UNIVERSITE JOSEPH KI-ZERBO

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BURKINA FASO

La Patrie ou la Mort, nous Vaincro

Order N°: ……………..

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MASTER THESIS

Subject:

Smart ICT-IoT System for Solid Waste Collection Management and Citizen Engagement in Ouagadougou

Presented (the 21 July of 2025), by:

Rasmata SIMPORE

Examination jury

President : Pr. DISSA Alfa Oumar, Full Professor at Université Joseph KI-ZERBO

Members :

- Dr Kisito KABORE , Assistant Professor at Université Joseph KI-ZERBO (external examiner) ;
- Dr Didier BASSOLE, Associate Professor at Université Joseph KI-ZERBO (supervisor) ;
- Dr Belko Abdoul Aziz DIALLO, Head of Data Management Department at WASCAL Competence Center (co-supervisor).

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DEDICATION

To my dear parents.

To my husband NANA Seni.

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TABLE DES MATIRES

ABSTRACT

Urban solid waste management in Ouagadougou faces persistent challenges, including inefficient collection, poor stakeholder coordination, and lack of real-time monitoring. This thesis introduces an intelligent system combining IoT and ICT to improve waste collection and promote citizen engagement.

Based on surveys with 196 households, public sanitation officials, and waste collection structures, key issues such as weak traceability and limited citizen involvement were identified. To address these, the **Trash App**, a web and mobile application, was developed for managing actors, bin geolocation, scheduling, notifications, and citizen reporting. Additionally, an IoT-based sensor was prototyped to monitor bin fill levels in real time and transmit data to a central platform. Results indicate improved monitoring, faster response times, and stronger community participation. Despite limitations like high initial costs and technical challenges, the study demonstrates the feasibility and potential scalability of smart waste management in resource-constrained urban settings across sub-Saharan Africa.

Keywords: citizen engagement, ICT, IoT, real-time monitoring, smart waste management, waste digital solutions.

RESUME

La gestion des déchets solides urbains à Ouagadougou est confrontée à des défis persistants, notamment l'inefficacité des processus de collecte, une mauvaise coordination entre les parties prenantes et l'absence de suivi en temps réel. Ce mémoire propose un système intelligent combinant les technologies de l'Internet des Objets (IoT) et des Technologies de l'Information et de la Communication (TIC) afin d'améliorer la collecte des déchets et de renforcer l'engagement citoyen.

Sur la base d'enquêtes menées auprès de 196 ménages, des responsables de la salubrité publique et des structures de collecte, des problèmes majeurs ont été identifiés, tels que la faible traçabilité et le manque d'implication des citoyens. Pour y remédier, **Trash App**, une application web et mobile, a été développée pour la gestion des acteurs, la géolocalisation des poubelles, la planification des collectes, l'envoi de notifications et la remontée d'anomalies par les citoyens. En complément, un capteur IoT a été prototypé pour surveiller en temps réel le niveau de remplissage des poubelles et transmettre les données à une plateforme centrale. Les résultats montrent une amélioration du suivi, une réduction des délais de réaction et une participation communautaire accrue. Malgré des limites telles que le coût initial élevé et certaines contraintes techniques, l'étude confirme la faisabilité et la possibilité de mise à l'échelle d'un système intelligent de gestion des déchets dans des contextes urbains à faibles ressources en Afrique subsaharienne.

Mots-clés: engagement citoyen, gestion intelligente des déchets, IoT, solutions numériques, suivi en temps réel, TIC.

ACRONYMS AND ABBREVIATIONS

3D	Three-Dimensional
AI	Artificial Intelligence
API	Application Programming Interface
App	Application
CAD	Computer-Aided Design
CCT	Centre de Collecte et de Tri des déchets
CSC	Collection and Sorting Centre
CTVD	Centre de Traitement et de Valorisation des Déchets
DSHP	Direction de la Salubrité et de l'Hygiène Publique
EIG	Economic Interest Groupings
GIS	Geographic Information Systems
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ICT	Information and Communication Technologies
IoT	Internet of Things
LoRaWAN	Long Range Wide Area Network
NB-IoT	Narrowband Internet of Things
OLED	Organic Light Emitting Diode
PCB	Printed Circuit Board
RFID	Radio Frequency Identification
RGPH	Recensement Général de la Population et de l'Habitat
SDG	Sustainable Development Goals
SDGD	Schéma Directeur de la Gestion des Déchets
SME	Small and Medium Enterprise
SMS	Short Message Service
SQL	Structured Query Language
UI	User Interface
USA	United States of America
Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Networks

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Solid waste management has become an urgent challenge in rapidly expanding urban areas, especially in developing countries where traditional systems often fail to keep up with accelerating population growth and urban sprawl (Kaza et al., 2018). In Ouagadougou, Burkina Faso, the city generates an estimated **800,000 tons of solid waste annually** according to the SDGD 2019, with per capita waste production projected to rise due to increasing urbanization and economic activity. However, inefficient collection schedules, the absence of real-time monitoring, and limited citizen engagement have led to frequent overflows, unsanitary conditions, and growing health and environmental risks. Current waste management systems remain largely reactive and lack the data-driven capacity required to meet the evolving needs of a modern city.

This research proposes a solution that integrates Information and Communication Technologies (ICT) and the Internet of Things (IoT) into Ouagadougou's waste collection infrastructure. By deploying smart sensors inside waste bins and creating a real-time digital platform, the municipality can significantly improve route optimization, reduce operational costs, and monitor bin fill levels with greater precision. These enhancements can help reduce overflow incidents, shorten response times, and improve overall service efficiency.

To promote active citizen participation, the study also involves the development of a mobile and web application that allows users to consult collection schedules, request services, reports issuses, and evaluate the performance of waste collection operators. On the management side, service providers can interact with residents, track service requests, and maintain digital records, while the city's sanitation department can access real-time data to supervise operations and respond proactively to challenges.

Furthermore, the study includes forecasting of future waste generation trends based on demographic and economic growth models, reinforcing the critical need for smart, scalable, and proactive waste management solutions in Ouagadougou and similar cities across sub-Saharan Africa.

To effectively carry out this research, a primary research question, hypothesis, and objective are established, along with three specific research questions, hypotheses, and objectives corresponding to each.

Research questions

In order to carry out this applied research, we formulate the main research question as follows:

How can an IoT-enabled, ICT-based integrated smart system improve the efficiency, citizen engagement, and real-time monitoring of waste collection management in Ouagadougou?

The specific research questions are:

- ❖ What are the current needs and gaps in the waste collection management system in Ouagadougou?
- ❖ How can digital technologies, such as web and mobile applications, influence the efficiency and effectiveness of waste collection management in Burkina Faso?
- ❖ In what ways can IoT-enabled sensors contribute to real-time monitoring and management of waste collection system?

Research hypotheses

The main research hypothesis is:

An integrated smart waste collection management system, leveraging ICT and IoT technologies, can significantly enhance operational efficiency, citizen participation, and real-time monitoring of waste collection activities in Ouagadougou.

The specific research hypotheses are:

- ❖ The existing waste collection management system in Ouagadougou suffers from critical inefficiencies due to limited digitalization, insufficient real-time monitoring, and minimal citizen involvement.
- ❖ Deploying a digital platform comprising web and mobile applications to map stakeholders, streamline management processes, and support real-time alerts and feedback will improve coordination, reduce inefficiencies, and promote accountability in waste services.
- ❖ The integration of IoT-based sensors to monitor waste bin will optimize household waste collection schedules, minimize overflow incidents, and improve overall responsiveness of the waste management system.

Research objectives

The main research objective is:

To develop an ICT and IoT-enabled smart system for waste collection management in Ouagadougou with real-time monitoring and citizen engagement.

The specific research objectives are:

- ❖ To assess the existing challenges, needs, and performance gaps in the current waste collection management system in Ouagadougou.
- ❖ To develop an integrated digital solution comprising a web platform and mobile application for mapping stakeholders, automating processes, scheduling collection, and enabling real-time notifications and feedback.
- ❖ To Implement an IoT-enabled sensor for real-time monitoring of fill level.

To achieve these goals, the research will start with a literature review, followed by the design and development of a mobile and web-based waste collection app, and conclude with implementation of an IoT-enabled Trash Bin monitoring sensor.

CHAPTER I: LITERATURE REVIEW

Waste management is a critical issue in urban areas such as Ouagadougou. The integration of Information and Communication Technology (ICT) and the Internet of Things (IoT) offers innovative solutions to optimize waste collection, improve efficiency, and enhance sustainability. The literature review is a very important chapter that presents existing research on intelligent waste management systems, with a focus on ICT and IoT applications.

I.1. ICT and IoT-Based Smart Waste Management in the world

Smart waste management systems are increasingly being adopted across urban areas worldwide, leveraging Information and Communication Technologies (ICT) and the Internet of Things (IoT) to enhance efficiency and environmental sustainability. Numerous studies confirm that these systems contribute to cost reduction, route optimization, and improved service delivery in the waste management sector.

In **Europe**, Norway's city of **Bergen** stands out for its early implementation of a pneumatic waste disposal network, which transports household waste via underground vacuum tubes to central facilities. This system has led to significant environmental and logistical benefits, including up to a 90% reduction in diesel emissions and improved recycling compliance under a user-pay billing model (The Washington Post, 2025). Across several European cities such as **Prague, Patras, Bratislava**, and **Rosenheim**, companies like **Sensoneo** have introduced smart waste systems using IoT-based fill-level sensors and data dashboards. These solutions have proven effective in lowering collection costs and reducing the number of unnecessary trips, saving an average of €156 per sensor in Prague alone (Sensoneo, 2023).

In **Asia**, **South Korea's** smart city of **Songdo** integrates waste disposal into its urban design through automated pneumatic systems connected to a centralized collection facility, enhancing both hygiene and efficiency (OpenGov Asia, 2020). In **Japan**, tourist cities such as Osaka and Kyoto have adopted "SmaGO" bins—solar-powered, smart trash receptacles that compact waste and notify municipal services when nearing capacity. These bins have contributed to better cleanliness and reduced maintenance needs in high-traffic areas (Reddit Economics Forum, 2023). In **Saudi Arabia**, researchers introduced the **TUHR** system in Makkah, combining IoT sensors and artificial intelligence to manage solid waste during high-density events like the Hajj pilgrimage. The system includes gas detection, ultrasonic monitoring, and automated reporting for hazardous conditions (Farooq et al., 2024).

Beyond hardware applications, several cities and private firms have turned to software-based waste management models. For instance, **Evreka**, a smart waste management company operating across **Europe and Asia**, uses AI and cloud-based software to optimize route planning, monitor collection progress, and enhance transparency in operations. In pilot projects, Evreka systems have reduced missed waste pickups by up to 89% and decreased total operational costs by 15% (Evreka, 2022). Similarly, studies from **India** show that combining IoT sensors with machine learning has led to improvements in sorting accuracy, cost-efficiency, and collection timeliness (ReaPress, 2023).

Evreka is a global provider of integrated smart waste management systems that utilize advanced technologies such as the Internet of Things and artificial intelligence to optimize waste collection and processing. Their platform combines real-time data collection from smart sensors with AI-driven analytics to improve operational efficiency and promote sustainability.

The solution includes a comprehensive software suite that oversees waste operations, including fleet management, workforce coordination, asset tracking, and citizen engagement. This integration enables effective communication among stakeholders and supports decisions based on data. Evreka's route optimization algorithms have led to significant cost savings, reducing operational expenses by around fifteen percent and decreasing call center costs by up to seventy-five percent.

On the hardware front, waste containers are equipped with IoT devices such as RFID tags, GPS trackers, and fill-level sensors. These devices provide continuous monitoring of container status, including location, fullness, and temperature. This monitoring facilitates proactive management to prevent overflow and container loss. The platform also offers tools to increase transparency and citizen participation, including real-time reporting and support for payment models like pay-as-you-throw.

Evreka's technology emphasizes environmental sustainability by contributing to circular economy initiatives through enhanced recycling and reduced carbon emissions. Although there are no documented implementations in Burkina Faso at this time, the system's flexibility and scalability suggest strong potential for deployment in developing urban areas. Adoption of such integrated smart waste management systems can improve operational efficiency, reduce environmental impact, and foster greater community involvement.

Figure 1: Smart waste management systems of Evreka

Overall, the experiences with smart waste management technologies demonstrate the transformative potential of integrating IoT infrastructure with municipal waste systems. These case studies highlight the importance of low-energy communication protocols, smart monitoring, real-time analytics, and AI-assisted logistics in building cleaner, more efficient urban environments.

I.2. ICT and IoT-Based Smart Waste Management in Africa

Recent advances in Information and Communication Technologies (ICT) and the Internet of Things (IoT) have prompted several initiatives aimed at transforming urban waste management in West Africa. These efforts emphasize cost-effective, sensor-driven, and data-informed systems designed to improve operational efficiency, responsiveness, and environmental impact.

A study conducted in **Parakou, Benin**, implemented a smart waste collection model integrating ultrasonic sensors and GPS modules to monitor bin fill levels and track container locations in real time. The system communicated with a central server and utilized route optimization algorithms to streamline collection operations. This pilot demonstrated measurable improvements in fuel efficiency, route planning, and labor deployment, providing evidence of the feasibility of such systems in mid-sized West African cities (Youssouf et al., 2023).

In **Lomé, Togo**, the SCoPE project introduced an open-source IoT platform for waste monitoring, using low-power LoRa communication, Arduino-based hardware, and solar-powered sensors. The system was designed with affordability and sustainability in mind, ensuring long battery life and reliable operation even in low-resource settings. Its modular design allowed adaptability for both rural and urban deployment, emphasizing community-led data usage and local assembly of components (SCoPE Project, 2022).

A feasibility assessment in **Ghana** examined the integration of smart bin technologies, including fill-level sensors, GPS tracking, and data analytics powered by artificial intelligence. The study also proposed blockchain-based solutions for tracking hazardous waste, particularly in urban health zones. While full-scale implementation remains in progress, the study outlined the potential benefits of public-private partnerships and digital infrastructure development to support long-term scaling (Mensah & Asiedu, 2024).

Although geographically located outside West Africa, a comparable project in **Windhoek, Namibia**, employed narrowband IoT (NB-IoT) connectivity to monitor both the volume and odor levels of waste bins. The real-time data was transmitted to a centralized dashboard, enabling city officials to make informed decisions on collection scheduling. The model is cited as a regional reference for its integration of environmental sensing and municipal workflow optimization (Ndhlovu et al., 2022).

Collectively, these studies underscore the growing interest and applicability of smart waste technologies across Sub-Saharan Africa. They highlight the importance of localized design, low-power communication, and community involvement as essential criteria for sustainable deployment. Furthermore, they offer practical insights for replicating such models in other West African cities, including Ouagadougou, where similar challenges persist in urban sanitation.

I.3. ICT and IoT-Based Smart Waste Management in Burkina Faso

Although the implementation of intelligent technologies for waste management remains limited in Burkina Faso, several initiatives demonstrate a growing commitment to modernizing the sector through ICT and the Internet of Things (IoT). These developments align with national and regional frameworks focused on improving sustainability and operational efficiency in waste collection and treatment services.

A key foundation for this progress is the **National Action Plan for Integrated Waste Management**, developed with support from the SWITCH Africa Green program. Finalized in 2019, this plan aims to promote a circular economy by encouraging waste valorization, formalizing stakeholders, and strengthening the waste management value chain. It provides a strategic and policy framework conducive to the future adoption of digital solutions in urban solid waste management.

Another significant development is the creation of a **data center powered by a waste-to-energy plant**. Led by Essor Services and Kaia Energy, this project aims to generate electricity from household waste to power digital infrastructure, expected to be operational by late 2025. This initiative exemplifies the promising integration of sustainable waste management, clean energy production, and ICT infrastructure.

Moreover, the **informal sector**, particularly in electronic waste (e-waste) management, presents considerable potential for IoT integration. Some reverse logistics operations, organized by humanitarian actors using empty return trucks to collect e-waste in rural areas, pave the way for implementing digital tracking and traceability systems tailored to local realities. This initiative, piloted by hulo, is a pooled effort for the management of e-waste, connectinghumanitarian organisations with Association Burkinabé pour la Promotion des Emplois Verts (ABPEV), acollector and dismantler based in Ouagadougou. ABPEV partners with WEEE Cycling, a final recyclerlocated in France. Unfortunately, theimplementation of environmentally sound disposal isstill hampered by the insufficient funds available tohumanitarian organisations for transporting thee-waste from field sites to the capital and coveringthe necessary recycling processing fees.

