and reliable network transmission for data exchange between the database server and the mobile application | 1. Development of a mobile application system for eco-incentives with four main function modules: user registration and login, viewing products' eco-information, obtaining eco-credits by recycling, and spending/donating eco-credits. 2. Successful illustration of the mobile application system through a case study and validation by user survey results. 3. Novelty of the research in providing a mobile application system with eco-incentive functions not found in existing applications. 4. Efficient support for consumers in recycling end-of-life products and managing their reward records through the mobile application system. 5. High performance and efficiency of the mobile application system, as evidenced by positive user feedback and performance testing results | 1. Recommendations for future improvements include enhancing user interface design, providing clearer instructions, developing an iPhone version of the app, and focusing on aesthetics and user-friendliness. 2. The mobile application system efficiently supports consumers in recycling end-of-life products and managing their rewards, enhancing awareness and implementation of recycling activities. 3. The research highlights the novelty of the eco-incentive scheme and mobile application system, offering unique features for incentivizing sustainable consumption 4. The performance testing results demonstrate the high efficiency and stability of the mobile application system, ensuring a quick response speed and effective resource allocation. 5. Overall, the study emphasizes the importance of eco-incentives in promoting sustainable consumption and provides a valuable framework for future research and development in this area | 1. Limited platform availability: The current version of the mobile application system only supports Android phones, indicating a gap in accessibility for iOS users 2. User experience issues: Some participants encountered difficulties in creating accounts, suggesting a need for further investigation to improve the user onboarding process. 3. Lack of similar applications: While some participants were aware of similar apps, the study found that existing applications lacked the comprehensive eco-incentive functions provided by the developed mobile application system, indicating a gap in the market |
|  | Electronic Waste Collection Incentivization Scheme Based on the Blockchain | Ala Abdulsalam Alarood, Adamu Abubakar, Abdulrahman Alzahrani and Faisal S. Alsubaei, 2023. | To develop an effective incentivization scheme for e-waste collection using blockchain technology.  To explore the use of case-based scenarios and a weighting scale scheme to determine incentives for e-waste collection.  To investigate the effectiveness of tailored incentive structures in motivating individuals and enterprises to engage in e-waste collection. | Design science research methodology was employed to develop and evaluate the incentivization scheme.  Utilization of case-based scenarios and a weighting scale scheme to determine incentives for e-waste collection.  Analysis of user engagement, attitudes, and behaviors to create efficacious incentive structures. | Blockchain technology for real-time tracking of e-products from creation to decomposition into e-waste.  Tailored incentive structures based on task and activity weighting to motivate e-waste collection.  Understanding user incentives, inclinations, and attitudes to design effective incentive mechanisms. | 1. The weighting scale scheme for incentives considers the complexity and effort involved in different e-waste collection tasks. 2. Tailored incentive structures based on individual cases can effectively motivate e-waste collection. 3. Blockchain-based incentive mechanisms show potential for promoting user engagement in e-waste collection. | 1. Future research should focus on scalable blockchain architectures to manage increasing e-waste volumes. 2. Electronic device manufacturers should consider implementing policies for task allocation and incentivization. 3. The methodology of tailoring incentives to individual cases holds significance for motivating e-waste collection. | 1. Scalability of blockchain-based incentive programs for managing large quantities of e-waste. 2. Ensuring fair task allocation and impartial reward distribution to prevent demotivation. 3. Establishing systematic regulations for token generation in incentivization schemes. |
|  | IoT Technology, Applications and Challenges: A Contemporary Survey | Balaji Subramanian et al, 2019. | 1. To provide an extensive overview of IoT technology and its applications in various domains. 2. To review recent research works and related technologies in the field of IoT. 3. To compare IoT with Machine-to-Machine (M2M) communication. 4. To highlight the disadvantages of IoT. 5. To explore existing protocols and security issues in IoT applications. 6. To identify potential future research directions and challenges in the IoT framework. | 1. Literature review to gather information on IoT technology, protocols, and applications. 2. Analysis of recent research publications and related works from 2013 to 2018 using the Scopus database. 3. Review of different IoT protocols and security issues. 4. Exploration of IoT-based lifesaving tools and real-world applications. 5. Comparative analysis of IoT with Machine-to-Machine communication. 6. Identification and discussion of emerging technologies and challenges in the IoT domain. | 1. Conceptual understanding of IoT as a dynamic network framework. 2. Utilization of communication protocols to merge physical and virtual domains. 3. Use of technologies such as RFID, Wireless Sensor Networks (WSN), and Bluetooth in IoT applications. 4. Integration of sensors, actuators, and intelligent algorithms for autonomous device operation. 5. Application of IoT in various sectors including defense, medicine, agriculture, and smart cities. 6. Exploration of machine-to-machine communication and its relationship with IoT. | 1. Identification of emerging applications of IoT and the exponential growth of research publications in this field. 2. Comparison between IoT and Machine-to-Machine communication. 3. Analysis of existing protocols, security issues, and lifesaving tools in IoT. 4. Exploration of real-world applications of IoT in sectors like agriculture, industry, and healthcare. 5. Identification of benefits, disadvantages, opportunities, and challenges associated with IoT technology. 