Modelling and Simulation of a Smart Dustbin Management System: Case Study of Obafemi Awolowo University, Nigeria

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ABSTRACT
The delay in the evacuation of waste from waste compartments by the waste management authorities at the Obafemi Awolowo University (O.A.U) campus has in most cases resulted in these compartments being overfilled and waste spillage around the waste compartment environment, leading to an eyesore, and unhealthy environment. O.A.U residents in their bid to keep their environments clean, sometimes resort to burning their waste instead of waiting on the waste management authorities for proper disposition. This practice brings about an unhealthy and unfriendly environment as it results in ozone layer depletion and other forms of harm to the climate from the carbon emitted from the burning of waste. To quell these problems, an effective and efficient waste collection system which gives a prompt notification when waste compartments are filled up would be modeled, simulated and implemented. The mobile application contains dashboards that works for different types of users; teams, collectors and a container for simulation and representation of the system. The system was tested with interactive mobile based application, and it is proved that it was effective to the public and the administrator.

General Terms
Waste management and mobile application

Keywords
Smart, Waste management, IoT (Internet of Things), sensor, internet, server, database, solid waste, data-driven

1. INTRODUCTION
The population growth and a marked increase in human production and consumption patterns in recent times have led to an increase in waste generation all around the world. An effective solid waste management system, a healthy environment, and a high standard of life must all work together for a country to qualify as a developed nation. Overflowing waste bins located in public areas are a sign of inefficiency in many cities across the world [1]. According to estimates from the World Bank for 2020, the world will produce 2.24 billion metric tons of solid garbage or 0.79 kilograms of waste per person every day. Generated waste is estimated to rise by 73% from its level in 2020 to 3.88 billion metric tons by the year 2050 as a result of growing urbanization and population expansion. The largest waste generators are middle-income countries and/or those countries with significant tourist populations. This is as a result of an increase in population resulting from tourist activities, less developed recycling culture etc. [2]. The urban population in Africa is growing at the rate of approximately 3.5% per year, which is faster than that of any other continent (United Nations, 2021). Despite the fact, that Africa today produces less trash than the industrialized world. If the current trends in waste generation hold, Sub-Saharan Africa is predicted to dominate waste generation globally.

For several years, waste production on the African continent has steadily increased, due to demographic growth and rapid urbanisation. In 2016, sub-Saharan Africa produced 174 million tonnes of household solid waste. While between 70% and 80% of this waste is recyclable, only 4% is actually recycled. According to estimates by the African Clean Cities Platform, it is anticipated that Africa would produce up to 244 million metric tonnes of waste production annually in 2025 [3]. It has been predicted that the increase in waste production in Africa will be so large that it will overwhelm any decrease in waste production around the world. The main countries responsible for waste sector emissions in Africa are Nigeria, South Africa, Algeria, Egypt, Morocco, Ethiopia and DR Congo. Over 32 million metric tons of waste productions are generated in Nigeria annually, according to research from the United Nations Industrial Development Organization (UNIDO). According to a World Bank report, each Nigerian produces at least 0.5 kg of waste per day. This statistic led to a forecast that predicted that by 2050, Nigeria would produce 107 million metric tons of waste annually, which presents both a threat and an opportunity [4].

There have been significant issues in the management of the waste generated in both developing and affluent nations due to reasons including population growth, changing lifestyles, rising incomes, and fast urbanization. Many African countries lack adequate infrastructure for waste collection, treatment, and disposal. Establishing an efficient system for the proper collection and disposal of waste, while adhering to health regulations to maintain a clean, orderly, and welcoming environment, is a challenge faced by state and city authorities worldwide [5]. When it comes to trash management, poor route planning, insufficient communication with the authorities and/or garbage collection service when the bins are full, and inefficient use of limited resources are just a few of the variables that have a big impact on waste collection. The ineffective and inefficient collection of wastes most times results in an overfilled waste bin, and sometimes people are forced to dump their refuse on public space, exposing the environment to diseases and environmental health hazards.