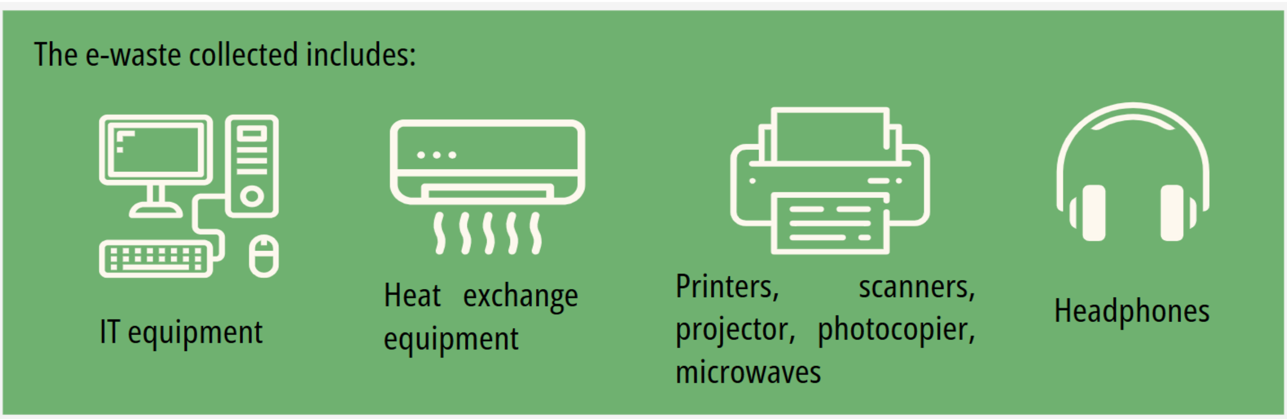


Figure 2: E-waste collected of Hulo

Source: Global Logistic Cluster's Environmental Sustainability Team, WREC Coalition

In summary, while smart bins or connected sensor projects are not yet widely deployed in Burkina Faso, the country possesses the political, economic, and technical foundations necessary to facilitate their development. Burkina Faso could benefit from regional experiences in countries such as Benin and Togo to design its own smart waste solutions, especially in urban centers like Ouagadougou.

I.4. Definition and regulations on waste

Logically, **waste** includes all solid, liquid, and gaseous substances that have a negative impact on the environment. In the following discussion, we will only consider solid waste.

Solid waste refers to any garbage, refuse, or unwanted material that is discarded as a result of residential, commercial, industrial, and institutional activities.

Regulations on waste management in Burkina Faso

- **Law No. 006-2013/AN of April 2, 2013: Environmental Code**

This law establishes the fundamental principles governing environmental protection in Burkina Faso. It prohibits the introduction of hazardous waste into the national territory without prior authorization and provides for severe penalties in case of violations.

- **Law No. 022-2005/AN of May 24, 2005: Public Hygiene Code**

This law stipulates that any individual or entity producing or holding waste must manage it in a manner that does not harm the environment, public health, or living conditions. It covers various aspects of public hygiene, including waste management.

- **Decree No. 2008-009/PRES/PM/MS/MECV of January 10, 2008: Management of Biomedical and Similar Waste**

This decree specifically regulates the management of biomedical waste, from its production to final disposal. It emphasizes proper sorting, collection, transportation, and treatment of such waste to protect public health and the environment.

- **Decree No. 2001-185/PRES/PM/MEE of May 7, 2001: Standards for Pollutant Emissions into Air, Water, and Soil**

This decree sets the standards for pollutant emissions into the air, water, and soil, aiming to prevent environmental pollution and protect public health.

- **Law No. 005/97/ADP of January 30, 1997 (Environmental Code of Burkina Faso)**

Article 31: Urban and Rural Solid Waste

Article 31 prohibits the possession or abandonment of urban waste in ways that could harm public health or the environment.

It requires waste producers or holders to dispose of waste or have it disposed of in accordance with legal and regulatory provisions

Article 36: Industrial Solid Waste

Article 36 states that all industrial waste must be disposed or recycled in a manner that does not endanger human health or the environment.

It also makes industrial waste producers responsible for the management, disposal, or recycling of their waste.

- **Decree No. 98-323 of July 28, 1998: Regulation of Urban Solid Waste Management**

This decree regulates the collection, storage, transportation, treatment, and disposal of urban solid waste.

It prohibits dumping or abandoning waste in public spaces, green areas, or forests.

It also outlines the responsibilities of local governments and relevant public services in managing solid waste.

- **Decree No. 95-176 of May 23, 1995: Establishing a Household Waste Fee**

Article 8: Specifies that each decentralized local authority is responsible for organizing the collection and disposal of urban solid waste within its jurisdiction.

I.5. Characteristics and waste treatment methods

In this section, we will discuss waste types and treatment methods.

I.5.1. Characteristics

According to the study conducted by Bagré D., Ouédraogo Y., and Tapsoba G. (2005) at the Sanitation Laboratory of the University Joseph KI-ZERBO, the characterization of household solid waste in the city, carried out between 2003 and 2005, reveals a clear dominance of organic materials. As shown in *Figure 3*, organic waste constitutes approximately 68% of the total household waste generated. This significant proportion reflects the high presence of biodegradable matter, particularly food residues and plant-based waste, which highlights the considerable potential for composting and organic waste valorization. Plastic waste accounts for 13% of the total, making it the second most common component. This is followed by paper and cardboard, which together represent 7%, and glass and metal, which comprise 6%. Although these fractions are less substantial than organic waste, they remain important due to their recyclability, provided that appropriate sorting and collection mechanisms are in place. The category labeled "Others," likely encompassing textiles and various non-classified residuals, also represents 6% of the waste stream. This distribution underscores the necessity of adopting a differentiated and strategic approach to waste management in Ouagadougou. Emphasis should be placed on the sustainable treatment of organic waste, alongside the development of efficient recycling systems for recoverable materials.

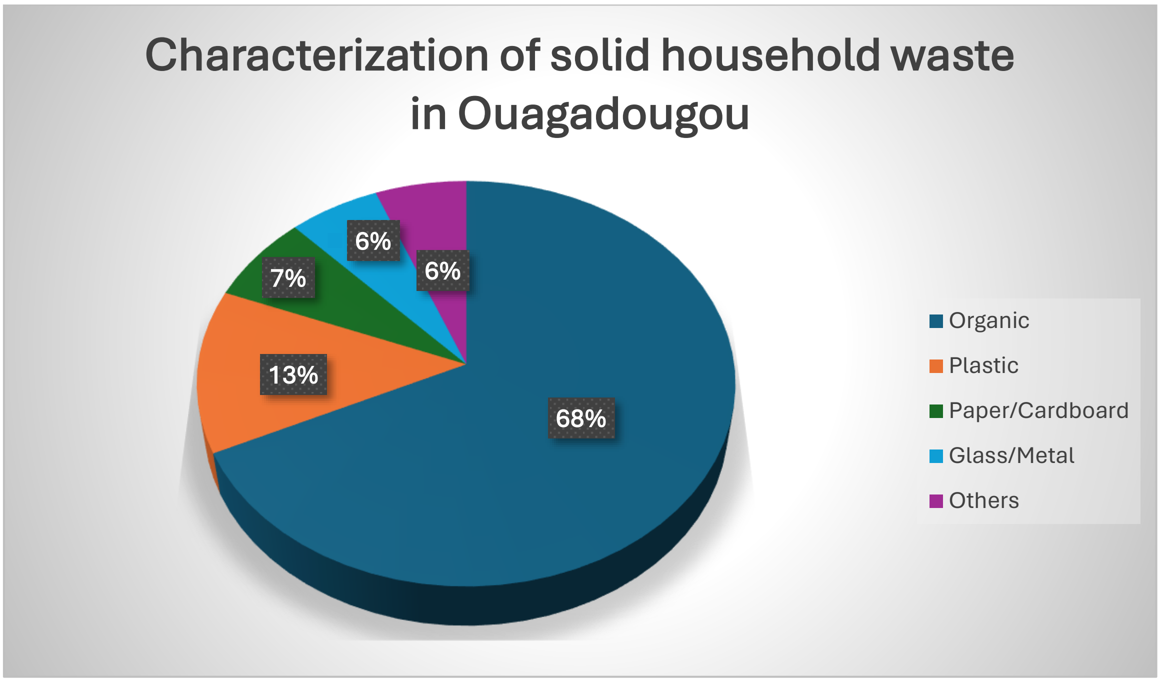


Figure 3: Typology of waste

Source: The Sanitation Laboratory of the University Joseph KI-ZERBO

I.5.2. Waste Treatment methods

The different types of waste treatment in Ouagadougou

- **Plastic recycling**

At the Waste Treatment and Recovery Centre in Ouagadougou, recycling activities are currently limited to plastic waste. This process entails collecting and transforming discarded plastics into reusable materials, contributing to environmental preservation by minimizing ecological harm.

- **Composting**

Composting is a biological process that transforms organic materials such as food scraps, garden trimmings, and agricultural residues into compost, a nutrient-rich substance that enhances soil fertility.

Waste incineration

Incineration is a waste treatment method that consists of burning dry materials—such as paper, cardboard, textiles, and combustible waste, at high temperatures. This process reduces waste volume to ash while enabling energy recovery.

- **Landfill of waste**

Landfilling is a waste disposal technique that entails the controlled burial of solid waste in specially designated sites. Its primary objective is to isolate waste from the surrounding environment, thereby reducing potential risks to human health and natural ecosystems.

I.6. Impact of solid waste on the environment

Poorly managed solid waste poses significant and wide-ranging threats to the environment and public health. Hazardous materials such as chemicals, heavy metals, and components from batteries can leach into the soil, degrading its fertility and impairing plant and crop development. Leachate from open dumps and landfills can seep into groundwater or flow into surface water bodies, contaminating aquatic ecosystems and increasing the risk of waterborne diseases like cholera and dysentery. Plastic waste frequently accumulates in rivers, lakes, and oceans, where it disrupts marine life. The open burning of waste, particularly plastics and rubber, releases harmful pollutants including dioxins, furans, and carbon monoxide. Additionally, the anaerobic decomposition of organic matter in landfills produces methane (CH_4), a greenhouse gas far more potent than carbon dioxide. These emissions, combined with dust and fine particulates, degrade air quality and pose serious respiratory hazards. Open dumping and inadequate sanitation also attract vectors such as rodents and mosquitoes, which can trigger the spread of infectious diseases in urban settings. Waste workers, often lacking proper protective equipment, are routinely exposed to toxic substances and health risks. Wildlife suffers through ingestion of or entanglement in plastic debris, and illegal dumping contributes to habitat destruction and ecosystem imbalance, threatening biodiversity. Furthermore, the cumulative greenhouse gas emissions from waste transport, combustion, and landfill operations exacerbate climate change. Visually, open dumps mar the landscape, decrease property values, clog drainage systems leading to urban flooding and render land unsuitable for agriculture or development.

I.7. Current method of waste management

In the city of Ouagadougou, the management of solid waste falls under the responsibility of the Directorate of Sanitation and Public Hygiene. The city is administratively divided into 12 districts and 55 sectors. Waste collection services are provided by officially recognized entities, primarily Economic Interest Groupings (EIG) and Small and Medium-sized Enterprises (SMEs).

A total of 12 formal structures has been appointed by the Directorate to handle household solid waste collection, with each one assigned to a single district. This one-to-one allocation model ensures that every district is served by a specific operator. In addition to these formal entities, several subcontractors operate under the coordination of the main service providers within their designated zones. Approximately 34 informal actors or individual collectors are also involved in waste collection activities, although these operate outside the legal and regulatory framework.

For the purposes of operational analysis, only the 12 officially mandated structures are considered. Subcontracted units are treated as extensions of their respective parent structures. Informal collectors, due to their non-compliance with established regulations and their unofficial status, are excluded from this framework.

Unplanned or non-parcelled neighbourhoods remain largely underserved, as they are not currently included in the coverage zones of the formal collection system. To address this gap, the Directorate of Sanitation and Public Hygiene is initiating a restructuring of collection zones. The proposed changes aim to assign waste collection responsibilities by sector rather than by district. This adjustment seeks to regularize informal actors, improve service coverage, and bring greater efficiency and inclusivity to the waste management system across the entire city.

The *figure 4* describes the waste collection current system of Directorate of Sanitation and Public Hygiene in Ouagadougou

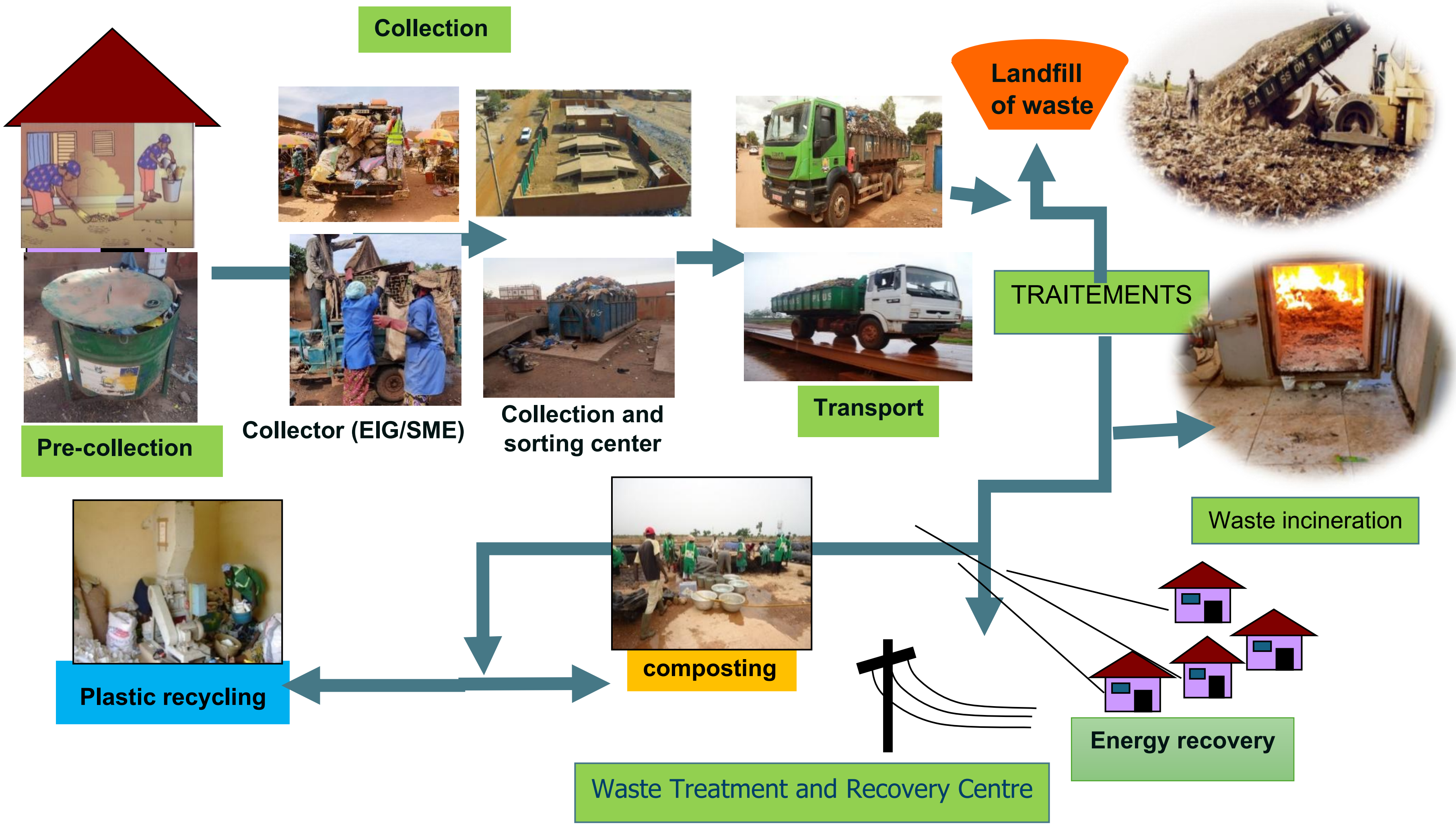


Figure 4: Waste collection current system

Source: DSHP

I.8. Critical analysis of the solid waste management system in Ouagadougou

From the initial stages of waste handling to final recovery, the solid waste management system in Ouagadougou faces a range of structural and operational challenges. Collection programs lack structure and depend largely on the availability of collection agents, with schedules rarely communicated to residents. The equipment used for collection remains manual and outdated, which limits efficiency and increases the workload. A significant number of collection and sorting centers are either non-functional or operating beyond their capacity. The limited availability of waste transport vehicles causes frequent delays in clearing these centers, disrupting the waste management cycle. The main incinerator at the city's treatment and recovery facility is currently out of service, which prevents the processing of certain waste types. In addition, the energy recovery unit at the same facility is not yet operational. As a result, methane produced by landfilling and composting is released into the atmosphere, contributing to air pollution and environmental degradation. Large peripheral areas of the city remain without access to formal waste collection services. This situation encourages the development of unauthorized open-air dumpsites, which pose health and environmental risks. The absence of real-time monitoring systems for tracking bin fill levels makes collection planning more difficult and less responsive to actual needs. Furthermore, the lack of effective communication tools prevents residents from actively participating in the management of their household waste, weakening efforts to improve overall waste management practices in the city.