6. Summary of research efforts and future research directions in the IoT domain. | 1. Emphasis on the importance of addressing security and privacy issues in IoT applications. 2. Need for further research and development in IoT protocols, architectures, and services. 3. Importance of considering end-to-end solutions and addressing challenges in specific application domains. 4. Recommendations for academia, industry, and policymakers to collaborate and advance IoT technology. 5. Conclusion on the transformative impact of IoT on various sectors and its potential for future innovation. | 1. Lack of comprehensive research addressing specific application domains and associated challenges. 2. Need for standardized protocols and architectures to ensure interoperability and security in IoT systems. 3. Challenges related to privacy, data security, and ethical considerations in IoT applications. 4. Gap in addressing security issues and vulnerabilities in emerging IoT technologies. 5. Challenges associated with scalability, reliability, and energy efficiency in IoT deployments. 6. Need for interdisciplinary collaboration and integrated approaches to address complex challenges in IoT development and implementation. |
|  | An Internet of Things (IoT) Based Solid Waste Monitoring Systems | Valerianus Hashiyana | 1. To address the challenge of solid waste management in urban areas, specifically focusing on Windhoek. 2. To develop an Internet of Things (IoT) based Solid Waste Monitoring prototype for real-time monitoring of garbage levels in bins. 3. To implement a system that detects when garbage bins are full and notifies relevant authorities with the bin location. 4. To prevent overflowing of waste bins, thereby maintaining a clean and safe environment for residents. | 1. Utilization of the Design Science Research Methodology (DSRM) for the development of the proposed prototype. 2. Integration of an Arduino microcontroller, sensor for garbage level monitoring, GPS module for bin location identification, and GSM module for SMS notifications. 3. Development of a webpage for remote monitoring of garbage bin levels by authorized users. 4. Real-time data collection and processing to ensure timely notifications when bins are full. | 1. Solid waste management is a critical issue in urban areas, impacting public health and environmental quality. 2. Population growth and urban development contribute to the challenges of waste management. 3. Environmental threats such as illegal dumping, poor sanitation, and poverty exacerbate the degradation of the environment. 4. Effective solid waste management programs are necessary to mitigate health hazards and environmental degradation. 5. IoT technology offers innovative solutions for monitoring and managing solid waste in urban environments. | 1. Development of an IoT-based Solid Waste Monitoring prototype capable of real-time garbage level detection and notification. 2. Implementation of a system that effectively detects when garbage bins are full and notifies relevant authorities with the bin location. 3. Prevention of overflowing waste bins, contributing to a cleaner and safer environment for residents. 4. Remote monitoring of garbage bin levels through a webpage accessible by authorized users. | 1. Emphasis on the importance of implementing IoT solutions for effective solid waste management in urban areas. 2. Integration of IoT technology into waste management systems to improve efficiency and sustainability. 3. Adoption of similar IoT-based approaches by other municipalities and institutions to address solid waste management challenges. 4. Continued research and development to enhance the functionality and scalability of IoT-based waste monitoring systems. | 1. Challenges may arise in the implementation and maintenance of the IoT-based Solid Waste Monitoring system, including technical issues and resource constraints. 2. Integration of the prototype into existing waste management infrastructure may require coordination with relevant authorities and stakeholders. 3. Ensuring the security and privacy of data collected by the IoT system presents a potential challenge. 4. Addressing the affordability and accessibility of IoT technology for widespread adoption in waste management practices. 5. Top of Form |
|  | Prioritized and predictive intelligence of things enabled waste management model in smart and sustainable environment | Sushruta Mishra, Lambodar Jena, Hrudaya Kumar Tripathy, et al | 1. Develop a smart waste management system using Intelligence of Things (IoT) and Artificial Intelligence (AI). 2. Implement a predictive model to optimize waste collection and prevent overflow. 3. Automate waste collection processes and minimize manual intervention | 1. Local Sink (LS) nodes with sensors deployed in designated locations, each containing three smart bins. 2. Random Forest algorithm for classification, estimation, and prediction of alert messages. 3. Sensor data from smart bins regarding fill level, weight, and potential poison gas presence. 4. Local Sink (LS) nodes analyze aggregated data and predict which LS needs emptying first based on threshold levels. 5. System triggers alerts for waste collection and notifies users of potential issues. | 1. Intelligence of Things (IoT): Network of sensors collecting data from the physical environment. 2. Machine Learning (Random Forest): Algorithm used for classification and prediction based on large datasets. 3. Predictive Analytics: Analyzing data to anticipate future events and make informed decisions. | 1. Achieved an average accuracy of 95.8% in predicting alert notifications using the Random Forest algorithm. 2. Observed faster bin filling rates near crowded areas compared to less populated locations. 3. The system effectively determines waste levels and prevents bin overflow through timely alerts. | 1. The proposed IoT-enabled smart waste management system with predictive capabilities offers an efficient solution for waste management in smart cities. 2. This model can improve waste collection processes, minimize overflow risks, and contribute to a cleaner and healthier environment. | 1. The research does not discuss the scalability of the system for deployment in very large areas. 2. The impact of communication network failures on system operation is not addressed. 3. The cost-effectiveness and long-term maintenance requirements of the system are not explored. 4. The security of data collected from sensors and potential vulnerabilities are not mentioned. |