The aim of this project work is to model and simulate a

technology and data-driven system of collecting waste for the Obafemi Awolowo University community. This system will provide waste collectors in the community with prompt information on when to collect waste from stationed waste bins within the campus environment which will birth a more affordable sanitary community.

2. LITERATURE REVIEW

In the work titled "A Smart Waste Management Solution Geared towards Citizens" [6] recognises the need for the development of sustainable and livable communities, where proper waste management is crucial but difficult in many developing nations and cities [7]. Cities' budgets are frequently threatened by the rising costs of effective garbage management. An integrated system that is efficient and sustainable is required to operate this crucial city service [8]. The work proposes a citizen centered, efficient, and real-time waste management model for cities [9]. The proposed system uses sensor technologies to obtain waste information from the smart bin in real-time, and then transmitted over the Internet, an internet based intelligent platform that is connected to a database and where citizens can access and check the availability of the compartments around them and the best route to getting to these compartments. A real prototype of the smart container was developed, evaluated, demonstrated, validated, and is ready-mapped in a real solution. The main contributions of this work to the existing knowledge are:

i. Proposal of a smart waste bin based on an IoT approach and the corresponding real prototype.

ii. Integration of the smart waste bin with an IoT middleware solution.

iii. Creation of a new mobile application and corresponding web version offering a better interaction with residential users (waste generators).

[10] highlighted the need for organic waste management in their work titled "IoT-Based Smart Waste Management System in a Smart City". The article reported that a survey conducted by the National Solid Waste Management Department in 2013 found that food waste makes up a higher percentage of institutional garbage than paper waste does [11].

The work evaluated a technologically based cost-effective waste management system and proposed an efficient waste management method by utilizing IoT to improve collection system activities in a source area, which is the most important stage of waste management, especially with regard to waste recycling in urban areas around the world [12]. Due to the increased ability of applications, cloud services, and databases to communicate with other IoT devices, the method created a significant number of new connections between the old system and the new system. As a result, a network of information is created that improves waste management practices while lowering costs and risks associated with the current system. IoT devices are expected to reduce the cost of rubbish collection by exploiting the information transferred between bins, containers, and vehicles [13 - 16].

[17] in their work titled "Solid Waste Collection as a Service using IoT-Solution for Smart Cities," proposed smart solid waste bins for both wet and dry garbage stationed at different locations with monitoring and collection schedules [18]. This system involved four significant phases, which are: hardware, software in the cloud, mobile application and routing information. A mobile application was created for waste collection drivers and municipal corporations to monitor and manage solid waste collection as a service, and a cloud-based system was created to organize the solid waste management process [19]. The waste collection drivers can use mobile applications to find the quickest and most direct paths to the trash cans. When waste bins are full, the suggested technology makes it easier for garbage collectors to evacuate material by providing route information. Additionally, it uses ThingSpeak to gather, visualize, and analyze data from sensors on the trash cans for use in decision-making. The system does not, however, have a feature that would alert the garbage collection through SMS when the trash cans are full.

3. METHODOLOGY

The study approach for simulating and modelling a smart waste management system is the main focus of this section. It gives a general summary of the instruments, research design, and data gathering techniques employed to accomplish the study's goals. The goal is to provide a thorough explanation of the procedures followed in order to gather, examine, and interpret the data necessary to put in place a smart waste management system. The smart waste management system is divided into 2 sections which include:

3.1 Hardware

This part of the system is the sensory part (sensor and the waste bin) of the system which generally should be handled using a sensor like an ultrasonic sensor but for the purpose of this research work, the sensor and the waste bin operation was mocked-up with a computer program. The program will consist of a GUI where users can specify the volume of waste, waste bin and drop the waste into the waste bin.

3.2 Waste Management Software

The waste management software is an android mobile application developed using flutter and javascript (Nodejs) for the server side of the software. This software is developed following the Software Development Life Cycle (SDLC) which is a systematic and iterative approach to software development.