Conclusion

In summary, the literature highlights the complexity of solid waste management, emphasizing the need for integrated approaches that combine technological innovation, community involvement, and effective policy frameworks. While various strategies have been explored, challenges such as rapid urbanization, limited infrastructure, and stakeholder coordination remain central issues. These findings underscore the importance of context-specific solutions and provide a foundation for this research. The next chapter will present the materials and methods used to achieve the research objectives.

CHAPTER II: METHODOLOGY AND MATERIALS

This chapter outlines the methodological framework used to conduct the study. It presents the research design, data collection techniques, tools developed, and the approach adopted for analysing the efficiency and feasibility of a digital waste management system in Ouagadougou. The materials, sources of data, and procedures followed during the field investigation and technical development are also described.

II.1. Study area

Ouagadougou, the capital city of Burkina Faso, spans an area of approximately 54,000 hectares and is administratively divided into 55 sectors grouped into 12 districts. According to data from SDGD 2019, the city produces an estimated 800,000 tonnes of solid waste annually. This situation is compounded by the rapid pace of urbanization and population growth, which intensifies the demand for effective and sustainable waste management systems. With a population exceeding three million, as recorded in the 2019 General Population and Housing Census (RGPH), the city is increasingly confronted with challenges related to the collection, monitoring, and disposal of solid waste. Existing infrastructure has not expanded at the same rate as demographic growth, leading to irregular waste collection services, poor coverage in informal settlements, and a lack of modern tools for waste tracking and management. Manual waste collection remains prevalent, and insufficient bin capacity frequently results in overflow, contributing to poor sanitation in public areas and raising public health concerns. In response to these conditions, a study is planned within selected districts of Ouagadougou. The objective is to evaluate the feasibility and performance of implementing a digital waste management solution, including a mobile application and a bin-fill alert system. These targeted districts reflect the city's social and spatial diversity and are particularly affected by issues related to population density and the complexity of managing waste in informal neighbourhoods. The f*igure 5* presents Ouagadougou districts and sectors.

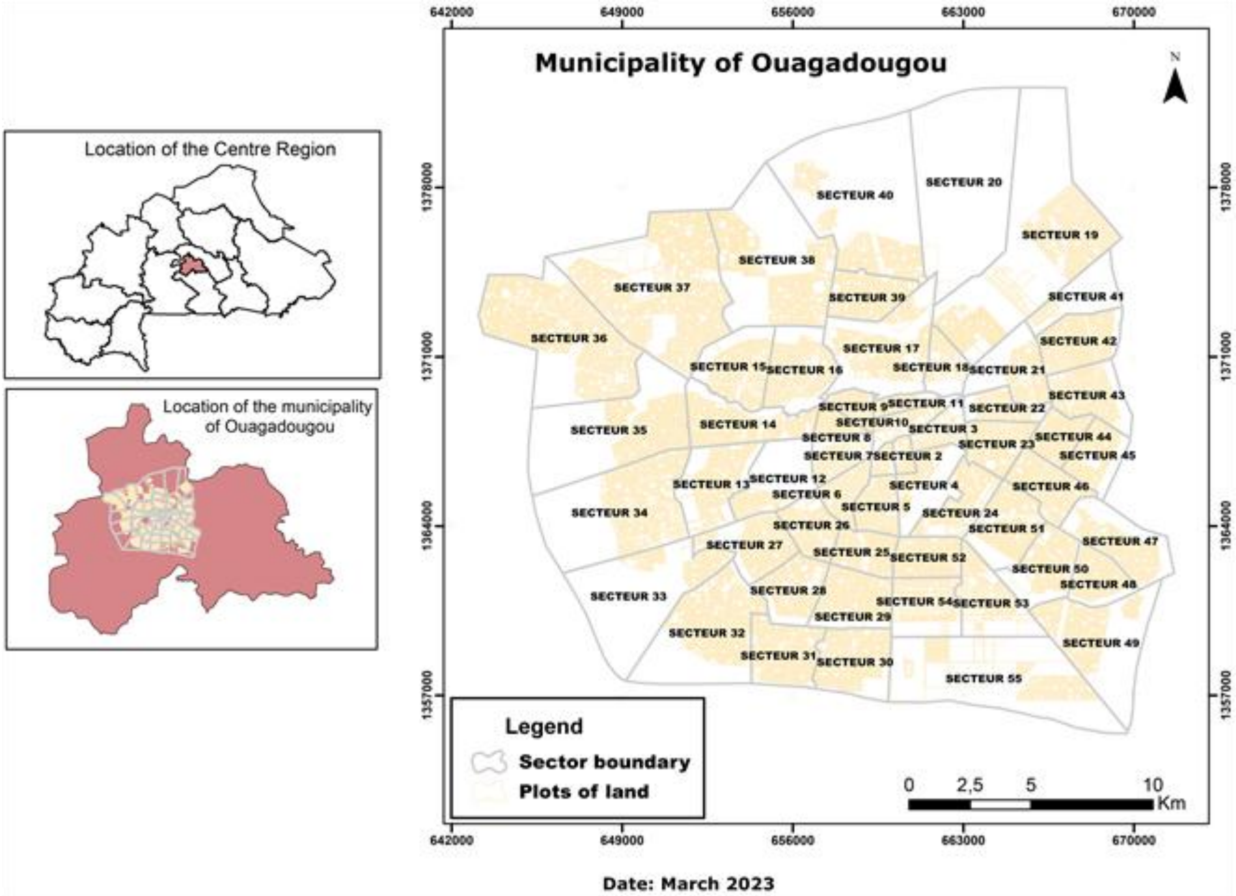


Figure 5:Ouagadougou card

Source: IGB

II.2. Methodology

This section presents the methodology adopted to achieve the objectives of the project. It outlines the systematic approach used for data collection, system design, development, and deployment. The methodology was structured in sequential phases, each contributing to the overall implementation of the smart waste collection management solution.

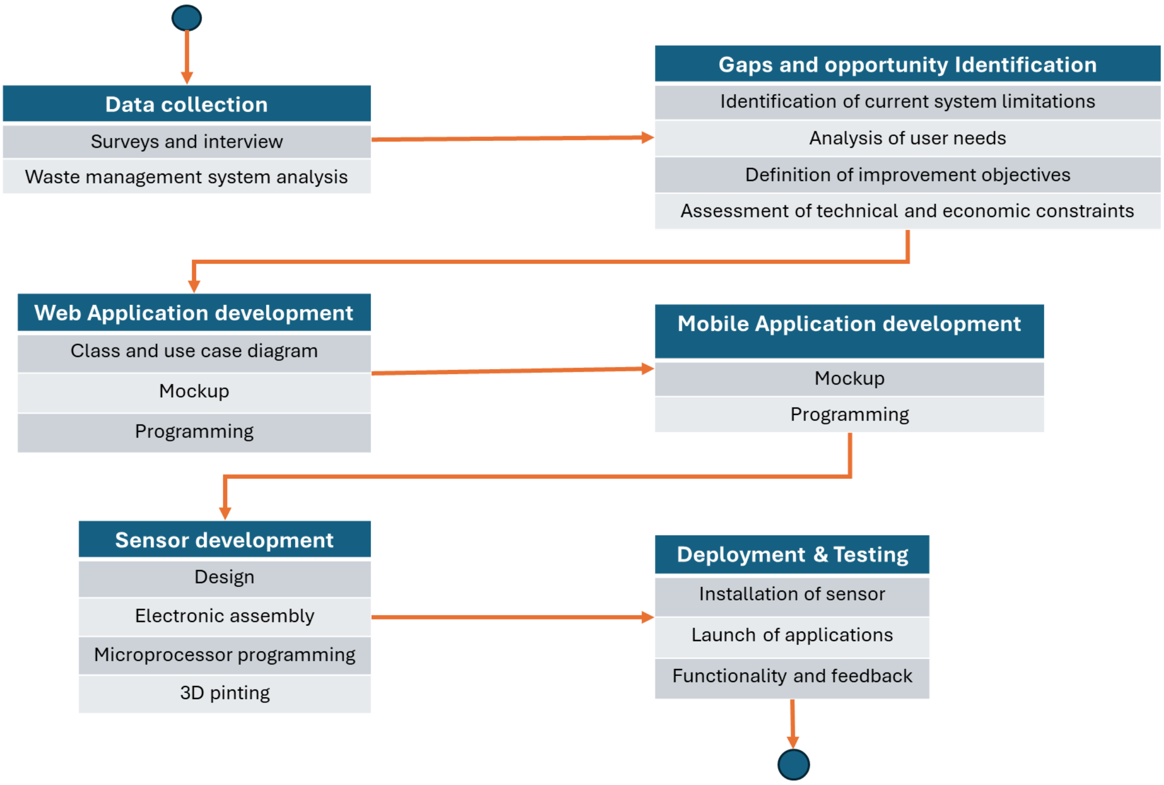


Figure 6:Workflow Diagram

II.2.1. Data collection

Data collection focused on understanding current waste collection practices in Ouagadougou, identifying key issues and assessing the feasibility of implementing a mobile solution with real-time tracking of bin fill. Data was collected from primary sources, including interviews, surveys and field observations, as well as secondary sources such as reports and publications.

II.2.1.1. Surveys and interviews

To carry out the surveys, it was necessary to conduct a population sampling. Calculations were therefore made to determine a representative sample. According to the 2019 General Population and Housing Census (RGPH), the total number of households in Ouagadougou is 610,052, which corresponds to an average of approximately 50,838 households per district (610,052 ÷ 12). Out of the 12 districts, surveys were conducted in 7. In each of these selected districts, 28 households were surveyed. Regarding the 12 formal structures recognized by the DSHP, interviews were conducted with the heads of 10 structures; the remaining two were unavailable.

Formular:

$$CR = (n/N) \times 100 \qquad (1)$$

Calculation:

SSR: (10/12) ×100=83.33%

SSR = 83.33%

DCR: (7/12) ×100=58,33%

DCR = 58,33%

HCR: (28/51) ×100=54.9%

HCR =54.9%

Where:

- **n** = number of structures surveyed
- **N** = total number of structures
- **CR** = Coverage Rate
- **SSR** = Structures Surveyed Rate
- **DCR** = Districts Coverage Rate
- **HCR** = Household Coverage Rate

To facilitate understanding, a summary table of the results obtained is presented below.

Table 1: Recapitulate table of sample formular

Indicator	Value
Total collection structure	12
number of structures surveyed	10
Structures surveyed Rate	83.33%
Total districts	12
Districts surveyed	7
District coverage rate	58.33%
Total households (Ouagadougou)	610,052
Average households per district	51
Average households surveyed per district	28
Total households surveyed	196
Household coverage rate (citywide)	54,9%

II.2.1.2. Field observations

Field observations led to the following findings: Ouagadougou has 60 Collection and Sorting Centres (CSCs), but a large number of these are out of service, primarily due to the lack of waste bins, resulting in the scattering of garbage on the sites. In some areas, the infrastructure is destroyed. These conditions have contributed to the emergence of unauthorized dumping sites across the city. According to the Department of Sanitation and Public Hygiene (DSHP) of Ouagadougou, 122 illegal dumpsites were identified in 2023.

The visit to the vehicle fleet of the DSHP revealed several resource limitations, including fuel shortages, and a lack of modern, waste-transport-adapted trucks. Additionally, there is no digital database to manage the collection teams and their clients, making coordination and performance monitoring extremely difficult.

Figure 7: Collection and sorting centre

Source: DSPH

Figure 8: Vehicle fleet of Department of Sanitation and Public Hygiene

Source: DSPH

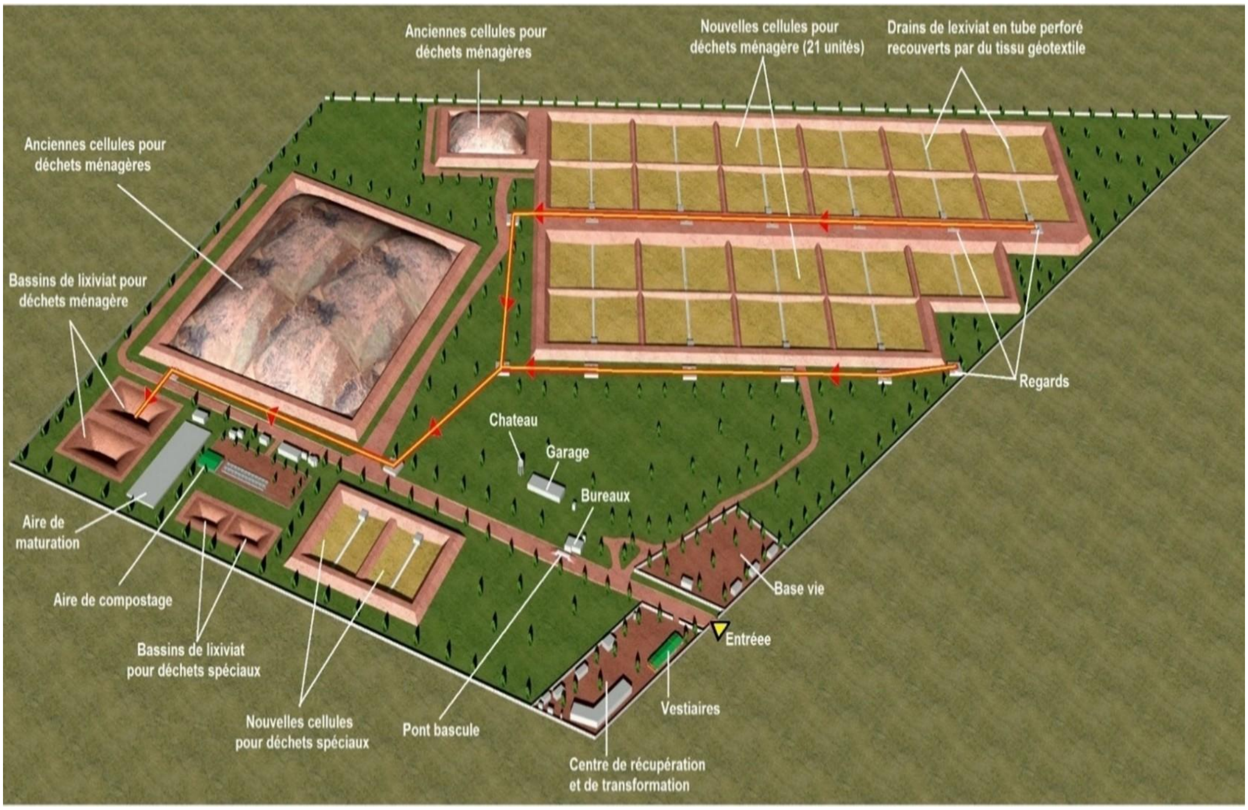


Figure 9: Waste treatment and recovery centre

Source: DSHP

II.2.1.3. Technology and infrastructure assessment

This assessment aims to evaluate the current technological infrastructure in Ouagadougou, Burkina Faso, with a focus on the following key areas:

- The availability and penetration of smartphones among the population
- Internet connectivity, including 3G/4G/Wi-Fi availability and associated costs
- The feasibility of deploying sensor technologies in waste bins for real-time monitoring
- The identification of technical requirements for a mobile application supporting waste management and fill-level notification systems

- **Current Mobile and Internet Landscape**

Smartphone Penetration:
Recent trends reveal a growing adoption of smartphones in Ouagadougou, particularly among individuals aged 15 to 35 living in urban areas. It is estimated that between 65% and 75% of this demographic group regularly uses smartphones, driven largely by the expansion of digital connectivity and increasing engagement with social media platforms.

Internet Access:

Most urban zones in Ouagadougou benefit from 3G/4G coverage, provided by major telecom operators such as ONATEL, Orange, and Telecel. Additionally, both public and private Wi-Fi hotspots are accessible in several areas. However, the high cost of mobile data remains a barrier for low-income users, which could limit the widespread use of mobile applications unless these are optimized for low-bandwidth environments.

- **Feasibility of Waste Bin Sensor Technologies**

Potential Solutions:

Technologies such as ultrasonic or infrared sensors can be used to measure the fill level of waste bins. Data transmission between bins and a central monitoring system can be achieved using communication technologies like LoRaWAN, GSM, or NB-IoT. Given the unreliability of the power grid in certain locations, bins should be equipped with solar-powered modules or rechargeable battery systems.

Challenges:

Key challenges include the high initial cost of smart bins and ongoing maintenance requirements. There may also be a shortage of local technical expertise for sensor installation, calibration, and troubleshooting. Moreover, the equipment must be durable and weather-resistant to cope with harsh environmental conditions.

II.2.2. Cleaning and processing of the raw data collected

Once raw data has been collected, it often contains inconsistencies, missing values, and irrelevant information that can hinder accurate analysis. Therefore, the cleaning and processing phase is essential to prepare the data for meaningful interpretation. This section displays data processed to guarantee its reliability and validity.