Table 1: Literature Review

## 2.1 REVIEW SUMMARY

The reviewed literature provides insights into the current state of waste, exploring the causes of waste generation and past methods used to address them. It enhances understanding of waste management processes, examining both failed and successful management systems, along with the components of well-designed waste management systems. The research based on the scope of study further highlighted literatures that emphasize the pivotal role of IoT in creating efficient waste management. It was observed that for an effective waste management system, it is crucial to involve all stakeholders in the solution process. This necessitates the integration of web and mobile applications, along with real-time monitoring and an incentive-based recycling system. This project emphasizes the vital role of database management in developing a technological solution to modern challenges. The database stores essential data, defining and creating information to support the functionalities of user devices, collection truck driver devices, and waste utility administrator devices.

# CHAPTER THREE - METHODOLOGY

This chapter outlines the procedures and methodologies employed in constructing the real-time monitoring and incentive-based recycling system for waste management. It delves into general database management principles and explores how they can be integrated with the Internet of Things (IoT) to address waste management challenges. It highlights the hardware and software components for the implementation of the system, giving the modeling and the structure of the system.

## 3.1 SMART WASTE MANAGEMENT SYSTEM

The concept of waste management refers to all the activities and actions that are undertaken to manage waste from the moment of its inception to its disposal. This comprehensive process involves the collection, storage, and scheduled pickup of waste from designated bins. It also considers the interaction between users and utility companies, emphasizing feedback and effective communication throughout the waste management cycle.

The smart waste management system serves as a solution to eliminate inefficient waste handling. It incorporates sensors, including ultrasonic sensors for distance calculation and weight sensors to measure recyclable material weight for incentive-based programs. Additionally, the system involves mobile development to facilitate interactions among utility administrators, pickup drivers, and end-users, recognizing the significance of effective communication among stakeholders.

Data and information on waste management can be a valuable resource in an effort to maximize management activities. With the application of information technology, it is expected that waste management activities can be monitored and controlled to be appropriate. Therefore, it takes a technology-based system that can provide solutions in order to increase effectiveness and efficiency of waste management.

In order to design this system the components used are categorized into hardware and software. The hardware components and their specifications are enlisted in the table below;

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| S/N | Components Name | Specification | Quantity | Unit (Naira) | Total cost (Naira) |
| 1. | Microcontroller | ESP 32 | 6 |  |  |
| 2. | Ultrasonic sensor |  | 1 |  |  |
| 3. | Communication module | A9G GSM module | 1 |  |  |
| 4. | Power module | 12V to 5V OR 3.3V | 1 | #780 | #780 |
| 5. | O LED |  | 1 |  |  |
| 6. | LIPO charger module |  | 1 |  |  |
| 7. | Weight sensor |  | 1 |  |  |
| 8. | Alarm buzzer (piezo) |  | 1 |  |  |
| 9. | Temperature & Humidity sensor | DHT 11 | 1 |  |  |
| 10. | Timer |  | 1 |  |  |
| 11. | LED indicator |  | 2 |  |  |
| 12. | lithium battery charge | 2AH 18650 lithium | 1 |  |  |
| 13. | PCB | Althium Designer | 1 |  |  |

Table 2: Hardware Components

The waste management system will consist of two sections integrated into a single bin. One section is dedicated to general waste, aimed to align with the principles of reduce, reuse, and recycle. The other section is exclusively designed for containing recyclable materials and offers incentives based on the weight of these materials by calculating their equivalent value.

The hardware design for this system involves the integration of an embedded system comprising a microcontroller, various sensors, and specific modules tailored for distinct functions. Additionally, the physical appearance of the waste management system or bin requires specific components, like a PCB design for the plastic or rubber waste bin. This design ensures durability, enabling the bin to withstand diverse weather conditions, including rain and sun exposure.

This paper focuses more on the database management of the system, delving into the backend development. It centres on how the database is related to the development of a smart waste management system, listing out the various types of databases that exist and based on requirement choosing to use one of the many databases to achieve the bigger picture of the project.

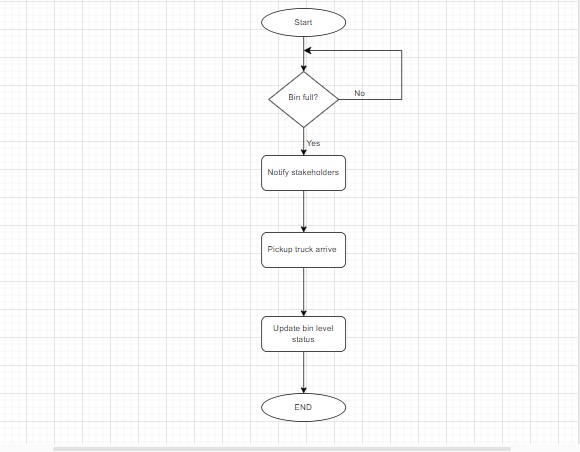
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Figure 1: Flowchart of Proposed Model

## 3.2 DATABASE MANAGEMENT SYSTEM

A database is a structured collection of information or data stored electronically in a computer system. It is typically managed by a database management system (DBMS). The combination of data, database management system (DBMS), and associated applications is collectively known as a database system. A database management system (DBMS) serves as an intermediary between the database and end-users or programs, offering a mechanism for users to retrieve, update, and oversee the organization and optimization of information. Furthermore, a database management system (DBMS) facilitates administrative tasks like performance monitoring, tuning, and backup and recovery, ensuring efficient control over databases. Database software is employed for creating, editing, and maintaining database files and records, streamlining operations such as file and record creation, data entry, editing, updating, reporting, and traversal using standard algorithms and queries. The software manages storage, backup, reporting, multi-access control, and security of data, playing a vital role in preventing data theft. This software simplifies data management by providing a structured storage system with a graphical interface for user-friendly data creation and management.

