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كلية علوم الحاسب والمعلومات
قسم تقنية المعلومات

{وأوحينا إِلَىٰ مُوسَىٰ وَأَخِيهِ أَن تَبَوَّءَا لِقَوْمِكُمَا بِمِصْرَ بُيُوتًا ... }

[يونس: 87]

IT 497: Graduation Project Report
Product Release-2

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[يونس: 87]

Which mean (and we directed Moses and his brother: ‘Prepare a few houses for your people in Egypt…’).

The term **Taboua** (تَبوأ) refers to the act of preparing and arranging the living space for increased comfort and that is what we are looking for in our project to create places where people can live in a healthy and comfortable environment [1].

Taboua (تَبوأ): Location Based Waste Management System with AI-Powered Recycling Solution

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Taboua is a waste management system aimed at addressing the pressing challenges faced by Saudi Arabia in managing its waste effectively. The purpose of this software system is to provide individuals and Riyadh Municipality with a user-friendly platform for waste management, integrating advanced technologies such as image classification and mapping APIs. The development methodology follows an agile approach, allowing for iterative development and continuous improvement. Through extensive research and analysis, we have selected Firebase Firestore for database management, Flutter for mobile application development, and react for web application development. TensorFlow and Keras are utilized for image classification, while integration with the Google Maps API enhances user experience with interactive mapping features. Evaluation of the system demonstrates its scalability, real-time data processing capabilities, and user-friendly interface. The main findings indicate that Taboua effectively addresses the waste management needs of both individuals and authority, providing efficient waste categorization, location-based services, and administrative capabilities. Overall, Taboua represents a significant advancement in waste management technology, offering a sustainable solution to the challenges faced by Saudi Arabia.

تبوأ هو نظام إدارة النفايات الذي يهدف إلى التعامل مع التحديات التي تواجهها المملكة العربية السعودية في إدارة نفاياتها بفعالية، يتمثل الغرض من هذا النظام التقني في توفير منصة سهلة الاستخدام للأفراد وأمانة منطقة الرياض لإدارة النفايات، مع استخدام تقنيات متقدمة مثل تصنيف الصور وواجهات التطبيقات للخرائط تفاعلية. يتبع تبوأ منهجية التطوير الرشيق (Agile approach)؛ مما يسمح بالتطوير التدريجي والتحسين المستمر، من خلال البحث والتحليل الموسع، وقع الاختيار على Firebase Firestore لإدارة قاعدة البيانات، وFlutter لتطوير تطبيقات الجوال، وReact لتطوير تطبيقات الويب. يتم استخدام TensorFlow وKeras لتصنيف الصور، بينما يعزز دمج واجهة التطبيق مع خرائط Google Maps تجربة تفاعلية للمستخدم. أظهر تقييم النظام قابليته للتوسع وقدرته على معالجة البيانات في الوقت ذاته وأن الواجهات تتميز بالوضوح وسهولة الاستخدام، تشير النتائج إلى أن تبوأ يعالج بفعالية احتياجات إدارة النفايات للأفراد والأمانة، بتوفير تصنيف فعّال للنفايات وخدمات قائمة على تحديد الموقع وخدمات إدارية. بالموجز، يمثل تبوأ تقدمًا كبيرًا في تقنيات لإدارة النفايات، مقدمًا حلاً مستدامًا للتحديات التي تواجهها المملكة العربية السعودية.

Keywords: Taboua; Waste management system; Image classification; Maps APIs; Garbage bins; Recycling center; Quality of life; Sustainability.

Chapter 1: Introduction

1 Introduction

A healthy, clean, and safe environment is a major concern for human rights and is critical for the well-being of both present and future generations [2]. In all communities, a certain amount of waste is inevitable. Effectively managing it is crucial to maintaining a healthy and clean environment. Year over year, the amount of waste is increasing massively. In 2019, Saudi Arabia established the National Center for Waste Management – MWAN (المركز الوطني لإدارة النفايات)[3]. MWAN is responsible for regulating and supervising waste management activities and promotes the principle of circular economy in waste management to achieve sustainable development goals [3]. One of the goals of the Kingdom of Saudi Arabia's Vision 2030 is to create sustainable cities and communities that enhance life quality while preserving the environment's natural resources for future generations [4]. However, Saudi Arabia encounters various obstacles in developing urban areas, related to waste management and recycling issues[5]. Since Saudi Arabia produces approximately 53 million tons of waste annually, this leads to contamination of its soil and groundwater [5]. Furthermore, half of the total waste comes from three major cities: 21% from Riyadh, 14% from Jeddah, and 8% from Dammam [5]. Promoting a circular economy is a shared responsibility where individuals hold half the key to success. Individuals play a critical role in improving the environment and promoting sustainability. By embracing sustainable practices and increasing awareness, individuals can effectively dispose of waste and contribute to an eco-friendlier world.

To achieve these goals, we propose the development of a waste management system called Taboua. This digital solution aims to address the challenges associated with the waste management sector. Taboua will use modern technology to facilitate communication between individuals in Riyadh city and waste management authority, encourage responsible waste disposal, and improve the overall quality of life and environmental sustainability.

1.1 Problem

The project addresses a significant real-world problem the challenge of waste management in Saudi Arabia, particularly in Riyadh city. Despite existing waste management services provided by applications such as "MyCity" and "أمانه ٩٤٠" these solutions fall short of providing the needed services such as locating nearby garbage bins and recycling centers [6]. According to MWAN, the environmental degradation caused by solid waste in 2021 was estimated at $1.3 billion, where is 21% of the waste comes from Riyadh [5]. Most landfills in Saudi Arabia are on the brink of reaching their capacity, presenting a growing concern where Individuals make heavy use of disposable products, notably single-use plastics [5]. However, existing recycling practices remain limited in scope. As a result, a significant portion of waste ends up in landfills without any prior treatment [5]. Amidst these challenges, Saudi Arabia (specifically Riyadh city) encounters various waste management issues, and Taboua aims to tackle these crucial issues, Such as:

- **Improper Waste Disposal:** Improper waste disposal harms the environment and health, requiring a viable solution. For instance, when people dispose of hazardous materials like batteries or chemicals in regular waste bins, it may lead to harmful substances leaching into the soil and groundwater. Also, see (Figure 1) as an example of the inadequate waste disposal of harmful material such as woods, tree branches and palm fronds.

Figure 1: Improper Waste Disposal [88]

- **Lack of Recycling Awareness:** Limited awareness of proper recycling methods hinders waste reduction and prevents positive environmental outcomes as shown in (Figure 2). Or instance, many individuals may not be aware of the appropriate separation and disposal of recyclable materials, causing valuable materials to end up in landfills instead of being recycled.

Figure 2: Lack of Recycling Awareness [7], [8]

- **Inefficient Communication Between Individuals and Riyadh Municipality:** The absence of a seamless communication channel hinders the reporting of complaints. For instance, when people encounter overflowing garbage bins or irregular garbage pickup schedules, if they cannot quickly report these problems, it slows down finding solutions.

- **Inefficient Garbage Bins Placement:** The improper positioning of garbage bins results in accumulation of waste in streets and public areas. as shown in (Figure 3)this picture was taken by one of the Taboua team member, which negatively impacting the urban landscape and citizen well-being (Figure 4). For example, in some neighborhoods in Saudi Arabia, where waste disposal involves a cumbersome process, individuals need to drive to reach the nearest container for disposal, and this is a disturbing matter for many individuals.

Figure 4: Inefficient Garbage Bins Placemen[89]


Figure 3: Accumulation of Waste in Streets

1.2 Solution

Therefore, investing in a proper waste management system is essential to improve the quality of life for individuals while reducing the environmental impact of urbanization, and promotes circular economy principle. Thus, Taboua is tailored to address these specific challenges and support Riyadh Municipality.

Our proposed solution Taboua is a waste management system that aims to bridge the gap between individuals and the waste management authority, Taboua offers two main components:

- An iOS mobile-based application for individuals, that enables users to easily locate or request garbage bin placements, report issues, access AI-Powered Recycling item.
- A web-based end for Riyadh Municipality to strategically plan garbage bin placements, handle complaints, and use the collected data for decision-making.

This dual approach ensures that Taboua offers advantages to both parties where individuals gain access to waste disposal services and relevant information, contributing to their well-being and environmental consciousness. At the same time, Riyadh Municipality benefits from improved communication with individuals, efficient waste management planning, and data-driven insights to enhance their operational strategies. Taboua focuses on tackling issues identified previously by proposing the following main features:

- **Improper Waste Disposal:** Taboua mobile application will facilitate proper waste disposal practices through user-friendly features that promote waste reduction. Individuals can easily locate garbage bins and recycling centers on a map using GPS.

- **Inefficient Communication Between Individuals and Riyadh Municipality:** Taboua mobile application serves as a direct communication channel between individuals and Riyadh Municipality, enabling individuals to report issues they encounter such as overflowing bins, illegal dumping, irregular garbage pickup schedules, and other concerns. This enhances communication efficiency and leads to quicker issue resolution. Also, Taboua web application will utilize the collected complaints data to visualize it using a heat-map to identify the most problematic areas.

- **Inefficient Garbage Bins Placement:** To facilitate a better arrangement of garbage bins in streets and public areas, Taboua web application empowers the authority to strategically plan garbage bin placements among neighborhoods using GPS mapping. In addition, the Taboua mobile application empowers individuals to locate and request a new garbage bin using GPS mapping.

- **Lack of Recycling Awareness:** Taboua mobile application provides an image classification model that helps individuals increase their awareness of recycling. The model assists users by allowing them to scan waste item. The model then will suggest the waste item category (plastic, paper, etc.), where the users can either approve the suggested category or correct it if it has been misclassified. Finally, the function will suggest the best recycling centers based on the waste item category.
  The model will be developed following an approach called transfer learning that involves repurposing a pre-existing model to address a new problem, typically accomplished by retraining the model using custom datasets [9].

Taboua mobile application features for the individuals includes:

- Users can locate garbage bins and recycling centers on a map using GPS.
- Users can request a new garbage bin using a map based on GPS.
- Users can raise a complaint to the authority and review the status of their reported issues.
- Users can benefit from an image classification model that helps them increase their awareness of recycling by scanning the waste item, then the model will categorize it by type (plastic, paper, etc.), and then provide guidance to nearby recycling centers.

Taboua web-based features for the Riyadh Municipality staff includes:

- Authority staff can plan and distribute garbage bins and recycling centers among neighborhoods using GPS mapping, where they can add, edit, or delete locations.

- Authority staff can manage the complaints received from the individuals by reviewing these issues, act accordingly and update the issue state.
- Authority staff will be able to visualize the received complaints using a heat-map associated with statistical details to identify the most problematic areas.

The scope of Taboua involves the development of both a mobile and web-based system waste management system that facilitates the communication between individuals in Riyadh city and Riyadh Municipality and help them in managing complaints, garbage bins, and recycling centers along with visualizing data and benefits from recycling item model. Taboua involves the development of a website for Riyadh Municipality (accessible on all platforms) and a mobile application for individuals (only available on iOS platform). The system, designed exclusively in Arabic and will cater to Riyadh city residents. Taboua primary users are individuals in Riyadh city and Riyadh Municipality authorized staff. The system will use the facilities provided by the Google Maps platforms.

1.3 Product Vision

The core vision of Taboua is to empower the individuals who need effective management of garbage bins and proper waste disposal practices, Taboua is a mobile and web-based system that assists with distributing and requesting garbage bins, visualizing data, benefits from AI-powered Recycling item, and managing complaints.

1.4 Software Process Methodology

In our development process, we are employing the agile methodology, which allows for iterative and flexible software development. We follow a structured approach to ensure user needs are understood and met at every stage of the software lifecycle:

- Requirements Elicitation and Planning: understand user needs and expectations through interviews and questionnaires.
- Design and Development: design user interfaces and database structure, implement system features and functionalities for both mobile and web applications along with the two main technical parts which are:

    - Integrating GPS mapping using Google API to develop a heat-map functionality that utilizes the collected complaints data.
    - Developing the image classification model by following an approach called transfer learning involves repurposing a pre-existing model to tackle a new issue, typically accomplished by retraining the model using custom datasets by following the necessary stages: collect datasets, preprocess the data, retrain the model, test the trained model, deploy the model.

- Testing the product: Test system functionality, usability, and performance, and gather user feedback and insights through testing for continuous improvement.
- Deployment and Maintenance: Deploy the system for access by individuals and the authority, then monitor user feedback and implement updates and enhancements over time.

1.5 Main Contribution

Unlike other waste management systems, our product offers comprehensive services to empower the role of individuals in their community for waste management and to visually handle waste disposal and recycling properly.

The impact of Taboua goes beyond the local community, helping Riyadh become more efficient and environmentally friendly. It can encourage local communities to be more responsible, supporting global efforts to promote eco-friendly practices.

1.6 Summary

This document introduces our project, Taboua. We begin by providing a thorough understanding of the problem domain, elucidating the challenges encountered in waste management, particularly in Saudi Arabia. We outline the objectives of the software development, emphasizing the need for a solution that can address these challenges effectively. Furthermore, we present a clear product vision statement, elucidating the future state that Taboua aims to achieve. We highlight the main contribution of Taboua, underscoring its potential impact on both the local and global communities.

In the subsequent sections, we will talk about the background of the project, providing essential context on waste management issues faced by Saudi Arabia and exploring existing solutions and initiatives. Following this, we conducted a detailed literature review, synthesizing existing research and solutions in the waste management domain, and positioning Taboua within this landscape. We then proceed to discuss the system design and development process, detailing the methodology used, system requirements, design architecture, and implementation details. Subsequently, we present the results of the system evaluation, including experimental findings and user acceptance testing results. Finally, in conclusion, we propose pathways for future advancement and acknowledge those who have assisted us in our project.

Chapter 2: Background

2 Background

This chapter will provide a background about the waste management in Saudi Arabia and current initiatives. Additionally, we will introduce all technical aspects that are involved in Taboua including Image Classification Model and Map APIs (Application Programming Interface).

2.1 Waste Management in Saudi Arabia

The National Center for Waste Management (MWAN), established in 11/8/1440H, focuses on regulating and enhancing waste management practices in the country. It oversees the entire waste management process, including import, export, collection, treatment, and disposal, with a strong emphasis on environmental protection and public health. MWAN actively promotes investment in sustainable waste management systems, aligns with circular economy principles, and contributes to sustainable development goals. It also leads capacity-building efforts and fosters innovation in waste management, showcasing its commitment to environmentally responsible practices nationally[3].

In Saudi Arabia, every city has a municipal entity known as "Amanah," overseeing a group of subordinate municipalities. For instance, Riyadh boasts the Riyadh Region Municipality, which, in turn, manages sub-municipalities like Al-Olaya Municipality, Al-Dawadmi Municipality, and Al-Zulfi Municipality, among others [10]. These municipalities bear the responsibility of implementing rules and duties delegated by MWAN. Their tasks encompass various activities, such as maintaining urban cleanliness, overseeing the establishment and management of parks and recreational areas, and managing waste distribution and disposal.

Saudi Arabia has embarked on a clear and ambitious path towards comprehensive waste management, positioning it as a vital component of its Vision 2030 initiative, which places a strong emphasis on sustainability and environmental responsibility [11]. The nation faces substantial challenges, including a daily per capita waste generation of 1.7 kilograms and an annual production of approximately 7 million tons of plastic waste [12]. A primary objective is to significantly enhance recycling rates. By 2035, Saudi Arabia aims to recycle 81% of its annual municipal solid waste, equivalent to 3.4 million tons, and 47% of its construction and demolition waste, amounting to around 5 million tons [13]. Achieving these targets necessitates the development of robust waste management infrastructure and recycling facilities.

Among the notable challenges faced by municipalities is the absence of an application for garbage bin inventory and a platform for tracking garbage bin updates. One solution proposed by the Municipality of Riyadh Region is to create an inventory application linked to the municipality and designed to ensure continuous updates. It is important to note that this concept is currently in the conceptual stage and has not yet been implemented.

Traditionally, garbage bins were distributed approximately every 25 meters, with the number of bins subject to adjustment based on specific requirements. Areas with dense residential complexes or numerous restaurants may necessitate a higher number of bins. However, there is no fixed percentage for bin distribution in each area; it relies on the municipality's assessments concerning the area's needs and expected waste volume[14]. Notably, the municipality has undertaken a project for optimizing waste container distribution which was completed on May 31, 2023[14]. This project entails determining the appropriate garbage container size for each area using the following equation:

> Actual demand = Number of household members * Average daily waste production per person * Number of households * Waste compaction factor[14].

An important sustainability initiative, "Neighborhood Without Bins," has been effectively piloted in the Al-Waha and Al-Rawdah districts of Riyadh. This initiative places a strong emphasis on waste segregation and recycling, achieved through the distribution of green bins for recyclable waste (plastic, paper, etc.) and black bins for other waste categories, as illustrated in (Figure 5) [15].

Figure 5: Distribution of Green and Black Bins [90]

Therefore, Saudi Arabia has demonstrated its commitment to sustainable waste management, reflecting its dedication to environmental protection and resource conservation in line with the goals of Vision 2030. While commendable progress has been made in this field, further efforts are still needed to address areas such as recycling and waste bin management [4].

2.2 Taboua Technical Aspects

Aligned with the goals of Saudi Arabia and the challenges it faces. We aim to develop the Taboua waste management system. Taboua will provide comprehensive waste management services to both individuals and the Riyadh Municipality. The Taboua system comprises two major components: a mobile application for individuals and a website application for Riyadh Municipality. In this section we will discuss the technical aspects related to Taboua database, mobile application, web application, as well as the two main technologies used (Image Classification Model and Maps).

Taboua Database Management: Among the available database technologies, there are several database types to choose from, two primary types are SQL (Structured Query Language) databases and NoSQL (Not Only SQL) databases.

SQL databases are relational databases that use predefined schemas, such as MySQL and PostgreSQL, they are often used in applications that require complex queries. While the NoSQL databases are non-relational databases that has a dynamic schema, such as MongoDB and Firebase Firestore, they're easy-to-use, flexible and offers high performance, they excel at handling large amounts of data, making them ideal for applications requiring scalability and real-time data processing [16].

Firebase Firestore stands out as the perfect choice for our Taboua system. Cloud Firestore is a flexible, scalable and NoSQL database for mobile, web, and server development from Google's Firebase and Google Cloud platforms [17]. Its capabilities make it ideal for handling dynamic data updates and providing responsive user experiences. Additionally, Firestore excels in storing geolocation data, such as latitude and longitude, which is important for our system's interactive map features.

Taboua Mobile Application: is an iOS application that will be developed using the Flutter framework. Flutter is a cross-platform technology created by Google[18]. The Taboua team has preferred Flutter over ReactNative and Swift. This is due to Flutter's rich set of widgets, flexible UI framework, direct compilation to native code, and the ability to see changes in real time via hot reload. Collectively, these features improve the team's ability to deliver applications with low development time and high performance. Flutter offers a wealth of resources, strong community support, and incorporates advanced operating system features. Offering advanced operating systems such as GPS coordinates as a Google-supported plugin. That will be one of the Taboua system's key components. Additionally, the Taboua team plans to launch the application for end-users in the future. Flutter is widely recognized as the optimal solution for creating high-quality applications for multiple platforms with a single codebase.

Taboua Web Application: Among the technologies available for web development, such as Angular, Vue.js, and React, we have chosen React for our Taboua web application. React is a powerful JavaScript library known for its component-based structure that promotes code reuse and maintainability, originally built by Meta [19].

This choice was made due to React's component-based structure that allows us to create modular and reusable code that can help us scale our Taboua web application as our business grows. Alongside React, we will use Firebase Firestore for our database needs for efficient data management, and Google Maps API to provide interactive mapping capabilities such as viewing recycling center locations and visualizing user's complaints. These three technologies align perfectly with our Taboua user experience goals, ensuring the development of an efficient waste management solution.

Additionally, the Taboua system comprises two main technologies: Image Classification Model and a Map API, which will be described in more detail in the following sections.

2.2.1 Image Classification Model

The absence of information regarding best recycling practices and the locations of recycling centers was a significant factor in the lack of recycling awareness. To address this need, the Taboua team will introduce recycling item model technology into the mobile application.

There are several pre-existing frameworks for machine learning models. The most widely popular are Scikit-Learn, PyTorch, and TensorFlow. Each framework will be described below, along with its advantages and disadvantages.

- **Scikit-Learn:** One of the oldest machine learning frameworks. The framework is built on top of several popular Python packages, namely NumPy, SciPy, and matplotlib [20].

  Advantages:
  - Beginner-friendly with accessible API and extensive documentation [21].
  - Easily integrated with other libraries and tools [21].

  Disadvantages:
  - Capable to deal with machine learning tasks with smaller datasets [21].
  - Less flexible [21].

- **PyTorch:** Open-source and supports cloud-based software development spearheaded by Meta's research [22]. The framework is integrated with Python and compatible with popular libraries like Numba and Cython [20], [23].

  Advantages:
  - Good debugging capabilities [24].
  - Capable to deal with large datasets [24].

  Disadvantages:
  - Does not cover end-to-end model building to deployment functions [20].
  - Visualization capabilities are limited [24].

- **TensorFlow:** End-to-end open-source library designed to support machine learning applications developed by Google Brain [20], [25].

  Advantages:
  - Large-scale deployment [26].
  - Capable to deal with large datasets [24].

  Disadvantages:
  - Complex to debug [24].
  - Spend more time to train machine learning model [20].

There are many factors that should be considered to achieve the best accuracy for any of the ML frameworks mentioned above. These include the quality and size of the training data, the complexity of the model architecture, and the selection of an appropriate optimizer and hyper-parameters.

Several factors have been considered while selecting a suitable and efficient machine learning framework for Taboua. These factors included the availability of a free framework, implementation of the Python programming language, the capability to manage large datasets, the ability to deploy models on multiple platforms, high performance, flexible, and better visualization.

After careful consideration, the Taboua team found the Scikit-Learn and PyTorch has limitations. Scikit-Learn is only capable of dealing with machine learning tasks with smaller datasets. While PyTorch Does not support end-to-end model building for deployment. To correctly distinguish between different waste types, it is necessary to train the model with large datasets. Furthermore, as the model will be integrated into the Taboua mobile application, it is necessary to select a framework that supports end-to-end model building for deployment. For that the Taboua team identified TensorFlow as the optimal framework for the Taboua recycling item model.

By adapting TensorFlow framework, we can develop Taboua recycling item model. There are different types of image classification, including binary, multi-class, multi-label, and hierarchical. Binary classification is used to distinguish between two classes of objects[27]. In contrast, multi-class classification categorizes items into more than two classes, whereas multi-label classification allows the item to be assigned to multiple labels[27]. Hierarchical classification is the top-down organization of classes into a hierarchical structure based on their similarities. A higher-level class represents broader categories, while a lower-level class is more specific [27]. The goal of the Taboua recycling item model is to categorize items into eight waste types, which is more aligned with the multi-class classification.

Image Classification Model Integration

To integrate the image classification model into the Taboua mobile application, the use of APIs (Application Programming Interfaces) is essential. APIs act as a bridge between the Flutter mobile application and the machine learning model, allowing seamless communication and data exchange. This allows the application to request a classification based on user-uploaded photos, with the back-end model processing these requests and returning the waste type as a response. APIs facilitate this interaction without requiring the application to understand the complex workings of the model, promoting a clean, maintainable, and scalable architecture.

Some of the most popular APIs include:

- **FastAPI:** is a modern, high-performance web framework for building APIs with Python 3.6+ types. It is known for its speed and ease of use, making it a popular choice for developing web APIs [28].

  Advantages:
  - Fast performance.
  - Automatic Swagger documentation for API endpoints.
  - Support for asynchronous request handling.
  - Type checking and validation built-in, reducing bugs.

  Disadvantages:
  - Smaller community compared to more established frameworks, potentially leading to fewer resources for troubleshooting.
  - The main file can become large and complex as the application grows.

- **Flask:** is a streamlined WSGI web application framework aimed at facilitating a swift and straightforward initiation process, while also offering the scalability needed for more intricate applications [29].

  Advantages:
  - Simplicity and ease of use, making it great for beginners.
  - Extensive ecosystem of extensions to add features as needed.

  Disadvantages:
  - Lacks built-in support for database abstraction layer, form validation, or authentication mechanisms, requiring external libraries or frameworks [28].
  - Not inherently asynchronous, which may impact performance under high load [28].

- **Django REST Framework:** is a powerful and flexible toolkit for building Web APIs on top of Django, offering comprehensive features like serialization, authentication, and custom query sets[30] .

  Advantages:

  - Mature and battle-tested, with a large community and extensive documentation.
  - Integrates seamlessly with Django's ORM and authentication mechanisms.
  - Robust serialization and validation mechanisms.

  Disadvantages:

  - May be too comprehensive for smaller projects or for those not previously utilizing Django.
  - Performance overhead due to its comprehensive features.

After considering the options, the decision to use FastAPI for Taboua is motivated by several key factors. FastAPI offers an exceptional combination of performance, ease of use, and modern Python features such as async/await support and type hints, which are critical for developing efficient and scalable APIs. Its automatic Swagger documentation facilitates easier testing and integration with the Flutter application. Despite its relatively newer presence in the ecosystem, FastAPI's growing popularity and adoption by tech giants underscore its capabilities and future potential. Thus, for a project requiring high performance and modern Python features, FastAPI emerges as the clear choice.

Image Classification Model Deployment

Deployment is critical for moving Taboua model from development to production and making it available to users. It involves setting up the necessary infrastructure to run the model in an efficient, secure and scalable way. For our Taboua system, choosing the right deployment platform is essential to ensure that our FastAPI application can reliably handle user requests, maintain data security, and scale as user demand grows.

- **Heroku:** is a cloud Platform as a Service (PaaS) that streamlines the deployment, scaling, and management of applications. It supports various programming languages and frameworks, offering a user-friendly platform for developers to bring their applications from development to production seamlessly [31].

  Advantages:

  - Easy to use and set up.
  - Supports a variety of programming languages and frameworks.
  - Offers a range of add-ons for database, caching, etc.

Disadvantages:

- Can be costly as the application scales.
- Limited in terms of control over the server and infrastructure.

- **AWS (Amazon Web Services):** is a cloud platform that provides a comprehensive suite of services, including computing, storage, and database options, suitable for deploying a wide range of applications. Its extensive offerings ensure that it can meet diverse deployment needs, from simple web applications to complex, large-scale enterprise environments[32].

  Advantages:
  - Highly scalable and reliable.
  - Offers a vast ecosystem of services.
  - Flexible pricing models.

  Disadvantages:
  - Complex pricing structure can make budgeting difficult.
  - The sheer breadth of services can be overwhelming.

- **Google Cloud Platform (GCP):** is a collection of cloud services, leveraging the same robust infrastructure Google utilizes for its consumer products. This platform offers an array of cloud computing solutions designed to meet various needs, including application deployment and data management [33].

  Advantages:
  - High-performance computing capabilities.
  - Global network of data centers.
  - Strong emphasis on security and compliance.

  Disadvantages:
  - Pricing can be complex and unpredictable.
  - May have a steeper learning curve for some services.

After evaluating the options, Google Cloud Platform (GCP) emerged as the most suitable choice for deploying the Taboua FastAPI application. GCP provides a robust infrastructure that meets our requirements for security, scalability and performance. With its global network of data centers, our application can deliver high availability and low latency to users. In addition, GCP's commitment to innovation and open-source technologies provides an agile environment for deploying and managing our FastAPI application.

While GCP's pricing structure can be complex, their pay-as-you-go model allows us to optimize costs by scaling resources based on demand. In addition, GCP's extensive documentation and community support can help us navigate its services and features effectively.

Ultimately, the combination of GCP's advanced security features, global reach and scalable resources makes it the ideal platform to ensure Taboua's success.

Taboua Recycling Item Model

One of the features of the Taboua mobile application is the recycling item model, which utilizes an image classification model to assist users in categorizing their waste. To utilize this feature, users should take a picture of their waste. The model will then propose a waste item category (plastic, paper, etc.). Users have the option to confirm or correct the waste type if it was misclassified. Finally, the Taboua mobile application will suggest the best recycling center based on the waste item category. As shown in (Figure 6), there are six steps to train a Taboua recycling item model**:**

1. Collect datasets, and we found many available datasets for recycle classification on Kaggle [34], [35], [36], [37], [38], [39], [40].
2. Train model on our dataset.
3. Test trained model.
4. Evaluate the accuracy of the model.
5. Integrate the model with FastAPI.
6. Deploy the model on Google Cloud.

For further details regarding the Taboua recycling item model training, please refer to (4.6.3:Taboua Recycle Item Model Implementation).

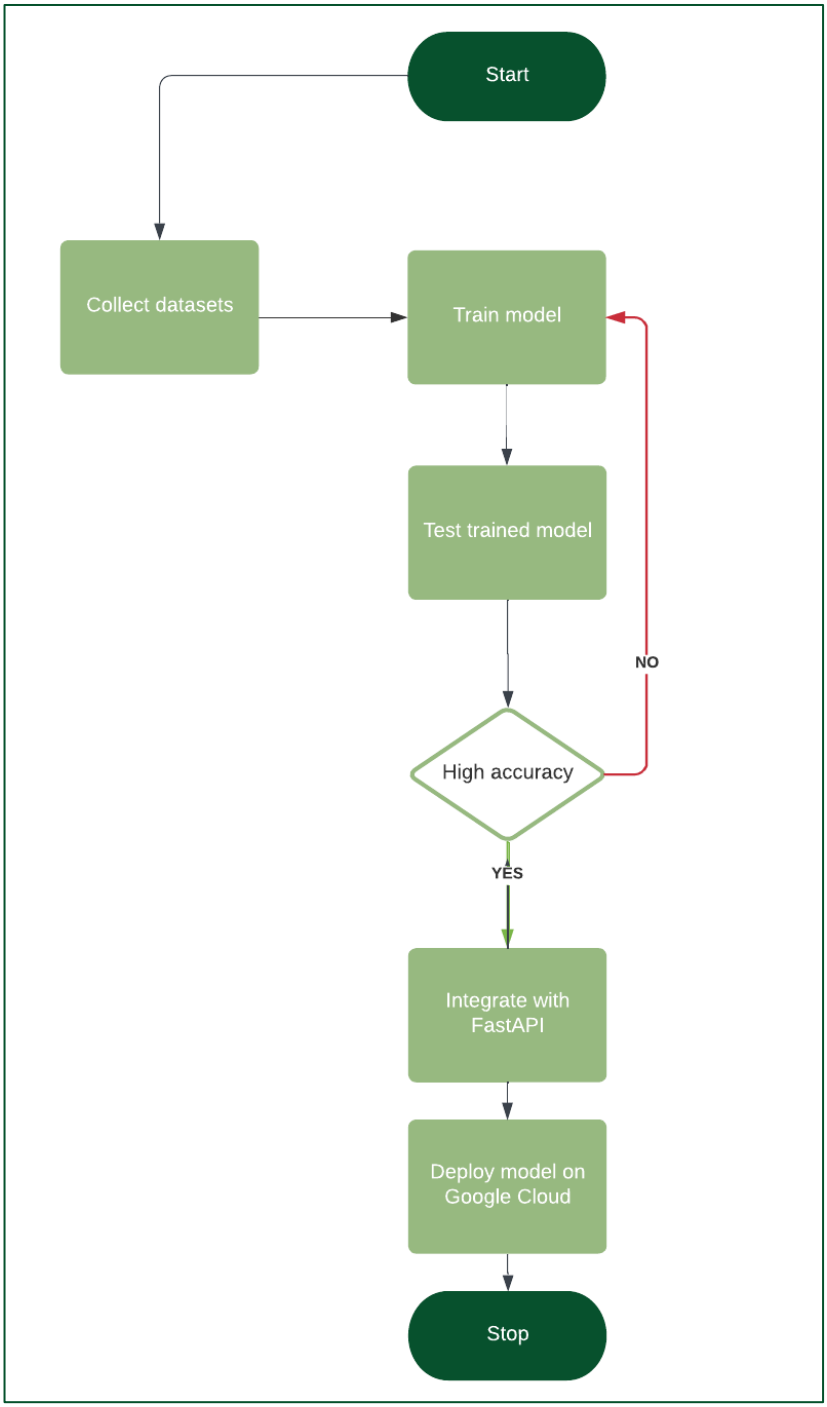


Figure 6: Image Classification Flowchart

2.2.2 Map API

In our Taboua system, the integration of Map API (Application Programming Interface) is essential because it plays an important role in enabling us to provide interactive maps and location-based services, such as viewing nearby garbage bin locations and requesting a new garbage bin placement in certain location.

In the field of geospatial services, Map APIs are software tools that enable the developers to effortlessly incorporate interactive maps and location-based services within their applications [41]. Map APIs offer developers a range of tools and features, including:

- Geocoding API: The conversion of a location's geographic coordinates (latitude and longitude) into a human-readable street address and vice versa [42].
- Geolocation APIs: Return the precise location of a device based on Wi-Fi or cell towers [42].
- Visualization: Map APIs can be used to perform spatial analysis and visualization, such as heat maps and 3D maps [42].
- Directions and Routing: Map APIs can provide routing and directions for various modes of transportation, featuring real-time traffic information[42].