Table 2: Synthetic Table of Responses from the DSHP interview

No.	Questions	Responses / Collected Information
1	How is waste collected and managed in Ouagadougou?	By GIEs/SMEs distributed across 12 zones; mostly private household collection; final treatment at the CTVD in Polosgo.
2	Current collection methods?	Manual collection, trucks, collection and sorting centers (CCT).
3	Directory of open-air dumps and municipal bins?	60 CCT and 122 illegal dumps identified in 2023.
4	Frequency of collection at public bins?	Variable, not specified.
5	Number of permanent dumping points?	Main center: CTVD (Polosgo, 70 hectares).
6	What happens to waste after being deposited at the CCT?	Transported to CTVD for treatment and recovery.
7	Public collection points for non-subscribers?	CCTs are accessible to local residents.
8	Types of collection structures?	☐ Public ☑ Private ☐ Mixed ☐ Other
9	Number of collectors?	Around 1,000 GIE members.
10	How are companies organized by the DSHP?	Divided by zone (12 zones → soon 55 sectors covered); directory to be completed.

11	Main challenges?	Mentalities, incivility, informal structures, tax evasion, unplanned areas not served.
12	Proposed solutions?	Awareness, enforcement, digital integration, accountability.
13	Digital management system?	Non-existent; use of agents to report anomalies and bin fill levels.
14	Need for a mobile app?	Yes. To report, locate, denounce, and consult collection data.
15	Location of illegal dumps and CCT?	Partially mapped; full mapping needed.
16	Inventory of 122 illegal dumps?	Method not specified; to be clarified.
17	Strategy for managing informal structures?	To be defined: possible integration, awareness, penalties.
18	Monitoring and emptying of CCT?	No standard form mentioned; needs verification.
19	Capacity of containers and burial pits?	Not specified; request needs to be made.
20	Why are unplanned areas not covered?	Reasons not specified; likely due to lack of formal structures.
21	Identification of authorized users in CCT?	Not specified; may require badge or physical control.
22	Addressing the needs of informal structures?	Restructuring collection zones into sectors.
23	Available connected equipment?	Wi-Fi, computer, Android phones.
24	Recruitment of agents?	Volunteers and GIE/SME members.
25	Amount of unsegregated waste buried annually?	Total: 800,000 tons/year (2019); partial sorting.
26	Cameras or monitoring system in CCT?	Not yet in place, proposed for surveillance and notifications.

Table 3: Synthetic Table of Responses from Formal Waste Collection Structures in Ouagadougou

Theme	Key Observations	General Trend (across 10 structures)
Geographic area served	Districts per structure	Districts 1, 3, 4, 5, 6, 7, 9, 10, 11, 12
Staff	Agents + informal workers	Average: 20 to 50 people
Collection frequency	Bi-weekly, weekly	36% bi-weekly, 64% weekly
Schedule adequacy	User satisfaction evaluation	54% Yes, 46% No
Methods used	Carts, tricycles, door-to-door, containers	Manual collection widespread; 40% use tricycles
Software/app used?	WhatsApp, Excel	2 Yes (basic tools), 8 No
Need for digital tools	Mobile management app, geolocation, notifications	10 Yes
Sufficiency of CCTs	Number of transfer centers per area	7 No (need for more CCTs)
Post-collection sorting	Sorting organization	Only plastic is sorted by some collectors
Client communication	Calls, WhatsApp, SMS	10 via calls, 6 via WhatsApp
Purchase of notification device	Conditioned by client participation	6 "Maybe", 3 Yes, 1 No
Relationship with informal collectors	Negotiation, disregard, subcontracting	1 negotiates, 6 disregard, 3 collaborate
Major challenges	Lack of equipment, inaccessible areas, low awareness, poor CCT management	Multiple combined challenges
Proposed solutions	More CCTs, mobile app, awareness, sorting, equipment subsidies	Consensus on digital and logistical solutions
Additional suggestions	Mobile payment, dump site control, better municipal management	Strong demand for coordination and regulation

Table 4: Summary table of residents' responses to the survey on urban waste management

Question	Response Options	Number	%
Are you a resident of Ouagadougou ?	Yes	190	96.9 %
	No	6	3.1 %
How would you rate the waste management in your neighborhood?	Very satisfactory	12	6.1 %
	Satisfactory	40	20.4 %
	Average	70	35.7 %
	Unsatisfactory	50	25.5 %
	Very unsatisfactory	24	12.2 %
How often is waste collected in your neighborhood?	Daily	15	7.7 %
	Twice a week	60	30.6 %
	Weekly	80	40.8 %
	Less frequently	30	15.3 %
	I don’t know	11	5.6 %
Who is responsible for managing your household’s waste?	Yourself	45	22.9 %
	Formal companies	85	43.4 %
	Informal collectors	60	30.6 %
	Other (specify)	6	3.1 %
Is the waste collected regularly as scheduled?	Yes	70	35.7 %
	No	60	30.6 %
	Sometimes	66	33.7 %
Do you have access to waste bins or collection centers in your neighborhood?	Yes, on every corner	35	17.9 %
	Yes, but very few	95	48.5 %
	No, I dispose waste elsewhere (e.g. open dumps)	66	33.7 %
Are you satisfied with the location and cleanliness of collection points?	Very satisfied	10	5.1 %
	Satisfied	40	20.4 %
	Moderately satisfied	80	40.8 %
	Not satisfied	66	33.7 %
Do you observe rule violations regarding waste disposal in your neighborhood?	Yes, frequently	85	43.4 %
	Yes, occasionally	70	35.7 %
	Rarely	25	12.8 %
	Never	16	8.1 %
What do you do with chemical or medical waste at home?	Throw them in the bin	80	40.8 %
	Burn them	55	28.1 %
	Store them until collected	45	22.9 %
	Other (specify)	16	8.1 %
Do you or your household practice waste sorting (recycling, composting)?	Yes, regularly	25	12.8 %
	Yes, but rarely	40	20.4 %
	No, we don’t sort	100	51.0 %
	I don’t know how to sort	31	15.8 %

Main problems in waste management (multiple choices allowed)	Lack of coordination	120	61.2 %
	Infrequent collection	135	68.9 %
	Poor waste handling in peripheral areas	100	51.0 %
	Lack of public awareness	110	56.1 %
	Poor interaction with collectors	85	43.4 %
	Open dumping and pollution	150	76.5 %
Should the municipality play a bigger role in waste management?	Yes, absolutely	120	61.2 %
	Yes, to some extent	55	28.1 %
	No, it already does enough	15	7.7 %
	No, it should be managed by others	6	3.1 %
Would you be willing to participate in testing our waste management app?	Yes	140	71.4 %
	No	20	10.2 %
	Maybe	36	18.4 %
Would you buy a device that notifies the collection service when your bin is full?	Yes	80	40.8 %
	No	30	15.3 %
	Maybe, if the service helps pay for it	86	43.9 %

II.3. Materials

This section presents the various materials used throughout the project. These include hardware components, software tools, and other essential resources required for the design, development, and implementation of the proposed system. Each item was selected based on its relevance, performance, and compatibility with the objectives of the study.

II.3.1. Tools

This section presents the tools used throughout the research process. The choice of these tools was guided by their relevance, availability and effectiveness in the context of assessing waste management in Ouagadougou. There are:

For the design and development of the IoT-enabled smart waste bin system, several digital tools were employed to ensure a structured and user-centered approach. Draw.io (*Figure10*), a versatile and free diagramming platform, was used to create UML class diagrams, flowcharts, and use case diagrams, offering clear visualizations of the system's architecture, operational logic, and user interactions. Figma (*Figure11*), a cloud-based UI/UX design tool, facilitated the creation of web and mobile application mockups, allowing for the definition of layouts, user journeys, and overall aesthetics prior to implementation. Its collaborative features enabled real-time feedback and seamless coordination with team members and supervisors. Additionally, SolidWorks (*Figure12*), a professional-grade 3D CAD software, was utilized to model the physical design of the IoT sensor unit, including the housing and internal components such as the microcontroller, sensors, and power module. This ensured a compact, functional, and durable prototype suitable for real-world installation in waste collection bins.

Figure 10: Draw.io

Figure 11: Figma

Figure 12: SolidWorks

To develop the web and mobile applications for the IoT-enabled smart waste bin system, a combination of modern frameworks and backend technologies was employed. The frontend was built using Flutter, a cross-platform framework by Google, which allows the creation of responsive and consistent user interfaces for Android, iOS, and web applications from a single codebase. The application logic and UI components were implemented using the Dart programming language, streamlining development and reducing maintenance complexity. For the backend, Supabase a backend-as-a-service platform based on PostgreSQL was used to handle core functionalities such as user authentication, real-time data management, RESTful API services, and storage. Supabase played a critical role in managing and delivering data collected from the IoT sensors, including bin fill levels and geolocation, ensuring seamless integration with both the web and mobile platforms.

Figure 13: Flutter

Figure 14: Supabase

II.3.2. Electronics components used to design the IoT-enabled sensor system

The IoT-enabled sensor system for smart waste management integrates key electronic components to ensure effective data collection, processing, and transmission. Central to the system is the **ESP32 microcontroller**, which manages sensor data and communicates with both the **NEO-6M GPS module** for geolocation and the **SIM800L GSM/GPRS module** for remote data transmission. The **HC-SR04 ultrasonic sensor** monitors waste levels by measuring the distance to the top of the garbage, triggering alerts when bins are nearly full. All components are assembled on a **Printed Circuit Board (PCB)** and powered by a **rechargeable battery**. Additional elements such as a **power switch**, **jumper wires**, and a **protective enclosure** support operation, connectivity, and durability. This configuration ensures real-time monitoring and facilitates reliable communication with the Trash App's backend system.

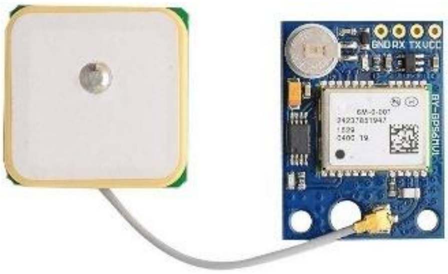


Figure 15: NEO-6M GPS

Figure 16: ESP32

Figure 17: HC-SR04

Figure 18: Interrupter

Figure 19: Pile

Figure 20: Jumpers

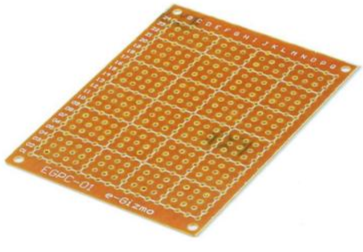


Figure 21: PCB

Figure 22: GSM GPRS SIM800L MODULE

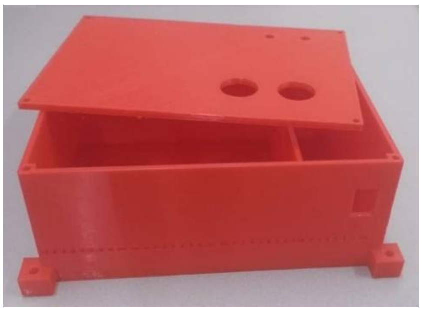


Figure 23: Hold box

Conclusion:

This chapter has presented the methodological approach adopted to design and implement a smart waste management system in Ouagadougou. It detailed the tools, technologies, and procedures used for data collection, sensor integration, and system deployment. The methodological framework combines field assessment with IoT-based infrastructure, ensuring the system is both technically viable and contextually adapted to local realities. The next chapter will focus on analysing the results obtained through this approach and evaluating the system's performance in real-life conditions.

CHAPTER III: IMPLEMENTATION, RESULTS AND DISCUSSION

This chapter presents the main findings of the study, followed by an analysis and interpretation of the results in relation to the research objectives. The effectiveness of the proposed digital tools is assessed based on the data collected, and the implications of these results are discussed in the context of improving waste management practices in Ouagadougou. The discussion also highlights the opportunities, challenges, and limitations identified during the implementation and testing phases.

III.1. Implementation

The development of the mobile and web waste collection management application and bin refill notification sensor will follow a structured approach including system design, prototyping and testing.

III.1.1. System design

Design a web-based application: it inventories waste collection actors and computerizes management and monitoring processes, tasks and schedules. Web application will serve as a database for collection structures and the Directorate of Public Health and Hygiene.

Mobile application design: The mobile application ais designed to allow residents to report that their bins are full, track collection schedules and receive notifications about waste collection. The application will also include communication functions between residents and waste collection management services, such as reporting missed collections or requests for special collections and violations.

To do this, a use case diagram is drawn up to identify the interactions that will take place between users, a class diagram is defined to establish the different tables and functions.

- Use Case Diagram

The use case diagram shows how different users (waste collection teams, administrators and citizen) and devices (IoT sensor) interact with the system. It defines each actor and their functionalities, such as viewing bin statuses, sending alerts, or managing system settings. This helps clarify system requirements and user expectations.

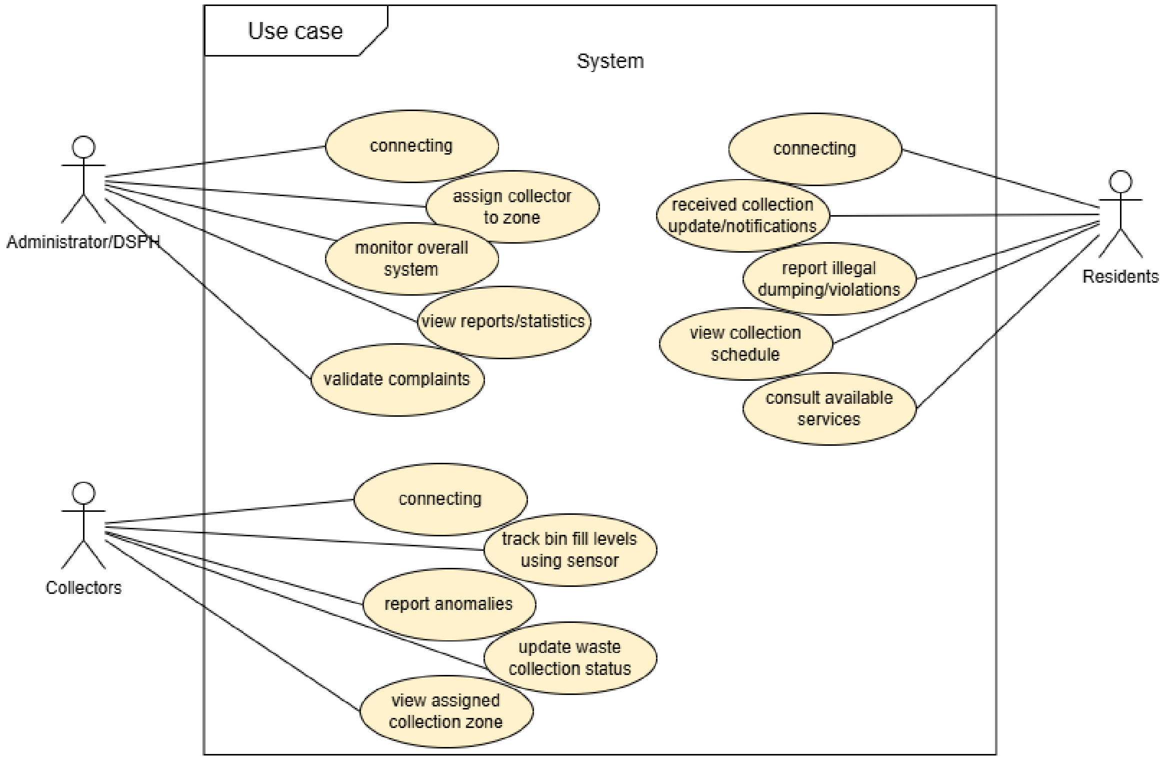


Figure 24: Use case diagram

- Class Diagram

The class diagram outlines the main components of the system, such as the microcontroller, sensors, mobile application, and database. It defines the attributes and methods of each class and shows how these components interact with one another. This helps in organizing the code structure and maintaining consistency between software and hardware modules.