It consists of three vital components: the database management system (DBMS) for data management, the database engine for data access, locking, and modification, and the database schema for defining the logical structure. These elements together ensure concurrency, security, data integrity, and standardized data administration procedures. The database management system (DBMS) is instrumental in performing various administrative tasks, including change management, performance monitoring, tuning, security, backup, and recovery. Moreover, most database management systems (DBMS) handle automated rollbacks, restarts, and logging and auditing of activities in databases and the associated applications.

With the widespread adoption of the Internet of Things (IoT), businesses now have access to unprecedented volumes of data. Databases play a crucial role in not only storing and managing this data but also in enabling organizations to analyse it effectively. The integration of databases with computing and business intelligence tools empowers organizations to derive valuable insights, enhance decision-making processes, and achieve greater agility and scalability. As data volumes continue to grow, optimizing access and throughput becomes paramount. The emergence of self-driving databases promises to revolutionize these capabilities by automating manual processes, freeing up resources, and providing users with greater control and autonomy, all while maintaining essential security standards.

Popular database management systems include Microsoft Access, Amazon RDS, Apache Cassandra, File maker, Google Cloud Spanner, IBM Db2, MariaDB, Microsoft Azure SQL Database, MongoDB, MySQL, Oracle, PostgreSQL, SAP HANA, SQL Server, SQLite, and Teradata. These systems offer a range of features, from open-source and cloud-based solutions to in-memory and NoSQL databases, catering to diverse data management needs.

## 3.3 TYPES OF DATABASE MANAGEMENT SYSTEM

Various types of databases exist serving different purposes. Here are seven common types:

1. Hierarchical databases
2. Network databases
3. Relational databases
4. Object-oriented databases
5. Graph databases
6. ER model databases
7. Document databases
8. NoSQL databases

### 3.3.1 HIERARCHICAL DATABASE

In a Hierarchical Database Management System (DBMS), data is structured in a parent-children relationship, forming a tree-like model. Records store information about parent/child relationships, and data is organized in fields, each holding a single value. Records are connected through one-to-many parent-child relationships, allowing each child to have only one parent and a parent to have multiple children.

To access data, traversal through the tree structure is required until the desired record is reached. These databases find applications in high-performance sectors like banking and telecommunications. Developed by IBM in the early 1960s, the hierarchical structure, though simple, can be inflexible due to the one-to-many relationship between parent and child. Examples of hierarchical databases include the IBM Information Management System (IMS) and the Windows Registry.

Advantages of Hierarchical Database:

1. Rapid Access and Updates: The hierarchical database's tree-like structure and predefined relationships between records enable swift access and updates.

Disadvantages of a Hierarchical Database:

1. Limited Relationships: Flexibility is limited as each child in the tree can only have one parent, and relationships between children are not allowed.
2. Redefinition Challenges: Updates become cumbersome since the addition of a new field or record necessitates redefining the database entirely.
3. Design Limitations: The hierarchical design imposes restrictions on the database structure.

### 3.3.2 RELATIONAL DATABASE

In a relational database management system (RDBMS), data is organized in tables, with each column representing an attribute and each row representing a record. Fields within each table hold data values.

Structured Query Language (SQL) is employed to query RDBMS, facilitating operations such as inserting, updating, deleting, and records searching. Relational databases use key fields in each table to uniquely identify rows, enabling the connection of data between different tables. Relational databases are widely recognized and extensively used. Some popular database management systems (DBMS) include Oracle, SQL Server, MySQL, SQLite, and IBM DB2.

Advantages of Relational databases:

1. Requires little or no training for usage.
2. Allows modification of database entries without specifying the entire content.

Properties of Relational Tables:

1. Values are Atomic.
2. Each Row is distinct.
3. Column Values are uniform.
4. Columns are indistinguishable.
5. The sequence of Rows is inconsequential.
6. Common name for each column.

### 3.3.3 ER MODEL DATABASE

In a standard relational database setup, an Entity-Relationship (ER) model is transformed, with each table row representing an instance of an entity type and each table field corresponding to an attribute type. The relational database establishes relationships between entities by storing the primary key of one entity as a 'foreign key' in the table of another entity. Entity- Relationship was introduced in 1976 by Peter Chen.

### 3.3.4 NoSQL DATABASE

NoSQL databases diverge from traditional databases by not using SQL as their primary data access language. Common types of NoSQL databases include graph databases, network databases, object databases, and document databases. If you're interested in delving deeper, you can explore the Introduction to NoSQL Databases article, which provides insights into what NoSQL databases entail.

One notable characteristic of NoSQL databases is their absence of predefined schemas, making them well-suited for dynamic development environments. Developers can implement changes seamlessly without impacting applications.

The major categories of NoSQL databases include Column, Document, Graph, Key-value, and Object databases.