Some of the most popular map APIs include:

- **Google Maps API:** a set of APIs provided by Google that allows developers to integrate dynamic and interactive maps, geolocation, and geographic data into their applications. It offers extensive geospatial capabilities, real-time data visualization, and interactive mapping features [43].

  Advantages:
  - The first $200 of usage each month is free.
  - Has the most comprehensive coverage.
  - Highly recognizable and trusted brand[44].
  - Extensive documentation, tutorials, and support.

  Disadvantages:
  - May perform slower than other mapping APIs[44].
  - Limits on the number of requests per second sent to their platform.
  - Not open-sourced, Google retains full control over its features.

- **Mapbox API:** is a collection of APIs and SDKs (Software Development Kits) that enable developers to have access to comprehensive location information to create and customize dynamic and static maps to incorporate into their applications [44].

Advantages:

- Well organized documentation.
- Easy customization of maps.
- User-friendly and easy to integrate with apps.

Disadvantages:

- Not a free service.
- Geared towards larger projects.
- The API is not customizable.

- **OpenStreetMap API:** OpenStreetMap is a free, editable map of the whole world that is being built by volunteers largely from scratch and released with an open-content license [44].

Advantages:

- Open-sourced.
- The API is completely free.
- Detailed map information on less popular locations [44].

Disadvantages:

- Higher level of technical complexity.
- Limited usage, as services like routing rely on third-party APIs [44].
- Incomplete documentation.

Among the available options, we have decided to go with the Google Maps API for our Taboua system since there are many reasons why this should be the one. The Google Map API offers a wide range of features, including geocoding and reverse geocoding, interactive mapping, and real-time data visualization. Moreover, its pricing is reasonable, with a generous free tier and affordable pricing for additional requests. Furthermore, Google Maps API is the industry leader in Map APIs for integrating maps into applications, it is widely used, has extensive documentation, and supports Arabic language.

Additionally, the Google Maps API empowers us to create an interactive heat-map. A heat-map is a visualization used to depict the intensity of data at geographical points, when the heat-map Layer is enabled, a colored overlay will appear on top of the map[45]. By default, areas of higher intensity will be colored red, and areas of lower intensity will appear green[45]. Where authority staff will be able to visualize the aggregated user's complaints on a heat-map to identify the most problematic areas. Also, the heat-map will be updated in real time as new complaints are received, aiding in the strategic placement of garbage bins and resource allocation.

Through the integration of the Google Maps API into our Taboua system, individual users can quickly access and find nearby garbage bin and recycling center locations and request new garbage bin placement. This integration significantly enhances user convenience and simplifies the waste disposal process. On the other hand, authority staff can visualize users' complaints through an interactive heat-map to spot areas with frequent issues, also helping them plan and distribute garbage bin placement locations strategically across the map. It is important to note that the addition of garbage bin locations on the map depends on the available garbage bin locations dataset we obtained from the Riyadh Region Municipality [46]. This integration improves our Taboua administrative capabilities, leading to efficient waste management decisions.

Chapter 3: Literature Review

3 Literature Review

In this chapter we will provide an evaluation of the local competitors, global competitors, as well as AI-specific solutions for waste management. At the end of this section, we will conclude with a summary of all competitors and identify the competitive advantage of Taboua.

3.1 Local Competitors

MyCity مدينتي [6]**:**

MyCity is an app developed by Riyadh Region Municipality, it offers a diverse range of electronic services that has been designed to enhance accessibility of essential functions for Riyadh citizens and residents. The app is available for android and iOS. There is also a website designed for individuals, companies, and municipality partners.

Main Services:

- Construction Permits such as Building Permit Issuance, Renovation Permit Issuance with Prior Permit, etc.
- City Services: Help users find the nearest park that suits their needs and access essential information about them.
- Informational Services such as Transaction Status Inquiry, Health Certificate, Release of Impounded Vehicles, etc.
- Appointment Services: Users can schedule appointments with Riyadh Municipality.
- Report 940: This service allows users to submit reports using various multimedia formats to ensure their voices are heard clearly.
- Waste Collection Schedule: This service allows users to input their address to determine the waste collection schedule specific to their area.

Advantages:

- Good UI design.
- Security: Synchronization with NAFATH is required for logging into your account, which enhances the security and makes it less vulnerable to hacking attempts.
- Responsiveness: It responds quickly and without noticeable delays.
- Users can track their complaints after submitting them.

Disadvantages:

- The app offers multiple functions unrelated to waste management, making it difficult for users to access the services they need. As it was not originally designed for waste management, it lacks the necessary functionality required by users.
- The app does not support English language.
- Users cannot upload a photo from the photo album when submitting a complaint.

Balady بلدي [47]:

The Balady app portal, developed in partnership with multiple municipal authorities, is designed to empower local communities. It offers interactive features for community engagement in service improvement, provides electronic tools for online license requests, and delivers informative services. This app is accessible on both Android and iOS devices.

Main Services:

- Daily Services such as Quranic verses, Prayer times, Qibla compass, etc.
- Services of Interest such as Request Municipal Services (road requests, lighting and signage requests, park requests), Online appointment booking, Vehicle retrieval request, etc.
- Municipal services such as Commercial services, Issuance of health certificates, Collective housing licenses, etc.
- Support Services such as Intelligent consultant, Fee calculator, etc.

Advantages:

- Security: Synchronization with NAFATH is required for logging into your account, which enhances the security and makes it less vulnerable to hacking attempts.
- Responsiveness: It responds quickly and without noticeable delays.
- The application has a great UX, UI design, with related services grouped together for easy access.
- Users can track their complaints after submitting them.

Disadvantages:

- The application was not designed for waste management; therefore, it lacks the necessary functionality required by the user.
- The app does not support the English language.
- The report section does not exclusively focus on waste management but rather comments on all street's problems.
- Users cannot upload a photo from the photo album when submitting a complaint.

Amaanah 940 / امانة ٩٤٠ [10]:

Amaanah 940 is a dedicated app created by the Riyadh Emergency Center to serve the citizens and residents of Riyadh Region. It is designed to streamline the process of submitting complaints and addressing the concerns of the city's residents efficiently.

Main Services:

- Complaint Submission.
- Track Previous Complaints.
- Multiple Complaint Channels: Users can choose to file their complaints via phone call, email, or Twitter.

Advantages:

- Security: Synchronization with NAFATH is required for logging into your account, which enhances the security and makes it less vulnerable to hacking attempts.
- Responsiveness: It responds quickly and without noticeable delays.
- It supports English and Arabic Language.
- Users can track their complaints after submitting them.

Disadvantages:

- Users cannot upload a photo from the photo album when submitting a complaint.
- Users cannot access the main menu at the home page.
- The app is designed for raising complaints and does not offer any additional functionality.

3.2 AI-Specific Competitors

Deep Waste [48]**:**

The Deep Waste system utilizes a machine learning model for waste categorization, offering an engaging approach to waste management. Users earn eco-points as rewards for recycling, and a leaderboard is established to rank users based on their accumulated points. The app is available for android and iOS devices.

Main Services:

- Waste Categorization: Deep Waste uses advanced machine learning to categorize users' waste items by uploading a photo, making disposal easy.
- Earn Eco-Points: Users get rewarded with eco-points for correctly categorizing and disposing of waste.
- Leaderboard Competition: Users Compete for the top spot on the dynamic leaderboard, adding a fun and competitive edge to their eco-friendly efforts.

Advantages:

- Encourages responsible waste disposal.
- Motivates users to participate in environmental efforts.
- Fosters competition and engagement through leaderboards.

- Raises awareness about eco-friendly practices.
- Good UX design easy to navigate through.

Disadvantages:

- Does not support Arabic language.
- Potential inaccuracies in waste categorization.
- Privacy concerns related to photo-sharing.

Horizon [49]**:**

The Horizon app empowers individuals with localized recycling instructions for products through barcode scanning. It encourages community engagement, offers insights into product ingredients, and provides educational content to promote eco-conscious choices and contribute to a cleaner environment. The app is available for android and iOS devices.

Main Services:

- Product recycling guide (by scanning the product barcode).
- Ingredient insights.
- Users can track their recycling.
- Community challenges.
- Educational content.
- Product insights.

Advantages:

- Environmental Impact: The application promotes eco-friendly choices.
- Community Engagement: Through challenges and shared sustainability goals.
- Educational Value: The application delivers informative material that empowers users to make well-informed decisions about their lifestyle choices and purchases.
- Good UX design easy to navigate through.

Disadvantages:

- Barcode Dependency: The app relies on barcode scanning, which may not always be practical for all products, especially if barcodes are missing or damaged.
- Does not support Arabic language.

3.3 Global Competitors

SENSONEO [50]**:**

The Sensoneo waste management system is a comprehensive solution designed to enhance waste management practices in cities all worldwide. The app is available for iOS and android devices.

Main Services:

- Find the nearest available bin.
- Check the bin's fullness status.
- Users can discover the right bin for their waste type.
- Users can get optimized routes for quicker disposal.
- Report bin issues by uploading a photo.

Advantages:

- The application has a simple and easy-to-navigate interface.
- Important waste management functions are included in the application.

Disadvantages:

- Incorrect distribution of bins.
- There is no tracking of your complaint after it is submitted.
- Poor responsiveness.
- Doesn't support all the regions and neighborhoods.

SALGA [51]**:**

The SALGA Waste Management app provides a convenient service for local governments and citizens via mobile technology. The app aims to improve waste management services by allowing the reporting of related issues and fostering greater engagement and communication with government officials and representatives. The app is available for South Africa citizens and residents, and it is available for iOS an Android devices.

Main Services:

- Search and engage with local government officials.
- Search and view facility details.
- Report an Issue.
- Track reported Issues and receive notification status updates.
- Receive global and local municipalities notifications and updates.

Advantages:

- Enhanced Citizen-Government Communication: The app fosters direct communication, promoting transparency and accountability in waste management services.
- Users can report and track Issues.
- Notification Updates: Users can stay informed about global and local waste management notifications and updates.

Disadvantages:

- Does not support Arabic language.
- It is not supported in Saudi Arabia.

NADEERA [52]**:**

Nadeera is a waste management application that aims to empower citizens to participate in waste reduction, reuse, and efficient sorting. It leverages technology to promote responsible waste management practices, track waste performance, and enhance the sustainability of cities. The app is available for users from France, Lebanon, Saudi Arabia, United Arab Emirates. The app is available for iOS an Android devices.

Main Services:

- View waste pickup schedule.
- Request pickups for recyclables and special waste.
- Learn about waste sorting and best practices.
- Receive instant feedback on waste sorting.
- Earn points and redeem rewards.
- Waste sorting dictionary.

Advantages:

- Improved waste management: Nadeera empowers citizens to actively participate in responsible waste management, leading to more efficient sorting and reduced waste.
- Good UX and UI design.

Disadvantages:

- Does not support Arabic language.
- During the registration process, community contact information is mandatory. However, it should be noted that the app's call feature is not operational.

3.4 Competitive Product Analysis

	Local Competitors			AI-Specific Competitors		Global Competitors			Our Solution
	MyCity مدينتي	Balady بلدي	Amaanah 940 امانة ٩٤٠ –	Deep Waste	Horizon	SALGA	NADEERA	SENSONEO	Taboua
Rise Complaints	✓	✓	✓			✓		✓	✓
Review Complaint status	✓	✓	✓			✓			✓
Locate Garbage Bins								✓	✓
Request Garbage Bins									✓
AI-Powered Model to Categorize Waste Type				✓	✓				✓ Also suggest the best recycling center
Request Pickups for Recyclables and Special Waste							✓		
Check Bin Fullness Level								✓	
Track Your Recycling				✓	✓				
Community Challenges				✓	✓				
Educational Content					✓		✓		
Earn Points and Redeem Rewards				✓			✓		

View Nearby Recycling Centers									✓
Waste Pickup Schedule	✓						✓		
Technologies	GPS			Image Classi-fication	Image Classi-fication			GPS	GPS + Image Recognition
Platform	app	app	app	app	app	app	app	app	app and web

Table 1: Competitive Product Analysis

3.5 Summery

The competitive product analysis table above reveals that MyCity, Balady, Amanah, Salga, and Sensoneo offer various features for managing complaints and tracking their status. Sensoneo, unlike the others, stands out by allowing users to monitor garbage bins and assess their fill levels. MyCity simplifies waste pickup schedules for users, while Salga fosters citizen-government communication through features like global and local municipality notifications, interaction with local officials, and facility information access.

On the other hand, Nadeera focuses primarily on recycling, offering features such as requesting pickups for recyclable and special waste, educational content, and a rewards program. Similarly, Deep Waste and Horizon employ AI-powered models to categorize waste types and enable users to track their recycling efforts and engage in community challenges. Additionally, Horizon also provides recycling-related educational content like Nadeera, while Deep Waste offers a points-based reward system.

Taboua, our solution, offers a comprehensive set of core features that are closely aligned with those found in comparable applications. These features include the ability to report complaints, track the status of complaints, and locate nearby garbage bins. Similar to apps like Horizon and Deep Waste, Taboua also integrates an AI-powered recycling item recognition system.

But what really sets Taboua apart is its unique ability to recommend the closest recycling center for specific items. In addition, users can effortlessly visualize recycling centers on a map and enjoy the convenience of requesting new bins. Highlighting this uniqueness is the fact that there are no local applications that provide up-to-date data on garbage bins, making Taboua a standout and an invaluable addition to our community.

Chapter 4: System Design and Development

4 System Design and Development

After discussing waste management in Saudi Arabia and the various technical tools required for the Taboua implementation, this chapter will delve deeper into the design and development of the Taboua system. The chapter will begin by discussing the agile methodology used during the project implementation. It will then move on to the system requirements, including Taboua system users, requirements elicitation and analysis for both interviews and questionnaires. Also presents the Taboua use case diagram and roadmap, which include all Taboua functions. It also discusses the product backlog, containing all Taboua system functional and non-functional requirements and their acceptance criteria. Following that, discuss the system design including the architecture diagram, class diagram, and component-level design.

In addition, the chapter covers data design, including ER diagrams and non-relational data models. The following section will address the critical aspects of data collection and preparation for the Taboua system, such as the locations of garbage bins and recycling centers, as well as waste images. Subsequently, the chapter will cover the interface design, which includes navigation diagrams for both web and mobile applications, as well as the UX guidelines that were followed during the design and implementation of the Taboua system. Finally, the chapter describes the implementation of Taboua's core functionalities and the challenges that the Taboua team overcame during the implementation process. Additionally, we will highlight the valuable resources that guided the team through the implementation.

4.1 Methodology

To develop the Taboua system, we adopted the Agile methodology, which is a project management strategy that divides the project into distinct phases. This approach emphasizes ongoing collaboration, iterative progress, and continuous improvement [53].

To develop the Taboua system, we divided our project into five sprints: Sprint 1 focused on basic web functionalities for viewing and managing garbage bins and recycling centers; Sprint 2 introduced advanced features on both web and mobile platforms, For example, on the web, we implemented the management of garbage bins requests, while on the mobile app, we added functionalities for viewing garbage bins and recycling centers and requesting garbage bins; Sprint 3 involved developing an AI model for image classification integrated into the mobile app; Sprint 4 addressed complaint management and response mechanisms on both platforms; and Sprint 5 finalized the system with complaint visualization on the web and guest user functionalities on the mobile app.

By dividing our project into five sprints, we ensured a structured and flexible development process. Strategically, to maximize efficiency and product consistency, we chose to work on both the application and website components simultaneously.

This concurrent development approach allowed us to ensure that each feature was fully realized across both platforms, providing a seamless user experience, and streamlining the development workflow.

We have also adopted the Scrum framework, following its 3-5-3 structure to support our agile practices [54]. This included identifying three core roles within our team, as shown in (Table 2), responsible for guiding the team in Scrum practices and removing obstacles. First, the Product Owner, responsible for aligning the team's output with business goals through backlog management and priorities. Then the Development Team, which is a multi-functional group that actively works on sprint tasks to achieve project goals. Additionally, the Scrum Master ensures that the team is following Agile practices, facilitates meetings and helps to remove obstacles to progress. Furthermore, our process was structured around five key Scrum events: Sprint Planning, Daily Scrums, Backlog Refinement, Sprint Reviews and Sprint Retrospectives. These events ensured continuous communication, alignment on priorities, and iterative improvement. The use of 3 Scrum Artifacts, mainly the Product Backlog, Sprint Backlog, and Product Increments. These artefacts facilitated clear communication of development progress and sprint planning, further increasing the productivity and efficiency of our team.

To streamline our development process, we relied on essential tools like Jira and GitHub. Jira helped us track our progress, organize sprints and manage tasks efficiently, ensuring the whole team was aligned[1]. GitHub allowed for easy collaboration on code, making it easier to maintain and update both the application and website simultaneously[2]. These tools were key to keeping our project organized and our team aligned, increasing our overall productivity in developing the Taboua waste management system.

Scrum Team	
Product Owner	Dr. Ebtisam Alabdulqader
Developers	Danah Alotaibi, Latifah Allaboun Fay Aljardan, Afnan Alotay
Scrum Master (SM)	Dr. Ebtisam Alabdulqader
Stakeholders	Examination Committee, Authority Staff, Authority Admin, Individuals (Citizens and Residents).

Table 2: Scrum Team - Roles and Responsibilities

[1] https://jira.external-share.com/issue/c142029b-7587-4229-a275-6c58a05d8e9e
[2] https://github.com/Taboua/2023-GP2-15

4.2 System Requirements

The focus in this section is on the systematic gathering of users' description, user requirements, and precise technical specifications.

Key components of this section include engaging with users through interviews and questionnaires to understand their needs, which help us to specify the system requirements. Then architecting the system's structure and visually mapping out interactions via use case diagrams. The wealth of data acquired in this phase serves as the bedrock upon which the system's design and functionality will be built, ensuring alignment with user preferences, regulatory compliance, and technological feasibility.

4.2.1 System Users

Taboua users comprised of four main categories, which are:

- **Guest User:** Any mature citizen or resident of Riyadh who accesses the Taboua mobile application without registration. To effectively use the Taboua mobile application, a basic level of technical skills is required, including familiarity with software applications, maps, and the ability to operate technical devices. These users can locate garbage bins and recycling centers on a map and benefit from an image classification model.

- **Registered User:** Any mature citizen or resident of Riyadh who utilizes and registered in Taboua mobile application to address their waste disposal requisites. To effectively use Taboua mobile application, a basic level of technical proficiency is required, including familiarity with software applications, maps, and the ability to operate technical devices. These users have access to the Guest users features; plus, they can manage their profile, request a new garbage bin, and raise complaints.

- **Authority Staff:** Encompass a diverse group of individuals who play integral roles in the Riyadh Authority and Municipality and will utilizes Taboua web application. These individuals should hold positions as employees within the Riyadh Municipality at the Environmental Compliance and Sustainability Agency. staff can manage garbage bins and recycling centers, manage the users' complaints and visualize the received complaints using a heat-map.

- **Authority Admin:** Hold a pivotal supervisory role within Taboua system. They are distinguished from the staff by their capacity to not only perform all tasks within the purview of authority staff users but also by their responsibility for managing and overseeing the staff engaged in Taboua operations.

4.2.2 Requirements Elicitation and Analysis

Taboua requirements elicitation started with a data collection process, which encompassing 22 interviews and 136 responses gathered from individuals through a designed questionnaire. The overarching objective of this research initiative is to attain a profound understanding of the prevalence of challenges encountered by individuals and to discern viable strategies for effective problem resolution. In the following sections we present the interview and questionnaire studies and findings.

Interview Study

We conducted interviews with 22 individuals hailing from various neighborhoods across all regions of Riyadh, encompassing the North, East, South, and West. During our interview, we encountered 7 men and 15 women. We engaged across a diverse range of ages: (19, 20, 21, 22, 25, 27, 31, 32, 33, 36, 39 and 62). We also encountered individuals with varying educational backgrounds: 8 with bachelor's degrees, 13 with Secondary education, and 1 with a master's degree. Special attention was directed towards securing responses from homeowners residing in various neighborhoods. The interviews were conducted with a standard duration ranging from 10 to 15 minutes. Data was gathered through personal interactions with acquaintances and associates, both in face-to-face settings at the university and within private domestic residences, as well as remotely via Zoom.

The primary objective was to gain insights into the challenges confronting our society and to elicit recommendations regarding the services they envision in a waste management application tailored for Riyadh. The full interview data can be accessed in (Appendix A. Requirements Elicitation Data). The findings exhibited a variance contingent on the specific neighborhoods and the array of services available in each respective locality.

Interview Questions:

1. Can you describe your current waste disposal practices at home? What do you usually do with different types of waste?
2. What problems do you face during waste disposal?
3. Do you consider the number of waste containers in your area to be sufficient or not? What problems do you face, and how do you seek to solve them?
4. Do you apply the concept of recycling before disposing of waste? Have you encountered any challenges with this concept, and which recycling centers do you typically utilize?
5. Have you ever reached out to waste management authority? If so, what was the reason for your communication and how was it conducted? How would you describe the quality and speed of response in the service provided?
6. Are there any waste-related problems in your neighborhood? How have the neighborhood inhabitants dealt with these issues?

7. Have you ever used any waste management application to communicate with competent authority? If yes, please specify which applications you have used and for what purposes.
8. If there were a waste management application available for communication with competent authority, what the services or features would you be looking for?

Interview Results:

Interview results are organized into four distinct categories, each providing valuable insights into waste management practices and preferences among Riyadh's residents. The first category, "Waste Disposal Practices," delves into how individuals dispose of their waste, highlighting whether waste segregation is common or if mixed waste disposal prevails. It also sheds light on challenges related to specific waste types, container distances, and waste accumulation. The second category, "Recycling Practices," explores the extent of individuals' engagement in recycling activities, from paper and clothes to electrical appliances. It examines reasons for not recycling and the barriers individuals face. "Communication with Authorities," the third category, investigates interactions between individuals and waste management authority, including requests for waste containers and reports of waste accumulation. It also scrutinizes the effectiveness of communication methods, such as mobile applications. Lastly, the "Issues with Waste Management" category addresses various concerns raised by individuals, from container maintenance and theft to their experiences with waste container request applications. These categories provide a good understanding of the community's waste management landscape, informing the development of a tailored waste management application that aligns with Riyadh residents' specific needs and challenges.

Waste Disposal Practices:

- Approximately 35% of respondents mentioned that they dispose of all types of waste together without any form of separation. This indicates a common practice of mixed waste disposal in Riyadh households.
- Approximately 15% of respondents described recycling practices or donating items like clothing, books, toys, or furniture to charitable organizations. This indicates a sense of community involvement and sustainability efforts among some residents.
- Approximately 20% of respondents cited difficulties related to the lack of suitable places for disposing of specific types of waste, such as batteries, mobile devices, and leftovers. This indicates a need for more specialized disposal options for certain waste categories.
- Around 15% of respondents expressed concerns about the distance of waste containers from their homes, stating that the containers are far away and not conveniently located. Additionally, some mentioned that the container size is insufficient for their household waste, highlighting challenges in waste disposal infrastructure.

- Approximately 10% of respondents mentioned issues related to sending usable waste to charitable associations. They reported that the association's location is far from their homes, making it time-consuming and challenging to send usable items for donation.
- Another 10% of respondents expressed concerns about the accumulation of waste at home due to the driver not always being available to transport it to the containers.

  Some noted that neighbors resorted to disposing of waste in front of their homes, which they considered harmful.
- Approximately 20% of respondents expressed concerns about the insufficiency of waste containers in their areas. They mentioned problems such as open containers attracting cats and making the area dirty due to residents disposing of their garbage improperly. Additionally, they cited delays in container emptying, leading to odor issues.
- Around 15% of respondents reported that waste container inadequacy led to them having to store garbage at home for extended periods, causing it to rot and creating safety concerns for workers and children. They suggested a solution involving small, fixed-to-the-ground containers with covers placed closer to homes to prevent smell and storage problems.
- A small percentage, about 5%, mentioned that the containers were not adequately distributed, resulting in a need for more frequent container unloading.
- Approximately 10% of respondents faced issues due to the absence of containers for their buildings, leading residents to dispose of garbage in front of entrances, creating a significant problem.
- Finally, approximately 10% of respondents reported that the number of containers in their areas was sufficient and appropriate.

Recycling Practices:

- Approximately 10% of respondents actively practice recycling on a small scale, such as paper, clothes, and electrical appliances, sending these materials to charity organizations.
- About 10% of respondents mentioned that they attempt paper recycling for items like schoolbooks and pamphlets, which they send to recycling associations, but they do not extensively apply recycling due to a lack of nearby containers.
- Another 10% of respondents do not apply recycling concepts.
- The remaining respondents provided a variety of responses, including those who used to practice recycling but faced difficulties upon returning to Riyadh, those who separate specific types of waste like paper or batteries, those who donate items to associations, and those who apply limited recycling practices for specific materials like food waste or books.

Communication with authority:

- About 10% of respondents indicated that they had contacted the authority to order a waste container. These individuals generally had positive experiences, there was one case where the container received was reported as unclean and without a cover.
- Around 5% of respondents mentioned that they contacted the "940 أمانة" [7] application to address waste accumulation problems in front of their building. Unfortunately, they reported a lack of interaction or response to their complaints, suggesting a communication issue with the application.
- Approximately 50% stated that they had never communicated with waste management authority, with some citing a lack of knowledge about how to initiate communication.

Issues with Waste Management:

- About 5% of respondents suggested the need for better container maintenance, including cleaning and sterilization to prevent unpleasant odors.
- About 5% of respondents mentioned issues related to container theft, requiring them to order new containers.
- Approximately 5% of respondents used the "940 أمانة" [10] application to request a waste container, and they reported fast response times.
- About 75% indicated that they had not used any specific applications or methods to contact authority responsible for waste management.

Users have put forth a range of valuable suggestions for the development of a waste management application. These suggestions encompass features such as easy access to waste container locations and recycling centers, guidance on proper waste disposal methods, interactive waste management maps, diverse waste services, streamlined issue reporting, specific containers tailored to different waste types within neighborhoods, user-friendly complaint submission processes, recycling education and awareness initiatives, improved communication channels with waste collection services, a dedicated section for user suggestions, guidance on reporting hazardous waste items and enhancing container security, and the convenience of external doorstep containers. These insights offer a clear roadmap for creating an application that effectively addresses the multifaceted needs and expectations of the community.

Questionnaire Study

The questionnaire was constructed through Google Forms and disseminated among friends, family, and classmates via WhatsApp.

A total of 136 responses were obtained. The questionnaire collected responses from a diverse age group, which are: 47.8% aged 18 to 25, 30.1% aged 26 to 40, 21.3% aged 41 to 65, and 0.7% over 65. The majority held a bachelor's degree (62.5%), and most were citizens (97.8%). In terms of housing, 80.9% resided in villa housing, while 19.1% lived in apartments.

Numerous neighborhoods in Riyadh were categorized based on their regions, including 28 in the North, 13 in the East, 4 in the South, and 8 in the West. Please refer to the table in Appendix B (Table 15) for further details. The questionnaire charts as well as the full questionnaire data can be accessed in (Appendix A. Requirements Elicitation Data).

Questionnaire Questions:

1. Age:
    - 18-25
    - 26-40
    - 41-65
    - Greater than 65

2. Identity Type:
    - Citizen
    - Resident

3. Housing Type:
    - Apartment
    - Villa

4. Neighborhood: (Please specify)

5. What is your level of satisfaction with garbage containers and neighborhood hygiene?
    - Excellent
    - Good
    - Bad

6. Are the number of waste containers in your home area enough for your needs?
    - Yes
    - No

7. If you have made a request for a waste container, how would you classify the quality of service provided?
    - Excellent
    - Good
    - Bad

8. Do you have problems communicating with the waste management authority?
    - Yes (If yes, please specify why you communicate and how you communicate)
    - No

9. Do you practice recycling concepts before waste disposal?
    - Yes (If yes, please specify what recycling centers you use)
    - No

10. Have you ever experienced problems with waste containers in your neighborhood?
    - Yes (If yes, please describe how people in your neighborhood handle these issues)
    - No

11. Have you ever used any waste management applications to communicate with responsible authority?
    - Yes (If yes, please specify which applications you have used and why you used them)
    - No

12. If there was a waste management technology for waste return and communication with responsible authorities, what features would you like it to provide? (Please describe your preferences)

Questionnaire Results:

We have organized our questionnaire results into distinct categories to offer a more structured comprehension of the Riyadh residents' sentiments and experiences in matters related to waste. The first category, "Satisfaction with Garbage Containers," unveils the prevailing sentiments concerning the garbage containers, with respondents rendering their verdict on their effectiveness. In the second category, "Waste Management and Recycling," we delve into the profound practices or the absence thereof, revolving around recycling and its prevalence among the Riyadh populace. This illuminates the disposition towards sustainable waste disposal practices and the challenges faced therein. The third category, "Issues with Waste Containers," brings to light the adversities encountered by a significant fraction of respondents concerning the functionality of waste containers.

This encompasses a spectrum of issues, ranging from improper waste disposal practices to the misplacement of containers. Our fourth category, "Communication with Waste Authority," describes the individual’s interactions with the waste management authority.
It delineates the modes of communication adopted by individuals, whether seamless or burdened with challenges, highlighting the efficacy of communication platforms. Lastly, the category of "Technology and Future Expectations" offers a glimpse into the community's technological engagement, notably their usage or non-usage of waste management applications.

This category also unveils the collective expectations and aspirations of Riyadh's residents, shedding light on the future trajectory of waste management within the city.

Satisfaction with Garbage Containers: Respondents generally expressed satisfaction with garbage containers, with 52.9% rating them as "Good" and 29.4% as "Excellent." Only 17.6% reported a negative perception, rating them as "Bad."

Waste Management and Recycling: A significant portion 82.4% admitted to not applying recycling concepts before waste disposal. Among those who did recycle, various locations were cited, including charities, the Bunyan Association, mosque containers, and more.

Issues with Waste Containers: A third of respondents 33.1% reported encountering problems with waste containers in their area. These problems included issues like improper waste disposal and container misplacement.

Communication with Waste Authority: The majority 87.3% reported no issues communicating with the waste authority. However, for those who faced problems, they reached out through various channels, including municipality applications and websites.

Technology and Future Expectations: Interestingly, most respondents 92.6% had not used waste management applications, but those who had used them or desired such technology expressed a range of expectations for improving waste management in Riyadh.

28% of respondents highlighted the importance of effective communication and responsiveness from the waste authority. Residents emphasized the need for easy and fast communication channels, including the use of modern technology.

Sufficient and properly sized waste containers were also a significant concern, with 21% of respondents highlighting this issue. They stressed the importance of containers that meet the needs of residents in terms of capacity and size, including provisions for construction waste.

Recycling services garnered attention from 14% of respondents, indicating a desire for more extensive recycling options, including services for items like books and metal-plastic waste. Timely waste removal, ease of use, and accessibility were also priorities, as mentioned by 9% of respondents.

Furthermore, 7% of residents expressed a need for additional containers for specific waste types, such as recycling or food waste. They also suggested the implementation of waste management technology, like tracking containers.

Two related themes included a call for stricter enforcement and penalties for littering 3% and a desire to follow established waste management systems 2%. Finally, 2% of respondents mentioned the need for a dedicated website to offer waste management information and services.

Overall Results

Based on the interviews, questionnaires, and Literature Review, the main system requirements for Taboua can be summarized as follows:

- Effective Communication Channels: The system should prioritize the establishment of efficient and user-friendly communication channels between individuals and waste management authority. This includes options for reporting issues, requesting garbage bins, and receiving timely responses.
- Waste Segregation Guidance: Incorporate features that guide individuals on proper waste segregation practices, encouraging them to separate different types of waste to raise awareness about recycling, waste management, and sustainability practices, promoting community involvement and responsibility.
- User-Friendly Interface: Ensure that the application has an intuitive and user-friendly interface that caters to individuals of varying technological proficiency, making it accessible to a wider audience.
- Garbage bin Locator: Implement a feature that allows users to easily locate nearby garbage bins and recycling centers, providing real-time information on their availability and capacity.
- Request a garbage bin: a feature that enables users to request garbage bin to accommodate their household waste.
- Issue Reporting: Streamline the process for reporting issues related to garbage bins, improper waste disposal, or other waste management concerns, ensuring prompt resolution and follow-up.
- Adherence to Standards: Ensure that the system aligns with established waste management standards and practices to promote consistency and reliability.

4.2.3 User Interactions

The following diagram illustrates a use case, providing a visual representation of the interactions between various Taboua users and their features, as shown in (Figure 7) below. To enhance several functions, the system makes use of the Google Maps API. For users, these features include viewing garbage bins, filtering garbage bins by size, viewing recycling centers, filtering recycling centers by type, requesting new garbage bins, viewing and managing requests, raising and managing complaints, and utilizing recycling items. For staff, the features include viewing and responding to requests, viewing and managing garbage bins, filtering garbage bins by size, viewing and managing recycling centers, searching recycling centers by name, filtering recycling centers by type, viewing complaint, and viewing complaints on a heat map.