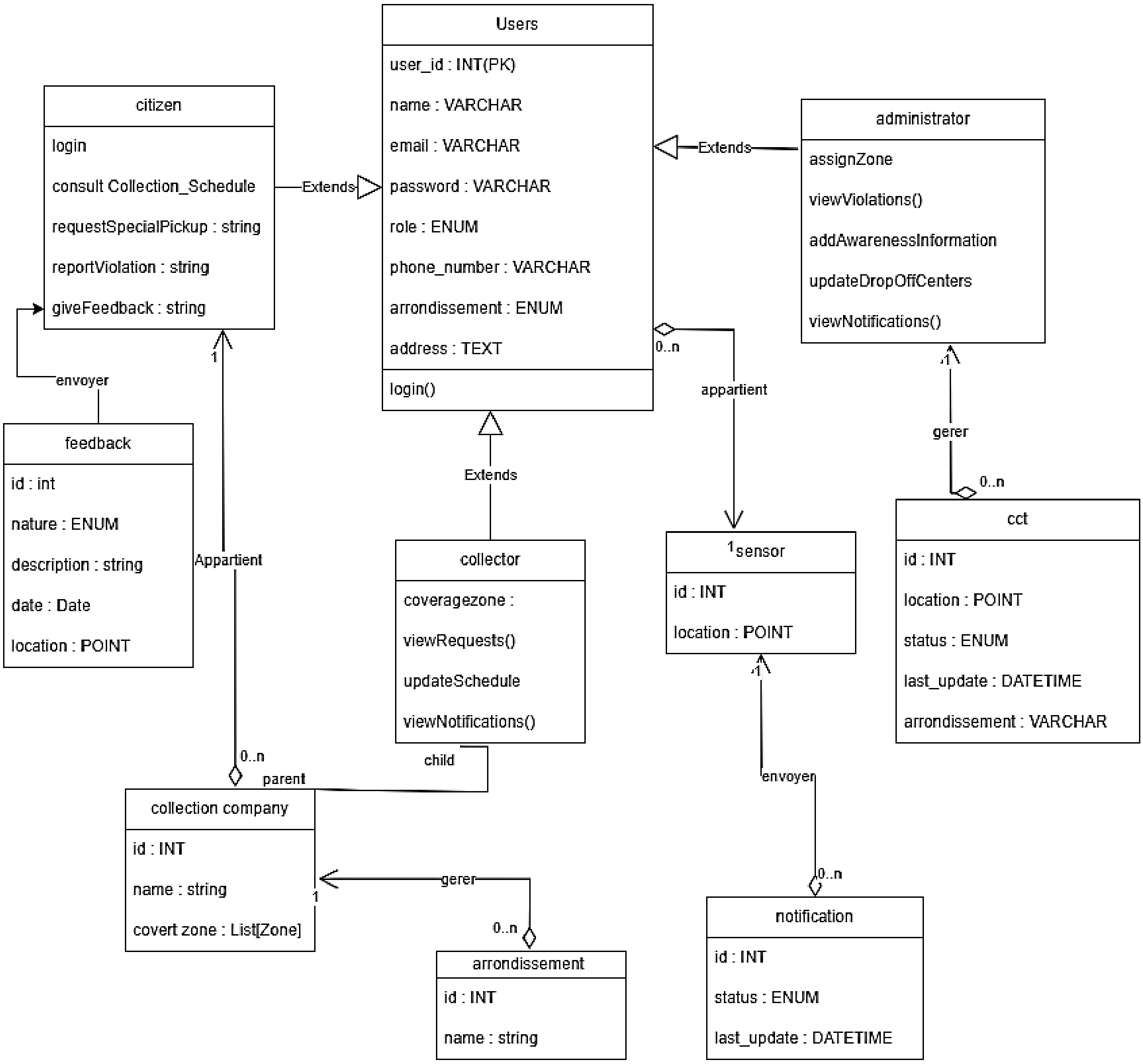


Figure 25: Class diagram

Implement an IoT-enabled sensor: A system of sensors will be developed to monitor how full the bins are in real time. The sensors will be installed in the bins and connected to a central server, which will monitor fill levels and send notifications to waste collection teams when the bins are almost full.

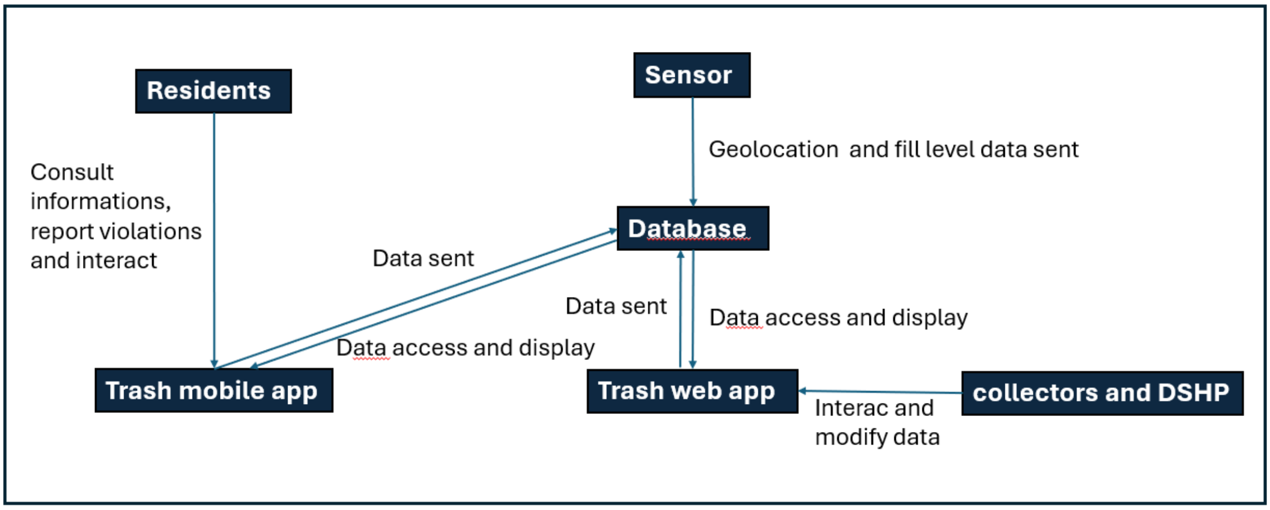


Figure 26: System functional architecture

- Flowchart

The flowchart illustrates the step-by-step process of the system, from sensor activation to data transmission and notification. It highlights the logical flow of operations, including decision points (e.g., whether the bin is full), actions (e.g., sending GPS data), and outcomes (e.g., notifying the waste collection team).

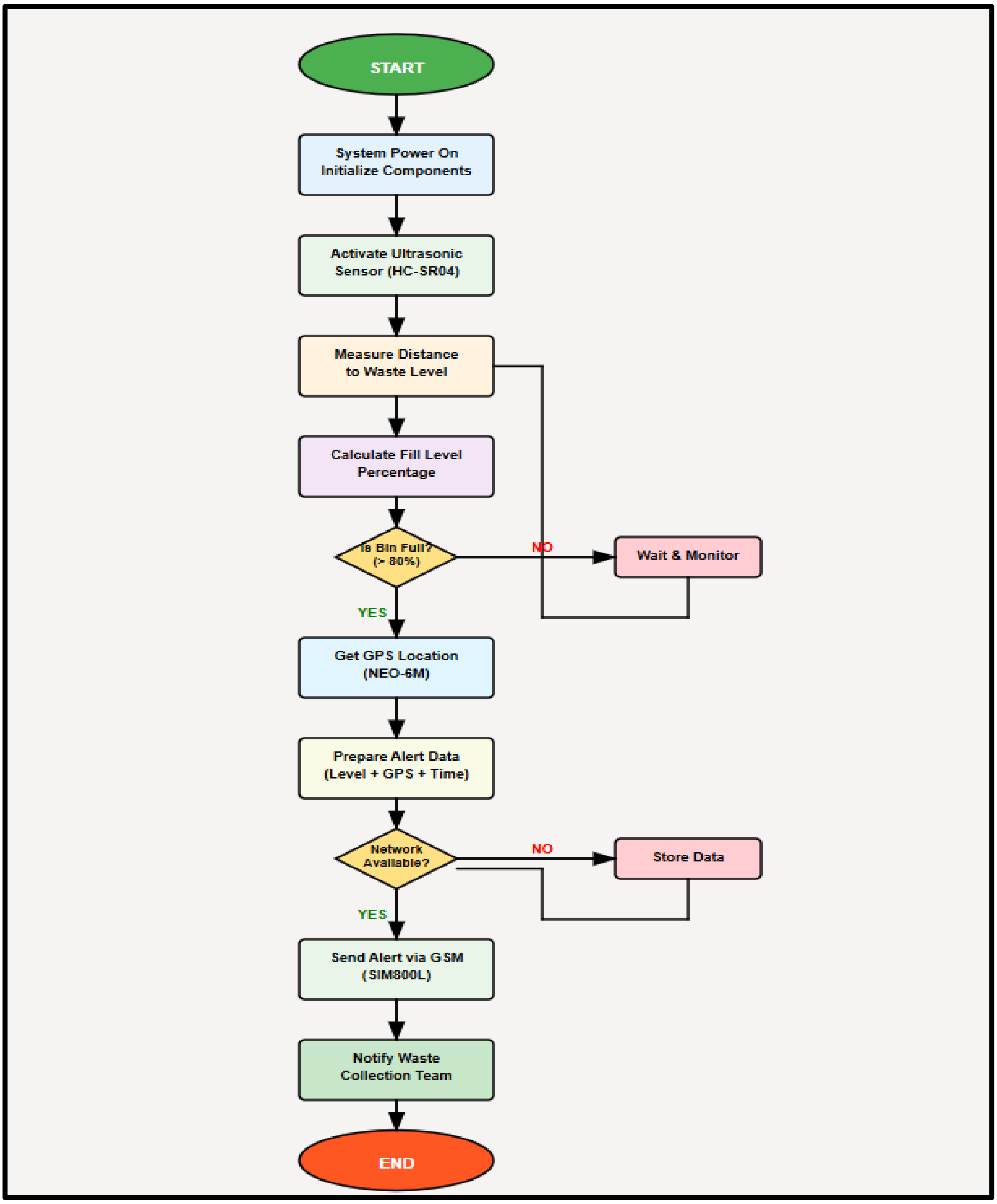


Figure 27: Flowchart

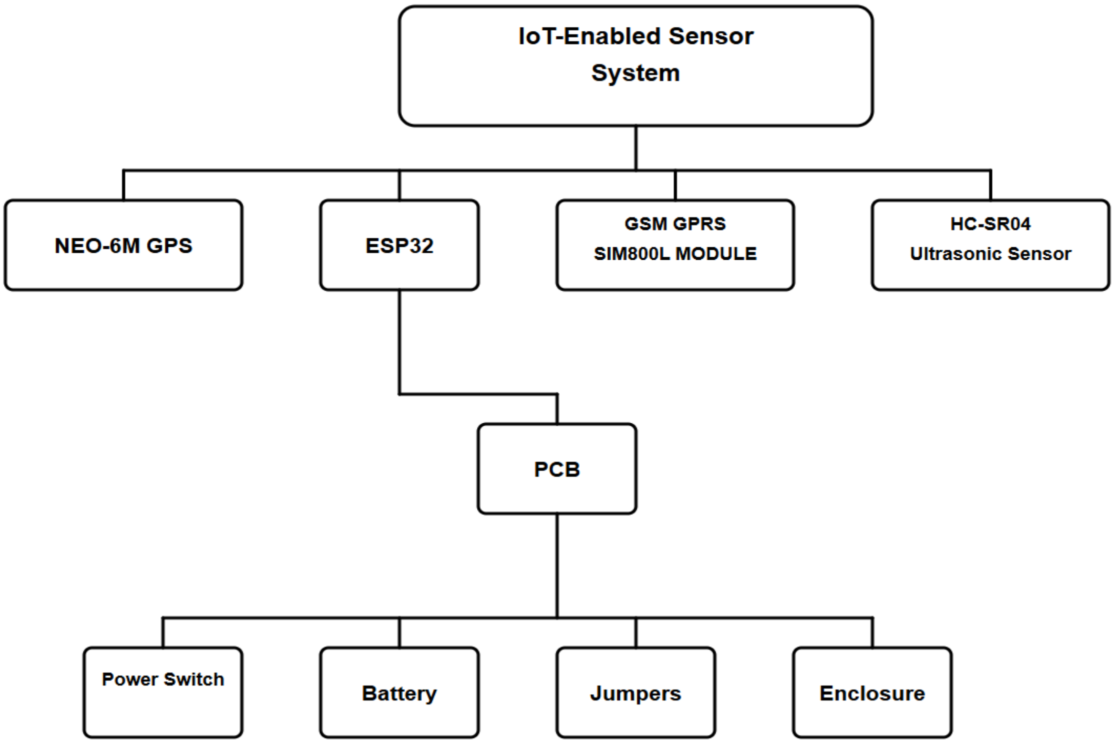


Figure 28: IoT-Enabled Sensor System

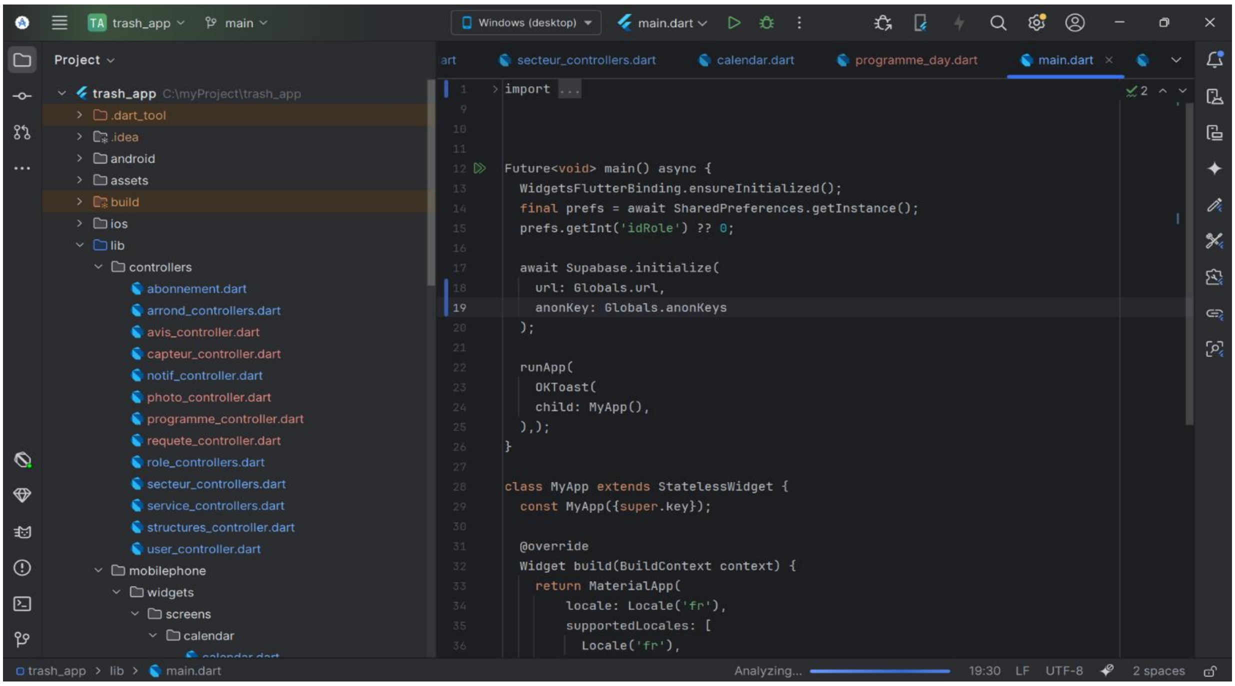
This diagram of figure 28 illustrates the assembly of the electronic components of the IoT-enabled smart sensor for waste management. All modules are connected to a ESP32 and a PCB (Printed Circuit Board), which organizes and stabilizes the connections. Supporting elements are also connected to the board, including a power switch, a rechargeable battery, jumper wires, and a protective enclosure. The entire setup forms a compact and autonomous device, suitable for outdoor environments.

In addition to these diagrams, we also created mockups of the mobile and web-based applications using Figma software (Figure 9) before developing them with Flutter.

III.1.2. Prototyping

The prototyping phase plays a crucial role in transforming design concepts into tangible, testable models. It allows for the early visualization of system components, identification of potential issues, and validation of core functionalities before full-scale development. In this project, prototyping involved the iterative development of both hardware (sensor) and software (web and mobile applications) components. This section details the steps taken to build, refine, and evaluate initial versions of the system.

The mobile and web application have been developed using Flutter Framework, Dart Language and Supabase (an open-source service platform built on PostgreSQL). here is a small part of the code



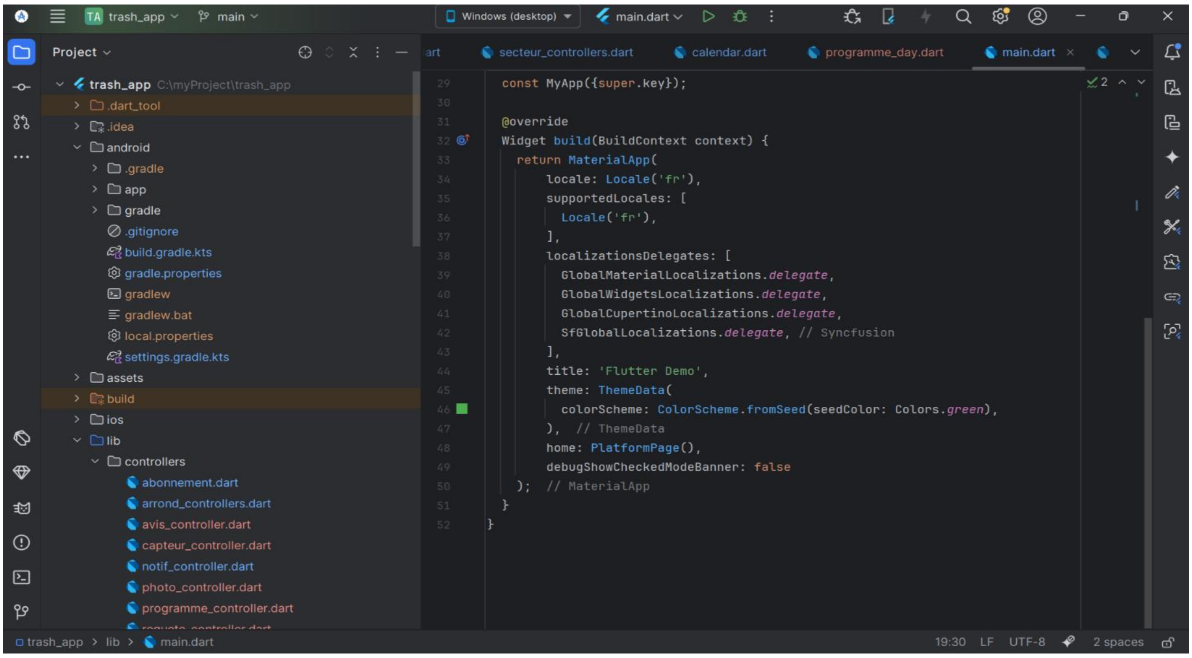


Figure 29:Trash_app main code

After assembling the sensor components, an Arduino IDE code was developed and uploaded to the microprocessor to integrate and operate them effectively. Also, the Hold box, designed in solidwork, was 3D printed.