Notable examples of popular NoSQL databases include Cosmos DB, ArangoDB, Couchbase Server, CouchDB, Amazon DocumentDB, MongoDB, CouchBase, Elasticsearch, Informix, SAP HANA, Neo4j, Hadoop/HBase, Cassandra, Hypertable, MapR, Hortonworks, Cloudera, Amazon SimpleDB, Apache Flink, IBM Informix, Elastic, and Azure DocumentDB. These databases offer flexibility and scalability, making them suitable for environments with rapidly changing development needs.

### 3.3.5 NETWORK DATABASE

Network Database Management Systems (Network DBMSs) use a structured network for entity relationships, resembling an interconnected network of records. They are primarily employed on large-scale digital computers. Unlike hierarchical databases, which allow nodes to have only one parent, network databases permit a network node to have relationships with multiple entities. The structure of a network database resembles a cobweb or interconnected network of records with each child referred to as a member and each parent as an occupier, members can have more than one parent, allowing for greater flexibility in relationships.

The network data model operates on a principle like that of the hierarchical data model, Charles Bachman developed the network database structure, where data is organized in many-to-many relationships. Some well-known network databases include the Integrated Data Store (IDS), IDMS (Integrated Database Management System), Raima Database Manager, TurboIMAGE, and Univac DMS-1100.

### 3.3.6 OBJECT-ORIENTED DATABASE

In this model, object-oriented programming extends beyond the storage of programming language objects. Object Database Management Systems (Object DBMS) enhance the semantics of languages like C++ and Java, offering full-featured database programming capabilities while maintaining compatibility with native languages. This integration seamlessly incorporates database functionality into object-oriented programming languages.

The Object-Oriented Programming approach streamlines application and database development, providing a unified data model and language environment. This simplifies code, supports natural data modelling, and enhances code base maintenance. Object developers can efficiently create comprehensive database applications with minimal additional effort.

Object-oriented database development leverages the synergy between object-oriented programming languages and consistent systems. Its effectiveness stems from the integrated treatment of both persistent data found in databases and transient data encountered in executing programs.

Object-oriented databases use small, reusable units called objects, each containing both data (e.g., sound, video, text, and graphics) and instructions (methods) on how to manipulate the data. The instructions or software programs which are known as methods helps to specify what actions to perform on the data.

In the early 1980s, Object-Oriented Database Management Systems (OODBMs) were introduced, tailored to work seamlessly with Object-Oriented Programming (OOP) languages such as Delphi, Ruby, C++, Java, and Python. Prominent examples of OODBMs include TORNADO, Gemstone, ObjectStore, GBase, VBase, InterSystems Cache, Versant Object Database, ODABA, ZODB, Poet, JADE, and Informix.

Object-oriented databases present challenges due to higher development costs, and many organizations are hesitant to shift away from conventional databases. However, the benefits of object-oriented databases are noteworthy, offering flexibility through the integration of reusable objects and delivering impressive multimedia capabilities.

### 3.3.7 GRAPH DATABASE

Graph databases, which fall under the category of NoSQL databases, utilize a graph structure for meaningful queries. Data is organized as nodes, edges, and properties in this model. Nodes represent entities or instances, similar to records in a relational database. Edges denote relationships connecting nodes, while properties furnish additional information linked to the nodes.

Famous graph databases encompass Neo4j, Azure Cosmos DB, SAP HANA, Sparks, Oracle Spatial and Graph, OrientDB, ArrangoDB, and MarkLogic. Notably, some relational database management systems (RDBMS), like Oracle and SQL Server versions from 2017 onwards, also embrace the graph database structure.

### 3.3.8 DOCUMENT DATABASE

Document databases, categorized as NoSQL databases, store data in documents, encapsulating information, relationships, and attributes. These databases organize data in a key-value structure.

The popularity of Document DB has grown recently, attributed to its document storage capabilities and NoSQL characteristics. NoSQL data storage offers a faster approach for storing and searching documents.

Database management is very key for the successful development of the waste management system as it is required that data be created for every operation and operators, ranging from end user to the utility administrators, to the drivers going for pickups.

For this project design, a Relational database management system will be employed from the various Database Management systems (DBMS) enlisted above. The specific relational database considered is MySQL, as it is the best fit for this job by inspection seeing that it is a very popular tool and has a vast usage. MySQL is an open source which is available for general view and modifications of data to suit the specific needs of users and developers, this flexibility is beneficial to businesses with unique requirements. From research MySQL is known as the most secure database management system in the world, it is also very scalable on demand, managing deeply embedded applications using a shallow footprint. It has a comprehensive workflow control with self-management features that automate everything from configuration and space expansion to data design and database management. It includes distinct storage engine software that allow administrators to configure the MySQL database server for flawless performance, by this, it does not matter how many million daily queries or high speed transactional processing system, this shows how high the efficiency is. One of the major advantages of MySQL is its cost efficiency, the reliability and maintainability of MySQL can save money and time spent on troubleshooting that is otherwise spent in fixing downtimes and performance issues.