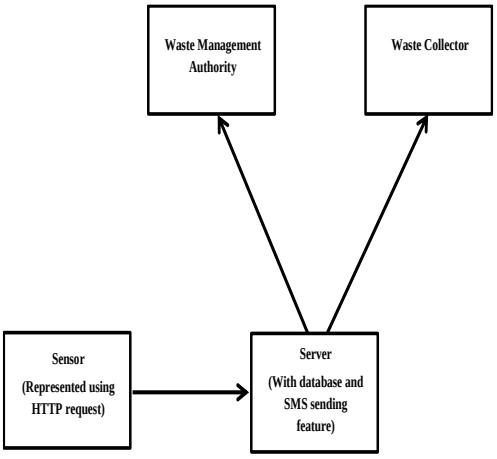


Fig 1: Architecture of the system

3.3 Requirement Gathering and Analysis phase

The requirements needed for the smart waste management system were created by direct observation of the current waste management system, record examination, and an unstructured interview approach. The proposed project's case study, the environmental management department of Obafemi Awolowo University in Ile-Ife, Osun State, was visited to observe the operating procedures in order to get insight into the present

waste management system. In order to develop a new system that results in effective and efficient waste collection, which in turn results in a clean and healthy environment, it is crucial to have a clear understanding of the current system and the people's thoughts (waste management officers), waste collection routines and patterns, and the general public.

The information gathered during the requirement gathering phase summarizes the expectation of the proposed system;

i. The proposed system should improve the efficiency of waste collection in the Obafemi Awolowo University community.

ii. The proposed system should be able to notify the waste collectors and the environmental department when waste bins are filled-up and need to be emptied.

iii. The system should uphold comprehensive and strong waste records using database management system technology, allowing a number of additional information systems to be integrated to the DBMS.

iv. The proposed system should be able to give waste management authorities with ease of access to information as regards the routing and pattern of waste generation in a particular area.

3.4 System Design

3.4.1. Use Case Diagram

In UML (Unified Modelling Language), a use case diagram is a type of behavioural diagram that offers a graphical depiction of the interactions between actors and the actions they carry out within a system. The use case diagram which will be used in modelling the smart waste management system is shown in figure 2. The waste management system is composed of 2 actors as shown in the use case diagram. These actors are: the administrator from the environmental/waste management authorities and the sensor which is mockup using a post HTTP request.

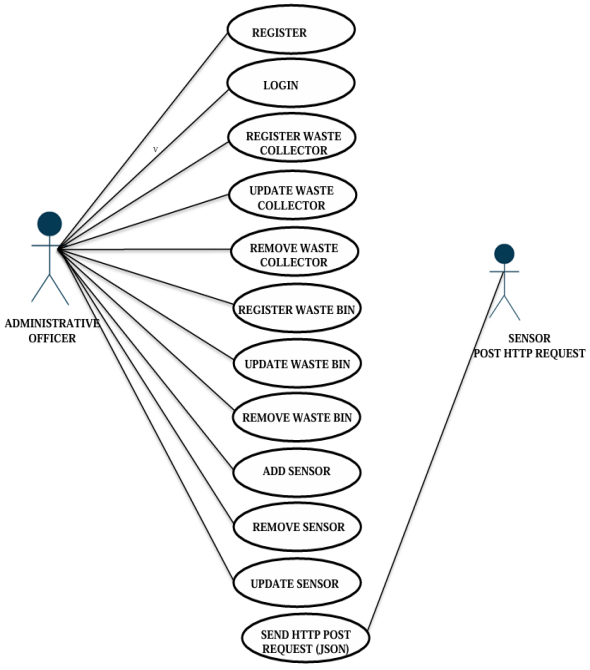


Fig 2: System use case diagram.

3.4.2. Class Diagram

A class diagram is a form of UML (Unified Modelling Language) diagram that exhibits the classes, properties, operations, and relationships between the system's objects to depict the system's structure. Class diagrams shown in figure 3 offers a visual depiction of the architecture of the system and aid in elucidating the connections between various parts.