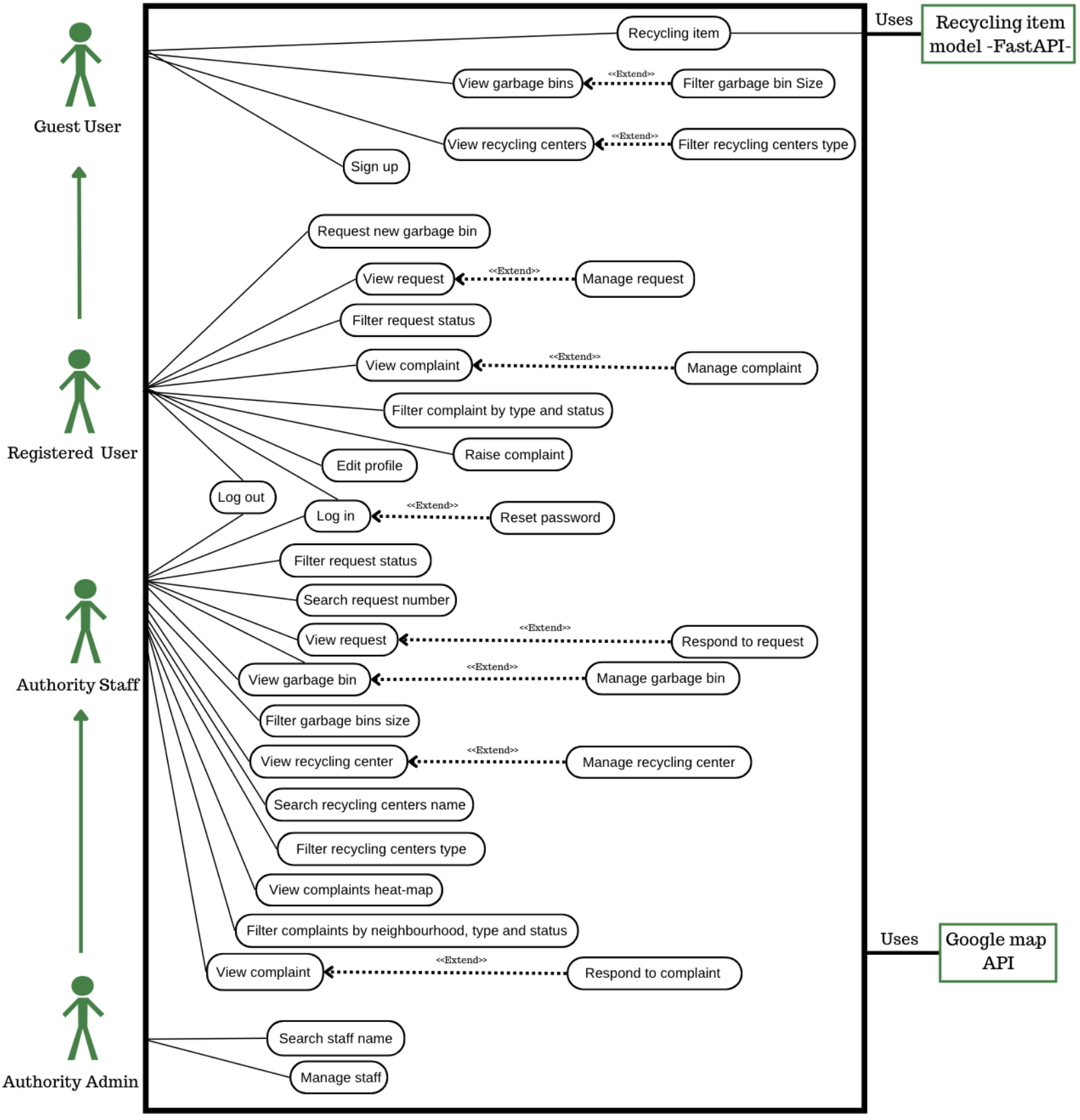


Figure 7: Use Case Diagram

4.2.4 Roadmap and Product Backlog

This section presents the Taboua roadmap and the product backlog. As illustrated in (Figure 8), the roadmap provides an overview of the project's journey. Additionally, as depicted in (Table 3), the product backlog outlines the functional and non-functional requirements in a user story format.

Roadmap

As illustrated in (Figure 8) the Taboua roadmap comprises five sprints, with sprints 1 and 2 implemented in release 1 and sprints 3, 4, and 5 implemented in release 2. Sprints 1 and 2 contain the fundamental Taboua functions, including the management and exploration of garbage bins and recycling centers. The objective of Sprint 3 is to train and evaluate the Taboua recycling item model. Sprint 4 is focused on the management and resolution of complaints. The final sprint, Sprint 5, incorporates the visualization of complaints by using heatmap.

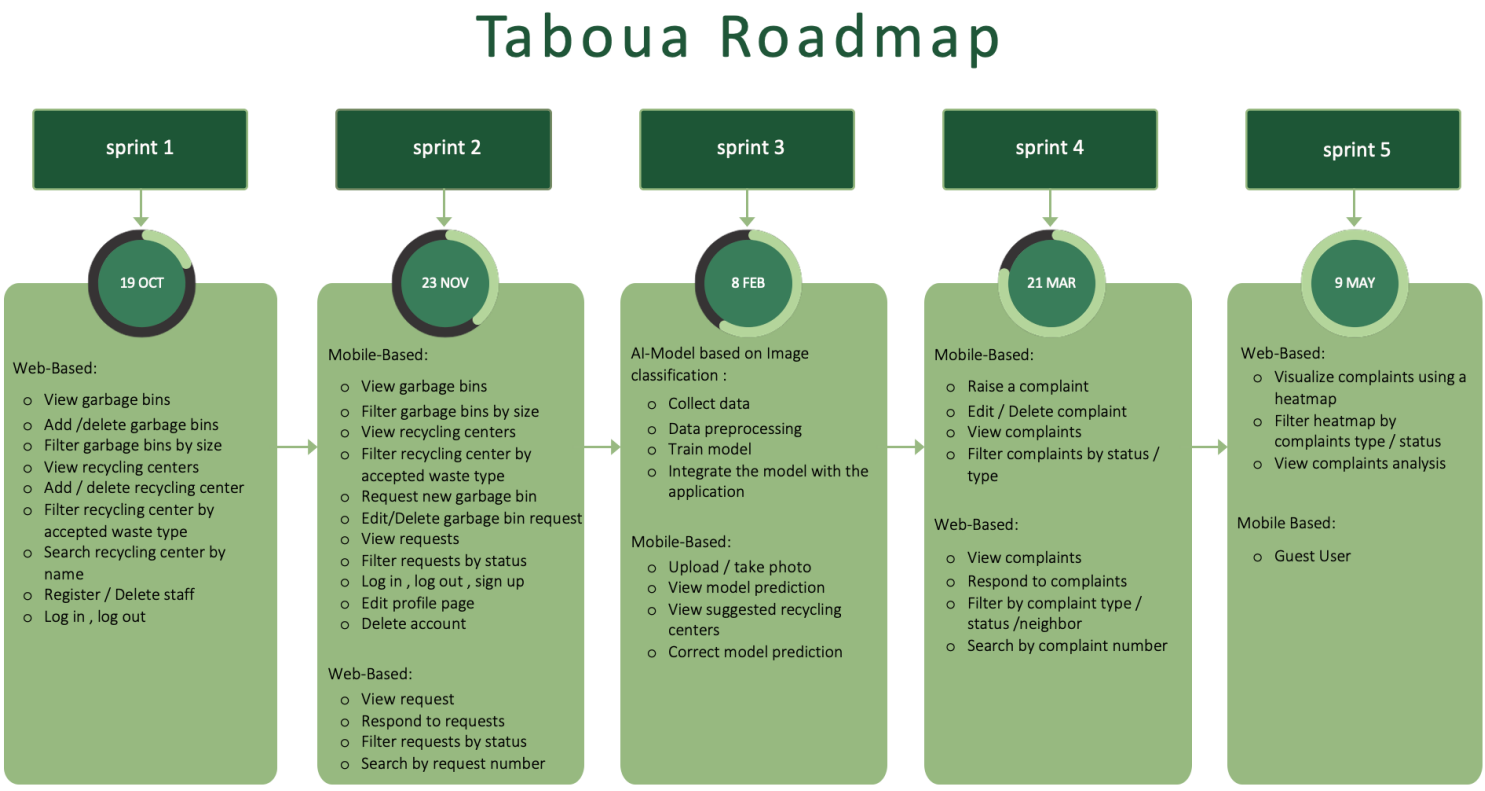


Figure 8: Taboua Roadmap

Product Backlog

The product backlog table contains the system requirements for Taboua (Table 3) covering both functional and non-functional[3] aspects. The requirements are systematically ordered, with the highest priority requirements at the top of the table. The product backlog includes all functions listed on the Taboua roadmap as well as additional functions implemented to support the core functions.

ID	Sprint#	PBI	Size	Type	Status	Acceptance Criteria
Functional						
1	Sprint-1	As a Taboua Staff, I want to view garbage bin locations on the map, so that I can manage garbage bin location properly.	1	Feature	Done	As a Taboua Staff, if I open the map page to view garbage bins, the new bin should be displayed on the map. As a Taboua Staff, if I click on a garbage bins marker, I should see the garbage bins information.
2	Sprint-1	As a Taboua Staff, I want to be able to view recycling center locations on the map, so that I can manage recycling center locations properly.	1	Feature	Done	As a Taboua Staff, if I open the map page to view recycling centers, the new recycling center should be displayed on the map. As a Taboua Staff, if I click on a recycling center marker, I should see the recycling center information.
3	Sprint-1	As a Taboua Staff, I want to add a new garbage bin location on the map, so that it can be placed at a designated location.	2	Feature	Done	As a Taboua Staff, if I add a new garbage bin successfully, I should receive a success message then the new

[3] Categories of Taboua Non-functional requirements adopted from https://priyalwalpita.medium.com/quality-attributes-in-software-architecture-cacffe0995aa , https://faq.arc42.org/questions/C-1-2/

						garbage bin should be displayed on the map. As a Taboua Staff, if I enter inputs that do not meet the required format or if any mandatory fields are left empty, an informative error message should be displayed by the system.
4	Sprint-1	As a Taboua Staff, I want to delete an existing garbage bin location from the map, so that it is no longer available for public use.	2	Feature	Done	As a Taboua Staff, when I delete a garbage bin a confirmation message should appear to confirm the deletion. As a Taboua Staff, if I delete a garbage bin successfully, I should receive a success message then the deleted garbage bin should disappear from the map.
5	Sprint-1	As a Taboua Staff, I want to add a new recycling center location on the map, so that it can be placed at a designated location.	2	Feature	Done	As a Taboua Staff, when I add a new recycling center by filling in all the required information a message should appear to confirm the addition. As a Taboua Staff, if I enter invalid or leave fields empty while filling in the center information, a message should appear to

						prompt me to complete the required fields. As a Taboua Staff, if I added a new recycling center successfully by filling in all the required information, I should receive a success message then the new recycling center should be displayed on the map.
6	Sprint-1	As a Taboua Staff, I want to delete an existing recycling center location from the map, so that it is no longer available for public use.	2	Feature	Done	As a Taboua Staff, when I delete a recycling center a confirmation message should appear to confirm the deletion. As a Taboua Staff, if I delete a recycling center successfully, I should receive a success message then it should disappear from the map.
7	Sprint-1	As a Taboua Admin, I want to be able to register new staff in the system, so I can expand the team of employees as needed.	2	Feature	Done	As a Taboua Admin, if I register a new staff a confirmation message should appear to confirm the registration. As a Taboua Admin, if I register a new staff successfully by filling in all the required information, I should receive a success message then the new register staff should be

						displayed in the existing staff list. As a Taboua Admin, upon successful registration of a new staff member, they should receive an email message from the Taboua system containing instructions for authentication and login. As a Taboua Admin, if I register a new staff member and enter inputs that do not meet the required format or if any mandatory fields are left empty or if the staff account already exist in the system, an informative error message should be displayed by the system.
8	Sprint-1	As a Taboua Admin, I want to be able to remove staff privileges from an existing staff list in the system, so I can control the access to the system.	2	Feature	Done	As a Taboua Admin, if I delete a staff, then a confirmation message should appear to confirm the deletion. As a Taboua Admin, if I delete a staff, I should receive a success message then it should disappear from the existing staff list.

9	Sprint-1	As a registered Taboua Staff, I want to log in to my account with my email and password, so that I can access Taboua's web features and information.	2	Feature	Done	As a registered Taboua Staff, if my email and password were valid then I should be directed to my account page. As a registered Taboua Staff, if the email or password were incorrect or I left inputs empty then a message should appear indicating an error.
10	Sprint-1	As a logged-in Taboua Staff, I want to log out of my account, so that my session is securely terminated.	1	Feature	Done	As a logged-in Taboua Staff, if I pressed the log out button then my account page will disappear, and I should be directed to the log in page.
11	Sprint-1	As a Taboua Admin, I want to edit staff information so that I can keep their details accurate and up-to-date.	1	Feature	Done	As a Taboua Admin, when I edit staff information, the system should update the staff information immediately.
12	Sprint-1	As a Taboua Staff, I want the ability to modify garbage bin details and location, so that I can efficiently monitor changes in garbage information and ensure efficient garbage bin management within the system.	3	Feature	Done	As Taboua Staff , if I want to edit garbage bin information then the system should provide a clear and accessible way to modify garbage bin details. As a Taboua Staff member, when I want to change the location of a garbage bin, the system should enable

						me to accurately select the new location on a map. As Taboua Staff, when I changed the location of the garbage bin, then the system should provide a confirmation message to me before changing the garbage bin location.
13	Sprint-1	As a Taboua Staff, I want the ability to modify recycling center details and location so that I can efficiently monitor changes in recycling center information and ensure efficient recycling center management within the system.	3	Feature	Done	As Taboua Staff , if I want to edit recycling center information then the system should provide a clear and accessible way to modify recycling center details. As a Taboua Staff member, when I want to change the location of recycling center, the system should enable me to accurately select the new location on a map. As Taboua Staff, when I changed the location of the recycling center, then the system should provide a confirmation message to me before changing the recycling center location.

14	Sprint-1	As Taboua Admin, I want to be able to search by staff name so that I can easily find the staff.	1	Feature	Done	As a Taboua Admin, I want the search bar to be easily accessible and visible to help me search easily. As Taboua Admin , when searching for a staff name that is not registered in the Taboua system, the system should display a message indicating that there is no staff with that name in the system.
15	Sprint-1	As a Taboua Staff, I want to be able to search for recycling centers by name in an efficient manner, so that I can quickly find the specific center I am looking for.	1	Feature	Done	As a Taboua Staff, I want the search bar to be easily accessible and visible to help me search easily. As Taboua Staff, if I search for a specific recycling center, the system should display real-time results.
16	Sprint-1	As a Taboua Staff, I want to be able to filter the garbage bins by size, so that I can easily explore and manage the garbage bins with the specified size.	1	Feature	Done	As a Taboua Staff, I want the filter option to be easily accessible and visible to help me filter garbage bins easily.

						As a Taboua Staff , when filtering the garbage bins I expect to have all the garbage bin size options available.
17	Sprint-1	As a Taboua Staff, I want to be able to filter the recycling center by the type of waste that it accepts, so that I can easily manage the recycling centers.	1	Feature	Done	As a Taboua Staff, I want the filter option to be easily accessible and visible to help me filter recycling centers easily. As a Taboua Staff , when filtering the recycling centers I expect to have all the waste type options available.
18	Sprint-2	As a Taboua User (Guest + Registered), I want to be able to view nearby garbage bin locations on the map, so that I can easily find a place to dispose of my waste.	2	Feature	Done	As a Taboua User, if I opened the map page to view nearby garbage bins, it should be displayed on the map.
19	Sprint-2	As a Taboua User (Guest + Registered), I want to be able to view nearby recycling center locations on the map, so that I can properly dispose of recyclable materials.	2	Feature	Done	As a Taboua User, if I open the map page to view nearby recycling centers, it should be displayed on the map. As a Taboua User, if I click on a recycling center marker, I should see the recycling center information.

20	Sprint-2	As a registered Taboua User, I want to be able to request a new garbage bin placement in a specific location using the map, so that I can contribute to better waste management in my area.	2	Feature	Done	As a registered Taboua User, if I send a request for a new garbage bin placement successfully, I should receive a success message.
21	Sprint-2	As a registered Taboua User, I want to view the request status, so that I can see if the request has been solved.	3	Feature	Done	As a registered Taboua User, if I send a request for a new garbage bin placement successfully, I should be able to track the request status (New, In progress, Rejected, Approved).
22	Sprint-2	As a registered Taboua User, I want the option to delete the garbage bin request I had sent, so that I can have control over the requests I have submitted.	2	Feature	Done	As a registered Taboua User, if I send a request for a new garbage bin placement successfully, I should be able to delete the request only if the status is “New “.
23	Sprint-2	As a Taboua Staff, I want to view user-requested garbage bin placements, so I can efficiently review and handle the requests.	3	Feature	Done	As a Taboua Staff, when I click on the received requests tab, the website should display all the users' requests information, including the request number, date of the request and the status of the request.
24	Sprint-2	As a Taboua Staff, I want to respond to the requested garbage bins, so that the individual user can know their request status.	3	Feature	Done	As a Taboua Staff, when I respond to requests (approve or reject with a comment) the website should display a success message indicating that

						the response has been successfully submitted.
25	Sprint-2	As a new Taboua User, I want to be able to register for a new account using the mobile application, so that I can access Taboua's application features.	2	Feature	Done	As a new Taboua User, if I fill in the register information successfully then I should be directed to the login page. As a new Taboua User, if I left some registration values empty then the process would not be completed, and a message should appear indicating an error.
26	Sprint-2	As a registered Taboua User, I want to log in to my account, so that I can access Taboua's application features.	2	Feature	Done	As a registered Taboua User, if my email and password were valid then I should be directed to my account page. As a registered Taboua User, if the email or password were incorrect or I left inputs empty then a message should appear indicating an error.
27	Sprint-2	As a logged-in Taboua user, I want to be able to delete my account so that I can permanently remove my personal information and data from the Taboua application.	2	Feature	Done	As a Taboua user, when I delete my account, I expect to not be able to log in to the Taboua application with the deleted account.

28	Sprint-2	As a logged-in Taboua User, I want to log out of my account, so that my session is securely terminated.	1	Feature	Done	As a logged-in Taboua User, if I press the log out button then my account page will disappear, and I should be directed to the log in page.
29	Sprint-2	As a registered Taboua User, I want to be able to modify my garbage bin request while it is in the "New" status. This feature enables me to simply update it if there is any incorrect information or if I want to change the location and size of the garbage bin.	2	Feature	Done	As a registered Taboua User, if I want to edit garbage bin request the application should provide a clear and accessible way to modify the request. As a registered User, if I want to change the location of the recycling center, I expect the application to provide clear instructions for changing the requested garbage bin location.
30	Sprint-2	As Taboua User (Guest + Registered), I want to be able to filter the garbage bins by size, so that I can easily explore the garbage bins with the specified size.	1	Feature	Done	As a Taboua User, I want the filter option to be easily accessible and visible to help me filter garbage bins easily. As a Taboua User, when filtering the garbage bins, I expect to have all the garbage bin size options available.

31	Sprint-2	As Taboua User (Guest + Registered), I want to be able to filter the recycling center by the type of waste that it accepts, so that I can easily find recycling center that accepts the specified waste type.	1	Feature	Done	As a Taboua User, I want the filter option to be easily accessible and visible to help me filter recycling centers easily. As a Taboua User, when filtering the recycling centers, I expect to have all the waste type options available.
32	Sprint-2	As registered Taboua User, I want to filter my garbage bin requests by status, so that I can easily manage and track the progress of my requests.	1	Feature	Done	As a registered Taboua User, I want the filter option to be easily accessible and visible to help me filter my garbage bin requests. As a registered Taboua User, when filtering the garbage bin requests, I expect to have all the request status options available.
33	Sprint-2	As a Taboua Staff, I want to be able filter garbage bin requests by status, so that I can easily manage and process the requests.	1	Feature	Done	As a Taboua Staff, I want the filter option to be easily accessible and visible to help me filter the garbage bin requests. As a Taboua Staff, when filtering the garbage bins requests, I expect to have all the request status options available.

34	Sprint-2	As a Taboua Staff, I want to be able search by garbage bin request number, so that I can easily figure out and process a specific request.	1	Feature	Done	As a Taboua Staff, I want the search bar to be easily accessible and visible to help me search easily. As Taboua Staff, if I search for a specific request, the system should display real-time results.
35	Sprint-3	As a Taboua User (Guest + Registered), I want to easily identify my waste type by scanning the item, so that save my time rather than manually searching for each waste item type on the internet.	3	Feature	Done	As a Taboua User, when I scan the waste item, I would be able to either rescan waste item or use a photo. As a Taboua User, when scanning a waste item using the photo function, the application should display the waste type.
36	Sprint-3	As a Taboua User (Guest + Registered), I want the ability to either approve or correct the waste type suggested by the recycling item model, so that I can ensure the accuracy of the categorization.	2	Feature	Done	As a Taboua User, if a waste item is misclassified, then the application should permit me to choose the correct waste item type.
37	Sprint-3	As a Taboua User (Guest + Registered), I want the recycling item feature to suggest the nearest recycling center location based on the type of waste identified so that I can easily dispose of my waste	5	Feature	Done	As a Taboua User, when the application displays recycling centers, the centers should be displayed from nearest to farthest from my current location.

		in an environmentally friendly manner.				
38	Sprint-4	As a registered Taboua User, I want to raise a complaint so that I can contact the authority to resolve the problems.	3	Feature	Done	As a registered Taboua User, when I raise a complaint, the application should display a confirmation message indicating that the complaint was submitted successfully. As a registered Taboua User, If I enter valid input, the complaint should be submitted, and the confirmation message should appear. However, if I leave fields empty or provide invalid input, the application should still prompt me to complete the required fields or correct the information.
39	Sprint-4	As a registered Taboua User, I want to view the complaint status and information, so that I can see if the issue has been resolved.	3	Feature	Done	As a registered Taboua User clicks on a previously filed complaint, the application should show the status of the complaint as either (New, In progress, Rejected, or Approved), and the complaint information including the complaint date, type, description, location, and images.

						As a registered Taboua User, when my complaint is either approved or rejected, I expect to be able to view the staff response.
40	Sprint-4	As a Taboua Staff, I want to view the complaints, so that I can resolve the problem.	3	Feature	Done	As a Taboua Staff, when I click on the received complaints tab, the website should display the complaints information, including the complaints, type, description, date, location, and image.
41	Sprint-4	As a Taboua Staff, I want to filter the complaints by complaint status, type, and neighborhood, so that I can easily manage and process the complaints.	1	Feature	Done	As a Taboua Staff, I want the filter option to be easily accessible and visible to help me filter the complaints. As a Taboua Staff, when filtering the complaints, I expect to have all the complaint status, type, neighborhood options available.
42	Sprint-4	As a Taboua Staff, I want to be able search by complaint number, so that I can easily figure out and process a specific complaint.	1	Feature	Done	As a Taboua Staff, I want the search bar to be easily accessible and visible to help me search easily.

						As Taboua Staff, if I search for a specific complaint, the system should display real-time results.
43	Sprint-4	As a Taboua Staff, I want to respond to complaints, so that the individual user can know the complaint status.	3	Feature	Done	As a Taboua Staff, when I click submit response, the website should display a confirmation message with a summary of the response with the ability to go back and make changes. As a Taboua Staff, when I click confirm response submission, the website should display a success message indicating that the response has been successfully submitted. As a Taboua Staff, I should be able to submit a response to complaints by entering valid data. If I enter invalid information or leave any required fields empty, I should not be able to submit the response, and a message indicating the need to provide valid data should appear.

44	Sprint-4	As a registered Taboua User, I want to be able to filter complaints by complaint status and type so that I can easily access the complaints I have previously submitted.	2	Feature	Done	As a registered Taboua User, I want the filter option to be easily accessible and visible to help me filter the complaints. As a registered Taboua User, when filtering the complaints, I expect to have all the complaint status options available.
45	Sprint-4	As a registered Taboua User, I want the option to edit my own raised complaints so that I can update the information and have control over the complaints I have submitted.	3	Feature	Done	As a registered Taboua User, I would be able to edit the complaint when the status is still “new”. As a registered Taboua User, when I already edited the complaint, the application should display a confirmation message indicating that the complaint has been successfully updated.
46	Sprint-4	As a registered Taboua User, I want the option to delete my own raised complaints so that I can have control over the complaints I have submitted.	2	Feature	Done	As a registered Taboua User, I would be able to delete the complaint when the status is still “new”. As a registered Taboua User, when I already deleted the complaint, the application should display a confirmation message indicating that

						the complaint has been successfully deleted.
47	Sprint-5	As a Taboua Staff, I want to visualize the collected complaints on a heat-map, so that I can identify areas with higher waste management issues and allocate resources effectively.	3	Feature	Done	As a Taboua Staff, When I click on the complaints heat-map section, a heat-map complaint hotspot should be displayed on a map and when I zoom in, the complaints markers should appear so I can view the complaint details.
48	Sprint-5	As a Taboua Staff, I want to filter the visualized complaints on a heat-map by type and status, so that I can easily visualize and allocate resources effectively.	1	Feature	Done	As a Taboua Staff, I want the filter option to be easily accessible and visible to help me filter the complaints hotspots. As a Taboua Staff, when filtering the complaints, I expect to have all the complaint status and type options available.
49	Sprint-5	As a Taboua Staff, I want to view the analysis of average resolution time of resolved (accepted, rejected) complaints, so I can track our efficiency over time.	2	Feature	Done	As a Taboua Staff, when I apply filters to complaints, the displayed average resolution time should update to reflect only the filtered complaints.
50	Sprint-5	As a Taboua Staff, I want to see the number of complaints received today, this week, and this month, so I can quickly grasp our current workload.	1	Feature	Done	As a Taboua Staff, when I apply filters to complaints, the displayed complaint numbers for the current day, week, month should update to reflect only the filtered complaints.

51	Sprint-5	As a Taboua Staff, I want to view the distribution analysis of complaint types as doughnut chart, so that I can easily identify the number of complaints for each type.	1	Feature	Done	As a Taboua Staff, when clicking on one of the complaint type parts in the chart, I expect it to view the complaint list of that type. As a Taboua Staff, when I apply filters to complaints, the displayed distribution analysis of complaint types should update to reflect only the filtered complaints.
52	Sprint-5	As a Taboua Staff, I want to view the distribution analysis of complaint status as vertical bar chart, so that I can easily identify the number of complaints for each status.	1	Feature	Done	As a Taboua Staff, when clicking on one of the complaint status parts in the chart, I expect it to view the complaint list of that status. As a Taboua Staff, when I apply filters to complaints, the displayed distribution analysis of complaint status should update to reflect only the filtered complaints.
53	Sprint-5	As a Taboua Staff, I want to view the distribution analysis of complaint by neighborhood names as horizontal bar chart, so that I can easily identify the number of complaints for each neighborhood.	2	Feature	Done	As a Taboua Staff, when clicking on one of the neighborhood names parts in the chart, I expect it to view the complaint list of that neighborhood name.

						As a Taboua Staff, when I apply filters to complaints, the displayed distribution analysis of complaint by neighborhood should update to reflect only the filtered complaints.
54	Sprint-5	As a Taboua Staff, I want to view the distribution analysis of complaint by month as a line chart, so that I can easily identify the number of complaints for each month.	3	Feature	Done	As a Taboua Staff, when clicking on one of the month parts in the chart, I expect it to view the complaint list of that month. As a Taboua Staff, when I apply filters to complaints, the displayed distribution analysis of complaint by month should update to reflect only the filtered complaints. As a Taboua Staff, when viewing the complaints by month, I expect it to have a year's filter option to choose from the years available.
55	Sprint-5	As a Taboua Guest User, I want to be able to browse functionalities of the application without registration, so that I can understand the overall layout and organization of the app to decide if it aligns with my needs.	1	Feature	Done	As a Taboua Guest User, if I access the login screen, I should see a clear and prominent option for "Continue as Guest" or similar wording.

						As a Taboua Guest User, if I attempt to access a feature unavailable in guest mode, the app should display a clear and concise message explaining the limitations.
Non-functional						
56		As a new Taboua User (Guest + Registered), I want to learn how to use each feature in the system within three minutes, so I can save time and not get frustrated and find another application to use. (Learnability)		Feature	Done	As a new Taboua User, if I use the application for the first time, the application user interface should be informative and simple to use within three minutes.
57		As a Taboua User (Guest + Registered), I want the recycling item model to be available 90% of the time I try to scan the waste item so that I can find the nearest recycling centers. (Availability)		Feature	Done	As a Taboua User, when I needed to identify the waste type, the waste recycling item model should be available 90% of the time and there to use.
58		As a Taboua User (Guest + Registered), I want the recycling item model to have a high accuracy of at least 90% in waste categorization so that I can rely on the system to correctly identify and classify the waste types. (Accuracy)		Feature	Done	As a Taboua User, when utilizing the recycling item model, I expected that the accuracy rate of correctly categorizing waste types should be at least 90%. As a Taboua User, I expect the recycling item model to be monitored and

						retrained monthly using new data to ensure high accuracy and optimal performance.
59		As a Taboua User (Guest + Registered), I want the system to have an intuitive and consistent user interface layout, so that I can easily locate and access different functionalities across the system. (Recognizability)		Feature	Done	As a Taboua User, I would like the system to follow established design patterns and conventions to ensure familiarity and ease of use.
60		As a Taboua User (Guest + Registered), I want the system to have descriptive and user-friendly error messages, so that I can understand and resolve any issues that may occur during system interactions. (User-Error Protection)		Feature	Done	As a Taboua User, I would like the system to provide clear and meaningful error messages that explain the problem and suggest possible solutions so that I can easily handle the issue.
61		As a new Taboua Staff, I want to learn how to use each feature in the system within three minutes, so I can save time and not get frustrated and find another application to use. (Learnability)		Feature	Done	As a new Taboua Staff, if I use the application for the first time, the application user interface should be informative and simple to use within three minutes.

62		As a Taboua Staff, I want the system to have an intuitive and consistent user interface layout, so that I can easily locate and access different functionalities across the system. (Recognizability)		Feature	Done	As a Taboua Staff, I would like the system to follow established design patterns and conventions to ensure familiarity and ease of use.
63		As a Taboua Staff, I want the system to have descriptive and user-friendly error messages, so that I can understand and resolve any issues that may occur during system interactions. (User-Error Protection)		Feature	Done	As a Taboua Staff, I would like the system to provide clear and meaningful error messages that explain the problem and suggest possible solutions so that I can easily handle the issue.

Table 3: Product Backlog

4.3 System Design

In this section, we will discuss the design process for the Taboua system, including architectural design, class diagram, component level design, data design, and interface design, as well as UX guidelines.

4.3.1 Architectural Diagram

Taboua system utilizes a client-server architecture, as illustrated in (Figure 9). We have chosen this architecture due to the several advantages it offers such as:

- Flexibility: Client-server architecture style is extremely flexible and can be adapted to handle different types of clients[55]. In Taboua, flexibility is crucial as it serves different client types, such as individual users and authority staff.
- Efficient Data Management: Taboua handles various data, including garbage bins and recycling center locations, as well as user complaints. Client-server architecture manages and stores Taboua data in a centralized database (all data and storage are in the same place). Where This centralization ensures data consistency, reliability, and ease of access [56]. This centralization is vital for efficient waste management and fast access to user data.

- Scalability and Performance: our Taboua must efficiently handle multiple users simultaneously, especially during busy times when many users are reporting complaints or viewing maps. Our Client-server architecture can efficiently handle multiple users simultaneously, ensuring fast response time, and a smooth user experience [56] . This is important to keep our users satisfied and ensure our Taboua runs effectively.