MySQL database management system is employed in this project because its data relationships are stored in a tabular format with columns and rows. Each table column represents an attribute, and each row represents a record while fields within a table hold data values. In this design there would be data IDs for customers or users, for admins, for drivers and all of these require different permissions to be granted, hence the need for a well-organized and structured database. Some components used for the hardware require IDs too, components such as ultrasonic sensors for the bin level, temperature sensor for prevention of fire outbreak, battery level sensor, GPS for present location of driver and bin. The IDs will enable easy identification of individual operators and operations under such, it enables easy access to stored data, it would also help during assignment for specific operators permission; end users access will be limited to their confines, same for drivers while the administrator would have more access than these two, the super administrator has the highest access and permission. Some of the project IDs for the mobile and web user friendly application include users ID, truck driver ID, conductor ID, sensor ID, time and date ID, payment ID, transaction ID, and so many others.

### 3.3.9 CLOUD SERVER

Cloud computing involves utilizing the internet for data storage rather than relying on individual storage devices, minimizing the risk of data loss. In this model, third-party providers manage resources at remote locations, reducing the cost and complexity associated with maintaining personal computer networks. The cloud offers scalability, reliability, and efficiency benefits, providing a robust and accessible solution for data storage. The structured management of data in the cloud minimizes the risk of misplacement, enhancing overall reliability and accessibility for users.

In future enhancements, the incorporation of a cloud server will be prioritized for enhanced security and improved data processing efficiency. Cloud storage stands out as the preferred choice for data storage in many modern developments due to its reliability and advanced capabilities.

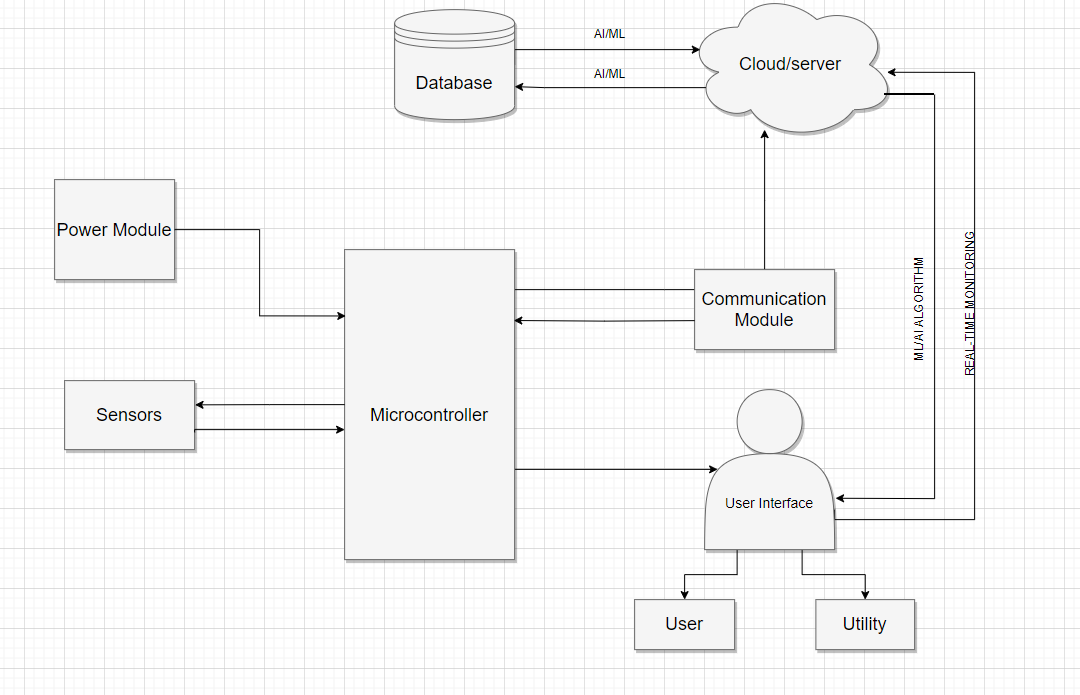


Figure 2: Overall block diagram of application workflow

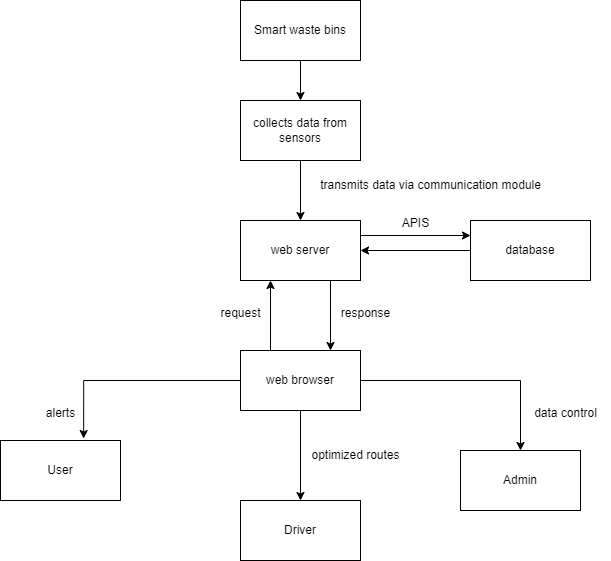


Figure 3:Interconnection between hardware and software components

# WORK YET TO BE DONE

Some of the works yet to be done are;

1. Acquisition of some project resources, equipment and facilities.
2. Physical implementation of the project.
3. Development of the database framework.