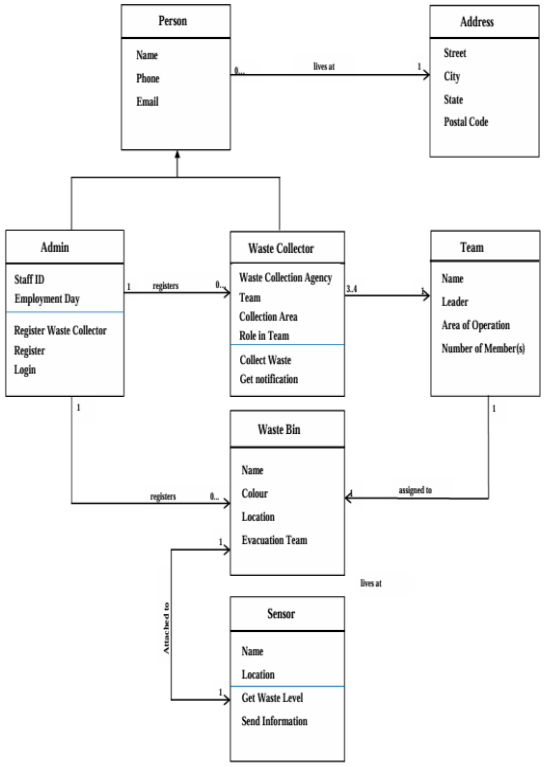


Fig 3: System Class diagram

3.4.2. Activity Diagram

The activity diagram which will be used in modelling the smart waste management system is shown in figure 4.

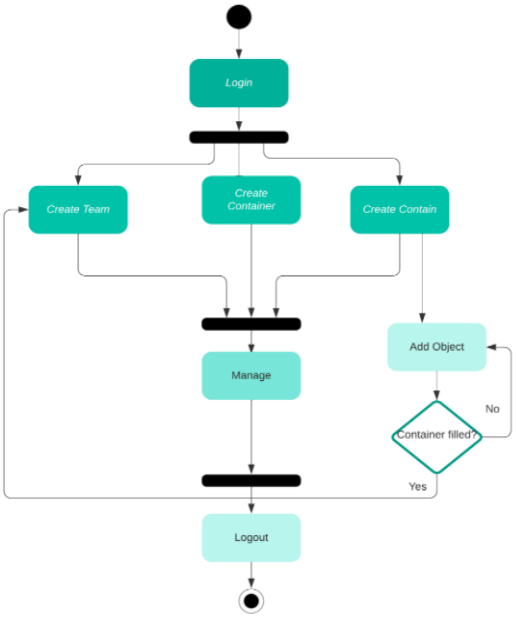


Fig 4: System activity diagram.

4. RESULTS AND DISCUSSION

The mobile application developed for simulating the smart waste system was tested with some staff of the environmental division of the Obafemi Awolowo University community.

Different sizes of objects were added into the system from the interface provided for adding objects on the application. Upon a filled container, email and SMS notification were sent to the concerned authority and the team responsible for evacuating the waste bin with a map link to the location of the waste bin for easy navigation.