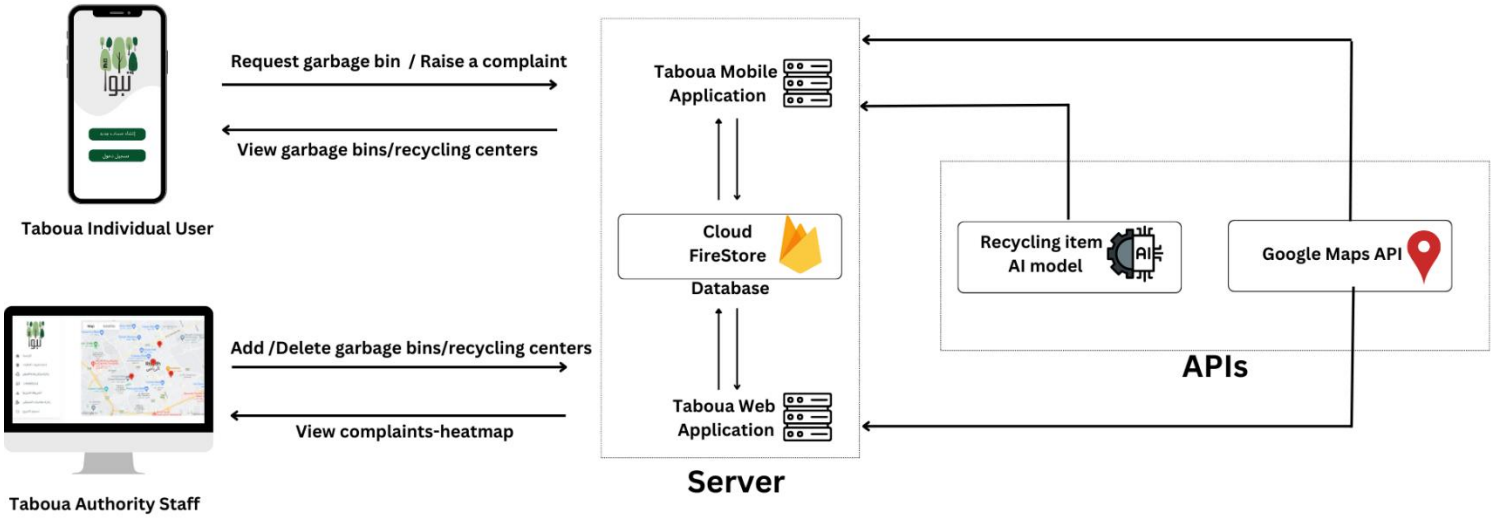


Figure 9: Taboua Client-Server Architectural Model

The client-side components include the mobile application users (individuals) and the web application authority users (staff, admins), each of whom provides a user interface for the user to interact with their respective servers. Mobile Application Users interact with the Mobile Application Server by viewing garbage bins and recycling centers, requesting garbage bins, benefiting from the recycling item model, and raising complaints. While Web Application Users interact with the Web Application Server by adding or deleting garbage bins or recycling centers, managing complaints and requests for garbage bins, and visualizing users' complaints through an interactive heat map.

The server-side components consist of mobile application server, web application server, and cloud Firestore as a database. These components handle server-side logic, process client requests and store all the related data in the database. Additionally, Taboua architecture benefits from a streamlined integration with External Services (APIs) including Google Maps API for both client-side components to handle needed maps interactivity and a Recycling Item AI Model that will handle the recycling item functionality only for mobile application users.

Overall, the Taboua client-server architecture enables the system to handle multiple users simultaneously and process requests efficiently. Also, it offers advantages such as the data is efficiently managed and stored in a centralized database, ensuring consistency, reliability, and security. These advantages will contribute to creating a strong and effective Taboua system.

4.3.2 Class Diagram

The illustrated class diagram in (Figure 10) displays the classes and their relationships in the Taboua system, including those involving the mobile application and the website application. The main classes for the Taboua system are GarbageBin, GarbageBinRequest, RecyclingCenter, Complaint, WasteTypeModel, RecyclingCenterRecommendation and Heatmap.

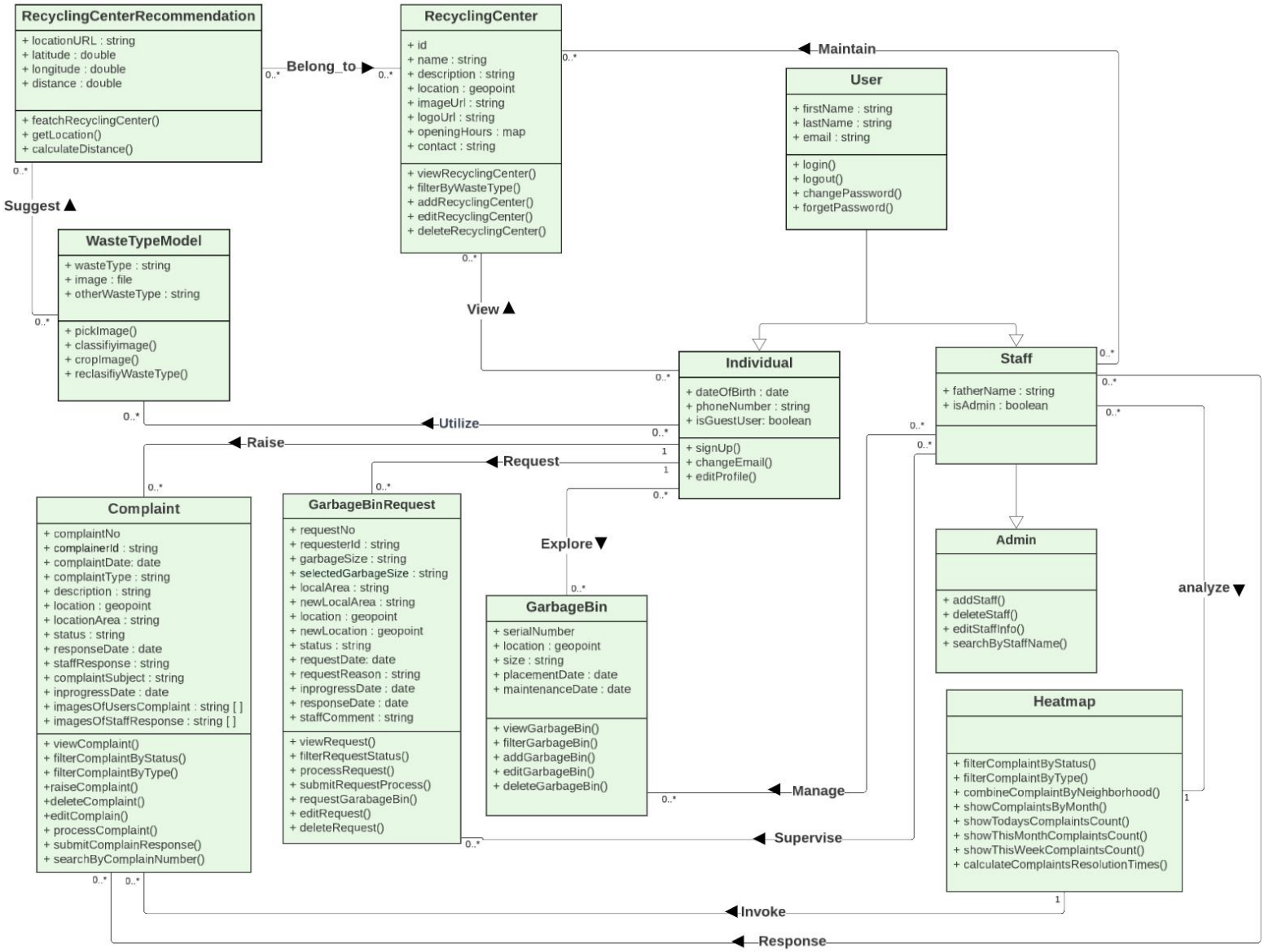


Figure 10: Taboua Class Diagram

4.3.3 Component Level Design

In this section, we will examine the detailed design of key components in our Taboua system. Our Component Level Design illustrates the implementation of each component through pseudocode and flowchart. Below, we will walk through the design process of important functions including Add Garbage Bin, Add Recycling Center, Request a Garbage Bin, and Recycling Item Model.

Add Garbage Bin

Staff should be able to add a new garbage bin by providing all the necessary information, (Table 4) shows the Add Garbage Bin Story. For the pseudocode see (Figure 11).

ID	Sprint#	PBI	Type
3	Sprint-1	As a Taboua Staff, I want to add a new garbage bin location on the map, so that it can be placed at a designated location.	Feature

Table 4: Add Garbage Bin Story

Construction:

- Inputs: garbage bin location, garbage bin size
- Precondition: staff must be logged in.
- Postcondition: The new garbage bin is added to the database and displayed on the garbage bins map.

Pseudocode:

```
IF the staff clicks on a designated location on the garbage bins map:
   Read garbage bin location

   // Determine the type of location where the staff clicked on
   locationType = checkLocationType(garbage_bin_location)

   IF locationType equals 'building' THEN
     DISPLAY a message to confirm if location is on street

      IF staff confirms:
          AddGarbageBin()
      ELSE:
          RETURN
      END IF

   ELSE
     AddGarbageBin()
   END IF


   // Function to add a garbage bin
   FUNCTION AddGarbageBin():
     DISPLAY "Add garbage bin" window
     Read garbage bin size

     WHILE garbage bin size is empty:
        DISPLAY a message to prompt the staff to enter the size.
        Read garbage bin size.
     END WHILE

     DISPLAY a message to confirm the addition.

     IF staff confirms:
        Add the new garbage bin information to the database.
        DISPLAY a success message.
        DISPLAY the new garbage bin on the garbage bins map.
     ELSE:
        CLOSE "Add garbage bin" window
     END IF
   END FUNCTION

END IF
```

Figure 11: Add Garbage Bin Pseudocode

Add Recycling Center

Staff should be able to add a new recycling center by providing all necessary information, (Table 5) shows the Add Recycling Center Story. For the pseudocode see (Figure 12).

ID	Sprint#	PBI	Type
5	Sprint-1	As a Taboua Staff, I want to add a new recycling center location on the map, so that it can be placed at a designated location.	Feature

Table 5: Add Recycling Center Story

Construction:

- Inputs: recycling center location, name, description, types of waste, PhoneNo, website URL, working hours, center logo, center image.
- Precondition: staff must be logged in.
- Postcondition: The new recycling center is added to the database and displayed on the recycling centers map.

Pseudocode:

```
IF the staff clicks on a designated location on the recycling centers map:
    Read recycling center location

    // Determine the type of location where the staff clicked on
    locationType = checkLocationType(recycling_center_location)

    IF locationType equals 'building' THEN
      AddRecyclingCenter()
    ELSE:
      DISPLAY a message to confirm if location is on building

      IF staff confirms:
        AddRecyclingCenter()
      ELSE:
         RETURN
      END IF
    END IF


    // Function to add a recycling center
    FUNCTION AddRecyclingCenter():
      DISPLAY "Add recycling center" window
      Read recycling center name, description, types of waste, PhoneNo, website URL, working hours,
center logo, center image.

      WHILE any field is empty:
        DISPLAY a message to prompt the staff to complete the required fields.
        Read the field.
      END WHILE


      DISPLAY a message to confirm the addition.

      IF staff confirms:
        Add the new recycling center information to the database.
        DISPLAY a success message.
        DISPLAY the new recycling center on the recycling centers map.
      ELSE:
        CLOSE "Add recycling center" window
      END IF
    END FUNCTION

END IF
```

Figure 12: Add Recycling Center Pseudocode

Request a Garbage Bin

Users should be able to request a new garbage bin by providing all the necessary information. (Table 6) shows the Request a Garbage Bin user story. For the pseudocode see (Figure 13).

ID	Sprint#	PBI	Type
20	Sprint-2	As a registered Taboua User, I want to be able to request a new garbage bin placement in a specific location using the map, so that I can contribute to better waste management in my area.	Feature

Table 6: Request a Garbage Bin Story

Construction:

- Inputs: garbage bin location, garbage bin size, request reason
- Precondition: user must be logged in.
- Postcondition: The garbage bin request will be stored in the database and displayed in the view request page.

Pseudocode:

```
IF the user clicks on a designated location on the map:
    Read garbage bin location
    DISPLAY "Request Garbage Bin" window
    Read garbage bin size
    Read request reason

    WHILE garbage bin size or request reason is empty:
        DISPLAY a message to prompt the user to enter both size and reason.
        Read garbage bin size.
        Read request reason.
    END WHILE

    DISPLAY a message to confirm the request.

    IF user confirms:
        Add the new garbage bin request with size and reason to the system.
        DISPLAY a success message.
        DISPLAY the new request on the requests page.
    ELSE:
        CLOSE "Request Garbage Bin" window
    END IF

END IF
```

Figure 13: Request a Garbage Bin Pseudocode

Taboua Recycling Item Model

Users should have the capability to identify waste types through item scanning and confirm or correct prediction for accuracy. For detailed information on the recycling item model user stories please refer to (Table 7). According to the flowchart in (Figure 14), the user begins by uploading a photo or taking an image. The user should then be able to crop the image to a square, as required by the model. Next, the photo is sent to the model. If the waste type is identified as 'none,' this indicates that the photo does not contain any recognizable objects. Otherwise, the model's prediction will be displayed to the user. If the model's prediction is incorrect, the user can correct it, allowing us to train our model and improve its accuracy. If the model's prediction is correct, we will check if the prediction is 'trash.' If so, a non-recyclable disposal information screen is shown. Otherwise, we will list the recycling centers that accept this type of waste.

ID	Sprint#	PBI	Type
35	Sprint-3	As a Taboua User (Guest + Registered), I want to easily identify my waste type by scanning the item, so that save my time rather than manually searching for each waste item type on the internet.	Feature
36	Sprint-3	As a Taboua User (Guest + Registered), I want the ability to either approve or correct the waste type suggested by the recycling item model, so that I can ensure the accuracy of the categorization.	Feature
37	Sprint-3	As a Taboua User (Guest + Registered), I want the recycling item feature to suggest the nearest recycling center location based on the type of waste identified so that I can easily dispose of my waste in an environmentally friendly manner.	Feature

Table 7: Taboua Recycling Item Model

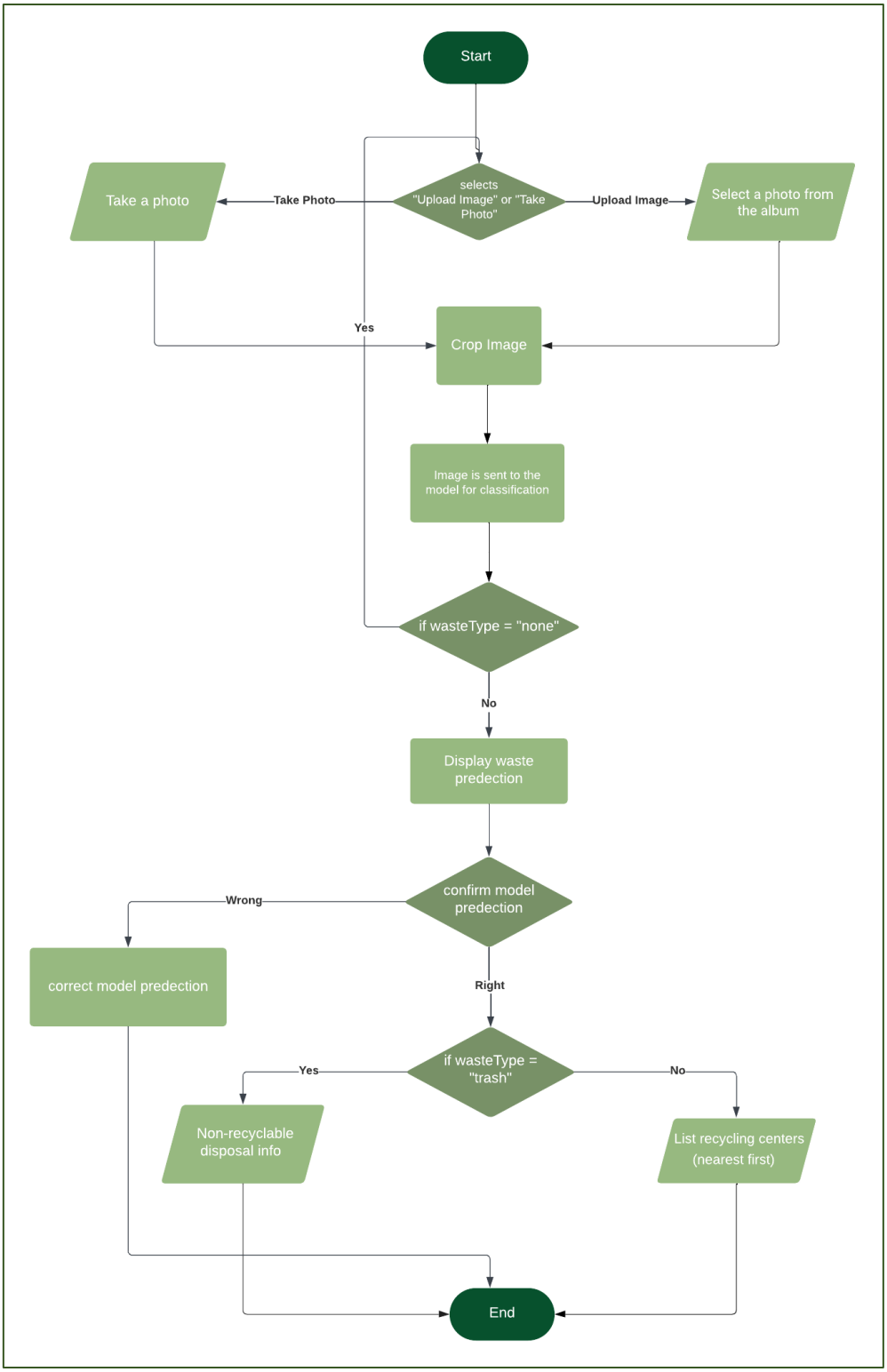


Figure 14: Taboua Model Flowchart

To illustrate the process of the recycling item model in Taboua mobile application, the following (Figure 15) shows the steps of how to use the model. Firstly, Taboua user will scan the item. Secondly, the recycling item model will show the predicted waste type of the scanned item. Thirdly, Taboua user can either approve or reject the provided prediction. If the user approves the prediction, the recycling centers are displayed in order of proximity to the user's location. If the user rejects the prediction, the user is asked to specify the correct waste type to help the Taboua team improve the model's performance.

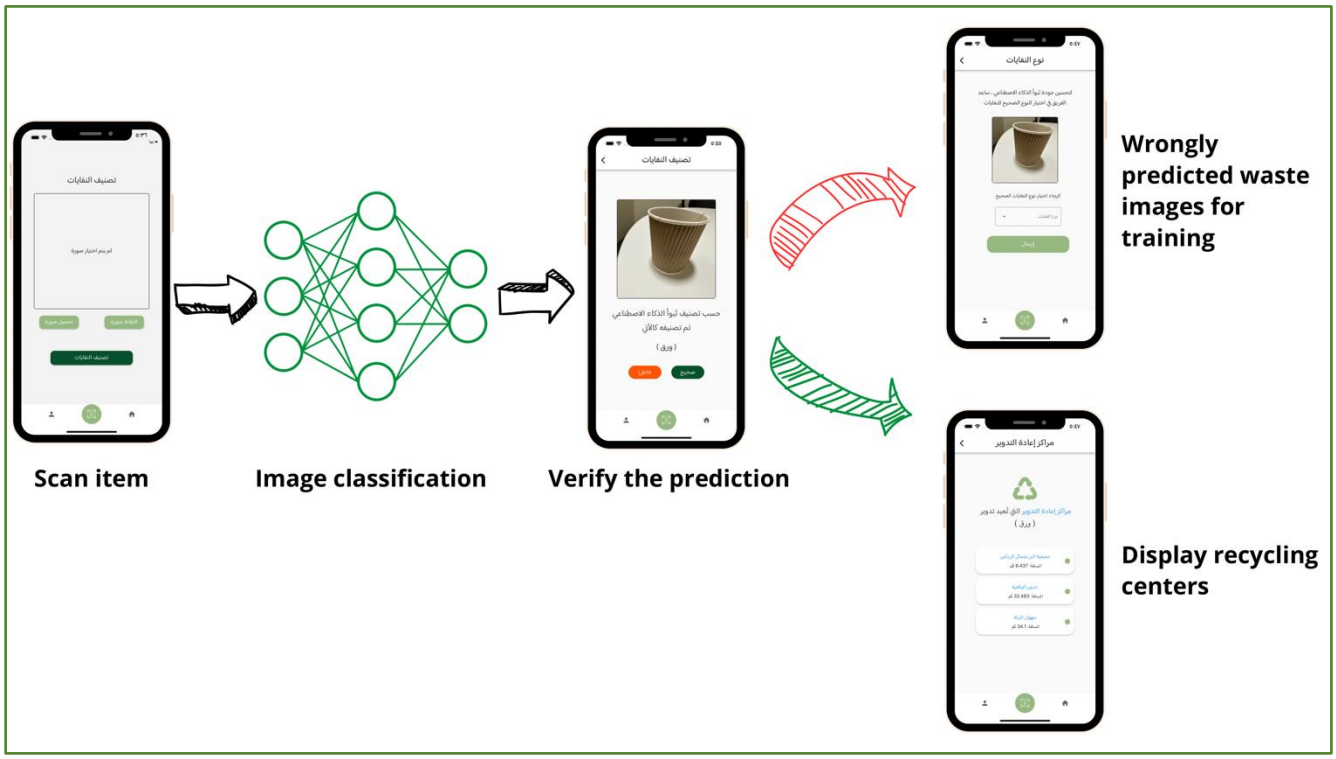


Figure 15: Taboua Recycling Item Model Process

4.4 Data Design

In designing our Taboua system, we carefully considered the most suitable database technology to meet our diverse data needs and evolving requirements. After thorough analysis, we determined that NoSQL was the optimal choice for several reasons. NoSQL is like a flexible toolbox for handling data, and it made sense for us because our system has diverse data types and changing requirements. It allows us to store and retrieve information in a way that fits the dynamic nature of our website and mobile app, providing scalability and adaptability as our system grows. The decision aligns with our goal to efficiently handle complex relationships and various types of data, contributing to a more effective and responsive system. In this section we will show Entity-Relationship (ER), Non-Relational, and Data Collection and Preparation.

4.4.1 Data Models

This section provides the conceptual design for Taboua website and mobile app involves an ER and non-relational diagrams.

ER diagram

The ER diagram outlining key entities and relationships. This graphical representation in (Figure 16) enhances our understanding of how different elements interact, providing a foundation for the seamless design and functionality of the website and mobile application.

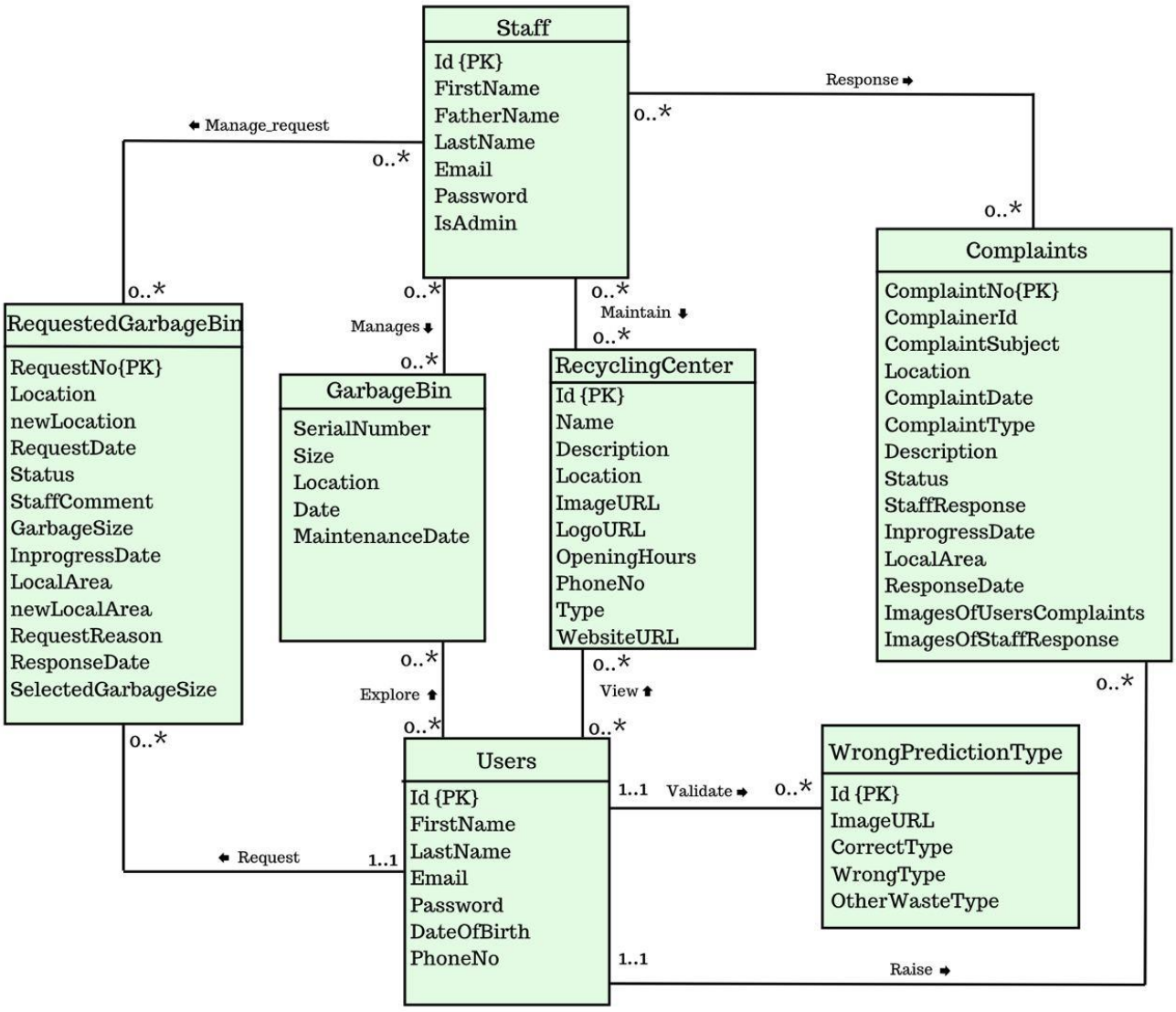


Figure 16: Taboua ER Diagram

Non-relational data model

The non-relational model below (Figure 17), customized for Firebase, embraces a document-oriented approach with a hierarchical structure. The choice of a hierarchical structure is a strategic decision based on the nature of our data, the requirements of Firebase, and the scalability and efficiency needed for our website and mobile app.

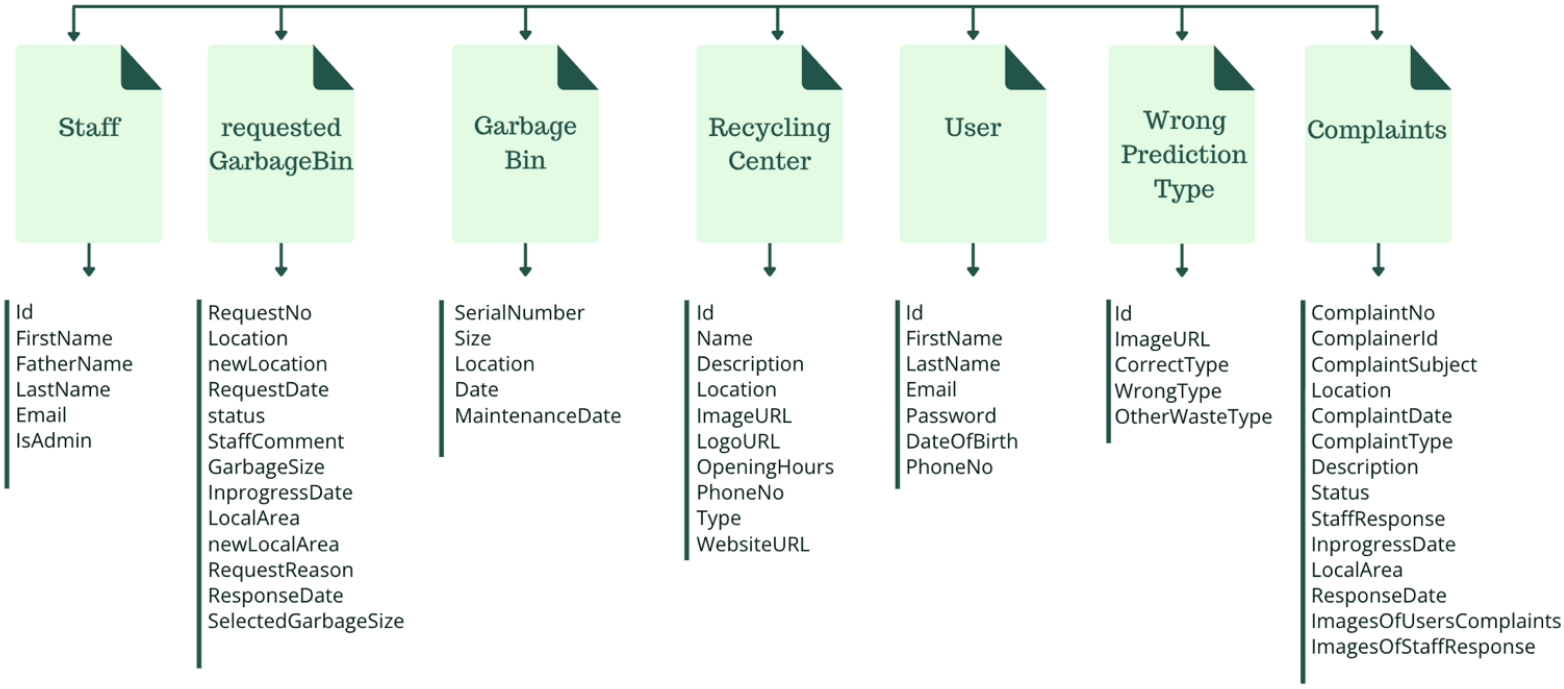


Figure 17: Taboua Non-Relational Data Model

4.4.2 Data Collection and Preparation

In this section, we will explore the process of gathering crucial data for our Taboua system, specifically focusing on information about garbage bin's locations, recycling centers data in Riyadh and waste images for the recycling item model. Navigating this task proved a bit challenging due to the intricate nature of the field and the limited availability of data. Throughout the upcoming sections, we will thoroughly outline the methods employed for garbage bins, recycling centers and waste images to provide a clear understanding of our data collection approach.

Data Collection for Garbage Bin Locations

We gathered information about garbage bin's locations because it's crucial for both the Taboua website and mobile applications. This way, users can easily locate the nearest bin on the map.

We reached out to the Riyadh Municipality staff, and one helpful staff member sent us an Excel Sheet with garbage bins locations data as Google Map short URLs for Riyadh's neighborhoods and including the bin size [46].

Our focus was on four neighborhoods: Al-Muhammadiyah (220 garbage bins), Al-Wadi (263 garbage bins), Al-Nafal (235 garbage bins), and Al-Hazm (104 garbage bins). Due to the extensive number of neighborhoods in Riyadh, focusing on these four allowed us to manage the validation process more efficiently, as validating data for all neighborhoods would have taken a long time. Additionally, our team lived in these areas, making data collection easier and more accurate.
It is important to note that due to the use of Google Maps short URLs, we had to manually extract the location coordinates data to make this information practical and accurate. In the process of making this information practical, we undertook the following steps for collecting and validating data on garbage bin locations:

1. Began with an Excel sheet containing Google Map short URLs for each bin location [46].

2. Opened each link to extract the location coordinates (longitude and latitude) of every bin due to the short URLs.

3. Conducted a manual check and verification of each location due to some sites being incorrect.

4. Removed any bins within buildings or non-existent locations during the verification process.

5. Stored the obtained location data along with the size information for each bin.

Data Collection for Recycling Center Locations

We collected data on recycling centers for our Taboua system to map their locations, making it convenient for users to find the nearest recycling center and view its information. This data is also crucial for the recycling item model. To ensure the information is useful, we took the following steps to gather and verify the locations of the recycling centers:

1. Initiated the data collection process by examining government sites like National Center for Waste Management (MWAN) to gather initial information on recycling centers in Riyadh [57].

2. Conducted extensive online searches on various platforms, such as search engines and social media, using keywords like 'recycling centers in Riyadh' to identify potential facilities[58].

3. Utilized suggestions from social media, which sometimes included only the name, requiring additional searches on Google Maps to gather additional details such as the website URL, working hours, and phone number [59], [60], [61].

4. Enriched the dataset by collecting insights through informal contacts, including friends and family.

Data Collection for Waste Images

The collection of waste images data for our Taboua mobile application was crucial to develop and train the recycling item model. This model enables users to accurately identify and categorize waste items, promoting responsible disposal and recycling practices. We recognized the necessity for a diverse and comprehensive dataset encompassing various waste images categories, including trash, plastic, glass, metal, electronic waste, clothes, paper, and cardboard.

To gather the required data, we initially explored available datasets from Kaggle and identified seven datasets matching Taboua recycle item model criteria [34], [35], [36], [37], [38], [39], [40]. However, we realized that these datasets were insufficient for our needs. We could not find additional datasets that matched the criteria required for training the Taboua recycle item model. Taboua team conducted manual data collection efforts. We captured images of waste items across its different categories and searched for waste images across the internet. Specifically, we utilized HARAJ platform to collect relevant electronic waste images from users' posts [62]. Also, we reached the help of our family and friends to collect images of various types of trash waste.

In total, our data collection efforts resulted in a dataset comprising 18,781 RGB images in JPG and PNG formats, consisting of different sizes, shapes, color, and background. Our resulting dataset is class balanced with 2260 trash images, 2467 plastic images, 2188 glass images, 2348 metal images, 2003 electronic waste images, 2351 clothes images, 2285 paper images, and 2879 cardboard images. Some of the sample images are shown in (Figure 18).