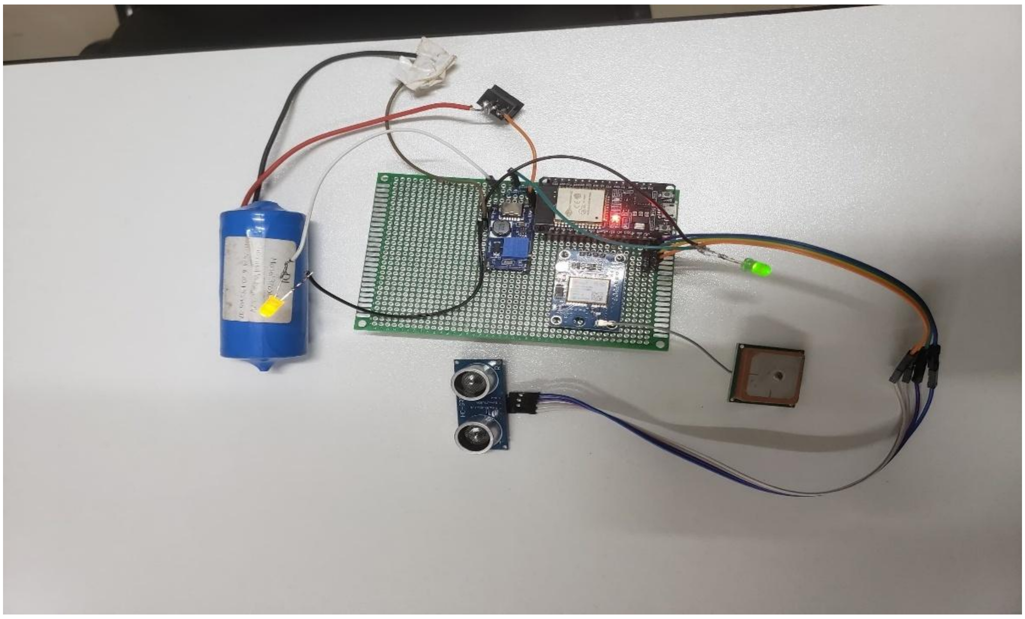


Figure 30: Components assembled

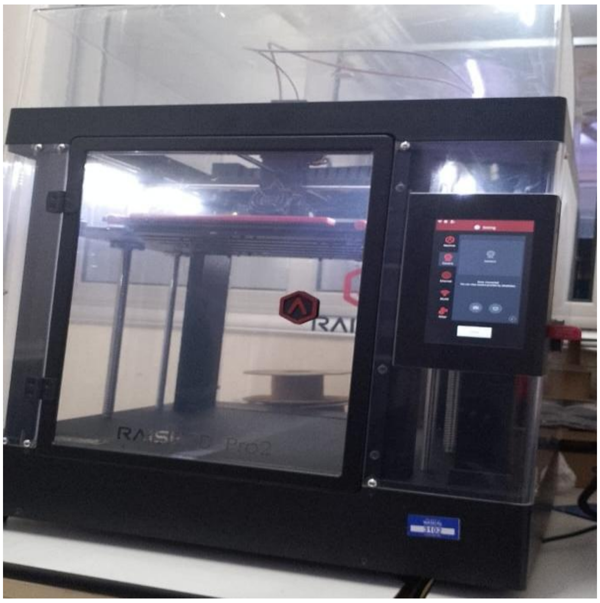


Figure 31: 3D Printing Hold box in WASCAL Competence Center

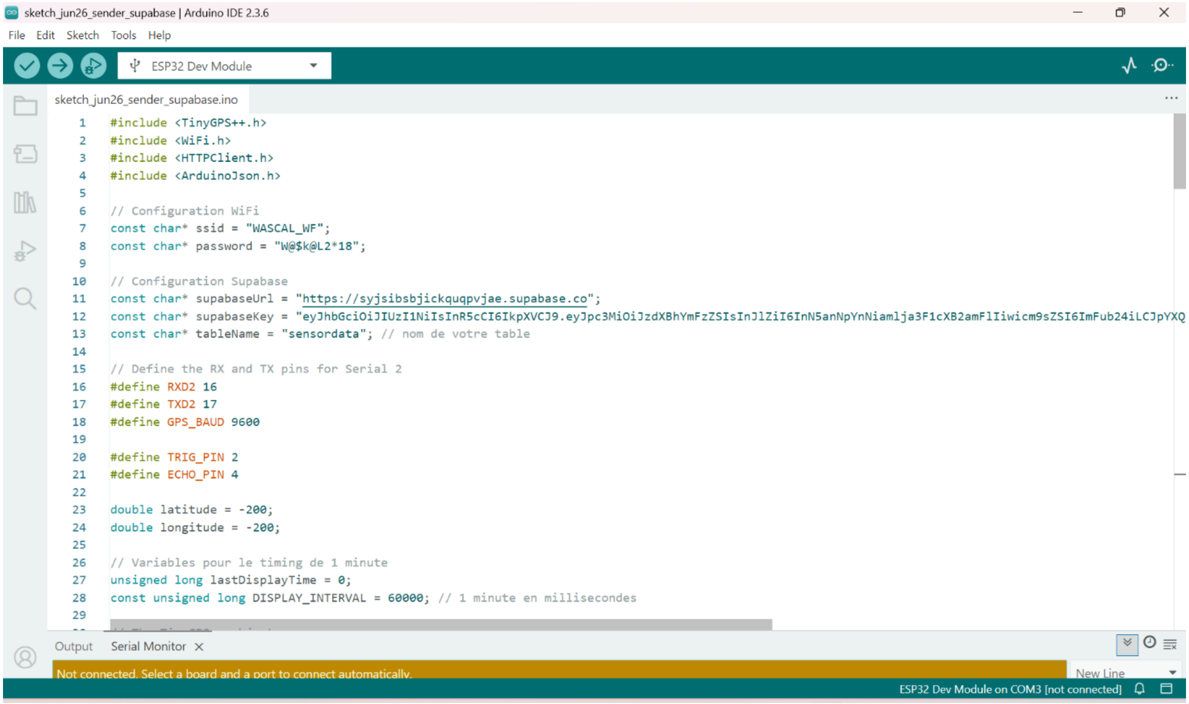


Figure 32: Sensor Arduino code

III.1.3. System testing and evaluation

Pilot test: A pilot test was carried out in selected districts of Ouagadougou. A small group of residents and waste collection agents used the mobile and web application.

A garbage can was fitted with a sensor to check that it could accurately detect the level of filling of the garbage cans, geolocation and communicate the data to the central system in order to test its effectiveness and reliability in real-life conditions.

Gathering feedback: During the pilot phase, users and waste collection staff gave feedback on the ease of use and efficiency of the system. This feedback was used to make any necessary improvements and adjustments.

Performance evaluation: The efficiency of the waste collection process is evaluated by comparing optimized collection routes and schedules (informed by real-time data from the system) with the existing waste collection process. Key performance indicators (KPIs) such as reduction in overflow incidents, collection time savings and user satisfaction are measured.

III.2. Results

The results of this research demonstrate the successful development and implementation of an IoT-integrated smart waste collection management system tailored to the context of Ouagadougou. A needs and gaps assessment of the existing system identified critical shortcomings in coordination, monitoring, and citizen engagement. In response, an IoT-enabled sensor was developed and tested to monitor the real-time fill level and geolocation of trash bins. Additionally, a web and mobile application was designed to digitalize the waste management workflow, providing features such as actor registration, task scheduling, service tracking, real-time notifications, and irregularity reporting. These results confirm the potential of combining digital tools and smart sensors to enhance operational efficiency, transparency, and responsiveness in urban waste management.

III.2.1. Needs and gaps assessment

To address the first objective, **which was to conduct a needs and gaps assessment of the current waste collection management system in Ouagadougou**, the research began with an in-depth analysis of the existing practices. This assessment revealed several critical shortcomings, including poor coordination among stakeholders, inadequate monitoring mechanisms, and limited opportunities for citizen involvement. These insights highlighted the necessity of a more integrated and responsive system to improve waste collection efficiency and accountability.

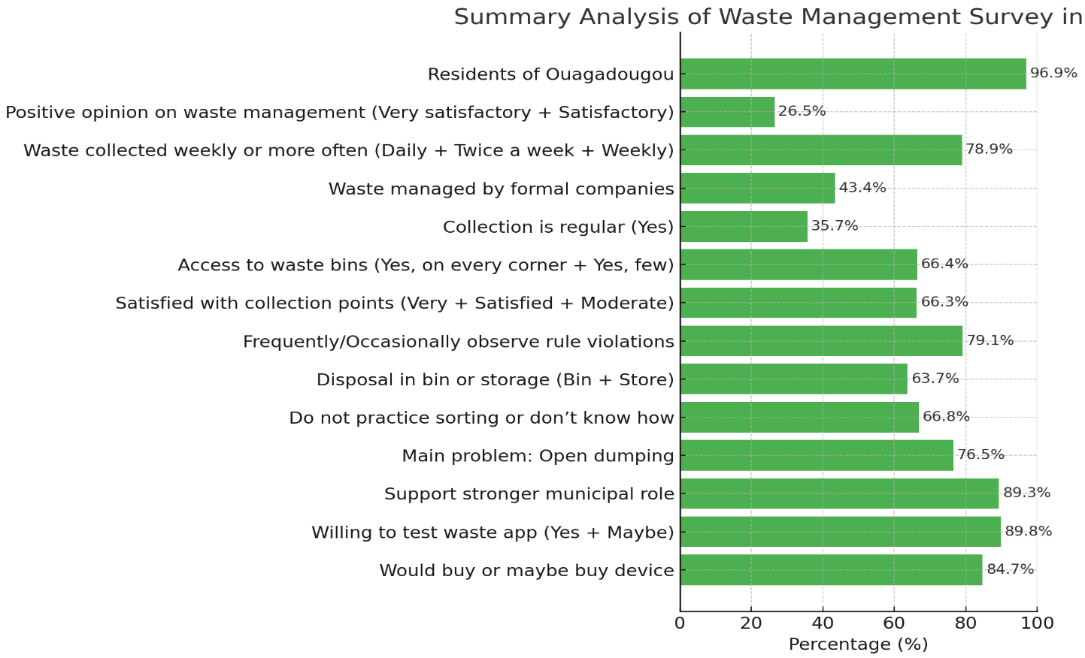


Figure 33: Waste management residents survey analysis

The diagram clearly illustrates the limitations of the current system (irregularities, improper behaviors, and lack of modern tools) but also reveals a strong openness among the population to digital and connected solutions such as those proposed in our project. This confirms the relevance of our ICT- and IoT-based system as an innovative, realistic, and well-accepted response by urban users in Ouagadougou.

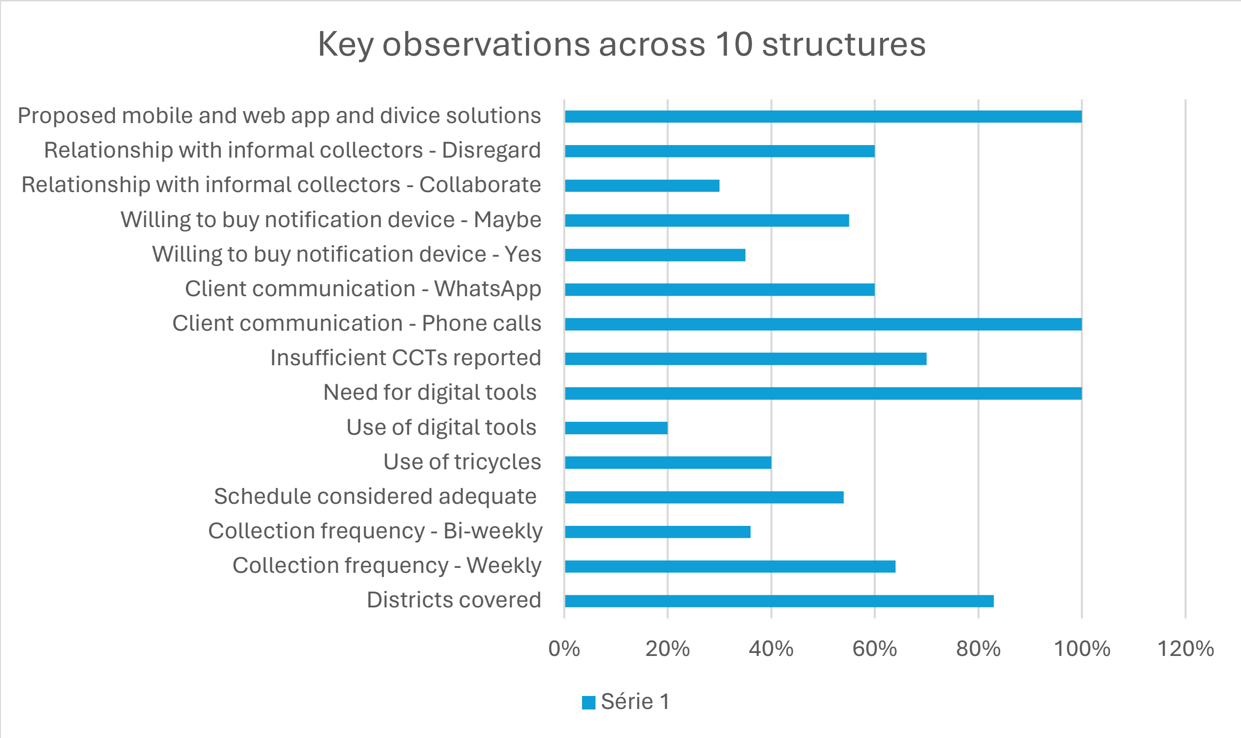


Figure 34: Structure diagram key observation across 10 structures

The analysis of waste collection structures highlights a strong demand for digital solutions, yet current use of such technologies remains limited. Communication is still dominated by traditional methods, and challenges persist in reporting, coordination, and collaboration with informal actors. Despite good geographic coverage and regular collection schedules, most structures lack the modern tools needed to optimize their operations. These findings support the relevance of implementing an ICT- and IoT-based smart waste management system to improve efficiency and coordination in Ouagadougou.

III.2.2. Web-based and mobile application

In response to the second objective, **which focused on developing a web-based and mobile application to support digitalized management and stakeholder engagement**, a user-friendly platform was created. This application enables actor registration, task scheduling, service tracking, and the automatic generation of real-time alerts and notifications. It also allows citizens to report irregularities, fostering transparency and collaboration between waste management authorities and the public. Together, these tools contribute to a smarter, more adaptive, and citizen-driven urban waste management system in Ouagadougou

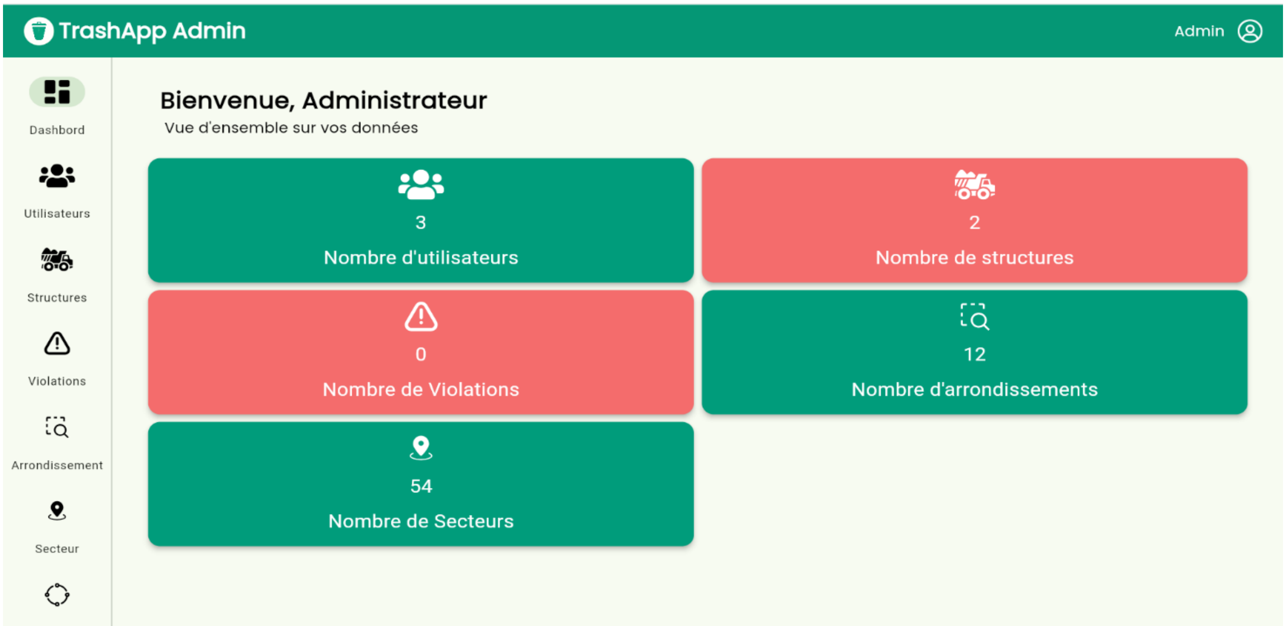


Figure 35: Web App administrator dashboard

Description:

The TrashApp web application is managed by a super administrator, which is the Directorate of Sanitation and Public Hygiene. This super administrator can view the list of users, the subscribers of each district, the list of waste collection companies, violations, and can assign a company to a specific collection zone. He can also assign a role to an agent or a person for a specific task. See images in Figure 44 in Annex 3.