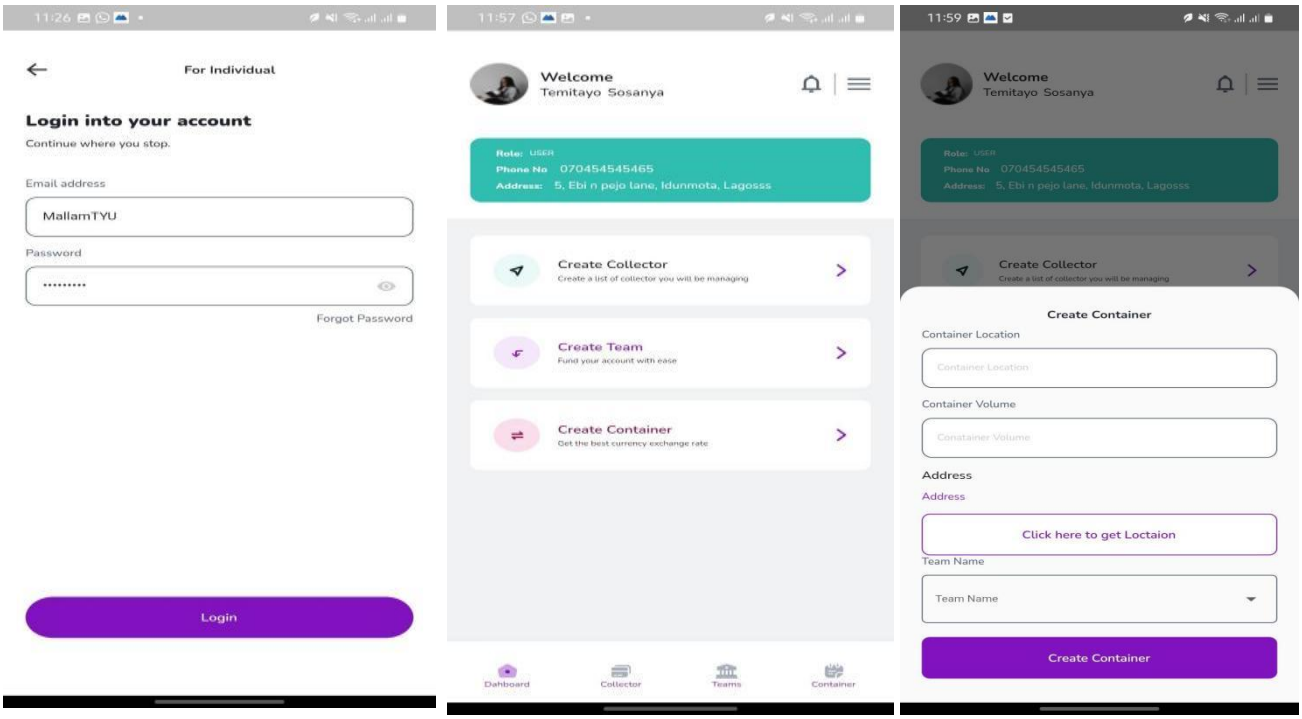


Fig 5: Showing the login, dashboard, and container (compartment) creation page.

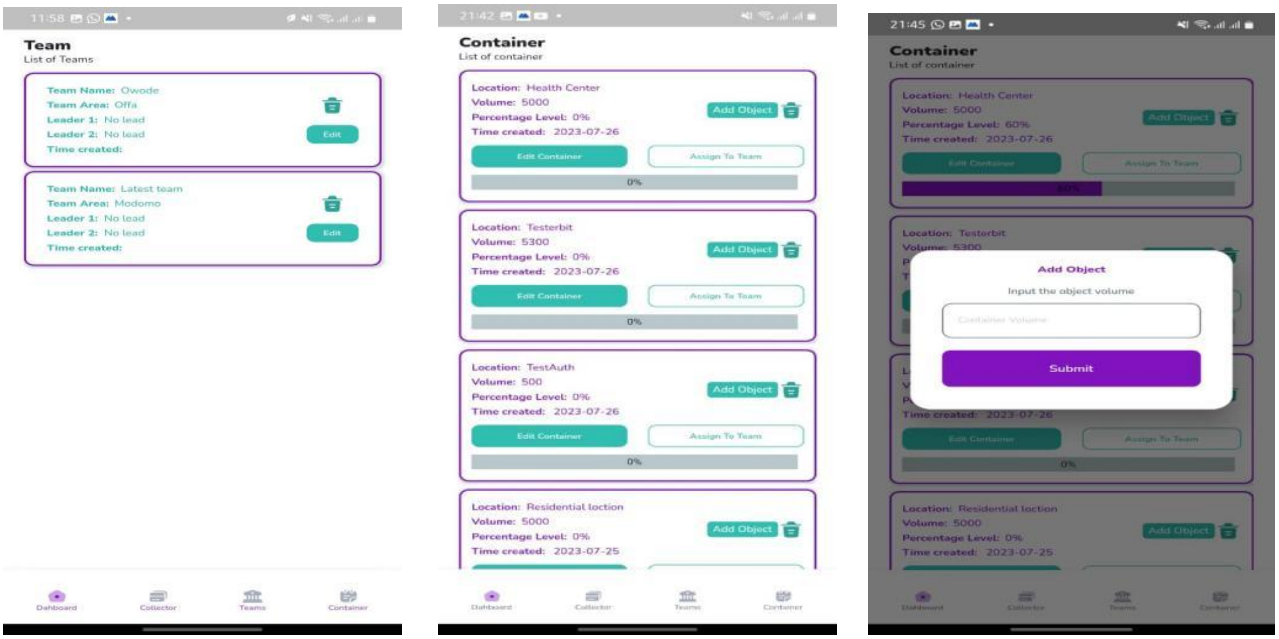


Fig 6: Showing list of teams, containers, and object addition screen.