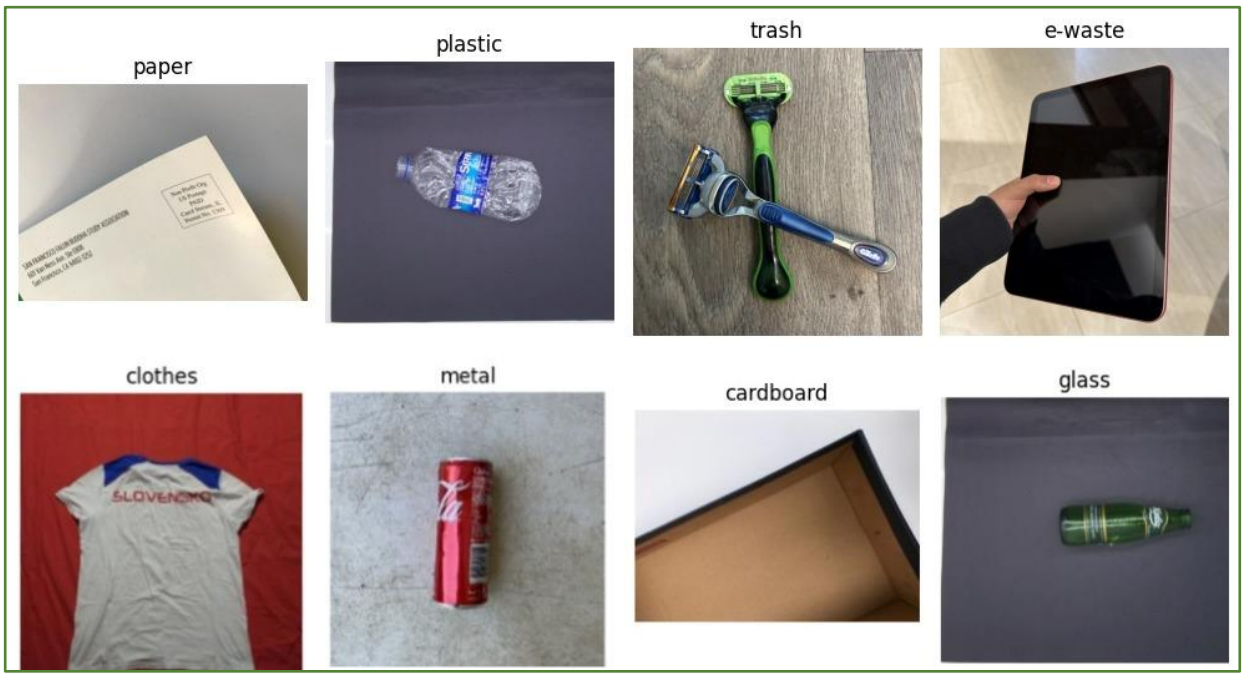


Figure 18: Sample Images

Following data collection, we undertook validation and preprocessing steps to enhance the dataset's quality and suitability for model training. These steps included:

1. The initial dimensions of the images were of varying sizes, so images were cropped to improve clarity and focus solely on the waste item.

2. Duplicate images were identified and eliminated to prevent redundancy and not affect the training process.

3. Images of low resolution, improper framing, or inadequate clarity were filtered out to maintain dataset quality.

4. To optimize upload speed and efficiency, the size of the images was reduced to 300kb and lower while preserving good image quality.

5. Non-image files were filtered out and images not supported by TensorFlow (not in formats like BMP, GIF, JPEG, PNG) were removed, resulting in a total of 50 such images being deleted from the dataset [63], [64], [65] (Figure 19).

```
#clean the dataset to filter non-image files& images with types not accepted by TensorFlow
count=0
image_extensions = [".png", ".jpg", ".jpeg"]
img_type_accepted_by_tf = ["bmp", "gif", "jpeg", "png"]

for filepath in Path(data_dir).rglob("*"):
    if filepath.suffix.lower() in image_extensions:
        img_type = imghdr.what(filepath)
        if img_type is None: # Check if the File is an Image
            print(f"{filepath} is not an image")
        if img_type not in img_type_accepted_by_tf: # Check TensorFlow Acceptance
            print(f"{filepath} is a {img_type}, not accepted by TensorFlow")
            os.remove(filepath)
            count+=1
print(f"Removed {count} images")
```

Figure 19: Filter Images

6. Split our 18,731 images into three sets: train, test, and validation. The train data contains 80% of total images that will be used to train the model, the validation contains 10% and is used for checking during training and adjusting parameters whereas the test contains 10% to evaluate the accuracy of the model on new data not used during training (Figure 20).

```
# divide the data from the dataset into three folders
splitfolders.ratio('/content/drive/MyDrive/../../../dataset',
output = 'data',
seed = SEED,
ratio = (.8,.1,.1),
group_prefix = None)
```

Figure 20: Splitting Images

In summary, we detailed the data collection and preparation for the Taboua system, focusing on garbage bin locations and recycling centers in Riyadh. Despite initial challenges, we successfully collected and verified data from Riyadh Municipality for bin locations and combined governmental and online sources for recycling centers. Resulting in a total of 822 garbage bins across 4 neighborhoods and 12 recycling centers. We also created a comprehensive dataset of 18,781 RGB images from various sources, including Kaggle and HARAJ. which were extensively preprocessed to train our recycling item model effectively.

4.5 Interface Design

The interface design section outlines our Taboua system's interactive and visual components. It shows the navigation diagrams for both the mobile and web applications of Taboua, Additionally, it presents the UI/UX guidelines that were incorporated into our Taboua system.

4.5.1 Web Application Navigation Diagram

Figure 21 shows the structure and flow of user interactions within the web application. It provides an overview of how users navigate through different sections and features.

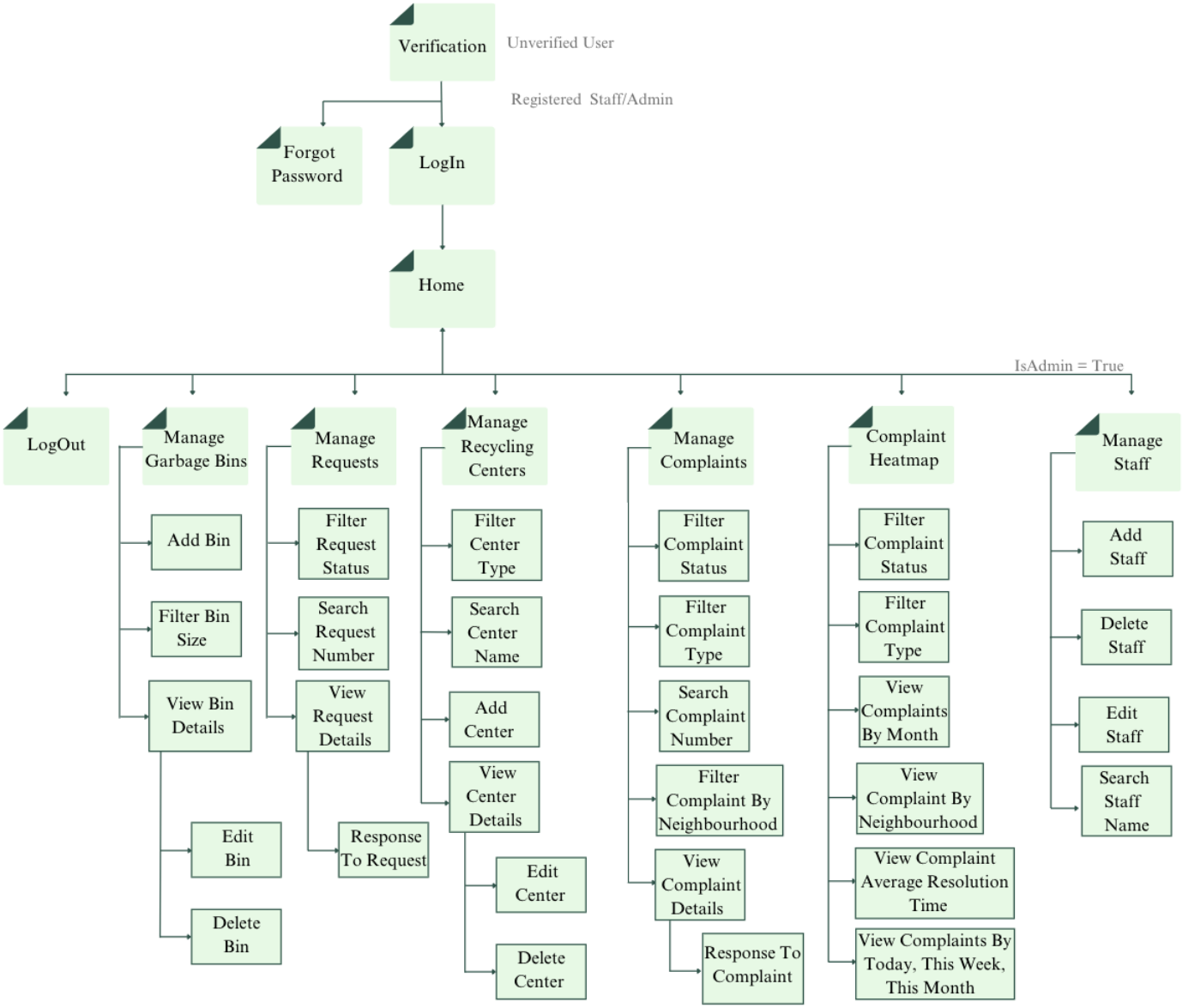


Figure 21: Taboua Web App Navigation Diagram

4.5.2 Mobile Application Navigation Diagram

The Mobile App Navigation Diagram is represented in two figures: Figure 22 for registered users (people who are signed in) and Figure 23 for guest users (people who aren't signed in). These figures illustrate the structure and flow of user interactions within the Mobile application. They serve as guides, providing an overview of how users navigate through different sections and utilize various features available within the app.

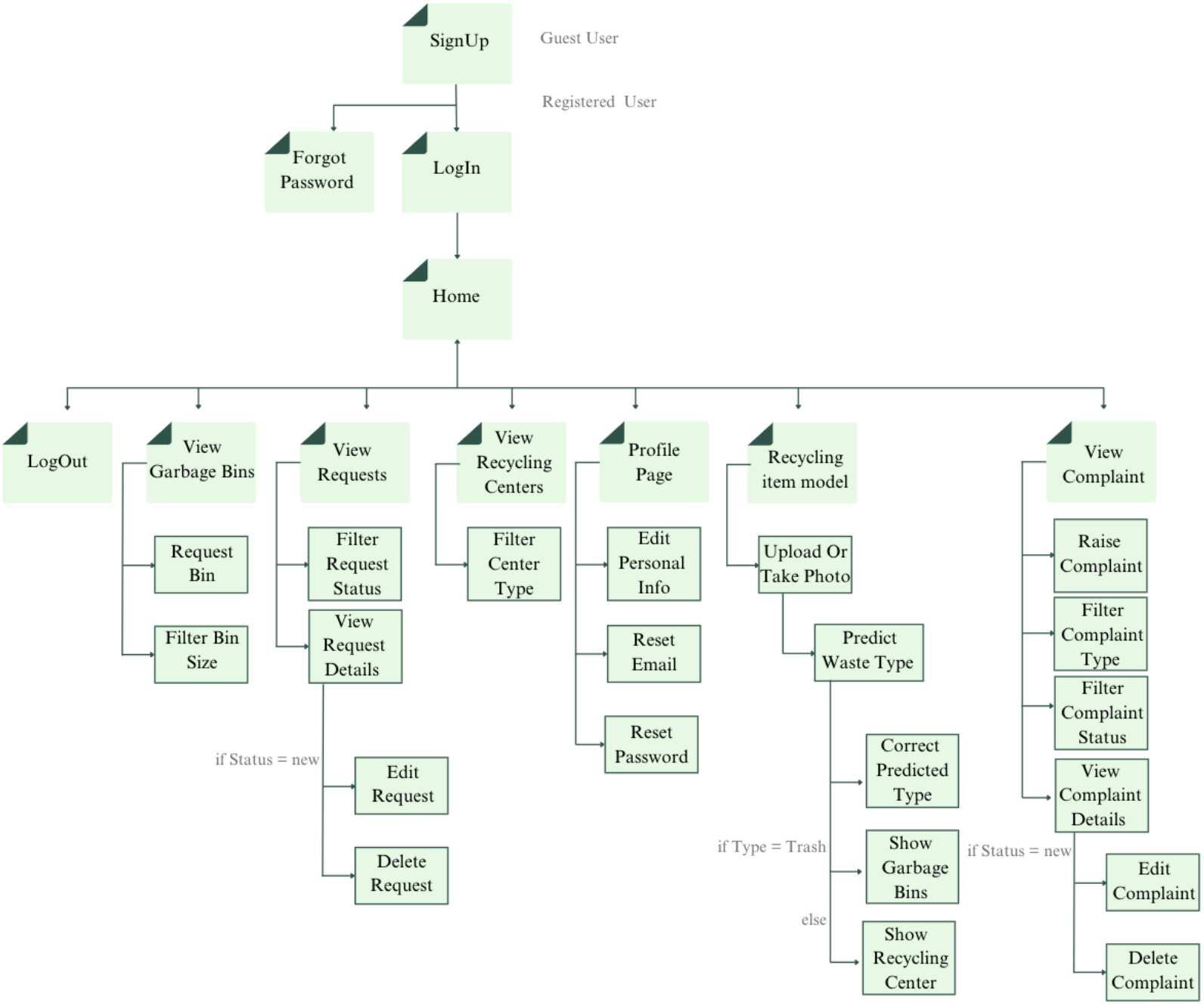


Figure 22: Taboua Mobile App Navigation Diagram (Registered User)

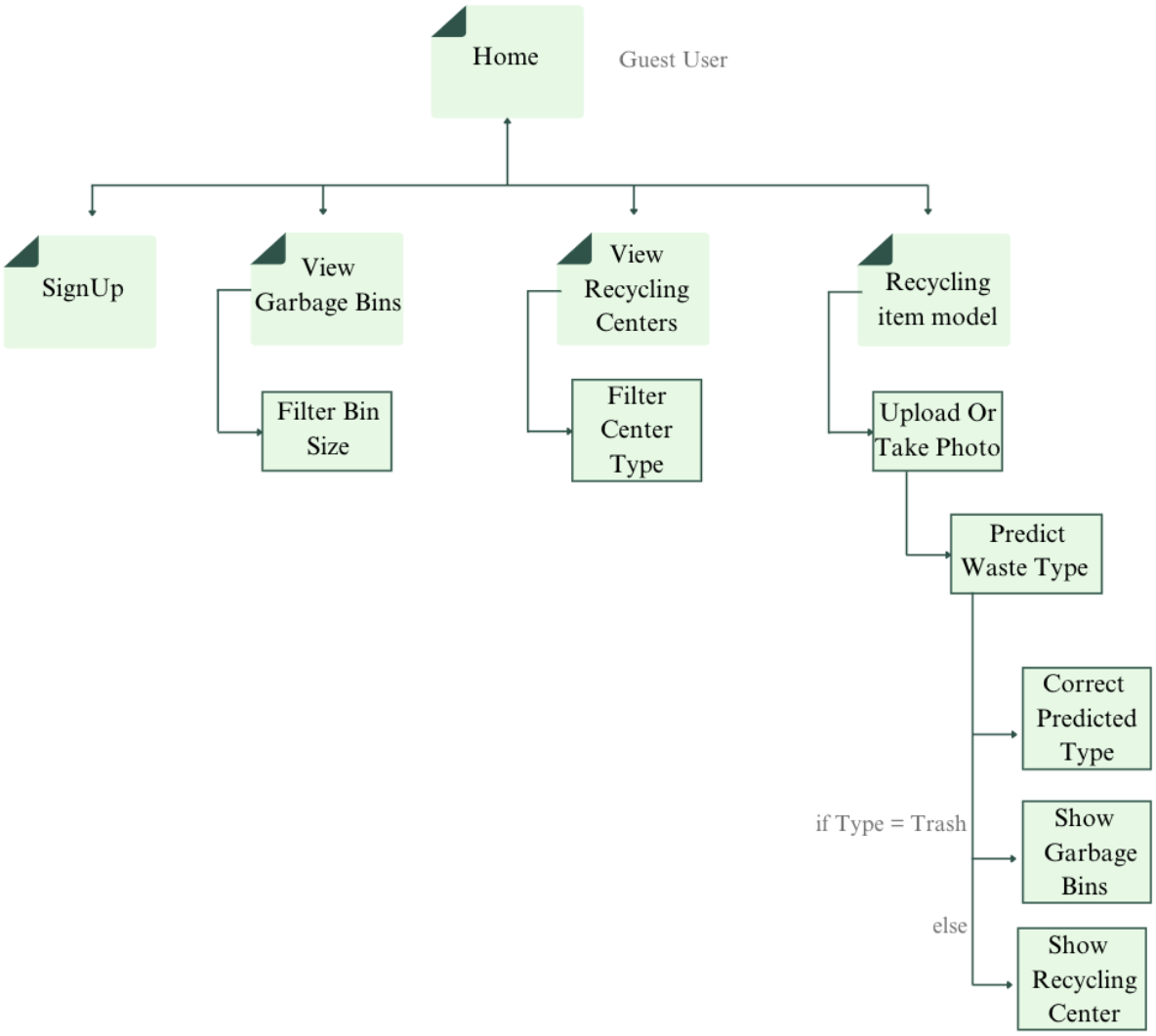


Figure 23: Taboua Mobile App Navigation Diagram (Guest User)

4.5.3 UX Guidelines

This section will present five UX guidelines that were applied to the Taboua System. The UX guidelines applied are recognition rather than recall, error handling, user-friendly input validation, offering informative feedback, and consistency and standards.

1. Recognition rather than Recall: Allowing Taboua users to recognize what they are looking for instead of having to recall the name or try to figure out where the intended features are. As shown in (Figure 24) the familiar icons and informative names for each Taboua service in both mobile and web applications were readily identifiable for Taboua users, eliminating the need for them to recall the information.

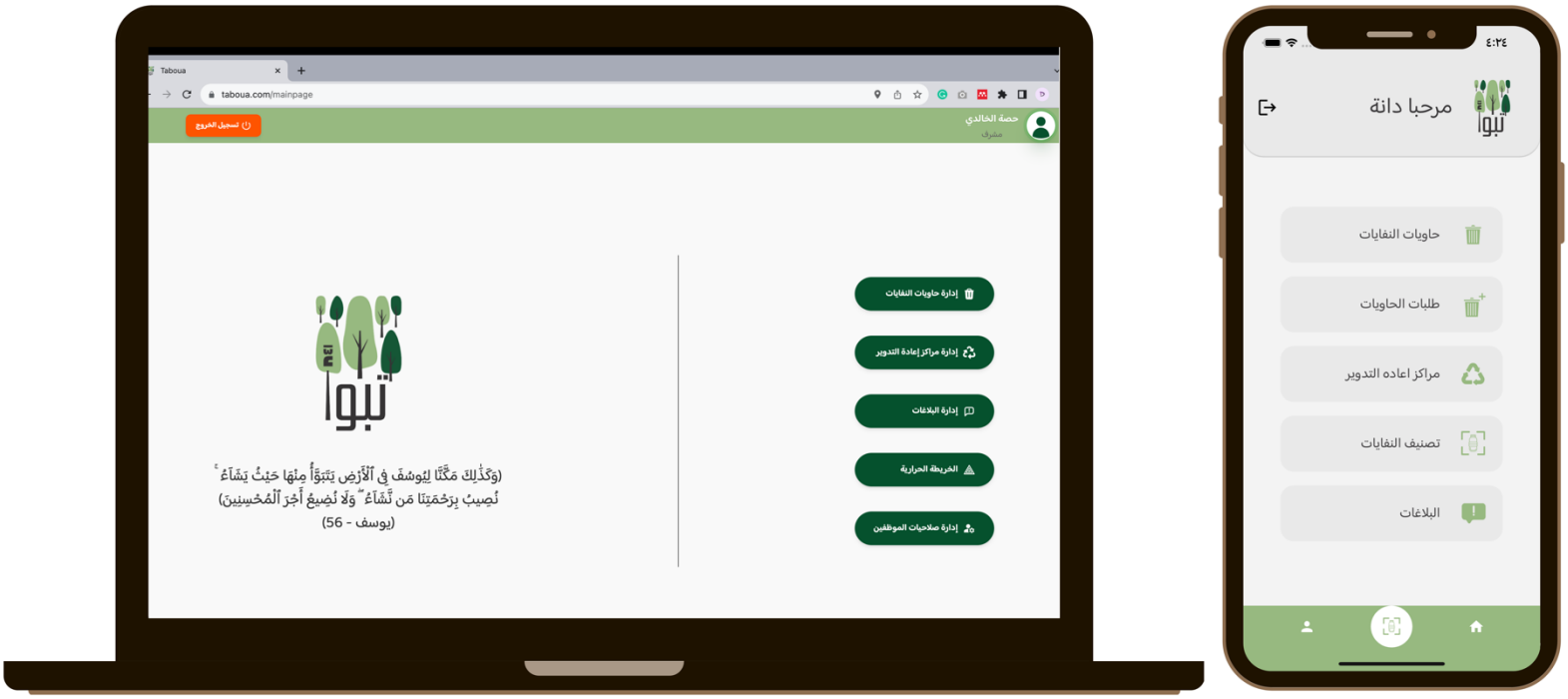


Figure 24: Taboua User Interface - Recognition rather than Recall

2. Error Handling: The error messages displayed by Taboua are clear and informative, guiding users through the issues they may encounter. As illustrated in (Figure 25), these error messages are displayed for both mobile and web applications, with the purpose of assisting Taboua users in correctly utilizing the service.

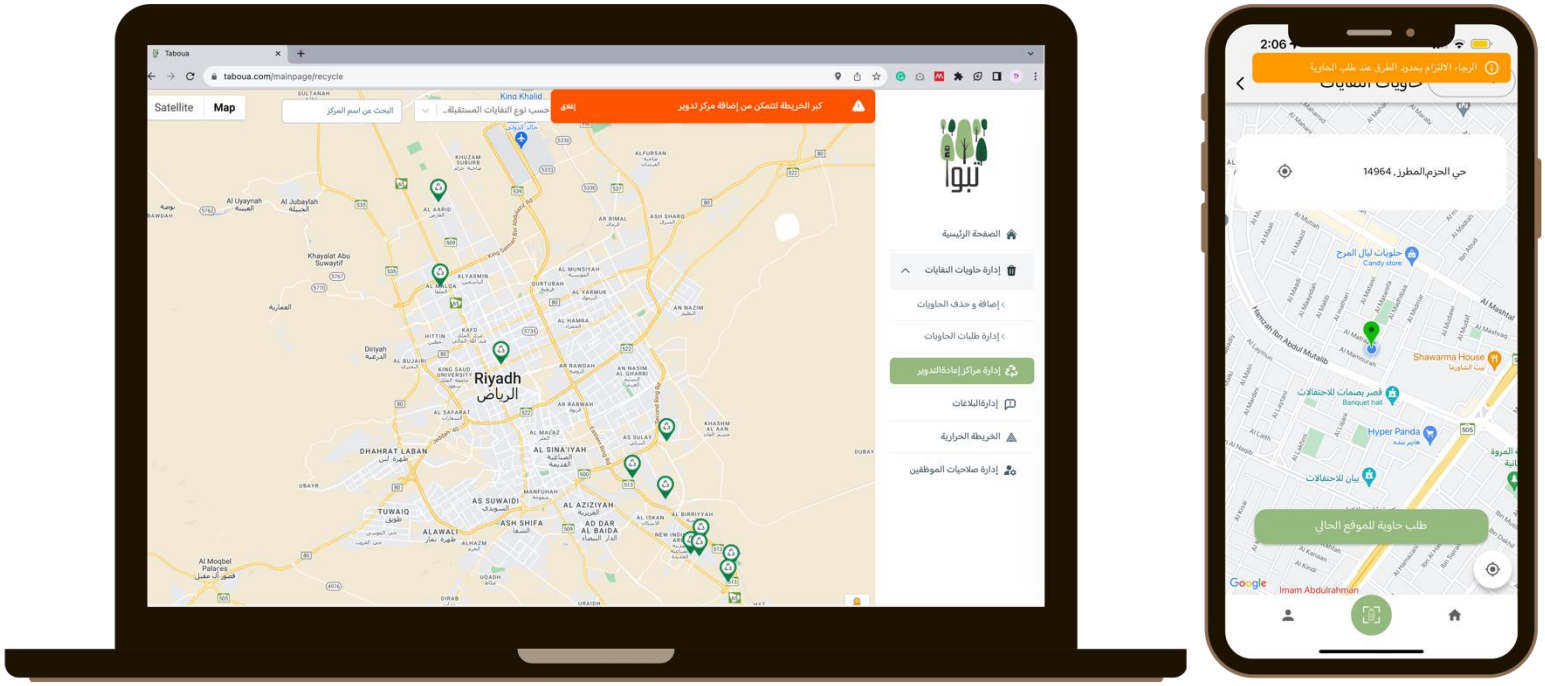


Figure 25: Taboua User Interface - Error Handling

3. User-Friendly Input Validation: The input validation demonstrated by Taboua provides a clear and concise representation of the necessary information. As illustrated in (Figure 26) the input validation is applicable to both mobile and web applications for various services, assisting Taboua users in accurately and efficiently filling in the required information.

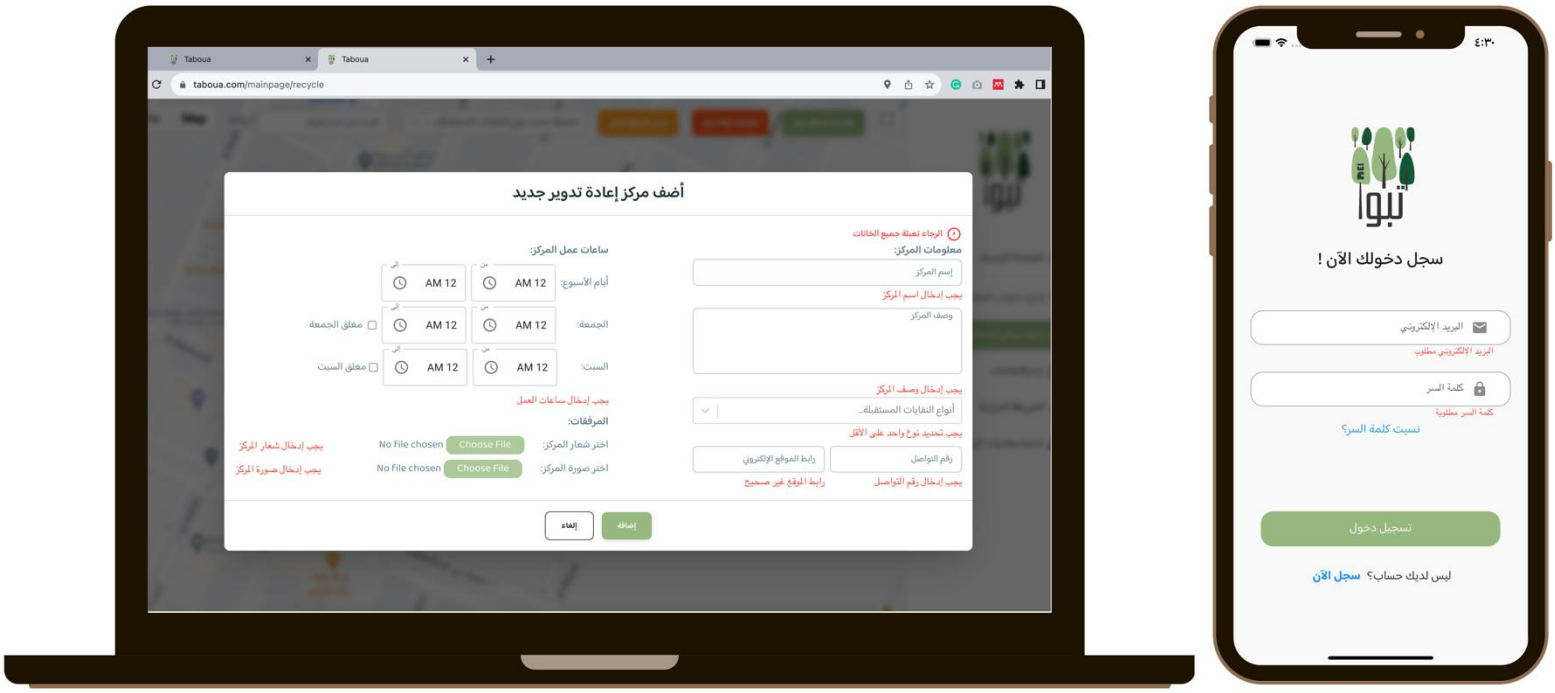


Figure 26: Taboua User Interface - User-Friendly Input Validation

4. Offer Informative Feedback: The Taboua system responds to user actions by displaying informative feedback messages to inform users of the status of their actions when using Taboua services. As shown in (Figure 27), this example demonstrates that both Taboua's mobile and web applications provide informative feedback messages in response to user actions.

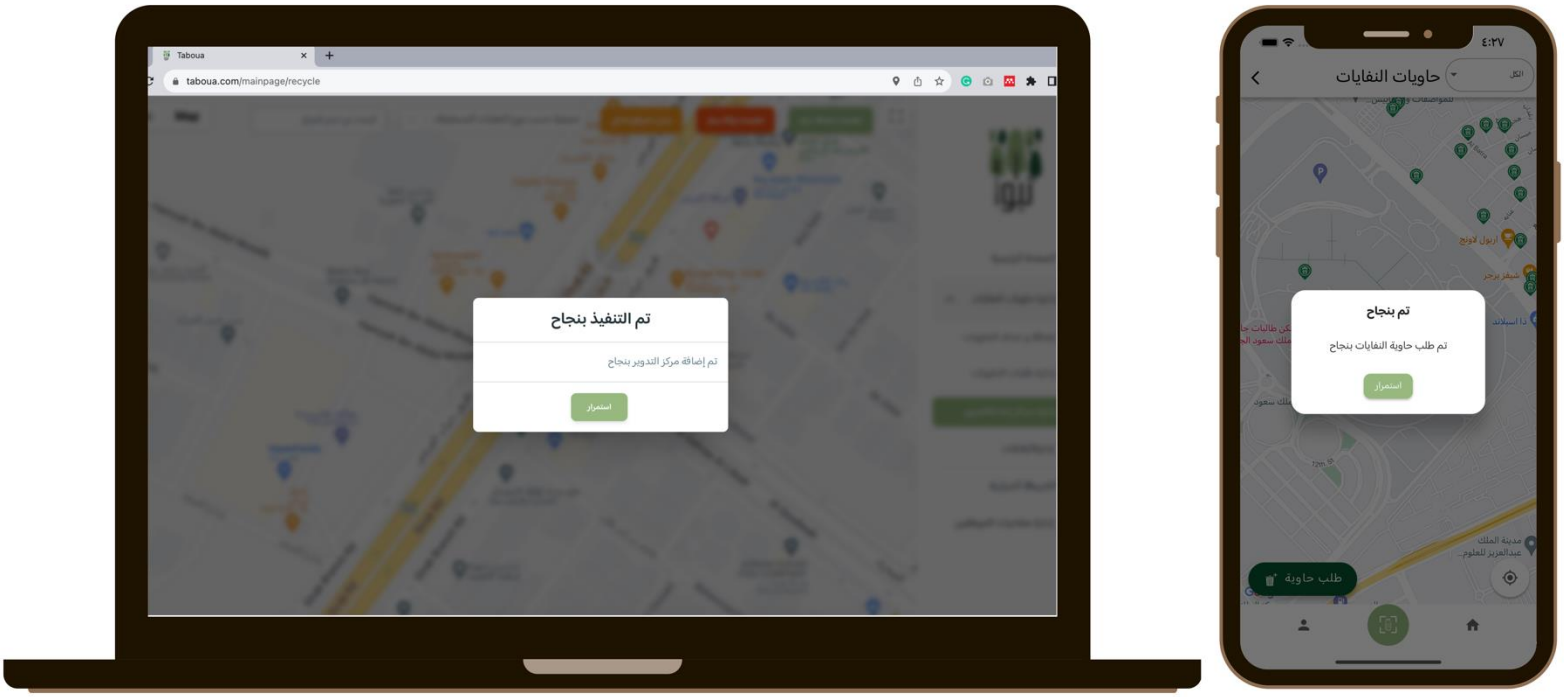


Figure 27: Taboua User Interface - Offer Informative Feedback

5. Consistency and Standards: Taboua adheres to a consistent approach to color, terminology, and design to ensure a consistent user experience. As illustrated in (Figure 28), the recycling center maps for both mobile and web applications consistently maintain a uniform design and follow the same methodology for displaying the recycling center marker locations. Additionally, another example can be seen in (Figure 29), where the complaint service is consistent for both mobile and web applications.