# CONCLUSION

This project goes beyond discussing the theoretical aspects of database management systems; it actively implements the use of a database management system in creating a smart waste management system. The project encompasses various stages, including data acquisition, storage, analysis, reporting, modelling, real-time data visualization, and historical data analysis. The overarching goal is to develop a smart waste management system that not only efficiently handles data but also ensures a user-friendly and engaging experience.

 It delves into the technologies and essential components required for implementation, expounding on their individual theoretical frameworks. It presents a methodology for real time monitoring, for smart waste bins to ascertain waste levels at defined intervals and specified thresholds. This is accomplished through the utilization of an ultrasonic sensor, an electronic device capable of measuring object distances using sound waves beyond the range of human hearing. This functionality aids in assessing the waste level within the waste management system.

Monitoring the waste level allows for timely notifications to utility sectors before the bins reach capacity. Upon reaching the designated threshold, which signifies near-full capacity, the system facilitates preparation for the required sector to schedule timely pickups.

# REFERENCES

[1] U. Henrietta Udeani, C. Tochukwu, and O. Daniel Okey, ‘DESIGN AND CONSTRUCTION OF A SMART DUSTBIN SYSTEM WITH INTERNET OF THINGS (IoT) NOTIFICATION’, 2022.

[2] T. Ali, M. Irfan, A. S. Alwadie, and A. Glowacz, ‘IoT-Based Smart Waste Bin Monitoring and Municipal Solid Waste Management System for Smart Cities’, *Arab J Sci Eng*, vol. 45, no. 12, pp. 10185–10198, Dec. 2020, doi: 10.1007/s13369-020-04637-w.

[3] A. Bano, I. Ud Din, and A. A. Al-Huqail, ‘AIoT-Based Smart Bin for Real-Time Monitoring and Management of Solid Waste’, *Sci Program*, vol. 2020, 2020, doi: 10.1155/2020/6613263.

[4] R. Agrawal, C. Kishore Singh, A. Goyal, and D. K. Singh, Eds., *Modern Electronics Devices and Communication Systems*, vol. 948. in Lecture Notes in Electrical Engineering, vol. 948. Singapore: Springer Nature Singapore, 2023. doi: 10.1007/978-981-19-6383-4.

[5] A. Noiki, S. A. Afolalu, A. A. Abioye, C. A. Bolu, and M. E. Emetere, ‘Smart waste bin system: A review’, in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing Ltd, Feb. 2021. doi: 10.1088/1755-1315/655/1/012036.

[6] F. Obi, B. Ugwuishiwu, and J. Nwakaire, ‘AGRICULTURAL WASTE CONCEPT, GENERATION, UTILIZATION AND MANAGEMENT’, *Nigerian Journal of Technology*, vol. 35, no. 4, p. 957, Sep. 2016, doi: 10.4314/njt.v35i4.34.

[7] S. Nižetić, P. Šolić, D. López-de-Ipiña González-de-Artaza, and L. Patrono, ‘Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future’, *J Clean Prod*, vol. 274, Nov. 2020, doi: 10.1016/j.jclepro.2020.122877.

[8] S. Balaji, K. Nathani, and R. Santhakumar, ‘IoT Technology, Applications and Challenges: A Contemporary Survey’, *Wireless Personal Communications*, vol. 108, no. 1. Springer New York LLC, pp. 363–388, Sep. 15, 2019. doi: 10.1007/s11277-019-06407-w.

[9] S. Islam, N. Rakib, and A. Coordinator, ‘Design and Implementation of an Automatic Waste Segregation System Submitted by Supervised by ………………………………’, 2022.

[10] R. A. Ro’zimurod O’g’li, ‘THE DIFFERENCE BETWEEN THE CONCEPTS OF DATABASE (DB) AND DATABASE MANAGEMENT SYSTEM (DBMS)’, 2022. [Online]. Available: https://conferencepublication.com

[11] H. Huang, D. Su, and W. Peng, ‘Novel Mobile Application System for Implementation of an Eco-Incentive Scheme’, *Sustainability (Switzerland)*, vol. 14, no. 5, Mar. 2022, doi: 10.3390/su14053055.

[12] P. Ramesh, S. Sudheera, and D. V. Reddy, ‘Distance Measurement Using Ultrasonic Sensor and Arduino’, *Technology and Management Sciences (JARTMS) Published By: Journal of Advanced Research in Technology and Management Sciences Published By: Journal of Advanced Research in Technology and Management Sciences*, [Online]. Available: http://www.jartms.org

[13] P. Kavipriya, A. Supriya, R. Meena, R. Charanya, and S. Jayakumar, ‘Intelligent Trashcan Monitoring System Using Iot’, in *International Conference on Emerging Trends in Information Technology and Engineering, ic-ETITE 2020*, Institute of Electrical and Electronics Engineers Inc., Feb. 2020. doi: 10.1109/ic-ETITE47903.2020.479.

[14] A. Okunola A, O. Kehinde I, A. Oluwaseun, and A. Olufiropo E, ‘Public and Environmental Health Effects of Plastic Wastes Disposal: A Review’, *Journal of Toxicology and Risk Assessment*, vol. 5, no. 2, Apr. 2019, doi: 10.23937/2572-4061.1510021.

[15] U. D. R. L. Vijayanthi, ‘Waste Monitoring System’, 2020.