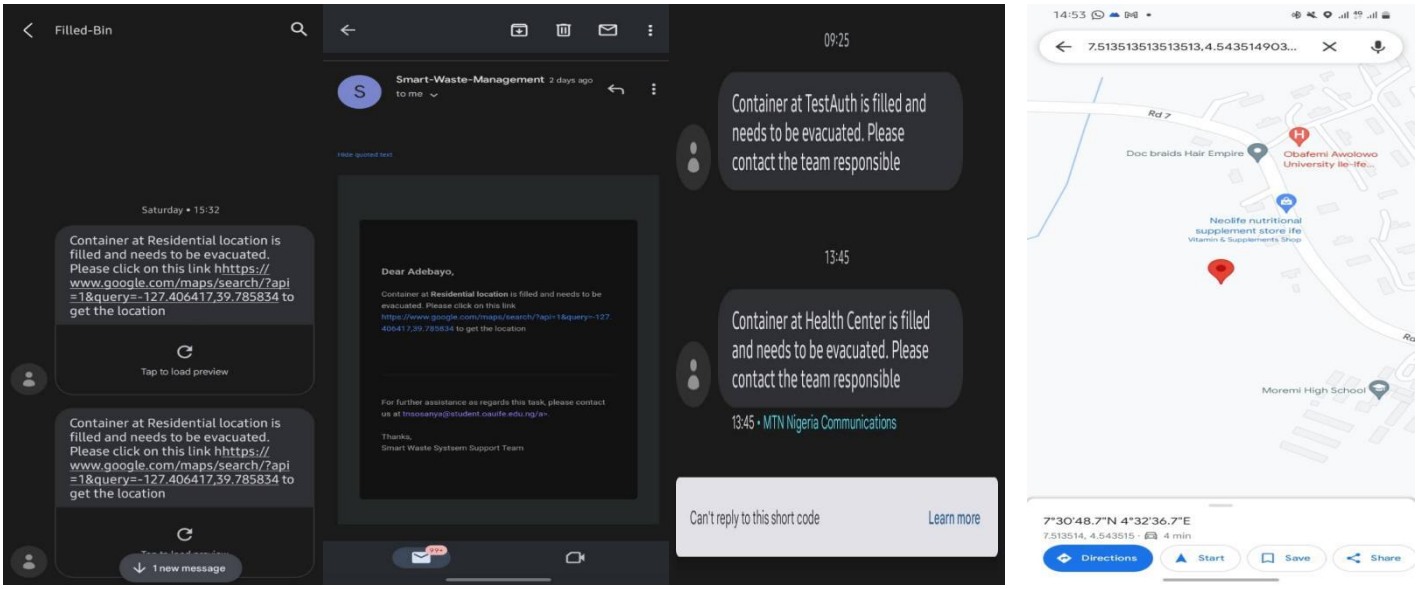


Fig 7: Showing SMS notification to evacuation team leader, email notification, SMS notification to waste management authority, and location of the compartment on Google map.

4.1 Login Dashboard

This section describes the user interfaces in the smart waste management system mobile application. There are 2 types of users that can make use of this mobile application. These users are classified on the basis of the privilege they have on the application. These users are; the administrator and the user. The administrative users on the application can add users' email; remove users email from the application. Upon login into the application, the user will be presented with a dashboard showing the name of the logged in users and the operations they can perform which include, creating team, creating container (com). Users logged in as regular users can also navigate to the container, team, and collector at the navigation bar under the application. Figure 5 shows a logged in user's dashboard.