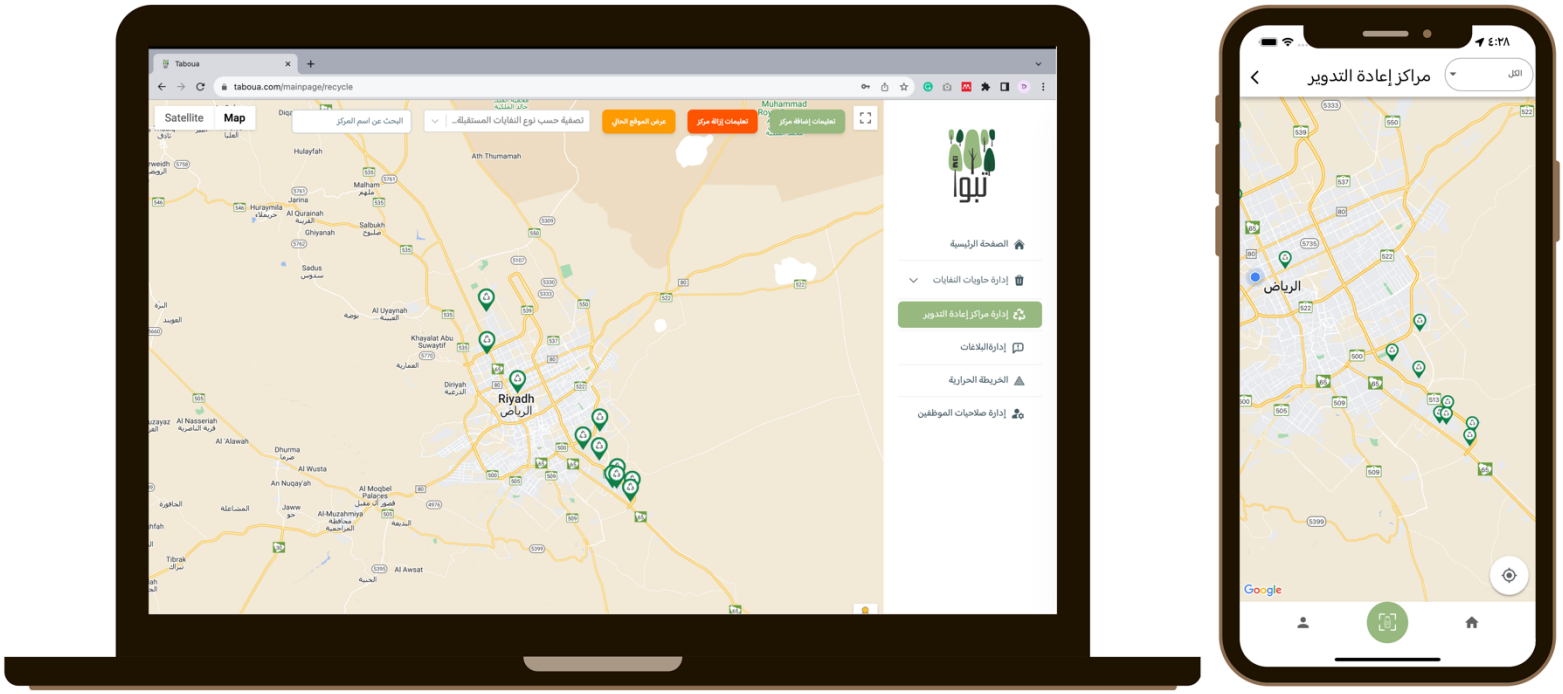


Figure 28: Taboua User Interface - Consistency and Standards (Recycling Centers Interface)

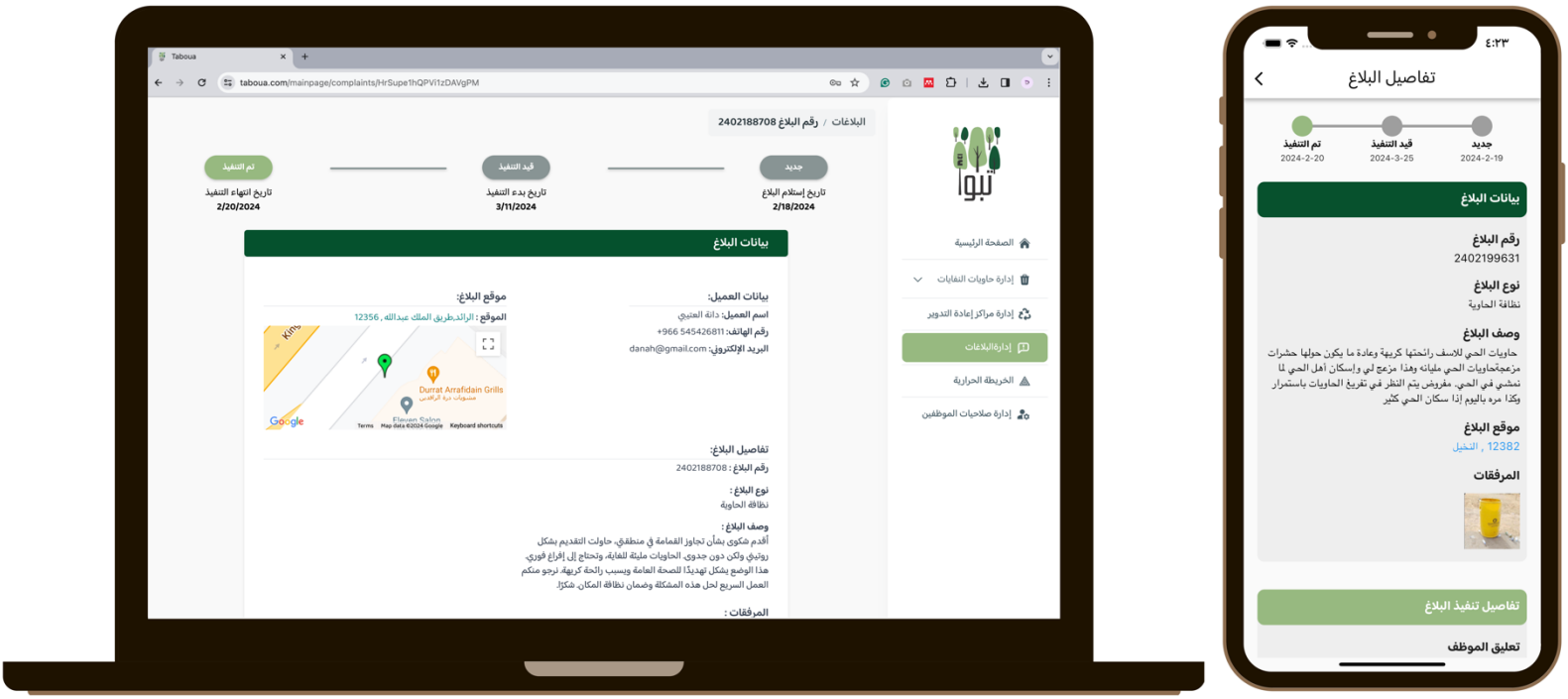


Figure 29: Taboua User Interface - Consistency and Standards (Complaints Interface)

4.6 System Implementation

Taboua is a waste management system that provides services for both the authority and individual users. Prior to implementing the Taboua system, we designed User Interfaces (UI) for both the web and mobile applications using the Figma tool to ensure a clear vision and agreement from the Taboua team members. The Taboua system is developed using different programming languages, namely React for the web side and Flutter for the mobile side. Throughout the development process, we took consultation and guidance from Flutter, React, and google maps communities' channels on various aspects of the implementation. Additionally, our Taboua team referred to the official documentation of Google Maps and Firebase. While developing Taboua, we encountered challenges and bugs, and to overcome them, we received assistance from both online platforms StackOverflow and ChatGPT. The Taboua system demo for both website and mobile applications can be found in (Appendix B. Taboua System Demo).

To efficiently manage the various aspects of Taboua system, we have created a Google Cloud Platform (GCP) project. Google Cloud is a suite of cloud computing service models offered by Google [66]. Where we can manage credentials, APIs, and SDKs and monitor usage of the following services:

Firebase:
Taboua utilizes Firebase for data storage and retrieval. The integration process begins by creating a new Firebase project. On the web side, the Firebase SDK is installed using `npm`. Configuration involves creating a firebase.js file in the source directory, where project details are added, followed by importing the required Firebase services [67]. For the mobile integration, the process starts by adding the Firebase pod dependency to the podfile. A GoogleService-Info.plist file is then generated in the IOS/Runner directory. Subsequently, the Firebase SDK is imported into the Flutter app's Dart files, and Firebase is initialized using the `Firebase.initializeApp()` method. Finally, the desired Firebase services are imported [68]. This complete integration approach ensures seamless connectivity between Taboua system and Firebase for both web and mobile platforms.

Google maps platform:
To provide dynamic and interactive mapping features, Taboua integrates with Google Maps API. Configuring this integration involved establishing connections between our system and the Google Maps service, allowing for functionalities such as displaying locations of garbage bins and recycling centers. On the web side, the integration with Google Maps is facilitated by using the **react-google-maps/api** library [69] it provides an easy way to use Google Maps JavaScript API features a react component.

On the mobile side, Taboua utilizes the google Maps SDK for iOS to obtain an API key and we used a Google Maps Flutter package **google_maps_flutter** from flutter for integrating Google Maps functionality into Taboua iOS application as a Flutter plugin [70].

In the next sections we will demonstrate the main functions for both web application and mobile application sides and how we solved the challenges we faced.

4.6.1 Taboua Mobile Application Implementation

During Releases 1 and 2, we implemented all the functions that were planned on the Taboua roadmap and discussed in the product backlog, as well as additional features to support the core functions. This section will discuss the implementation of functions on the Taboua mobile application, including valuable open sources that have aided us in implementing our application, solving the problems we encountered, and improving the user experience of Taboua mobile application.

Map Markers

The size of the markers' images posed a challenge for us. The markers, which are pins displayed on the map, indicate recycling centers and garbage bins. Our custom marker was too large for phone screens, even after we resized its image. We found a solution by reusing the **`getBytesFromAssets`** function, which we discovered on The Tech Brothers YouTube channel [71]. As shown on Figure 30 this function works by converting an image to bytes with a selected width.

```
Future<Uint8List>getBytesFromAssets (String path , int width) async{
// Load the byte data of the image from the assets
ByteData data = await rootBundle.load(path);
// Instantiate an image codec from the byte data with a target width
ui.Codec codec = await
ui.instantiateImageCodec(data.buffer.asUint8List(),targetHeight:width );
// Get the frame information from the codec
ui.FrameInfo fi = await codec.getNextFrame() ;
// Convert the image to byte data with a specified format png
return (await fi.image.toByteData(format: ui.ImageByteFormat.png))!.buffer.asUint8List();

}
```

Figure 30: GetBytesFromAssets Function

As illustrated in Figure 31, call the **`getBytesFromAssets`** function, specifying the custom icon and the desired width for the marker. The function will return bytes in the PNG format.

```
final Uint8List markerIcon = await getBytesFromAssets("images/trash.png", 100);
```

Figure 31: Call getBytesFromAssets Function

Marker is one of Widget from Google map package. As illustrated in Figure 32, for displaying markers on map we call **BitmapDescriptor** is bitmap image format to set image of marker icon by converting bytes to encoded as PNG format with suitable size to appear on map.

```
final marker = Marker(
        markerId: MarkerId(garbageBin.serialNumber!),
        position: LatLng(lat, long),
        icon: markerIcon != null ? BitmapDescriptor.fromBytes(markerIcon) : BitmapDescriptor.defaultMarker,
        infoWindow: InfoWindow(
          title: "حجم الحاوية:",
          snippet: garbageBin.size, // Display the size in the info window
        ),
      );
```

Figure 32: Map Markers

Geocoding API

To simplify the process of requesting bins and raising complaints for Taboua users. We have used the Geocoding API is a service provided by Google Map that provides two services geocoding and reverse. Taboua mobile app uses reverse service to convert latitude and longitude into readable addresses. Geocoding API provides extensive information regarding designated areas, including postal codes, streets, and districts. To accomplish this, we adapted the **`getRequest`** function as shown in Figure 33.

```
static Future<dynamic> getRequest(String url) async{
    http.Response response = await http.get(Uri.parse(url));

    try{
      if (response.statusCode == 200){
        String jsonData = response.body;
        var decodeData = jsonDecode(jsonData);
        return decodeData;
      }
      else {
        return "failed";
      }
    }
    catch(e){
      return "failed";

    }
  }
```

Figure 33: GetRequest Function

GoogleMap API

For displaying the map on the mobile screen, we used the **`GoogleMap`** widget provided by the Google Map package as shown in Figure 34. To simplify the process of changing the location on the map, we employed the **`gestureRecognizers`** function, which was obtained from the StackOverflow community [72].

```
GestureDetector(
          child: GoogleMap(
           zoomGesturesEnabled: true,
           myLocationButtonEnabled: true,
           scrollGesturesEnabled: true,
           rotateGesturesEnabled:false,
           tiltGesturesEnabled: true,
            myLocationEnabled: true,
            zoomControlsEnabled: true,

           onMapCreated: _onMapCreated,
              initialCameraPosition: CameraPosition(
                    target: LatLng(
                      _currentLocation?.latitude ?? 0.0,
                      _currentLocation?.longitude ?? 0.0,
                    ),
                    zoom: 11.5,
                  ),
                  markers: _markers, // Set of markers


                  gestureRecognizers: Set()
        // recognizer handles panning or dragging gestures
          ..add(Factory<PanGestureRecognizer>(() => PanGestureRecognizer()))
      // recognizer handles pinch-to-zoom gestures.
          ..add(Factory<ScaleGestureRecognizer>(() => ScaleGestureRecognizer()))
    // recognizer handles single-tap gestures.
          ..add(Factory<TapGestureRecognizer>(() => TapGestureRecognizer()))
   //recognizer handles vertical dragging gestures.
          ..add(Factory<VerticalDragGestureRecognizer>(
              () => VerticalDragGestureRecognizer())),
          ),

        ),
```

Figure 34: Google Map Widget

FastAPI

To integrate Taboua recycling item model into Taboua mobile application, we have chosen to use FastAPI. The code shown in Figure 35, outlines the creation of a FastAPI application. Following a guideline, we begin by importing all the necessary libraries [73]. A FastAPI application is then instantiated. The model is then loaded into the application.

Next, we define the expected image size for the model and create a list called class_name, which maps class indices to waste types. A crucial part of the application is the definition of an endpoint to accept an uploaded image. After receiving an image, it is resized. To determine whether the image does not contain any objects, we use the `is_solid_or_empty()` function which checks if an image does not contain any recognizable objects by analyzing its pixels. If the image is not already a numpy array, it converts it into one. Then, if the image is in color (RGB), it converts it to greyscale to simplify the analysis, then it calculates the variance of the greyscale pixel values; if this variance is below the threshold, it suggests that the image may just be a solid color or essentially empty, indicating that no objects are present.

The final step involves making predictions using the loaded model to predict the class probabilities for the given image. The result includes extracting the class index with the highest probability and returning the corresponding waste type as a JSON response.

```python
from fastapi import FastAPI, File, UploadFile, HTTPException
from fastapi.responses import JSONResponse
import tensorflow as tf
import numpy as np
from PIL import Image
import io
import os


app = FastAPI()

# Initialize the model variable
model = None

# Define the target image size
target_size = (384, 384)

# Define the mapping between class indices and labels
class_names = ['نفايات لا يعاد تدويرها', 'بلاستيك', 'ورق', 'معدن', 'زجاج', 'إلكترونيات', 'أقمشة', 'كرتون']

# Function to lazily load the model
def load_model():
    global model
    if model is None:
        model_path = "garbage_classification.h5"
        model = tf.keras.models.load_model(model_path)

# Endpoint for waste classification
@app.post("/classify")
async def classify_waste(file: UploadFile = File(...)):
    try:
        # Ensure the model is loaded
        load_model()

        contents = await file.read()
        image = Image.open(io.BytesIO(contents)).convert("RGB")
        image = image.resize(target_size)

        # Check if the image is solid color
        if is_solid_or_empty(image):
            return JSONResponse(content={"waste_type": "none"})

        # Make prediction
        predictions = model.predict(np.expand_dims(image, axis=0))

        # Get the index of the class with the highest probability
        pred_class_index = np.argmax(predictions[0])
        pred_class_prob = predictions[0][pred_class_index]*100
        pred_class = class_names[pred_class_index]

        # Return the result with class name and probability
        return JSONResponse(content={"waste_type": pred_class, "probability": float(pred_class_prob)})
    except Exception as e:
        # Handle any exceptions that may occur during processing
        return HTTPException(status_code=500, detail=str(e))


def is_solid_or_empty(image, variance_threshold=10):

    # Convert the image to a numpy array if it's not already
    if not isinstance(image, np.ndarray):
        img_array = np.array(image)
    else:
        img_array = image

    # Ensure the image is in RGB format
    if img_array.ndim == 3 and img_array.shape[2] == 3:
        # Convert image to grayscale using the luminosity method
        gray_img = 0.2989 * img_array[:, :, 0] + 0.5870 * img_array[:, :, 1] + 0.1140 * img_array[:, :,
2]
    elif img_array.ndim == 2 or (img_array.ndim == 3 and img_array.shape[2] == 1):
        # Image is already grayscale
        gray_img = img_array
    else:
        raise ValueError("Image format not recognized. Ensure it is either grayscale or RGB.")

    # Calculate the variance of the pixel values
    variance = np.var(gray_img)

    # If the variance is below a certain threshold, it's likely a solid color or empty
    return variance < variance_threshold
```

Figure 35: FastAPI Implementation

Recommending Nearest Recycling Centers

The Taboua mobile application will suggest recycling centers ranging in proximity from the user's current location to the furthest away that when Taboua user approve of the correct waste type of recycling item model prediction. The distance function is computed using the Google Maps Directions API, as Figure 36 illustrates. We found the function's implementation in the Devbrite resource [74], [75].

```
Future<double> calculate_distance(LatLng origin, LatLng destination) async {
final GoogleMapsDirections _directions =
GoogleMapsDirections(apiKey:"");

final DirectionsResponse response = await _directions.directionsWithLocation(

  Location(lat: origin.latitude, lng: origin.longitude),
  Location(lat: destination.latitude, lng: destination.longitude),
);

if (response.isOkay) {
final route = response.routes!.first;
final distanceInMeters = route.legs!.fold<num>(0, (prev, leg) => prev + leg.dis

final distanceInKilometers = distanceInMeters / 1000;
setState(() {
distance = distanceInKilometers;
});
}
return distance;
}
```

Figure 36: Calculate Distance between Taboua user and recycling centers

4.6.2 Taboua Web Application Implementation

In Releases 1 and 2, we implemented all the features listed in the Taboua roadmap and product backlog, as well as additional features to support the main functionalities. This section will explain how the Taboua web application's features were implemented, including the open sources used to develop the application, solutions to issues encountered, and enhancements to the user experience.

Tailwind Material UI Library

For the design components of Taboua web application, we have utilized the Material Tailwind UI library [76]. It combines the flexibility of Tailwind CSS with React to build unique, visually appealing, and responsive user interfaces. The code shown in Figure 37, demonstrates how we configured Material Tailwind UI to style components and maintain a consistent design throughout the application. Also, The **`ThemeProvider`** component in Figure 38, ensures that our entire Taboua application adheres to the design principles provided by Material Tailwind UI.

```
// Root Component
import React from 'react';
import ReactDOM from 'react-dom/client';
import App from './App';
import { ThemeProvider } from "@material-tailwind/react";

ReactDOM.createRoot(document.getElementById('root')).render(
  <ThemeProvider>
    <App />
  </ThemeProvider>,
);
```

Figure 37: Material Tailwind Configuration

```
// Tailwind Material UI Configuration
import withMT from "@material-tailwind/react/utils/withMT";

export default withMT({
  content: [
    "./index.html",
    "./src/**/*.{js,ts,jsx,tsx}",
  ],
  theme: {
    extend: {},
  },
  plugins: [],
});
```

Figure 38: ThemeProvider Component

Integration of Timepicker Component

Taboua web application incorporates a feature that allows staff members to input working hours when adding a new recycling center. To facilitate this, as shown in Figure 39, we integrated a **`<TimePicker/>`** component from MUI (Material UI) library using **`@mui/x-date-pickers`** for selecting time with the keyboard[77].

```
// Importing necessary libraries for date and time handling from Material-UI and other packages
import { AdapterDayjs } from '@mui/x-date-pickers/AdapterDayjs'; // Adapter for using Day.js
import { LocalizationProvider } from '@mui/x-date-pickers/LocalizationProvider'; //Provides localization support
import { TimePicker } from '@mui/x-date-pickers'; // TimePicker component for selecting time with keyboard
import dayjs from 'dayjs'; // A minimalist JavaScript library for handling dates and times
```

Figure 39: Libraries to Integrate TimePicker Component

The below code snippet in Figure 40 uses LocalizationProvider to wrap the two **`<TimePicker/>`** components of a day, each representing the 'From' and 'To' time selection. The **`dateAdapter={AdapterDayjs}`** property ensures that the date handling is localized using the **`Day.js`** library. The **`views={['hours']}`** property is used to display only the hours section in the **`<TimePicker/>`**, and the **`onChange`** handler updates the form data based on the selected time. The successful integration of the **`<TimePicker/>`** component into the Recycling Center addition form enhances the user experience and provides an efficient way for staff to input working hours.

```
{/* Wrap the TimePicker components with LocalizationProvider to provide localization context */}
<LocalizationProvider dateAdapter={AdapterDayjs}>
  {/* TimePicker for 'From' */}
  <TimePicker
    className='w-32'
    views={['hours']} // Display only the hours section
    label="من" // Label for the 'From' TimePicker
    value={formData.openingHours.weekdays.from || time} // Set the initial value based on form data
    onChange={(time) => handleOpeningHoursChange(time, 'weekdays', 'from')} //Handle changes and update formData
  />
  {/* TimePicker for 'To' */}
  <TimePicker
    className='w-32'
    views={['hours']} // Display only the hours section
    label="إلى" // Label for the 'To' TimePicker
    value={formData.openingHours.weekdays.to || time} // Set the initial value based on form data
    onChange={(time) => handleOpeningHoursChange(time, 'weekdays', 'to')} // Handle changes and update form data
  />
</LocalizationProvider>
```

Figure 40: Use of LocalizationProvider Component

EmailJS Tool

To improve the process of adding staff, EmailJS [78] has been implemented. The EmailJS API helps the admin send emails to newly added staff members, as shown in Figure 41.

```
const sendEmail =  () => {
    const templateParams = {
email: formData.email,
firstName: formData.firstName,
password: formData.password,
    };

    try {
      const serviceId = '';
      const templateId = '';
      const publicKey = '';
     const form = formRef.current;

      const response =  emailjs.send(serviceId, templateId,templateParams , publicKey);

    } catch (error) {
      console.error('Email sending error:', error);
    }
  };
```

Figure 41: SendEmail Function

Handling garbage bin requests

In handling user requests for garbage bins, staff members must carefully assess if the requested bin location is suitable or not. To facilitate an informed decision-making process, as shown in Figure 42, the **`fetchGarbageBins`** function retrieves the garbage bin's locations data from the database that is in close proximity to the requested garbage bin location represented by the **`request.location`** geopoints.

```
// Load the garbage bin data from the database that are near the requested garbage bin location request.location

const fetchGarbageBins = async () => {
    try {
        // Retrieve all documents from the "garbageBins" collection in Firestore
        const querySnapshot = await getDocs(collection(db, "garbageBins"));
        const binsData = [];

        // Iterate through each document in the collection
        querySnapshot.forEach((doc) => {
            // Extract data from the document
            const data = doc.data();
            const location = data.location || {};

            // Calculate the distance between the user's location and the bin's location
            const distance = calculateDistance(
                request.location._lat,
                request.location._long,
                location._lat,
                location._long
            );

            // Check if the bin is within a 100-meter radius
            if (distance <= 100) {
                // If within range, add bin information to the binsData array
                binsData.push({ id: doc.id, location, size: data.size });
            }
        });

        // Set the state with the filtered garbage bin data
        setGarbageBins(binsData);
    } catch (error) {
        // Handle errors during the fetching process
        console.error('Error fetching garbage bins:', error);
    }
};
```

Figure 42: FetchGarbageBins Function

The underlying mechanism involves the utilization of the **`calculateDistance`** function shown in Figure 43, which implements the Haversine formula. This formula is well-known in geospatial calculations used to calculate the shortest distance between two geographical points over the earth's surface [79]. And credit for the formula's implementation goes to the original source from which it was obtained [79].

```
// Function to calculate distance between two points using Haversine formula
const calculateDistance = (lat1, lon1, lat2, lon2) => {
// Haversine formula
const R = 6371e3; //R is earth's radius in meters (mean radius = 6,371km);

//φ is latitude, λ is longitude in radians.
const φ1 = (lat1 * Math.PI) / 180;
const φ2 = (lat2 * Math.PI) / 180;
const Δφ = ((lat2 - lat1) * Math.PI) / 180;
const Δλ = ((lon2 - lon1) * Math.PI) / 180;
const a =
  Math.sin(Δφ / 2) * Math.sin(Δφ / 2) +
  Math.cos(φ1) * Math.cos(φ2) *
  Math.sin(Δλ / 2) * Math.sin(Δλ / 2);
const c = 2 * Math.atan2(Math.sqrt(a), Math.sqrt(1 - a));

const distance = R * c;// in metres
return distance;
};
```

Figure 43: CalculateDistance Function

Staff members who review request details and assess the location of the requested bin for approval benefit significantly from this functionality. The **`calculateDistance`** function, utilizing the Haversine formula, enhances the **`fetchGarbageBins`** function by calculating the distance between the requested bin and other bin's locations within a 100-meter radius. This allows the **`fetchGarbageBins`** function to display nearby garbage bins that are within a 100-meter radius of the requested bin location, aiding staff in making informed decisions about bin placement for optimum convenience and accessibility.

Restricting marker placements on the Map

In managing the garbage bins and recycling centers, we implemented a feature to control marker placements on the map, such that garbage bins can only be added on streets, while recycling centers can only be added on buildings. The key method for enforcing this restriction is the **`checkLocationType`** function shown in Figure 44. The **`checkLocationType`** function utilizes the Google Maps Reverse Geocoding API to initiate a request to determine the location type (building or other) at a given set of coordinates (latitude and longitude). In the response, the result is analyzed using the **`types`** array to check if it includes **`'premise'`**, which typically indicates a building.

```
const checkLocationType = (lat, lng) => {

  return new Promise((resolve, reject) => {

    if (window.google) {
      const geocoder = new window.google.maps.Geocoder();
      const latLng = new window.google.maps.LatLng(lat, lng);

      geocoder.geocode({ location: latLng }, (results, status) => {
        if (status === 'OK') {
          const types = results[0]?.address_components.map((component) => component.types[0]);

          // Check if 'types' array contains 'premise' (building)
          if (types.includes('premise')) {
            resolve('building');
          } else {
            resolve('other');
          }
        } else {
          reject('Error checking terrain type');
        }
      });

    } else {
      reject('Google Maps API not loaded');
    }
  });
};
```

Figure 44: CheckLocationType Function

In the **`checkLocationCondtion`** function shown in Figure 45 and Figure 47, before allowing the addition of a recycling center or garbage bin, a condition check is performed based on the current map zoom level. If the zoom level meets the specified minimum, the location type is assessed using the **`checkLocationType`** function.

Recycling Center Addition Condition Check:

- If the location type is identified as a 'building', the recycling center is added at the specified location on the map.
- If the location type is different (not a building), a check message is displayed shown in Figure 46 , allowing staff to decide on the suitability of the location.

```
  //check condition for recycling centers

const checkLocationCondtion = async (lat ,lng) =>{

if (currentZoomLevelRef.current >= minZoomLevel) {

    const locationType = await checkLocationType(lat, lng);

    setNewRecyclingCenterLocation({ lat, lng });

    if (locationType === 'building') {
      handleOnMapClick(lat,lng); // handle the clicked location for adding/changing the recycling center location.
     } else {
       // Show an alert message indicating that a recycling center can only be added on a building.
       setCheckMessageVisible(true);
     }
   } else {
        // Show an alert message indicating that a recycling center can only be added on a specefic scale.
        handleAlertZoom();
     }
}
```

Figure 45: CheckLocationCondtion for Recycling Centers

```
<Confirm
  open={checkMessageVisible}
  handler={handleCheckMessage}
  method={() => {
    handleOnMapClick();
    setCheckMessageVisible(false);
  }}
  message="هل انت متأكد من أن الموقع المحدد يقع على مبنى؟"
/>
```

Figure 46: CheckMessage Component for Recycling Center

Garbage Bin Addition Condition Check:

- If the location type is identified as a 'building' a check message is displayed shown in (Figure 48) allowing staff to decide on the suitability of the location.
- If the location type is different (not a building), the garbage bin is added at the specified location on the map.

```
  //check condition for garbage bins

const checkLocationCondtion = async (lat ,lng) =>{

if (currentZoomLevelRef.current >= minZoomLevel) {

   const locationType = await checkLocationType(lat, lng);

    setNewGarbageBinLocation({ lat, lng });

    if (locationType === 'building') {
    setCheckMessageVisible(true);//Show a check message to let staff decide if the location is building or not.
    } else {
    handleOnMapClick(lat,lng);  // handle the clicked location for adding/changing the garbage bin location.
    }
} else {
// Show an alert message indicating that a garbage bin can only be added on a specific scale.
handleAlertZoom();
}
}
```

Figure 47: CheckLocationCondtion for Garbage Bins

```
<Confirm
  open={checkMessageVisible}
  handler={handleCheckMessage}
  method={() => {
    handleOnMapClick();
    setCheckMessageVisible(false);
  }}
  message="هل أنت متأكد من أن الموقع المحدد يقع على شارع؟"
/>
```

Figure 48: CheckMessage component for Garbage Bin

While the **`checkLocationType`** function provides a practical approach, it's important to acknowledge its limitations and may not always guarantee that the location is a building. Especially for streets validation, where the **`types`** array for a street may include **`'premise'`**. This scenario can lead to misinterpretation,

considering a street as a building. In case of that, we implemented a manual validation for accurate location type classification to ensure reliable decision-making by staff.

Heatmap layer of complaints component

To integrate a heatmap of user complaints where authority staff can visualize the aggregated user's complaints to identify the most problematic areas, we used Google Maps API heatmap layer component (Figure 49) that read the complaints geolocation to display a colored overlay on top of the map, where areas of higher intensity will be colored red, and areas of lower intensity will appear green. Also, the map displays markers of the complaints at a certain zoom scale to enable the staff to easily access the complaint details by clicking the complaint marker.

```
 <HeatmapLayer
            data={complaints.map(comp => new google.maps.LatLng(comp.location._lat,
comp.location._long))}
            options={{radius: 25, opacity: 0.7, }}
            />


{visibleMarkers.map((complaint) => (
     <Marker
              key={complaint.id}
              position={{ lat: complaint.location._lat, lng: complaint.location._long
}}           onClick={() => handleMarkerClick(complaint.id)}
               />
     ))}
```

Figure 49: Heatmap Layer of Complaints Component

Calculating average resolution time of complaints

The **`calculateComplaintsResolutionTimes()`** function (Figure 50) calculates the average duration that complaints take from the moment they are received until they are resolved. So, the authority can evaluate the effectiveness and speed of the staff response in handling the complaints. The function first filters out unresolved complaints and calculates the resolution times for the rest. If there are no resolved complaints, it returns 'لا يوجد' for the average resolution time. Otherwise, it calculates the average resolution time in milliseconds and then converts this duration into a suitable format of days, hours, and minutes. To build this function, we utilized solutions from specific Stack Overflow discussions [80].

```
const calculateComplaintsResolutionTimes = (complaints) => {
  // Filter complaints that is resolved
  const validComplaints = complaints.filter(complaint => complaint.complaintDate &&
complaint.responseDate);
  const resolutionTimes = validComplaints.map(complaint => {
    const createdAt = complaint.complaintDate.toDate().getTime();
    const resolvedAt = complaint.responseDate.toDate().getTime();

    // Calculate time in milliseconds
    return resolvedAt - createdAt;
  });


  if (resolutionTimes.length === 0) {
    return {
      resolutionTimes: [],
      averageResolutionTime: 'لا يوجد'
    };
  }

  // Calculate the average resolution time in milliseconds
  const averageResolutionTimeInMilliseconds = resolutionTimes.length > 0
? Math.abs(resolutionTimes.reduce((a, b) => a + b, 0) / resolutionTimes.length)
: 0;

  // Convert milliseconds to days, hours, and minutes
  let remainingTime = averageResolutionTimeInMilliseconds;

  const days = Math.floor(remainingTime / (1000 * 60 * 60 * 24));
  remainingTime %= (1000 * 60 * 60 * 24);
  const hours = Math.floor(remainingTime / (1000 * 60 * 60));
  remainingTime %= (1000 * 60 * 60);
  const minutes = Math.floor(remainingTime / (1000 * 60));

  // Construct the formatted average resolution time string
  let formattedAverageResolutionTime = [];
  if (days > 0) formattedAverageResolutionTime.push(`${days} يوم`);
  if (hours > 0) formattedAverageResolutionTime.push(`${hours} ساعة`);
  if (minutes > 0) formattedAverageResolutionTime.push(`${minutes} دقيقة`);

  return {
    resolutionTimes,
    averageResolutionTime: formattedAverageResolutionTime.join(', ')
  };
};
```

Figure 50: Calculating Average Resolution Time of Complaints

ChartJs Library

To display meaningful visualized analysis of complaints data, we integrated the Chart.js library and react-chartjs-2 wrapper for Chart.js, for creating different interactive charts [81], [82]. It enabled us to render different types of charts including distribution of complaint types as Doughnut Chart, distribution of complaints status as Vertical Bar Chart, number of complaints for each neighborhood as Horizontal Bar Chart, number of Complaints for each month of the year as Line Chart.