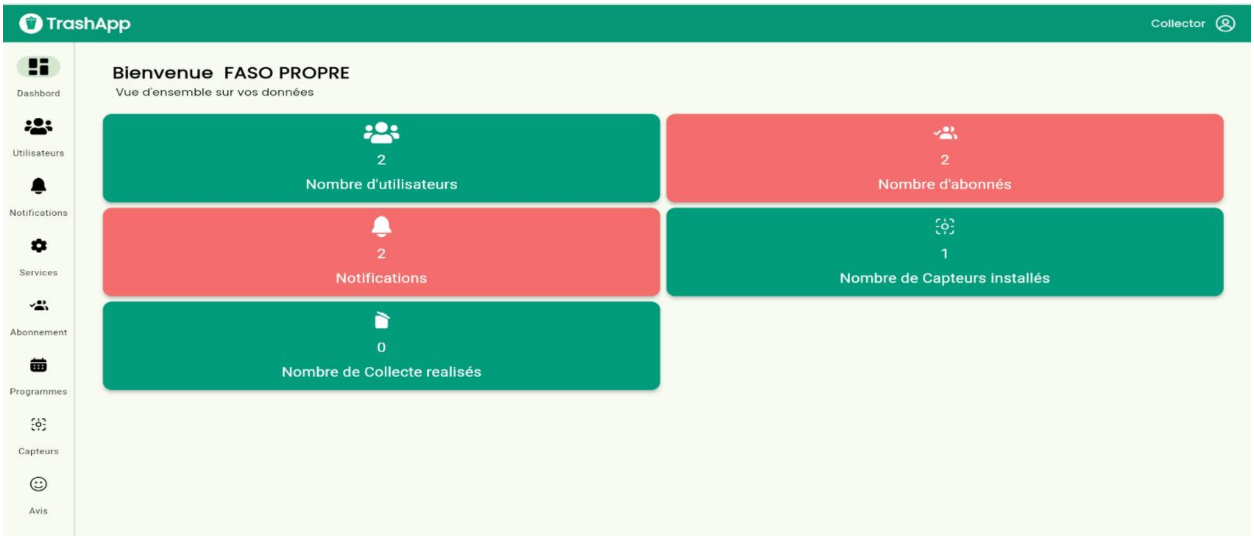


Figure 36: Web App collector dashboard

Description:

On the web app, the managers of collection companies can:

- Create a User Account for a Client,

- View the list of their subscribers,
- See the requests sent by clients,
- Monitor the fill levels of trash bins equipped with sensors and their geolocation,
- Modify services, pricing, and waste collection schedules,
- View customer feedback

See images in Figure 43 in Annex 3.

Figure 37: Mobile Application

Description:

The resident installs the TrashApp mobile application on his phone and then creates a user account by entering his first and last name, phone number, a password, and selecting his district. Since in Ouagadougou each district is linked to a single formal collection company, the resident is automatically assigned to the waste collection company of his district.

In the **" structure "** tab of the app, the user can view information about the company, the various services it offers, and the pricing. They can also make a special collection request, track the status of the request, and submit feedback on the company's service.

In the **"Violation"** tab, the user can report an offense by taking a photo or providing a description of the violation, including the location and date.

In the **"Calendrier"** tab of the mobile application, the user can view the waste collection schedule for their area.

In the **"Informations"** tab, the user can access useful information related to waste management.

III.2.3. IoT-enabled sensor

To achieve the third objective, **which aimed to implement an IoT-enabled sensor for real-time monitoring of trash bin fill levels**, a functional prototype was developed and tested. The sensor, equipped with an ultrasonic module and geolocation capabilities, was designed to measure the fill level of trash bins and transmit this data in real time. This innovation allows for more efficient route planning, timely collection, and the prevention of overflows, thereby enhancing the operational effectiveness of waste management services.

Figure 38: IoT system

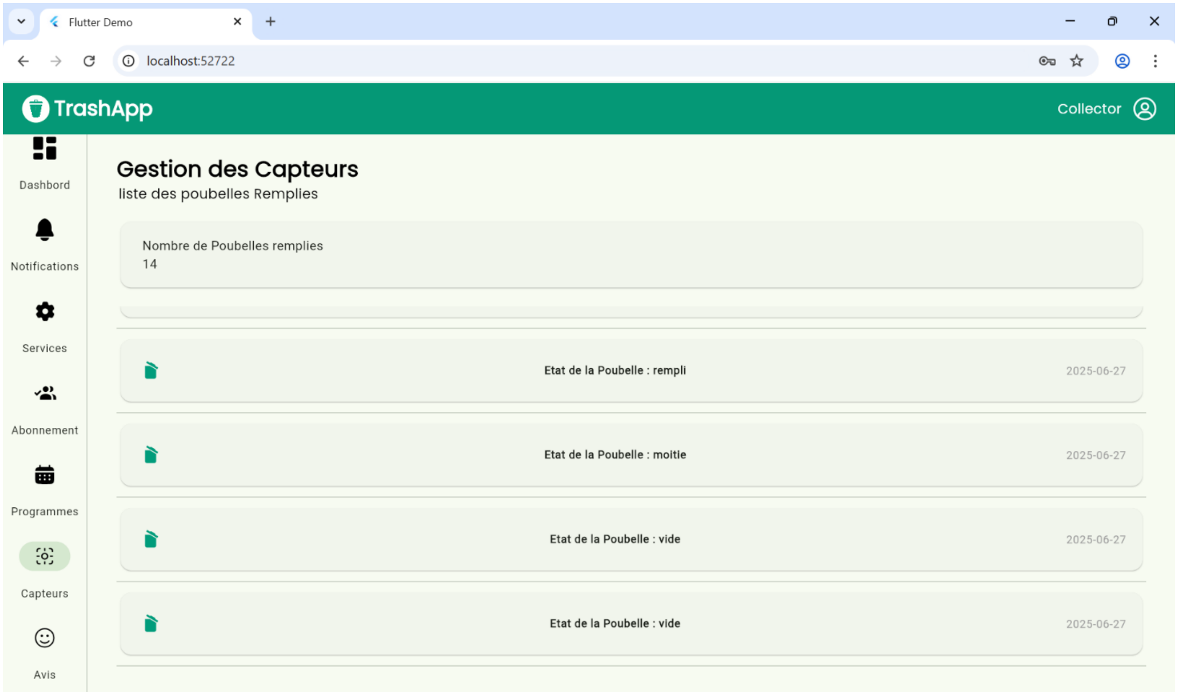


Figure 39: Data received from the sensor

Description:

Once the sensor is fixed inside the lid of the bin, it determines the depth of the empty bin. Each time waste is added, the sensor sends the bin's fill level and its geolocation to the waste collection company assigned to the district. When the bin is full, the sensor sends a collection request notification to the company through the web application.

This allows collectors to view full bins, along with their geolocation and the timestamp of the notification.

Table 5: Indicative cost estimate

Components	**Cost (€)**	**Cost (FCFA)**
Software development (Web + Mobile Trash App)		
Mobile App Development (Flutter) : User interface, request management, user interactions	760	500,000
Web App Development (Admin, Collection, DSHP) Admin interface, sensor and user management, notifications	1,060	700,000
Supabase Integration (Authentication, DB, API) : Database setup, real-time synchronization	460	300,000
Testing and Debugging : Scenario simulations, troubleshooting and fixes	300	200,000
Development Subtotal	**2,580**	**1,700,000**
Cloud services cost estimation		
Supabase Hosting (free or premium plan) 1 year	0 to 300	0 to 200,000
Domain name + Web hosting 1 year	75	50,000
Cloud Services Subtotal	**75 to 375**	**50,000 to 250,000**
IoT-sensor		
Ultrasonic Sensor (HC-SR04)	3.82	2,500
ESP32 Microcontroller (Wi-Fi + Bluetooth)	11.45	7,500
GPS Module (NEO-6M)	4.58	3,000
SIM800L (GSM GPRS)	6,87	4,500

PCB	4.58	3,000
Tenson lift	2.29	1,500
Protective Case + Power	21.37	14,000
Wiring, soldering, and assembly	22.90	15,000
IoT-Sensor Subtotal	**51.86**	**51 000**
Total	**2,706.86 to 3,006.86**	**1,801,000 to 2,001,000**

III.3. Discussion

Smart waste management systems have seen significant advancements worldwide, particularly in Europe and Asia, where IoT technologies and digital platforms are widely implemented. For instance, European cities such as Bergen and Amsterdam utilize sophisticated sensors, artificial intelligence algorithms, and centralized management systems to optimize waste collection, reduce carbon emissions, and maximize recycling efforts. In Asia, metropolitan areas like Songdo in South Korea and Singapore have deployed complex IoT networks that enable real-time container monitoring, dynamic route planning, and strong citizen engagement through integrated mobile applications.

In West Africa, initiatives remain more recent and often at a pilot stage. Countries such as Benin and Togo are experimenting with solutions that combine fill-level sensors and digital platforms; however, deployments remain limited, primarily due to financial, technical, and structural constraints. In Burkina Faso, current efforts mainly focus on organizational improvements and sporadic energy recovery projects, with little advanced digital integration in urban waste management.

The system developed in this study, through the Trash App combined with a simple yet effective IoT sensor, stands out due to its tailored adaptation to Ouagadougou's local context. Unlike European and Asian solutions that frequently rely on expensive equipment and complex infrastructures, this approach prioritizes simplicity, modularity, and affordability while delivering essential features such as bin geolocation, collection scheduling, and active citizen involvement through a direct reporting channel.

This innovation is particularly significant for Burkina Faso as it addresses the country's specific constraints: limited resources, a strong informal sector presence, the need for enhanced coordination among stakeholders, and the necessity to strengthen citizen participation. The solution enables proactive and transparent waste management, improving collection teams' responsiveness and reducing overflow risks. Moreover, integrating a cross-platform mobile application allows broad user engagement, including urban youth, fostering greater environmental awareness.

In summary, this system positions itself as an innovative, pragmatic, and scalable alternative to the heavier, more complex models deployed elsewhere. It represents a concrete first step toward digitalizing waste management in Ouagadougou, with strong potential for replication in other Burkinabe cities or sub-Saharan African urban centers facing similar challenges. Its success could catalyze a broader transformation of the sector at the intersection of technological, social, and environmental priorities.

In conclusion, the results obtained have provided valuable insights into the key issues addressed by the study. The analysis revealed both strengths and weaknesses in the current system, highlighting significant trends and areas for improvement. The discussion of these findings, in light of existing literature and contextual realities, supports the formulation of practical recommendations and paves the way for further research and action.

CONCLUSION AND PERSPECTIVES

This thesis focused on the development of an integrated smart system to modernize solid waste collection management in Ouagadougou, leveraging Information and Communication Technologies (ICT) and the Internet of Things (IoT). The work led to the design and deployment of a comprehensive solution combining an IoT sensor for real-time monitoring of bin fill levels, alongside a web application and a mobile application to facilitate management, supervision, and citizen engagement.

The results demonstrate that this integrated system significantly improves coordination of collection operations, reduces bin overflow, optimizes resource allocation, and fosters active citizen participation in waste management. This innovative approach effectively addresses the limitations of traditional systems by providing accurate, real-time data accessible to all relevant stakeholders.

Looking ahead, several avenues for future work are identified. Scaling the deployment to cover additional other cities would enable validation of the system's scalability and robustness. Incorporating advanced features such as predictive analytics using artificial intelligence, or gamification elements to further enhance citizen engagement, presents promising opportunities.

Moreover, the sustainable success of this system depends on a supportive institutional framework and strengthened collaboration between local authorities, waste collection operators, and the community. Promoting public policies that encourage technological innovation and community involvement is essential to ensure the long-term impact of these advancements.

In conclusion, this research makes a significant contribution to the digital transformation of solid waste management in Ouagadougou by providing a complete and contextually appropriate solution. It also lays the groundwork for future innovations in smart urban infrastructure management.

The findings suggest that an integrated, smart waste management system will not only improve operational efficiency and service delivery in Ouagadougou but also contribute to a cleaner, healthier, and more sustainable urban environment.

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ANNEXES

Annex 1: field observation

Figure 40: Overflowing bins in CSC

Figure 41: Vehicle fleet of DSPH

Annex 2: Survey

Questionnaire sur la Gestion des Ordures Urbaines

Nom de la Maire : Maire de Ouagadougou

Nom du service : Direction de la salubrité et de l'hygiène publique (DSHP)

Quartier/zone de couverture : les 12 arrondissements de Ouagadougou

Il y a-t-il des démembrements du service pour chaque arrondissement?

Oui, il y a les Services techniques d'arrondissement dirigé par des Chef de sections

Chaque commune de Ouagadougou dispose-t-elle des directions ? : non

Nom du responsable du service des déchets : M. Nassouri Saidou

1. **Comment est fait la collecte et la gestion des déchets à Ouagadougou**

Il y a la pré-collecte qui se fait par les GIE/PEM de porte à porte,

La collecte des portes à porte au Centre de Collecte et de Tri (CCT),

Le transport des CCT au Centre de Traitement et de Valorisation des Déchets (CTVD),

Le tri et le traitement au CTVD

Et la valorisation des déchets comme les plastiques.

2. **Quelles sont les méthodes actuelles de collecte des ordures ?**

Cela dépend de chaque structure de collecte

3. **Avez-vous un répertoire de poubelle à ciel ouvert et des poubelles municipales de la ville de Ouagadougou ?**

En 2023, on a dénombré 122 poubelles à ciel ouvert (dépotoirs clandestins) et 60 CCT

4. **À quelle fréquence les ordures sont-elles récupérés au niveau des poubelles municipaux ?**

Cela dépend des zones et de la fréquence de remplissage des contenaires

5. **Le nombre de points de dépotoirs définitifs (comme Polosgo)**

Il y a un seul CTVD à Ouagadougou et c'est à Polosgo

6. **Que deviennent les ordures après le dépotoir municipal ?**

Ils sont transportés des CCT au CTVD pour être trier et traiter

7. **Y a-t-il des points de collecte publique (contenaire, ...) pour les populations qui ne veulent pas des services de collecte prive ? Si oui, où sont-ils situés, sont-ils répertorier ?**

   Non, seuls les riverains des CCT sont autorisés à déposer leurs ordures au CCT

8. **Les Type de structure de collecte des ordures à domicile à Ouagadougou :**
   ☐ Publique

☒ Privée : des Groupement d'Intérêt Economique (GIE) et des Petites et Moyennes Entreprises (PME)
☐ Mixte
☐ Autre (préciser) :

9. **Le nombre des sociétés de ramassage des ordures à Ouaga :**

Il y a 12 structures Formelles recrutées par la DSHP, des structures sous-traitant avec les structures formelles et des structures informelles (clandestines).

10. **Comment sont organisées les sociétés de ramassage au niveau de la mairie ?**

    Ouagadougou compte 12 arrondissements = 12 zones de collecte (chaque arrondissement a sa société de pré-collecte)

11. **Quels sont les principaux défis rencontrés dans la gestion des déchets urbains ?**

Signalisation des irrégularités, manque de base de données de la collecte des déchets.

12. **Quelles solutions envisagez-vous pour améliorer la situation ?**

Changement des mentalités : payer les ramasseurs, être responsables des ordures dont on a produit

13. **Il y a-t-il un système numérique de gestion des ordures a cette direction (logiciel ou application) :**

Non, il a des permanenciers qui notifier actuellement le remplissage de centenaires dans les CCT a la DSHP

Localiser les points de dépotoir,

Consulter la liste des sociétés de ramassage et leurs zones de couverture,

Pouvoir notifier qui de droit, lorsqu'on constate des poubelles pleines ou endommagées dans la ville.