4.2 Collectors

This part of the mobile application as shown in figure 5 is concerned with the registration, deletion, edition, and other operation on teams responsible for evacuating waste in waste containers when they are filled. The need to assign a team to be responsible for the evacuation of waste containers in various locations makes this so pertinent in the application. Since the scope of this project has been limited to modelling and simulation of the smart waste management system, there is a need for a container representation in the system. An Authorized user in the system can create a container, delete a container, edit a container etc. For simulation sake, users can add an object of different volumes to the container and see the level of the container in which they are adding the object shown in percentage at the top right corner.

4.3 Teams

This part of the mobile application is concerned with the registration, deletion, edition, and other operation on teams responsible for evacuating waste in waste containers when they are filled. The need to assign a team to be responsible for the evacuation of waste containers in various locations makes this so pertinent in the application. The team in this system consists of at most 4 team members which are; a Leaders1, a Leader2, and Members (which is at most one). Upon filled waste containers, the leader1 of the team responsible for the evacuation of the waste bin gets an SMS notification on the need to evacuate a filled container at a specific location. A team can be updated, deleted from the system by an authorized user of the system. When a team is deleted, every members attached to the team automatically have no team and are free to be assigned to another team. Figure 6 is used to demonstrate this scenario.

4.4 Container

Since the scope of this project has been limited to modelling and simulation of the smart waste management system, there is a serious need for a container representation in the system. An Authorized user in the system can create a container, delete a container, edit a container etc. For simulation sake, users can add an object of different volumes to the container and see the level of the container in which they are adding the object shown in percentage at the top right corner. When the container is filled (95% of the volume of the container), an SMS notification is sent to the leader1 of the team responsible for the evacuation of the waste in the container. The user generates their current location while creating a container in the system and that location is stored into the system which is further used when notifying waste management authority and team leader when the container is filled. When the container is full and needs to be evacuated, the team leader is sent the location of the container on a map using the location information. Figure 6 shows a container status page. In this page, users who are staff of the environmental division of Obafemi Awolowo University can get to see the status of a selected waste container and also view the chat which shows the history of the waste container in the past which can be weekly or monthly.

4.5 Notification

Upon a filled waste container, 2 stakeholders in this project (staff of the environmental division of Obafemi Awolowo University and Leader1 of the team responsible for evacuating the waste container) get an SMS information about the status of the waste container and the need to evacuate it. The message received by these two stakeholders differs in content. The leader1 of team responsible for evacuation gets information with a Google map link to the location of the waste container while the staffs of the environmental division of Obafemi Awolowo University health center gets an SMS notification informing them of the need to evacuate the waste container at the location

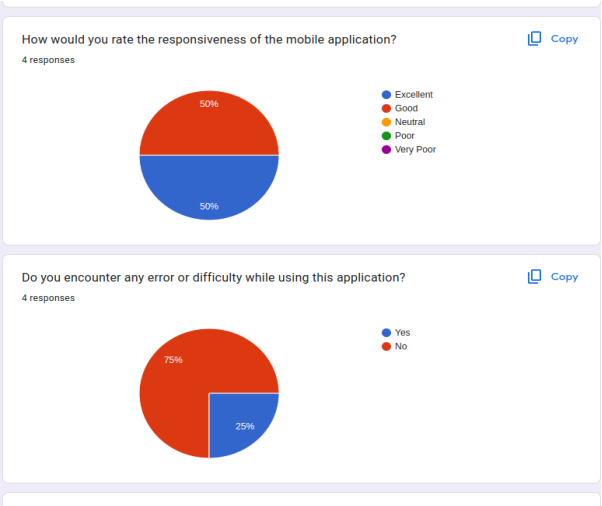
and also inform the team responsible. This authority also receives email notification of the status of the waste container. This is to ensure that the information is passed across upon a filled container in case a system fails. Figure 7 shows an SMS notification to waste management authority received upon a filled container. A waste container's location is seen in Figure 7. When a waste container is filled, an SMS alert is delivered to the team leader with a link. The team leader can navigate more easily after tapping this link to view the location of the filled container on their smartphone map.