Calculating Number of Complaints for each neighborhood

To calculate the number of complaints for each neighborhood (Figure 51), we utilized two functions **`extractNeighborhood()`** and **`combineComplaintsByNeighborhood()`** to process and combine complaints based on neighborhood names extracted from a local area description. **`extractNeighborhood(localArea)`** This function extracts the neighborhood name from a given **`localArea`** string that can either start with a postal code followed by the neighborhood name or just the neighborhood name. The **`combineComplaintsByNeighborhood(complaints)`** function counts complaints by neighborhood names, it utilizes the **`extractNeighborhood()`** function to determine the neighborhood for each complaint.

```
 const extractNeighborhood = (localArea) => {
  // Check if localArea starts with a postal code
  const postalCodeRegex = /^\d+\s*,\s*/;
  if (postalCodeRegex.test(localArea)) {
    // Extract the part after the postal code
    return localArea.replace(postalCodeRegex, '').trim();
  } else {
    // Extract the first part
    return localArea.split(',')[0].trim();
  }
};

const combineComplaintsByNeighborhood = (complaints) => {
 const complaintsByNeighborhood = {};

 complaints.forEach(complaint => {
   const neighborhood = extractNeighborhood(complaint.localArea);
   complaintsByNeighborhood[neighborhood] =
(complaintsByNeighborhood[neighborhood]||0)+1;
 });

  return complaintsByNeighborhood;
};
```

Figure 51: Calculating Number of Complaints for each Neighborhood

4.6.3 Taboua Recycle Item Model Implementation

The primary objective of this experiment is to leverage machine learning techniques, specifically feature extraction transfer learning to adapt a pre-trained Convolutional Neural Network (CNN) model to construct a classification model capable of accurately categorizing recyclable and non- recyclable items based on their visual attributes into the following classes: trash, glass, plastic, paper, cardboard, metal, electronic waste, and clothes.

The intuition behind transfer learning for image classification is that if a model is trained on a large and general enough dataset, this model will effectively serve as a generic model of the visual world then we can take advantage of these learned feature maps without having to start from scratch by training a large model on a large dataset [63].

Building Taboua recycling item classification model involves two key phases as the following:

- Feature Extraction: Initially, we utilize the pre-trained EfficientNetV2S model to extract meaningful features from new images of recyclable items without modifying the weights of the pre-trained model by simply adding a new classifier, which will be trained from scratch on top of the pre-trained model so that it repurposes the feature maps learned previously for the dataset, enabling effective classification of waste items into predefined categories [63].

- Fine-tuning: We fine-tune our model to further improve its performance and adapt it to our specific classification task by unfreezing certain layers of the frozen base model and training them along with the newly added classifier layers with our recycling waste dataset [63].

While building our model, essential Python libraries were used. TensorFlow and Keras for creating neural network models. Splitfolders, os, and shutil modules are used for splitting datasets and file manipulation. NumPy and pandas for data analysis and numerical operations. Matplotlib and seaborn for data visualization. Lastly, Scikit-learn for model evaluation metrics like classification reports and confusion matrices.

Throughout the development of our recycling item model, we draw inspiration and guidance from TensorFlow tutorials and insightful Kaggle notebooks code examples that facilitated the development of our model [63], [64], [65], [83].

The following pre-trained models experiments (Table 8) were implemented and trained using our preprocessed dataset. The selection of the pre-trained models was based on their ability to perform the image feature vector task effectively while meeting our specific criteria of the recycling item classification task.

Model	Test Accuracy	Training Time(seconds)
ResNet50	91.71%	1025.94
ResNet101	89.57%	2725.66
InceptionV3	91.49%	2872.86
MobileNetV2	90.17%	2823.13
EfficientNetV2S	95.72%	4445.97

Table 8: Pre-trained Models Experiments

There are two competing criteria we considered while selecting a pre-trained model: we aimed for high validation accuracy for reliable predictions while also prioritizing fast training and prediction to meet real-time demands because, we might need to serve hundreds or thousands of predictions every second. All the pre-trained models' experiments were trained using the same settings.

Categorical crossentropy was used as the loss function to compute the crossentropy loss between the labels and predictions. Accuracy was used as the metric for the model's performance and were compiled using the adam optimizer. Additionally, for the other models than EfficientNetV2S, normalization preprocessing step was implemented on images since these models do not have a built-in rescaling layer. As we can see, EfficientNetV2S offered the highest test accuracy of 95.72%.

The training was performed using GoogleColab platform with the following specifications: GPU RAM of 40GB, GPU of A100, TensorFlow 2.15.0V.

In the following steps, we will show the process of implementing the Taboua recycling item classification model. It includes the following stages: preprocessing by preparing the data and applying techniques such as augmentation. Then model building to construct the model architecture and select layers and activation functions. Next, model evaluation to evaluate its performance and adjust hyperparameters. Finally, we fine-tune the model and deploy it.

Preprocessing:

As we previously preprocessed our dataset in(4.4.2:Data Collection and Preparation), now as shown in (Figure 52), **`train_data, test_data, validation_data`** sets are being loaded from their respective directories with images resized to 384x384 which is the recommended image size of the EfficientNetV2S model, then add labels to them by **`label_mode='categorical'`** parameter where it converts the labels into a one-hot encoded format. Then specify the **`batch_size=BATCH_SIZE`** to determine how many samples are processed before the model is updated. then the **`shuffle=True`** for training and validation ensures that the data is shuffled for each epoch, reducing model bias, and improving generalization:

```
#The number of images in each.
BATCH_SIZE = 32

#image size
IMG_SIZE = (384, 384)

train_data = tf.keras.utils.image_dataset_from_directory(train_path,
                                                         image_size=IMG_SIZE,
                                                         label_mode='categorical',
                                                         batch_size=BATCH_SIZE,
                                                         shuffle=True,
                                                         seed=SEED)

test_data = tf.keras.utils.image_dataset_from_directory(test_path,
                                                        image_size=IMG_SIZE,
                                                        label_mode='categorical',
                                                        batch_size=BATCH_SIZE,
                                                        shuffle=False)

validation_data = tf.keras.utils.image_dataset_from_directory(val_path,
                                                              image_size=IMG_SIZE,
                                                              label_mode='categorical',
                                                              batch_size=BATCH_SIZE,
                                                              shuffle=True,
                                                              seed=SEED)
```

Figure 52: Distribute Data into Packages

Because we do not have a large image dataset we applied data augmentation techniques such as random flips, rotations, zooms, and adjustments to height and width to expose the model to different aspects of the training data and reduce overfitting (Figure 53):

```
#create a data augmentation layer to improve classification accuracy.
data_augmentation = tf.keras.Sequential([
                                         tf.keras.layers.RandomFlip("horizontal"),
                                         tf.keras.layers.RandomRotation(0.2),
                                         tf.keras.layers.RandomZoom(0.2),
                                         tf.keras.layers.RandomHeight(0.2),
                                         tf.keras.layers.RandomWidth(0.2),],
                                         name ="data_augmentation")
```

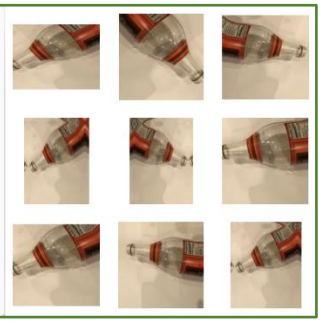


Figure 53: Data Augmentation Code and Sample Image

Model Building:

The model building involves first loading the pre-trained EfficientNetV2S model and excluding the top (output) layer to allow for our custom classification layers and freeze all its layers so that its parameters do not change during training. Then we construct our final model configuration by specifying the input and output layers. As shown in (Figure 54) we incorporated the base model (EfficientNetV2S) and additional layers for data augmentation, pooling, and classification:

```
# Define input layer
inputs = tf.keras.Input(shape=(384, 384, 3), name="input_layer")

# Apply data augmentation
x = data_augmentation(inputs)

# Apply base model
x = base_model(x, training=False)

# Add global average pooling layer
x = tf.keras.layers.GlobalAveragePooling2D()(x)

# Add dense layer with 128 units and relu activation
x = tf.keras.layers.Dense(128, activation='relu')(x)

# Add dropout layer with rate 0.2
x = tf.keras.layers.Dropout(0.2)(x) # Regularize with dropout

# Add output layer with softmax activation
outputs = tf.keras.layers.Dense(len(class_names), activation='softmax')(x)

# Create model
EfficientNetV2S_model = tf.keras.Model(inputs=inputs, outputs=outputs,
name="EfficientNetV2S")
```

Figure 54: Construct Taboua Model

First, we define the input layer that specifies the shape of the images that the model will receive. Then we apply the data augmentation layer we previously introduced. Then the base model EfficientNetV2S applied to the augmented images to act as a feature extractor converting input images into a high-dimensional feature vector. Then added a Global Average Pooling (GAP) layer to reduce the dimensions of the feature map output by the base model. Then added a dense (fully connected) layer with 128 units and ReLU (Rectified Linear Unit) activation to learn complex patterns from the GAP layer's summarized features. Then added a dropout layer to prevent overfitting by randomly turning off 20% of the neurons during training, which helps in making the model more robust. Finally, added the output dense layer (final layer) with a unit for each class in our dataset and a softmax activation function to calculate a probability distribution over the classes.

Then we compile the model before training it, we choose categorical_crossentropy as our loss function to measure the difference between the predicted labels and the actual labels. Also, we used the Adam optimizer to adjust the learning rate throughout training, and accuracy as our metric. Then we trained our model for 20 epochs, and during training, we used callbacks to monitor the training process for early stopping, which monitors validation loss and stops the training process if it stops improving for 3 epochs to prevent overfitting. Another callback reduces the learning rate if the validation set performance does not get better. Here are the learning curves of our model's learning progress shown in (Figure 55).

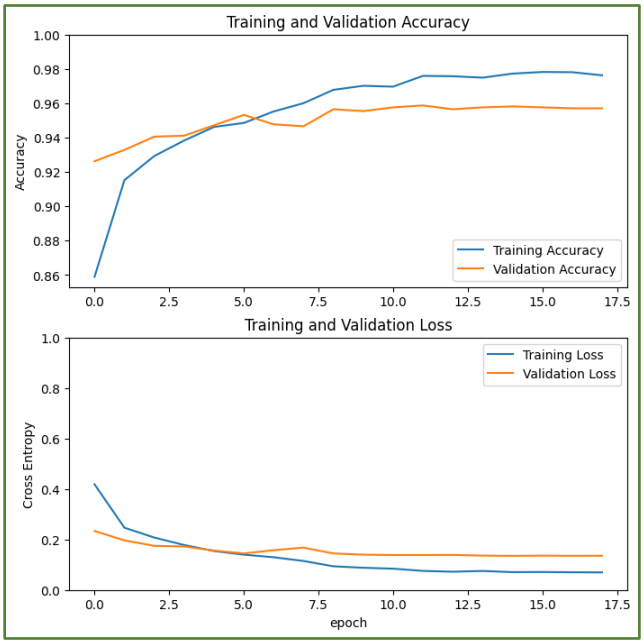


Figure 55: Learning Curves

Evaluation:

We evaluate the model's performance using the test dataset to assess the model's effectiveness in classifying recycling waste items as shown in (Figure 56). Our recycling item model achieved an excellent accuracy rate of 95.72%.

```
# evaluate the accuracy of the model on new data
test_loss, test_accuracy = EfficientNetV2S_model.evaluate(test_data, verbose=0)
```

```
Test Loss: 0.14484
Test Accuracy: 95.72%
```

Figure 56: Model Evaluation

Hyperparameter tuning:

Now we will select the optimal set of hyperparameters for our recycling item model to improve accuracy in classifying recycling items. As shown in (Figure 57) we will use Bayesian Optimization tuner from Keras tuner library to tune 3 hyperparameters: learning rate, dropout rate, number of units for the dense layer [84]. This algorithm first chooses a few combinations of hyperparameters randomly, then based on the performance of them it chooses the next best possible hyperparameters to find the optimal solution [85]. The model's hyperparameters were tuned over 30 trials with a focus on maximizing validation accuracy.

```
import keras_tuner as kt
from keras_tuner.tuners import BayesianOptimization

def build_model(hp):

 # Use hyperparameters to define the dropout rate, dense units and optimizer learning rate
    lr = hp.Float('learning_rate', min_value=1e-4, max_value=1e-2, sampling='LOG')
    DROPOUT_RATE = hp.Float('dropout_rate', min_value=0.0, max_value=0.5, step=0.1)
    DENSE_UNITS = hp.Int('dense_units', min_value=32, max_value=512, step=32)

 # Model architecture
    inputs = tf.keras.Input(shape=(384, 384, 3), name="input_layer")
    x = data_augmentation(inputs)
    x = base_model(x, training=False)
    x = tf.keras.layers.GlobalAveragePooling2D()(x)
    x = tf.keras.layers.Dense(DENSE_UNITS, activation='relu')(x)
    x = tf.keras.layers.Dropout(DROPOUT_RATE)(x)
    outputs = tf.keras.layers.Dense(len(class_names), activation='softmax')(x)
    model = tf.keras.Model(inputs=inputs, outputs=outputs, name="EfficientNetV2S")

    # Compile the model using the hyperparameters
    model.compile(loss='categorical_crossentropy',
                  optimizer=tf.keras.optimizers.Adam(learning_rate=lr),
                  metrics=['accuracy'])

    return model

# BayesianOptimization tuner
tuner = kt.BayesianOptimization(
    build_model,
    objective='val_accuracy',
    max_trials=30,  # number of trials
    directory='/content/drive/MyDrive/../../../',
    project_name='keras_tuner_bayesian'
)

# Search for the best hyperparameters
tuner.search(train_data, epochs=20, validation_data=validation_data,
             callbacks=[tf.keras.callbacks.EarlyStopping(monitor='val_loss',patience=3)])
```

Figure 57: Hyperparameter Tuning

After the search, the best hyperparameters were extracted: Dropout Rate of 0.2, Dense Units of 512, Learning Rate of 0.000546. These hyperparameters were then applied to our model (Figure 58), leading to a test accuracy of 96.21% (Figure 59).

```
# get the best hyperparameters, build the best model
best_hps = tuner.get_best_hyperparameters()[0]
EfficientNetV2S_model = tuner.hypermodel.build(best_hps)

#  train the model
EfficientNetV2S_history = EfficientNetV2S_model.fit(
                                                    train_data,
                                                    epochs=EPOCH,
                                                    steps_per_epoch=len(train_data),
                                                    validation_data=validation_data,
                                                    validation_steps=len(validation_data),
                                                    callbacks=EfficientNetV2S_callback)
```

Figure 58: Train Model with Best Hyperparameters

```
# evaluate the accuracy of the model on new data
test_loss, test_accuracy = EfficientNetV2S_model.evaluate(test_data, verbose=0)
```

```
Test Loss: 0.13077
Test Accuracy: 96.21%
```

Figure 59: Hyperparameter Tuning Model Evaluation

Fine-tuning:

To fine-tune our model, as shown in (Figure 61), we unfreeze the top 20 layers out of 513 layers (the less data we have, the less layers we can unfreeze) and continue training our model with a lower learning rate for another 20 epochs so only the weights in the unfrozen layers will be updated during training so the model's performance improves. Here are the learning curves before and after fine-tuning (Figure 60).

```
# make all layers in the base model trainable
base_model.trainable = True

# Fine-tune from this layer onwards
fine_tune_at = 20

# Freeze all layers except for the last 20
for layer in base_model.layers[:-fine_tune_at]:
  layer.trainable = False

# Compile the model
EfficientNetV2S_model.compile(loss='categorical_crossentropy',
                              optimizer=tf.keras.optimizers.Adam(
                              learning_rate = 0.0005461836650512608/10
                              ), metrics=['accuracy'])

# train the model
history_fine=EfficientNetV2S_model.fit(train_data,
                                       epochs=40,
                                       initial_epoch=EfficientNetV2S_history.epoch[-1],
                                       steps_per_epoch=len(train_data),
                                       validation_data=validation_data,
                                       validation_steps=len(validation_data),
                                       callbacks=EfficientNetV2S_callback)
```

Figure 61: Fine Tuning

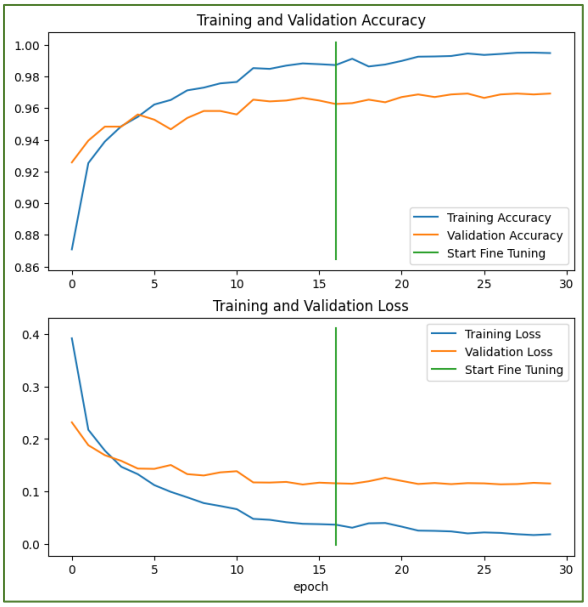


Figure 60: Fine-tuning Learning Curves

We evaluate the model's performance using test dataset to assess the model's effectiveness in classifying recycling waste items after fine-tuning (Figure 62). Our model has gained a few percentage points by 0.33% and result in test accuracy of 96.54%.

```
# evaluate the accuracy of the model on new data
test_loss, test_accuracy = EfficientNetV2S_model.evaluate(test_data, verbose=0)
```

```
Test Loss: 0.13116
Test Accuracy: 96.54%
```

Figure 62: Fine Tuning Evaluation

Model deployment:
In the final stage we selected Google Cloud Run as the platform of choice for deploying our model, following the deployment guidelines provided by Google [86], [87]. The process began with the installation of the Google Cloud SDK, followed by the initialization of the gcloud command line tool, which laid the groundwork for the subsequent steps. Next, we created a Dockerfile to specify the environment for our application and configured our project to use the Cloud Run service to ensure compatibility with Google's cloud infrastructure. We created a requirements.txt file to identify the dependencies required by our model. The deployment phase concluded with building and deploying the Docker image to Cloud Run, setting the stage for our model to run efficiently and at scale within the Google Cloud.ecosystem.

4.6.4 Taboua Mobile App Launch

Finally, we are pleased to announce the Taboua mobile application is now available for download on the Apple Store. This is a significant milestone in our commitment to advancing waste management practices in Riyadh city. Achieving this milestone was not easy; it took a while, and we faced many challenges and failed attempts along the way. But it is a big improvement towards reaching our goal.

- To download Taboua application from Apple store: Taboua Application
- To access the source code from our GitHub repository: Taboua GitHub Repository
- To explore the live version of our Taboua system: Live Taboua Website

Chapter 5:
System Evaluation

5 System Evaluation

In this chapter, we present the system evaluation for the Taboua mobile application, web application, including the experimental results for Taboua recycling item model, User Acceptance Testing (UAT), and quality attributes non-functional requitements (NFR) testing.

The Taboua team begins by evaluating the system function by function and conducting integrated function tests each time a new function is added. Then, in the experimental results phase for Taboua recycling item model, we assessed the performance of five different pre-trained CNN models to identify and classify various recyclable materials, namely ResNet50, ResNet101, InceptionV3, MobileNetV2, and EfficientNetV2S. However, among the models tested, EfficientNetV2S stood out with a test accuracy of 95.72%, which was further enhanced to 96.54% through hyperparameter tuning.

Next, we detail the results we obtained from the UAT for both Taboua web and mobile applications. During the UAT for Taboua system, we engaged twenty participants to evaluate Taboua system, with ten testing the mobile application and ten testing the web application. To gather comprehensive data, we used both interviews and questionnaires to collect valuable data from the participants refer to (Appendix C. Testing Data). This diverse approach allowed participants to describe their experience with the Taboua system through recorded spoken conversations in interviews and online written responses in questionnaires.

Finally, we discuss the quality attributes for Taboua system that evaluate the non-functional requitements. Some of the were evaluated through direct observation of user behavior during the testing of the Taboua system, while others were assessed through user feedback.

5.1 Experimental Results

After experimenting with various pre-trained CNN architectures including MobileNetV2, ResNet50, ResNet101, InceptionV3, and EfficientNetV2S that trained using our preprocessed dataset, as shown in (Table 9) metrics such as test accuracy, recall, f1-score, time taken to train the model, and number of epochs were measured.

Model	Test Accuracy	Precision	Recall	F1 score	Training Time(seconds)	Epochs
ResNet50	91.71%	0.92	0.92	0.92	1025.94	14
ResNet101	89.57%	0.90	0.90	0.90	2725.66	13
InceptionV3	91.49%	0.92	0.91	0.91	2872.86	20
MobileNetV2	90.17%	0.91	0.90	0.90	2823.13	20
EfficientNetV2S	95.72%	0.96	0.96	0.96	4445.97	18

Table 9: Pre-trained Model Experiments Results

We analyzed the training logs for each of them, where the ResNet50 was improving up to epoch 14 when early stopping was triggered due to the validation loss did not improve further. ResNet101 showed a similar result with early stopping at epoch 13. EfficientNetV2S showed steady progress and stopped early at epoch 18 due to no further validation loss improvement. In contrast, InceptionV3 kept improving throughout the full 20 epochs. On the other hand, MobileNetV2 showed slower progress, completing all 20 epochs without significant improvement, indicating potential under-fitting.

We found that EfficientNetV2S offered the highest test accuracy of 95.72%. It significantly outperforms other implemented models, gives higher accuracy, and less overfitting. although it had the longest training of 4445.97 seconds (approximately 1 hour and 24 minutes) than other models like ResNet50 and MobileNetV2. This trade-off in training time is justified by the superior performance metrics it achieves.

In the classification report (Figure 63), our recycling item model has very high precision across all classes (the lowest being 0.92 for 'trash'). The recall and F1 scores are high across all classes, showing our model's strong and balanced performance in accurately classifying different recyclable materials. In the visualized confusion matrix (Figure 64), the diagonal cells (from top left to bottom right) represent the number of correct predictions for each class and the non-diagonal cells show the instances of misclassifications. Our model is effective at classifying 'clothes' and 'glass', with a 0.98 accuracy rate for both, and minor confusion occur between 'cardboard' and 'paper', as well as 'plastic' and 'trash'.

Classification Report

	precision	recall	f1-score	support
cardboard	0.95	0.94	0.95	283
clothes	1.00	0.98	0.99	236
e-waste	0.98	0.98	0.98	155
glass	0.99	0.97	0.98	214
metal	0.94	0.97	0.96	234
paper	0.94	0.93	0.94	228
plastic	0.95	0.95	0.95	247
trash	0.92	0.94	0.93	224
accuracy			0.96	1821
macro avg	0.96	0.96	0.96	1821
weighted avg	0.96	0.96	0.96	1821

Figure 63: Model Classification Report

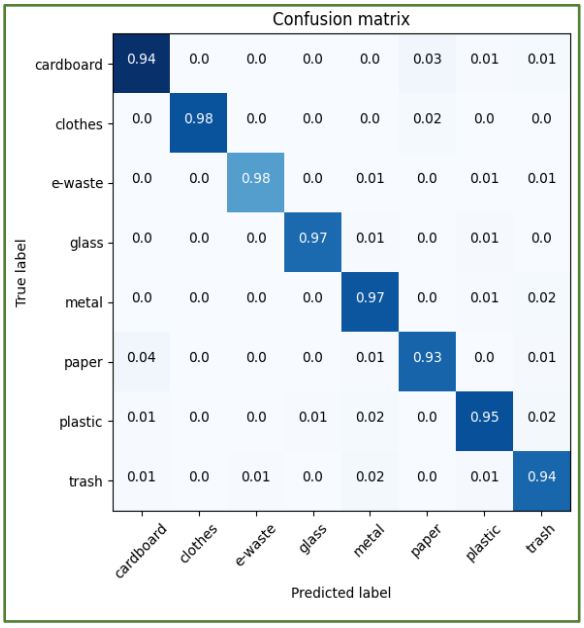


Figure 64: Model Confusion Matrix

After the model's hyperparameters were tuned over 30 trials, the best hyperparameters were extracted: Dropout Rate of 0.2, Dense Units of 512, Learning Rate of 0.000546. These hyperparameters were then applied to our model, leading to a test accuracy of 96.21% representing an improvement over our previous model, increasing the accuracy by 0.51%. After fine-tuning our model, it has gained a few percentage points by 0.33% and resulted in test accuracy of 96.54%. As shown in (Figure 65) we have tested our model with a sample of test images.

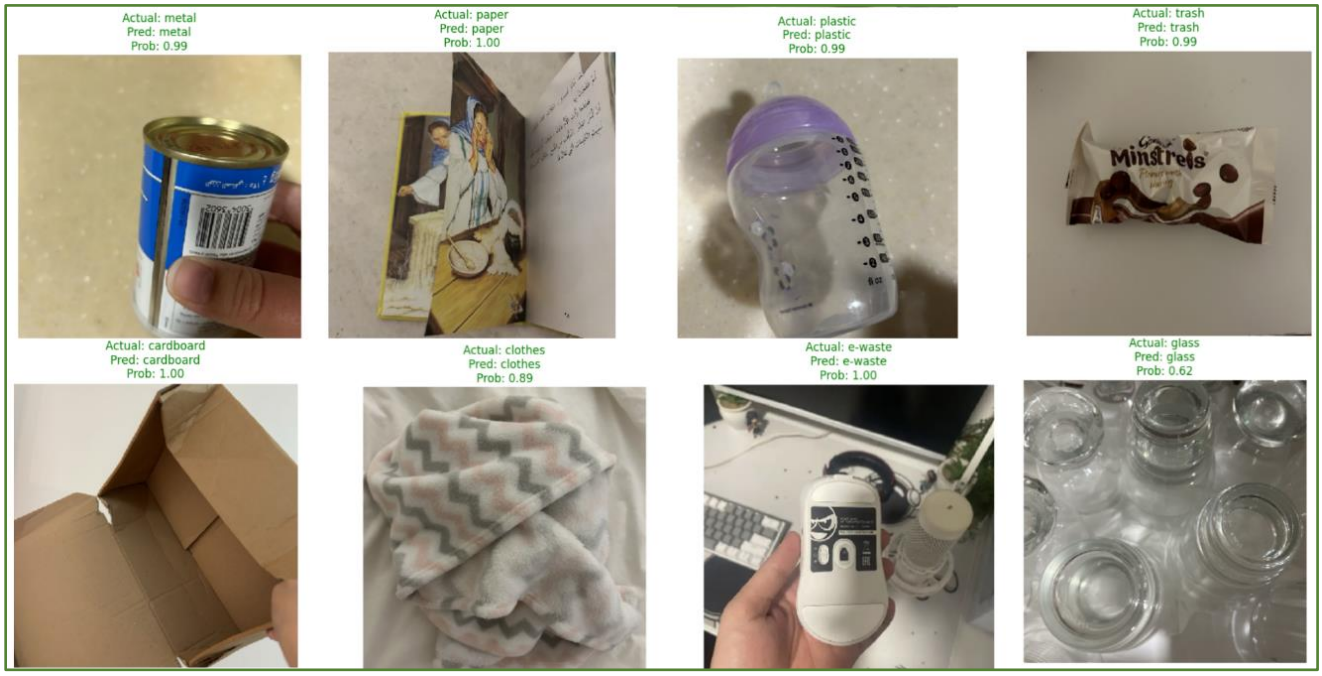


Figure 65: Sample of Images Prediction

5.2 User Acceptance Testing for Taboua Web Application

The user acceptance testing of our Taboua web application was conducted to evaluate its functionalities and user experience and verify it meets the standards. The test involved ten participants, three of the participants were from the Riyadh Municipality. Specifically, one participant works at the Customer Experience Center, and the second is associated with the Digital Transformation & Smart Cities Agency, while the third works as Web Developer. All participants from the Riyadh Municipality were reached through LinkedIn.

It is important to mention that we faced challenges in conducting the testing with the intended authority staff who hold positions at the Environmental Compliance and Sustainability Agency within the Riyadh Municipality. It was difficult to reach any other employees in this section as we could not find a way to contact them.

Before the Taboua system evaluation began, we greeted the participants and introduced them to our Taboua system and briefed them on how the web application manages the mobile application side and its essential functionalities so that they would be familiar with it.

The testing sessions were a combination of face to face and remotely. We conducted face to face testing for seven participants and the other three participants opted for remote testing through the Zoom application due to their busy schedules and some of them were outside Riyadh city at that time.
During these remote sessions, we observed their interaction by having them share their screens and enabling their cameras for an accurate observation.

During both face to face and remote testing sessions, participants were provided the website link with the needed user credentials and asked them to use their own devices to access the Taboua web application, which included a mix of laptops and desktop computers. Each participant's testing session lasted between 30 minutes to 1 hour.

At the end of the testing session, we conducted the interview questions and provided the participants access to an online questionnaire to collect their feedback.

The interview questions were as follows:

1. How was the garbage bin management process? Do you have any suggestions for improvement?
2. How was the recycling center management process? Do you have any suggestions for improvement?
3. How was the process of managing and processing garbage bin requests? Do you have any suggestions for improvement?
4. How was the process of managing and processing complaints? Do you have any suggestions for improvement?
5. How was the heat map of complaints and the analysis of its data? Do you have any suggestions for improvement?
6. As a supervisor at Taboua, how was the process of managing employee permissions? Do you have any suggestions for improvement?
7. Do you have any additional comments you would like to share about your experience with the Taboua system?

The interview questions were designed to gather in-depth insights into users' experiences with each of the web application functionalities such as garbage bin and recycling center management, garbage bin requests management, complaint management and heatmap, and if they have any suggestions for improvements. Lastly, Participants completed questionnaires that addresses specific aspects of Taboua web application non-functionalities and UX design. The questionnaires aimed to gather structured

feedback on various aspects of the website's usability, consistency, and reliability. The detailed questions in the questionnaires can be found in (Appendix C. Testing Data).

5.2.1 Participants Demographics

The participants selected for the Taboua web application UAT were chosen based on their expertise in using management systems within their professional roles. The demographics of the participants include individuals with ages ranging from 18 to 40 years old, with a gender distribution of 5 males and 5 females. In terms of educational background, the participants consist of 8 individuals with a bachelor's degree and 2 with a master's degree. The table below (Table 10) provides additional details about each participant, including their job title and whether they work at Riyadh Municipality.

Participants #	Gender	Age Range	Educational Level	Job title	Work on Riyadh Municipality
A1	Male	26-40	Master's degree	Digital Product Manager	Yes
A2	Female	18-25	Bachelor's degree	Accounting Manger	No
A3	Female	18-25	Bachelor's degree	Web Developer	Yes
A4	Female	18-25	Bachelor's degree	Senior digital experience specialist	Yes
A5	Female	26-40	Master's degree	Senior Awareness Specialist	No
A6	Male	26-40	Bachelor's degree	Project Manager	No
A7	Male	26-40	Bachelor's degree	Project Manager	No
A8	Male	26-40	Bachelor's degree	Business Developer	No
A9	Female	26-40	Bachelor's degree	Learning and Development Specialist	No
A10	Male	26-40	Bachelor's degree	Senior Project Manager	No

Table 10: Demographics of Participants (Taboua Web Application)

5.2.2 Questionnaire and Interview Results

In this part, we present the results obtained from UAT interview questions that focused on the functionality aspect of the Taboua web application. And we also present the results obtained from UAT questionnaire that focused on the website's usability, consistency, and reliability.

Interview Results

The overall feedback results obtained from UAT interview questions was positive, suggesting a high level of user satisfaction. Most of the participants did not encounter any challenges, where it emphasizes the excellent results and the ease of use of the system. The following points represent participants' feedback results on each of the website functionalities:

- **Garbage Bin Management:** The participants reported a high satisfaction level, indicating that retrieving bin information was straightforward. Also, they found that the process of adding and deleting garbage bins is intuitive and user-friendly. They suggested changing the tooltip appearance as it looked like a button. Also, to view the bin information as a window instead of a drawer and postal code search for easy bin tracking. Finally, they mentioned that when filtering the bin size, it's better to show how many bins are of that size.

- **Recycling Center Management:** The participants expressed satisfaction with the ease of accessing information about recycling centers. Also, they found that the process of adding and deleting recycling centers is easy. They suggested putting an image loader indicator, and when clicking on the center website link it should open in another window instead of the same window. Also, when adding a new center, they wished for the ability to determine the waste type if it is not listed. Finally, they suggested enhancing the opening hours functionality and making direct communication with centers via WhatsApp or calls.