14. **La mairie a telle besoin d'une application mobile de gestion des ordures ?**

Absolument

des suggestions pour améliorer l'appli : Pouvoir dénoncer les structures qui jettent les déchets dans les poubelles à ciel ouvert

15. **Informations complémentaires :**

Centre d'enfouissement des déchets (CED) ouvert 15 avril 2005 a Polosgo : convertis en centre de traitement et de valorisation des déchets (CTVD)

Au niveau du pont de basculement du CTVD : Quantité, types de déchet sont défini pour permettre le traitement de ce déchet.

Ouaga produit 800 000 tonnes de déchet/an (0,60 kg /personne/jour en 2019)

Population de Ouagadougou 3 000 000 + les communes rurales périphérique de Ouaga + PDI

Les sociétés de ramassage à Ouagadougou ne paient pas les taxes à la commune

Le méthane produit par l'enfouissement des déchets n'est pas utilisé, il s'échappe dans l'air

Superficie du CTVD : 70 Hectare

Nouveau aménagement, géolocalisation des GIE proche de sa position

Pour signaler un besoin de ramassage : Commune- arr- secteur -zone- GIE- contact

Les structures Fromelles sont gérées par M. SEYNOU 70243642

Structures informelles non reconnu par la maire qui jettent les ordures dans les ravins, poubelles publiques.

Questionnaire sur la Gestion des Ordures Urbaines à des residents de Ouagadougou

Informations Générales

1. **Quel est votre quartier ou secteur d'habitation à Ouagadougou ?**

   ____

2. **Êtes-vous résident(e) de Ouagadougou ?**
   - o Oui
   - o Non

Gestion des Ordures

3. **Comment évaluez-vous la gestion des ordures dans votre quartier ?**
   - o Très satisfaisante
   - o Satisfaisante
   - o Moyenne
   - o Insatisfaisante
   - o Très insatisfaisante
4. **Quelle est la fréquence de collecte des ordures dans votre quartier ?**
   - o Quotidienne
   - o Deux fois par semaine
   - o Hebdomadaire
   - o Moins fréquente
   - o Je ne sais pas
5. **Qui est responsable de la gestion des ordures chez vous ?**
   - o Vous-meme
   - o Entreprises formelles
   - o Collecte informelle par des individus ou des groupes
   - o Autre (précisez) : ____________
6. **Est-ce que la collecte des ordures est régulièrement effectuée comme annoncé ?**
   - o Oui
   - o Non
   - o Parfois

7. **Avez-vous accès à des Centres de collecte et de tri ou conteneurs à déchets dans votre quartier ?**
    - Oui, à chaque coin de rue
    - Oui, mais ils sont peu nombreux
    - Non, je dois jeter les ordures ailleurs (poubelle à ciel ouvert)
8. **Êtes-vous satisfait(e) de l'emplacement et de la propreté des points de collecte des ordures ?**
    - Très satisfait(e)
    - Satisfait(e)
    - Moyennement satisfait(e)
    - Pas satisfait(e)

Comportement des Citoyens

9. **Avez-vous observé des comportements de non-respect des règles de gestion des ordures dans votre quartier (jeter des déchets dans la rue, dans les caniveaux, etc.) ?**
    - Oui, fréquemment
    - Oui, parfois
    - Non, très rarement
    - Non, jamais
10. **Que faites-vous des déchets chimiques ou médicaux chez vous ?**
    - Je les jette dans les bacs à ordures
    - Je les brûle
    - Je les entasse jusqu'à ce qu'ils soient collectés
    - Autre (précisez) : ____________
11. **Pratiquez-vous ou votre famille des actions de tri des déchets (recyclage, compostage) ?**
    - Oui, nous trions régulièrement
    - Oui, mais rarement
    - Non, nous ne trions pas
    - Je ne sais pas comment trier

Problèmes et Solutions

12. **Quels sont selon vous les principaux problèmes liés à la gestion des ordures à Ouagadougou ?** (Cochez toutes les options pertinentes)
    - o Manque de coordination des structures et les clients
    - o Fréquence insuffisante de collecte
    - o Mauvaise gestion des déchets dans les quartiers périphériques
    - o Manque de sensibilisation des citoyens
    - o Manque d'interaction avec les collecteurs
    - o Décharges à ciel ouvert et pollution
    - o Autre (précisez) : ____________
13. **Quelles améliorations suggéreriez-vous pour mieux gérer les ordures urbaines à Ouagadougou ?**
    (Réponse ouverte)

14. **Pensez-vous que la mairie devrait jouer un rôle plus important dans la gestion des déchets ?**
    - o Oui, absolument
    - o Oui, dans une certaine mesure
    - o Non, elle fait déjà ce qu'il faut
    - o Non, la gestion doit être confiée à d'autres acteurs
15. **Seriez-vous prêt(e) à participer au développement de notre application de gestions des déchets dans votre quartier ?**
    - o Oui
    - o Non
    - o Peut-être
16. **Etes-vous disposer à acheter un appareil qui permettra de notifier le service de collecte lorsque votre poubelle contient des ordures**
    - o Oui
    - o Non
    - o Peut-être, si la structure de collecte accepte participer au frais d'achat
17. **Avez-vous d'autres suggestions ou remarques concernant la gestion des ordures à Ouagadougou ?**
    (Réponse ouverte)

Questionnaire pour les Structures de Collecte des Ordures à Ouagadougou

I. Informations Générales

1. **Nom de la structure de collecte des ordures** :

2. **Type de structure** :
   ☐ coalition
   ☐ Privée
   ☐ Mixte
   ☐ Autre (préciser) :

3. **Zone géographique desservie par la structure** :

4. **Date de recrutement de la structure** :

5. **Nombre de personnes travaillant dans votre structure (y compris les travailleurs informels)** :

II. Organisation et Fréquence de la Collecte

6. **À quelle fréquence les déchets sont-ils collectés dans votre zone d'intervention ?**
   ☐ Quotidienne
   ☐ Bi-hebdomadaire
   ☐ Hebdomadaire
   ☐ Autre (préciser) :

7. **Les horaires de collecte sont-ils adaptés aux besoins des habitants ?**
   ☐ Oui
   ☐ Non
   Si non, quelles sont les améliorations à apporter ?

8. **Quelles sont les principales méthodes de collecte utilisées par votre structure ?**
   ☐ Ramassage manuel (Charettes)
   ☐ Tricycle
   ☐ Conteneurs fixes
   ☐ Collecte porte-à-porte
   ☐ Autre (préciser) :

III. Logistique et Matériel

9. **Disposez-vous des logiciels ou applications nécessaires pour une collecte efficace des ordures ?**

☐ Oui

☐ Non

Si Oui, préciser le logiciel ou application dont vous disposez

Si non, quels logiciels seraient nécessaires à l'amélioration de votre travail ?

10. **Avez-vous suffisamment de points de dépôt (centre de collecte et de tri) dans votre zone ?**

☐ Oui

☐ Non

Si non, quelle est la demande en termes de nouveaux points de collecte ?

11. **La gestion des ordures ménagères est-elle bien organisée (tri des ordures après collecte) ?**

☐ Oui

☐ Non

Si non, quelles améliorations pourraient être apportées ?

12. **Comment communiquer vous avec les clients**

☐ Par appel

☐ Par message WhatsApp

☐ SMS

☐ Autre (préciser) :

13. **Avez-vous besoin d'une application mobile de gestion des ordures ?**

☐ Oui

☐ Non

14. **Seriez-vous prêt(e) à participer au développement d'une application de gestions des déchets dans votre zone ?**

☐ Oui

☐ Non

15. **Etes-vous disposer à acheter un appareil qui permettra de notifier le service de collecte lorsque les poubelles sont pleines**

☐ Oui

☐ Non

☐ Peut-être, si les clients acceptant de participer au frais d’achat

IV. Défis et Problématiques

16. **Comment collaborez-vous avec les structures de collecte informelles intervenant dans votre zone**

☐ vous les ignorez

☐ vous tentez des négociations

☐ Autre (préciser) :

17. **Quels sont les principaux défis auxquels vous faites face dans la gestion de la collecte des ordures à Ouagadougou ?** (Cochez toutes les réponses pertinentes)

☐ Manque d'équipements

☐ Difficulté d'accès à certaines zones

☐ Manque de personnel

☐ Difficulté d'accès à certains domiciles

☐ Manque de sensibilisation de la population

☐ Gestion inefficace des points de dépôt (CCT)

☐ Autre (préciser) : _________________

18. **Avez-vous des difficultés particulières à gérer les déchets spécifiques, tels que les déchets électroniques ou les déchets plastiques ?**

☐ Oui

☐ Non

Si oui, comment cela pourrait-il être amélioré ?

19. **Quelles solutions proposez-vous pour améliorer la collecte et la gestion des déchets à Ouagadougou ?**

V. Collaboration et Partenariats

20. **Travaillez-vous en partenariat avec d'autres structures ou institutions (municipalités, ONG, entreprises privées, etc.) pour la collecte des ordures ?**

    ☐ Oui

    ☐ Non

    Si oui, lesquels ?

VI. Suggestions et Commentaires

21. **Avez-vous d’autres suggestions ou commentaires concernant l’amélioration de la collecte des ordures à Ouagadougou ?**

Merci de votre participation!

Annex 3: web and mobile applications

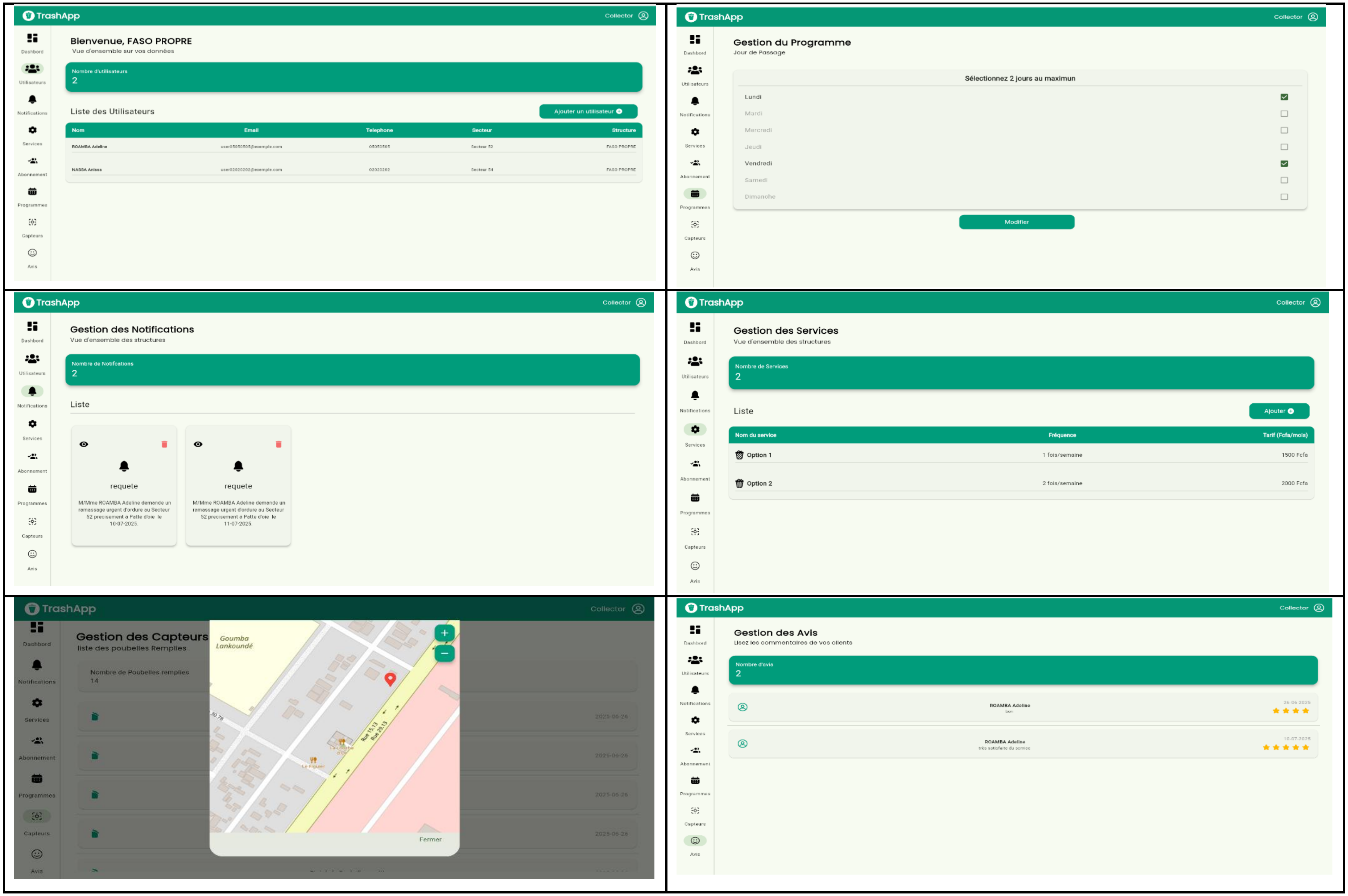

Figure 42: Various collector access pages on the web application

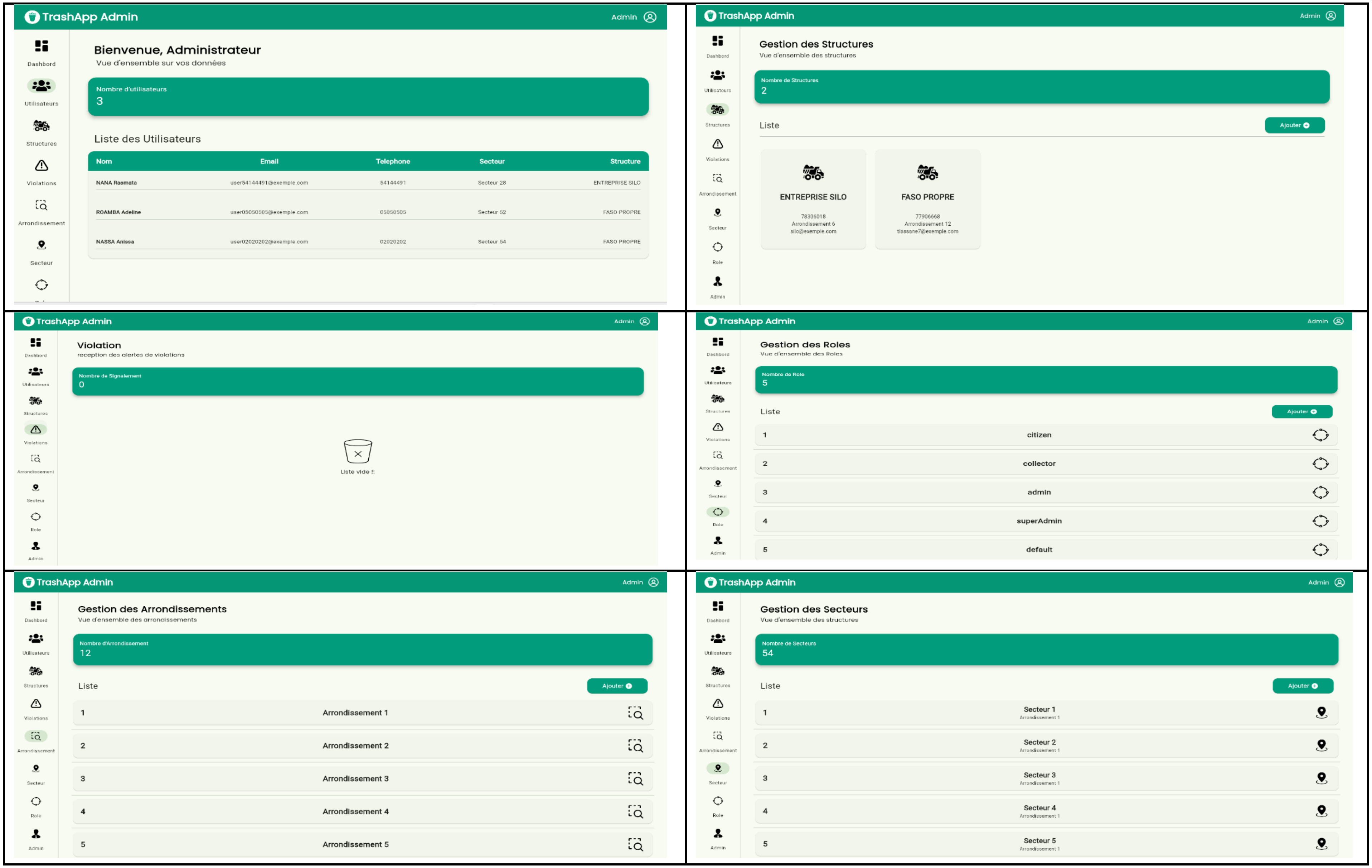

Figure 43: Various administrator access pages on the web application