[16] K. Kabirifar, M. Mojtahedi, C. Wang, and V. W. Y. Tam, ‘Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review’, *Journal of Cleaner Production*, vol. 263. Elsevier Ltd, Aug. 01, 2020. doi: 10.1016/j.jclepro.2020.121265.

[17] S. Aisyah, Y. Ali, S. Suhendra, K. Saharja, and A. Sani, ‘Development of Smart Rubbish Bin Connected with SMS Gateway Based on Arduino Uno’, European Alliance for Innovation n.o., Dec. 2022. doi: 10.4108/eai.16-11-2022.2326065.

[18] K. Pardini, J. J. P. C. Rodrigues, O. Diallo, A. K. Das, V. H. C. de Albuquerque, and S. A. Kozlov, ‘A smart waste management solution geared towards citizens’, *Sensors (Switzerland)*, vol. 20, no. 8, Apr. 2020, doi: 10.3390/s20082380.

[19] D. Vorobeva, I. J. Scott, T. Oliveira, and M. Neto, ‘Adoption of new household waste management technologies: The role of financial incentives and pro-environmental behavior’, *J Clean Prod*, vol. 362, Aug. 2022, doi: 10.1016/j.jclepro.2022.132328.

[20] M. H. Kabir, S. Roy, A. Tofail, M. Alam, and T. Ahmed, ‘IoT Based Solar Powered Smart Waste Management System with Real Time Monitoring-An Advancement for Smart City Planning’, 2020.

[21] B. Diène, J. J. P. C. Rodrigues, O. Diallo, E. H. M. Ndoye, and V. V. Korotaev, ‘Data management techniques for Internet of Things’, *Mech Syst Signal Process*, vol. 138, Apr. 2020, doi: 10.1016/j.ymssp.2019.106564.

[22] K. Srisabarimani, R. Arthi, S. Soundarya, A. Akshaya, M. Mahitha, and S. Sudheer, ‘Smart Segregation Bins for Cities Using Internet of Things (IoT)’, in *Lecture Notes in Electrical Engineering*, Springer Science and Business Media Deutschland GmbH, 2022, pp. 717–730. doi: 10.1007/978-981-16-9488-2\_68.

[23] P. B. Mohanram, S. Karthik Viswanath, P. M. Mohamed Musaraf, R. Karthikeyan, K. R. Sarath Chandran, and S. Angel Deborah, ‘IoT Based Smart Waste Management Reporting and Monitoring System’, in *2021 5th International Conference on Computer, Communication, and Signal Processing, ICCCSP 2021*, Institute of Electrical and Electronics Engineers Inc., May 2021, pp. 208–215. doi: 10.1109/ICCCSP52374.2021.9465507.

[24] M. Zamroni, R. S. Prahara, A. Kartiko, D. Purnawati, and D. W. Kusuma, ‘The Waste Management Program of 3R (Reduce, Reuse, Recycle) by Economic Incentive and Facility Support’, in *Journal of Physics: Conference Series*, Institute of Physics Publishing, Mar. 2020. doi: 10.1088/1742-6596/1471/1/012048.

[25] M. Mohammed, N. Shafiq, N. A. W. Abdallah, M. Ayoub, and A. Haruna, ‘A review on achieving sustainable construction waste management through application of 3R (reduction, reuse, recycling): A lifecycle approach’, in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Jun. 2020. doi: 10.1088/1755-1315/476/1/012010.

[26] J. Zhou, P. Jiang, J. Yang, and X. Liu, ‘Designing a smart incentive-based recycling system for household recyclable waste’, *Waste Management*, vol. 123, pp. 142–153, Mar. 2021, doi: 10.1016/j.wasman.2021.01.030.

[27] J. Yang, P. Jiang, M. Zheng, J. Zhou, and X. Liu, ‘Investigating the influencing factors of incentive-based household waste recycling using structural equation modelling’, *Waste Management*, vol. 142, pp. 120–131, Apr. 2022, doi: 10.1016/j.wasman.2022.02.014.

[28] W. Asare, S. Oduro-Kwarteng, E. A. Donkor, and M. A. D. Rockson, ‘Recovery of municipal solid waste recyclables under different incentive schemes in Tamale, Ghana’, *Sustainability (Switzerland)*, vol. 12, no. 23, pp. 1–19, Dec. 2020, doi: 10.3390/su12239869.

[29] S. Mondal and S. G. Kulkatni, ‘Incentivization Model for Better Plastic Waste Management using Blockchain’, in *International Symposium on Advanced Networks and Telecommunication Systems, ANTS*, IEEE Computer Society, 2022, pp. 476–481. doi: 10.1109/ANTS56424.2022.10227749.

[30] A. A. Alarood, A. Abubakar, A. Alzahrani, and F. S. Alsubaei, ‘Electronic Waste Collection Incentivization Scheme Based on the Blockchain’, *Sustainability (Switzerland)*, vol. 15, no. 13, Jul. 2023, doi: 10.3390/su151310209.

[31] M. Ling and L. Xu, ‘Incentivizing household recycling crowds out public support for other waste management policies: A long-term quasi-experimental study’, *J Environ Manage*, vol. 299, Dec. 2021, doi: 10.1016/j.jenvman.2021.113675.