4.6 System Evaluation

To ensure the validation of the developed system for simulating and modelling a smart waste system and to ensure it met with the settled objectives, the system was evaluated by conducting a usability test. For the staff of the environmental division of the Obafemi Awolowo University health centre, the system was taken to them for use and evaluation. The usability test was centered on the ease of use of the system, responsiveness, error, how helpful it will be in the operation of waste management in the Obafemi Awolowo University, Ile-Ife. This was achieved by using an instrument of data collection (Questionnaire). This questionnaire was designed to capture 5 areas essential for the system evaluation and administered using the Google form. The questionnaire was administered to a few respondents who interacted with and tested the system. Half of the system testers are staffs of the environmental division of the Obafemi Awolowo University health centre who are the real target users of the system. Figure 8 is the response of the stakeholder users of the system after being shown and worked through the system and Figure 9 shows the analysis of the response of non-stakeholder users who tested the system and gave their feedback based on their experience through the Google form.

A	B	C	D	E	F
User	How would you rate the overall user experience of the mobile application?	How easy would you rate the use of the mobile application?	How would you rate the responsiveness of the mobile application?	Do you encounter any error or difficulty while using this application?	Do you think this project if fully implemented will result in prompt notification of collection team to evacuate containers upon filled?
User A	Good	Good	Good	No	Strongly Agree
User B	Excellent	Good	Good	No	Agree

Fig 8: Showing response to the questionnaire by stakeholders



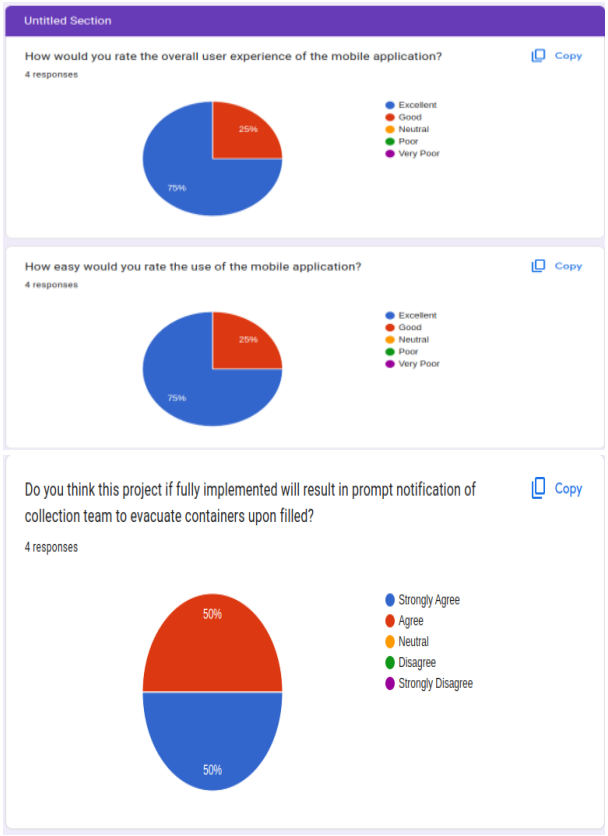


Fig 9: Showing analysis of response to system test questionnaires by non-stakeholders.

5. CONCLUSION

This paper aimed at the modelling and simulation of a smart waste management system presents a promising solution to address the challenges associated with traditional waste management practices in the Obafemi Awolowo University community. The modelling and simulation of a smart waste management system has demonstrated its potential to revolutionize waste management practices and contribute to the creation of cleaner, greener, and more sustainable cities. By harnessing the power of technology and data-driven insights, this research work can pave the way for efficient waste management, improved quality of life, and a healthier environment for present and future generations. Through the integration of advanced technologies, such as IoT sensors, data analytics, and real-time monitoring, the system can offer numerous benefits, including optimized waste collection routes, reduced operational costs, improved efficiency, and enhanced environmental sustainability.

6. ACKNOWLEDGMENTS

This Research was funded by the TETFUND Research Fund and Africa Centre of Excellence OAK-Park, Obafemi Awolowo University, Ile-Ife, Nigeria.

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