- **Garbage Bin Requests Management:** The participants expressed satisfaction with handling users' garbage bin requests describing it as clear, and easy to use. They praised the way of locating and changing the requested bin where it cannot be moved from the requested location more the 50 meters, so it guarantees user satisfaction. They suggested that the user can attach a photo of where the bin is requested. Also adding more tracking status for control. Finally, it would be better to have information about the employee who handled the request.

- **Complaints Management:** The participants expressed satisfaction with handling users' complaints, describing it as clear, and easy to use. Most of participants expressed a positive experience without encountering any challenges. They suggested the ability to edit the complaint status after rejection, as it can be made by mistake. Also adding the response date along with the other info on the complaints list. Finally, it would be better to have information about the employee who handled the complaint.

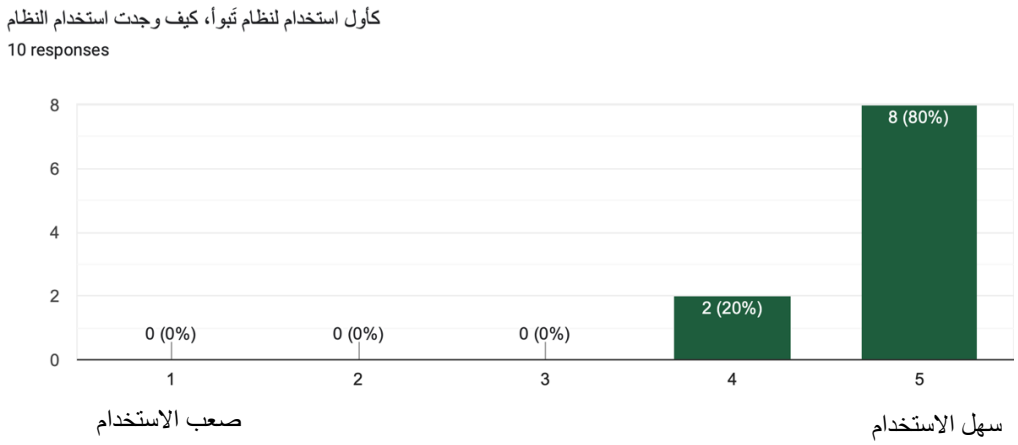
- **Complaints Heat-map:** The participants were impressed by the complaint heat-map functionality where they find it one of the best features on the website. They reported that the insights had clear and beautiful interfaces, and comprehensive information that will affect the decision-making process, especially the distribution of complaints among neighborhoods.

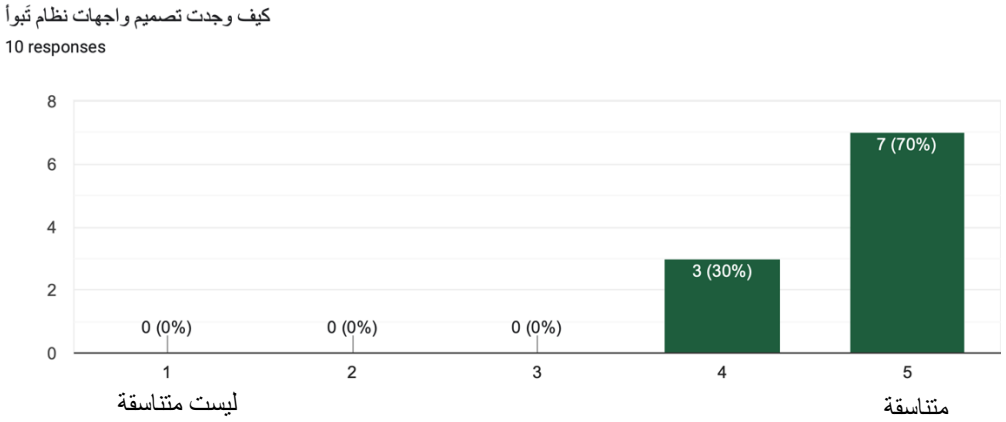
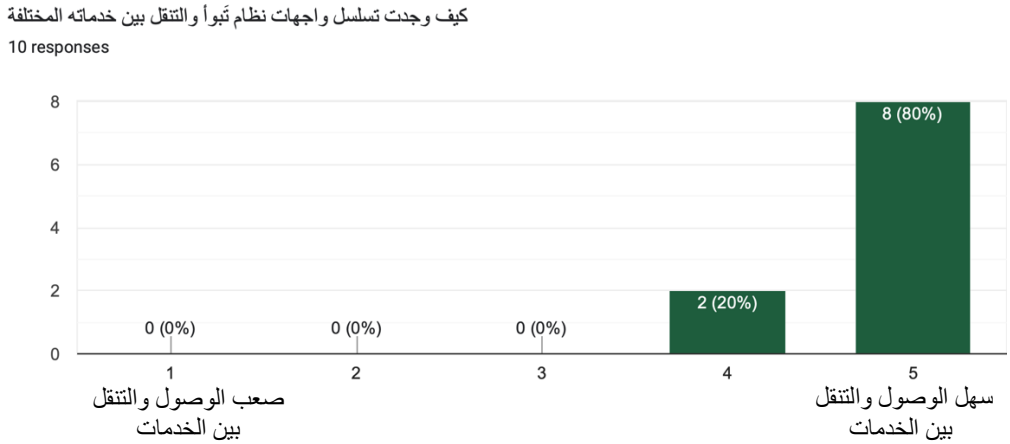
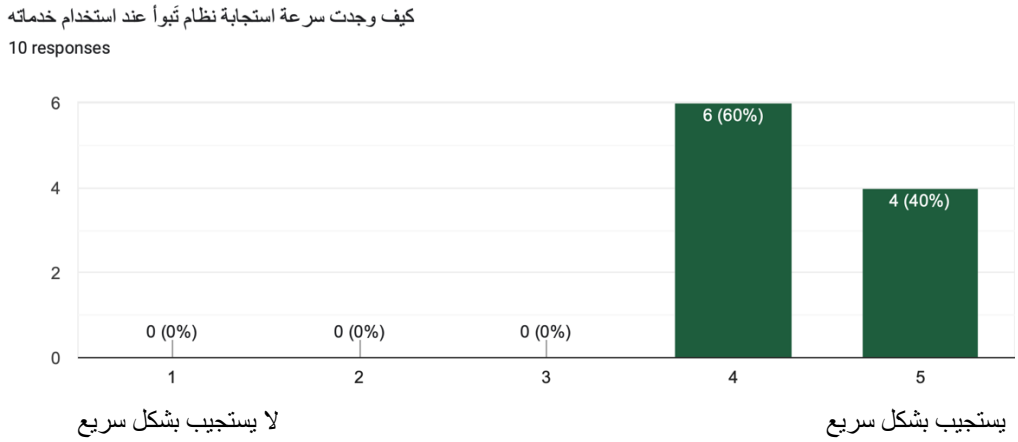
- **Staff Management:** The participants were fully satisfied with the staff management functionality, and they found that the process of managing staff registration was straightforward. They suggested adding more specified permissions and controls for each service on the web for more security.

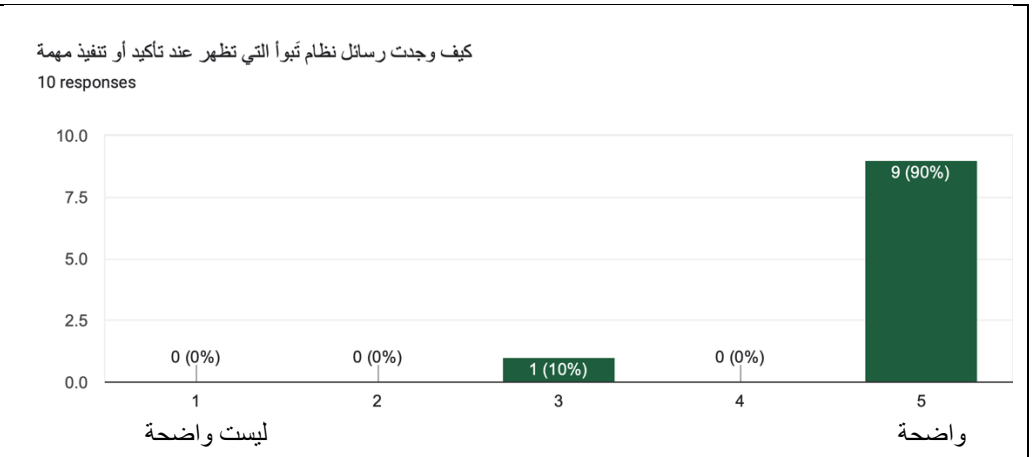
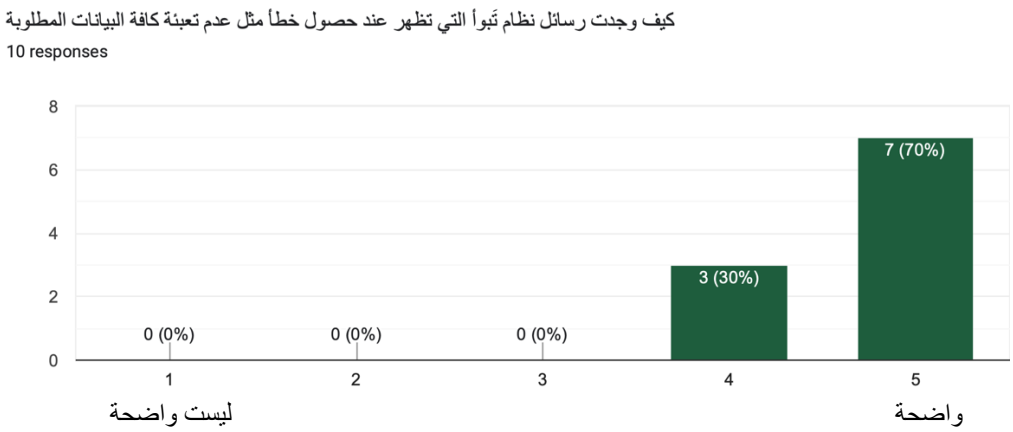
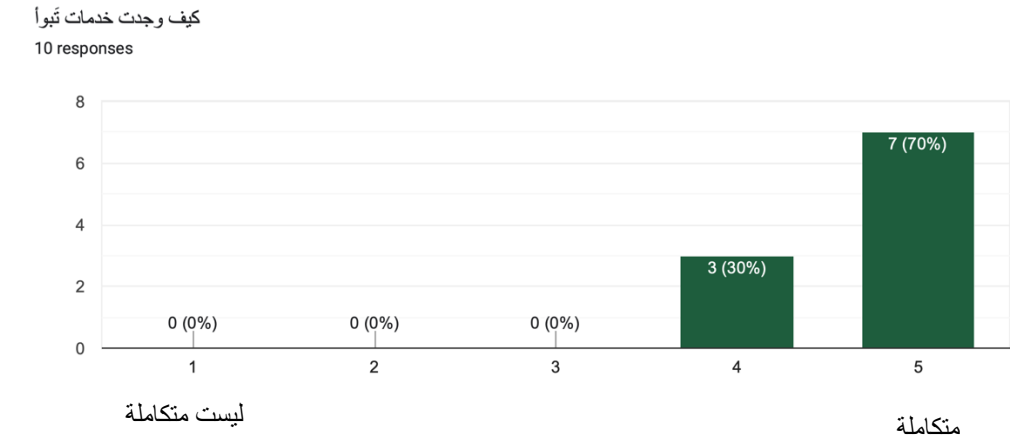
In conclusion, the feedback indicates that participants are generally satisfied with the Taboua web application, which offers a comprehensive range of services that align with their needs. Although some improvements and suggestions have been identified, there is an overwhelming feeling of enthusiasm for future enhancements, which indicates a positive outlook for the evolution of the Taboua web application.

Questionnaire Results

From the obtained UAT questionnaire results, the participants provided valuable feedback on usability, design, and functionality. The analysis provided in (Table 11) reflects participants' opinions on system usability, design, and navigation. Where participants found the Taboua system easy to use and had a consistent interface design. Also, they found the system responded rapidly and had clear confirmation and error messages. Finally, they agreed that the services are comprehensive and believed that Taboua services would be efficient and applicable in real-world settings.

Question	Response Analysis	Chart
For your first use of the Taboua system, how did you find the system to use?	80% of participants agreed that Taboua is easy to use. While 20% find it less easy to use.	

How did you find the design of the Taboua system interfaces	70% of participants agreed that interface design of Taboua app was consistent. While 30% find it less consistent.	
How did you find the sequence of system interfaces and navigation between its various services	80% of participants agreed that various Taboua services were easy to access and navigate. While 20% find it less easy.	
How did you find the response speed when using Taboua system services	40% of participants strongly agreed that Taboua responds rapidly when utilizing its services. 60% of participants found the response speed to be less rapid.	

How did you find Taboua messages that appear when confirming or executing a task	90% of participants agreed that Taboua confirmation messages are sufficiently clear. While 10% of participants unbiased.	
How did you find Taboua messages that appear when an error occurred like not filling all the required data	70% of participants strongly agreed that the Taboua error messages are sufficiently clear. While 30% find it less clear.	
How did you find Taboua system services	70% of participants strongly agreed that the Taboua system services are comprehensive and complete. 30% of participants agreed that the Taboua app services are comprehensive and completed.	

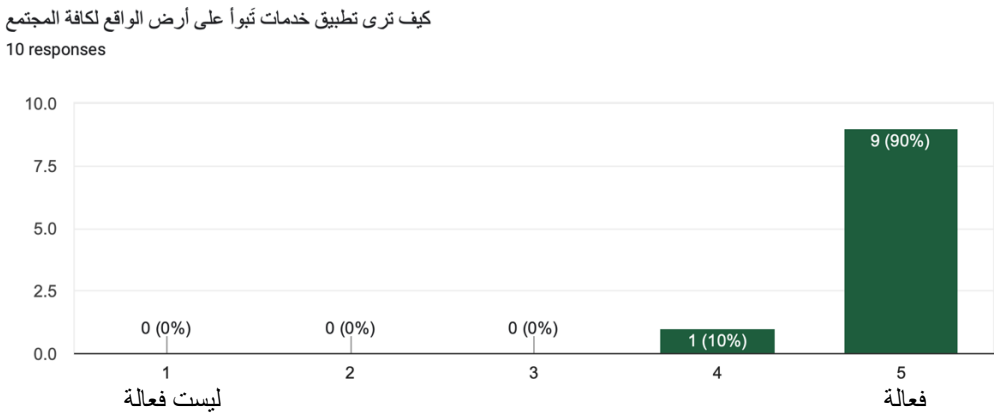
What are your thoughts on the potential application of Taboua services in a real-world setting?	90% of participants strongly agreed that Taboua services would be efficient and applicable in the real world. While 10% of participants agreed.	

Table 11: UAT Questionnaire Results (Taboua Web Application)

The last two questionnaire questions were open-ended questions to gather their overall experience with the system and if there are any features they look for in the future, refer to (Appendix C. Testing Data). The participants overwhelmingly express satisfaction with Taboua, describing it as clear, easy to use, and navigable. With some participants even characterizing the system as excellent and unexpectedly impressive. As A8 participant mentioned in (Figure 66):

Figure 66:User Acceptance Testing - A8 participant Feedback for Web Application

This positive feedback suggests a high level of user satisfaction with the overall usability and experience of Taboua. Also, for the features that participants look for in the future, they suggested a reporting functionality, bins GPS tracking and fill level sensors, date-based filtering for complaints and requests, and hope for the system to cover all regions of Saudi Arabia.

5.3 User Acceptance Testing for Taboua Mobile Application

The user acceptance testing of our Taboua mobile application was conducted to evaluate its functionalities and user experience and verify it meets the standards. During participant selection, we ensured a diverse age range to optimize the usability and efficiency of the Taboua mobile application for different age ranges to use the application and benefit from Taboua services.

The system testing was conducted with 10 participants representing a diverse age range and districts. We conducted in-person interviews with participants in their homes, scheduling according to their availability.

Before the Taboua mobile application evaluation began, we welcomed the participants and provided an overview of our Taboua system, outlining the key features and benefits of the service. We also took the permission of the participants to record their voice, which will assist us in analyzing their feedback effectively.

During the testing session, participants were instructed to download the Taboua mobile application from the Apple Store and to register. Following this, we requested that participants utilize the Taboua services. The duration of each participant's testing session ranged from 20 minutes to 30 minutes.

At the end of the testing session, we conducted interview questions and provided the participants access to an online questionnaire to collect their feedback.
The interview questions were as follows:

1. How was the display of the garbage bins? Do you have any suggestions for improvement?
2. How was the process of requesting garbage bin? Do you have any suggestions for improvement?
3. How was the display of the recycling centers? Do you have any suggestions for improvement?
4. How was the process of raising complaint? Do you have any suggestions for improvement?
5. How would you describe your use of the AI model? Do you have any suggestions for improvement?
6. Do you have any additional comments you would like to share about your experience with the Taboua mobile application?

The interview questions were designed to gather in-depth insights into users' experiences with each of the mobile application functionalities such as the effectiveness of the map in displaying garbage bins and recycling centers, requesting garbage bins, raising complaints, utilizing Taboua recycling item model, and if they had any suggestions for improvements. Finally, participants completed questionnaires that addresses specific aspects of Taboua mobile application non-functionalities and UX design. The questionnaires aimed to gather structured feedback on various aspects of the application's usability, consistency, and reliability. The detailed questions in the questionnaires can be found in (Appendix C. Testing Data).

5.3.1 Participants Demographics

The demographics of the participants selected for the Taboua mobile application UAT include individuals with ages ranging from 18 to 55 years old, with a gender distribution of 3 male and 7 females. In terms of educational background, the participants consist of one individual with PhD degree, 1 with master’s degree, 4 with a bachelor’s degree, 1 diploma’s degree, and 3 with high-school degree.

Participants are distributed between South and North Riyadh and from different districts such as Alaqiq, Alnafal, Alshifa, Alhazm, King Salman, and Alwadi. The table below (Table 12) provides additional details about each participant, including their educational qualifications, housing type, and district of residence.

Participants #	Gender	Age Range	Identity Type	Educational Level	Residence area in Riyadh	Housing Type	District
B1	Male	26-40	Citizen	Bachelor's degree	North	Apartment	Alaqiq
B2	Male	26-40	Citizen	Master's degree	North	Villa	Alnafal
B3	Female	41-64	Citizen	Bachelor's degree	South	Villa	Alshifa
B4	Female	18-25	Citizen	High-School degree	South	Villa	Alhazm
B5	Female	18-25	Citizen	High-School degree	North	Villa	King Salman
B6	Female	18-25	Citizen	High-School degree	North	Villa	King Salman
B7	Female	26-40	Citizen	Bachelor's degree	North	Apartment	King Salman
B8	Female	41-64	Citizen	PhD degree	North	Villa	King Salman
B9	Male	18-25	Citizen	Bachelor's degree	North	Villa	Alwadi
B10	Female	41-64	Citizen	Diploma's degree	North	Villa	Alwadi

Table 12: Demographics of Participants (Taboua Mobile Application)

5.3.2 Questionnaire and Interview Results

In this part, we present the results obtained from UAT interview questions that focusing on the Taboua mobile application's functionality. Also, we present the results obtained from UAT questionnaire that focused on the mobile application's usability, consistency, and reliability.

Interview Results

The overall feedback results of the UAT interview questions were positive, indicating a high level of user satisfaction. Most participants did not encounter any difficulties, which is indicative of the application's excellent performance and ease of use. The following points represent the participants' feedback findings on each of the mobile functionalities:

- **Garbage Bin Placements:** The participants expressed a high level of satisfaction, indicating that retrieving bin information was straightforward. Additionally, the participants expressed satisfaction with the integration of Google Maps with the location of garbage bins. They noted that this feature facilitates convenient access to garbage bins, improving waste management in their daily lives.

- **Recycling Center Placements:** The participants expressed satisfaction with the ease of accessing information about recycling centers. Furthermore, they reported the effectiveness of the map, which displays the centers and their respective information in a comprehensive and clear manner. Additionally, they recommended that the map be updated to include more recycling centers in applications that accept different types of waste.

- **Garbage Bin Request:** The participants expressed satisfaction with the process of requesting a garbage bin, describing it as clear and flexible. Furthermore, the participants indicated that the process of requesting a garbage bin is straightforward and accessible to anyone, without the need for assistance from an authority. Furthermore, one of the participants proposed that the message that appears when a request for a garbage bin should be more explicit regarding the request for the placement of the bin on the street.

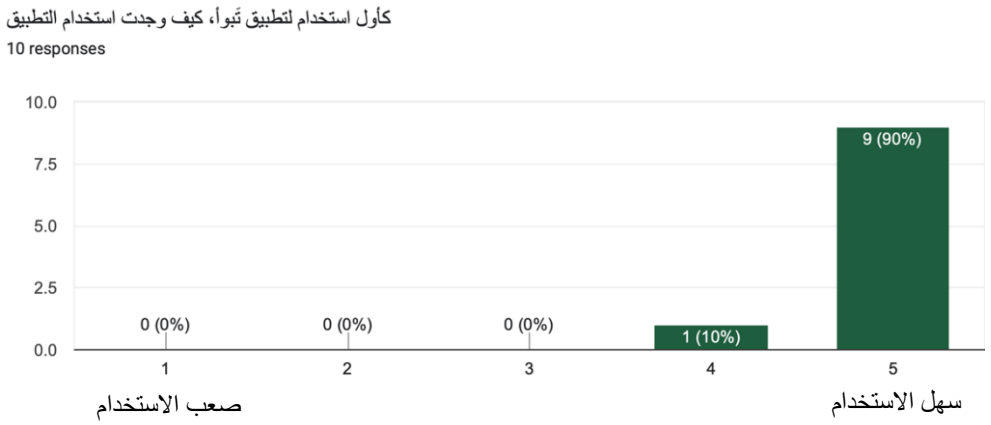
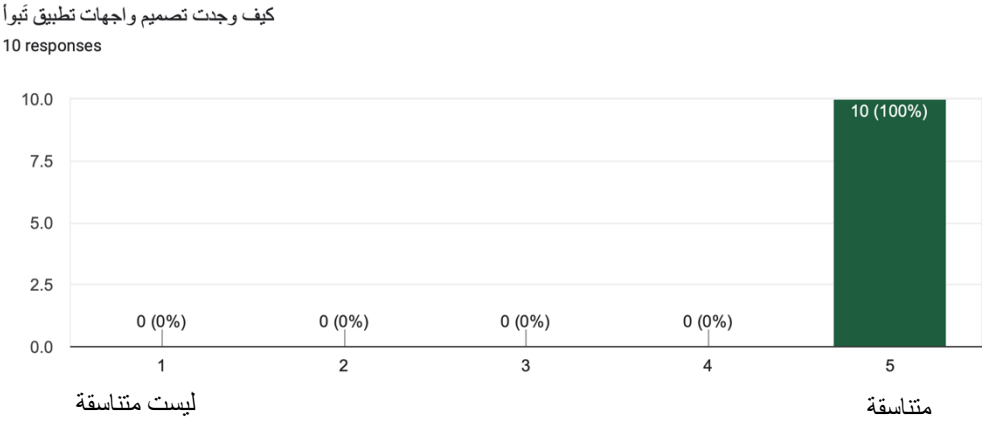
- **Raise Complaint:** The participants expressed a high level of satisfaction, indicating that the process of raising a complaint was straightforward. Additionally, they noted that the procedure for raising a complaint was clearly outlined and that all the necessary information to do so was readily accessible.

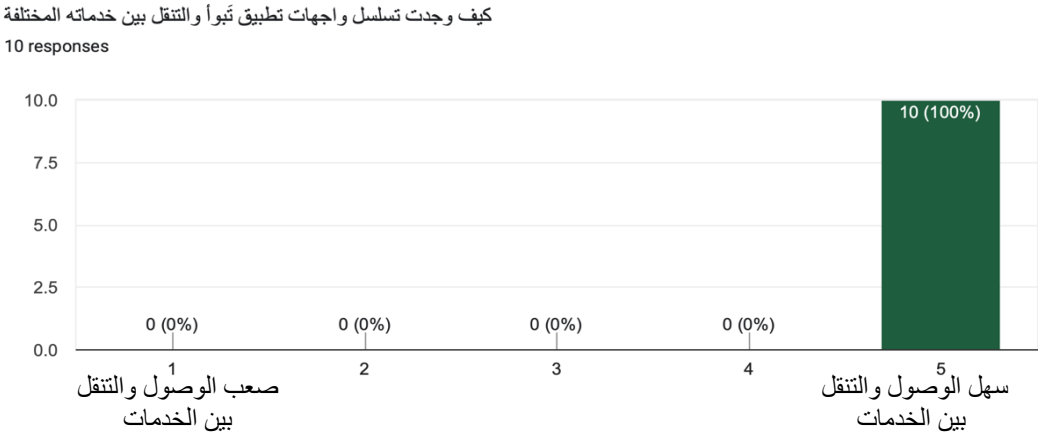
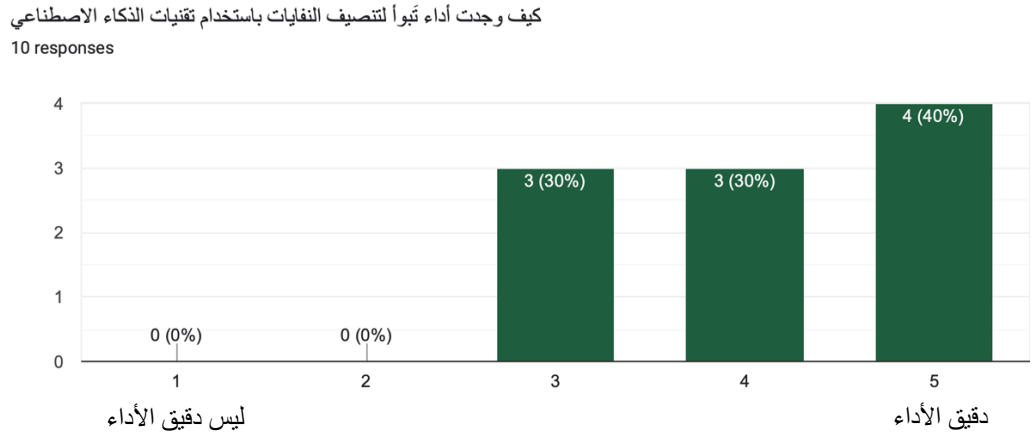
- **Taboua Recycle Item Model:** The participants were highly impressed by the incorporation of AI into the classification of waste, which they regarded as one of the most notable features of the Taboua mobile application. Additionally, they expressed a high level of satisfaction with the display of recycling centers based on waste type. They propose that the model prediction time be enhanced to achieve greater speed. In addition, the participants suggest that the waste type be predicted for more than one item on the same image and that a greater variety of waste types be included into Taboua Recycle Item Model.

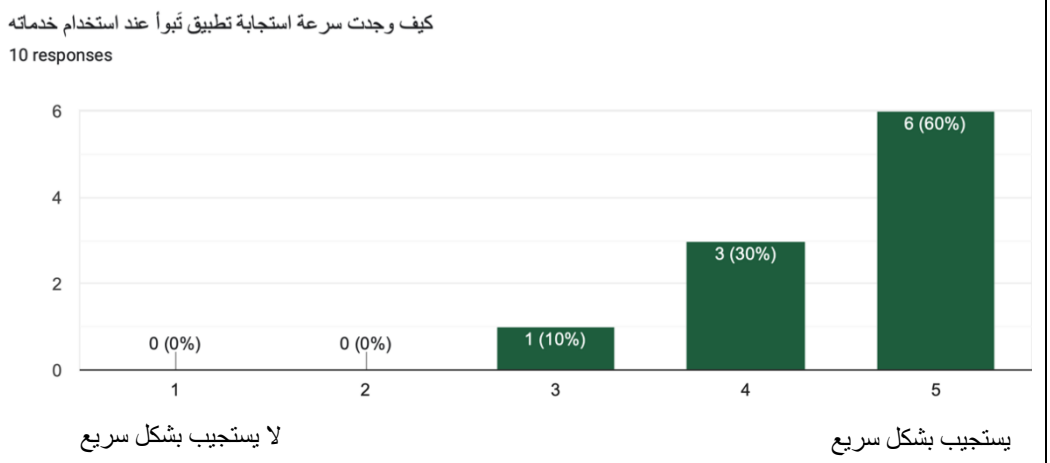
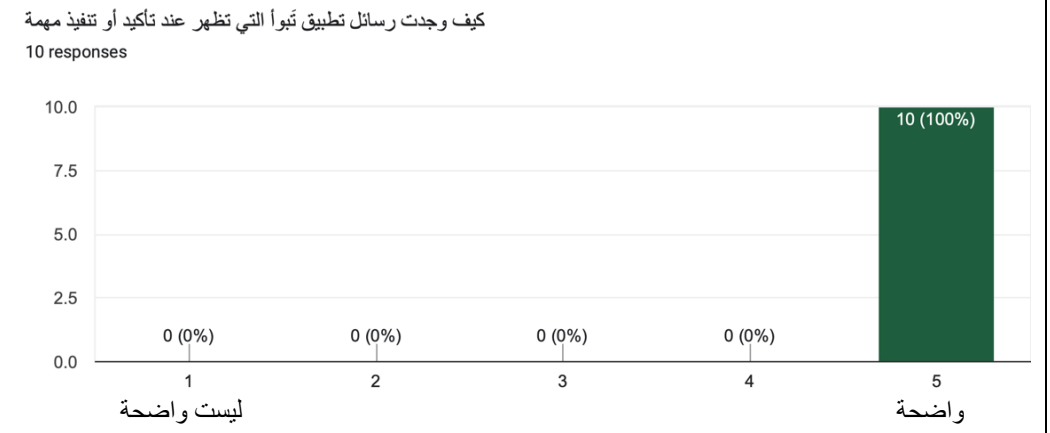
In conclusion, the feedback indicates that participants are generally satisfied with the Taboua mobile application, which offers a comprehensive range of services that align with their needs. Although some improvements and suggestions have been identified, there is an overwhelming feeling of enthusiasm for future enhancements, which indicates a positive outlook for the evolution of the Taboua mobile application.

Questionnaire Results

As illustrated in (Table 13), the questionnaire analysis reflects the participants' opinions on the mobile application regarding various non-functional measures, including usability, consistency, and reliability. The participants indicated that the Taboua system was straightforward to use and had a consistent interface design. Furthermore, the system was observed to respond promptly and to provide clear confirmation and error messages. Finally, the participants agreed that the services were comprehensive and believed that the Taboua services would be effective and applicable in real-world settings.

Question	Response Analysis	Chart
For your first use of the Taboua system, how did you find the system to use?	90% of participants agreed that Taboua is easy to use. While 10% find it less easy to use.	
How did you find the design of the Taboua system interfaces	All participants agreed the interface design of Taboua app was consistent.	

How did you find the sequence of system interfaces and navigation between its various services	All participants agreed that various Taboua services were easy to access and navigate.	
How did you find a performance of Taboua waste classification that used artificial intelligence technologies	40% of participants strongly agreed the Taboua waste classification is the had accurate performance. 30% of participants agreed the Taboua waste classification is had accurate performance. While 30% of participants unbiased.	

How did you find the response speed when using Taboua system services	60% of participants strongly agreed of Taboua responds rapidly when utilizing its services. 30% of participants agreed of Taboua responds rapidly when utilizing its services. While 10% of participants unbiased.	
How did you find Taboua messages that appear when confirming or executing a task	All participants agreed that Taboua confirmation messages are sufficiently clear.	

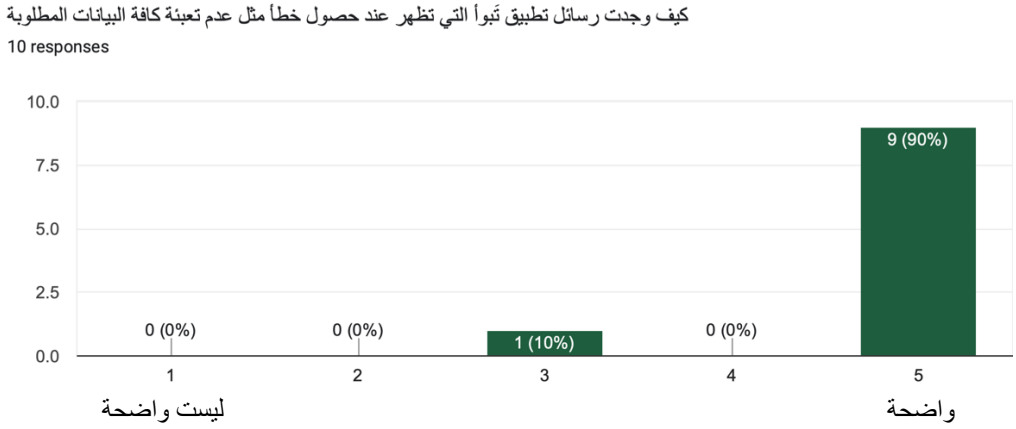
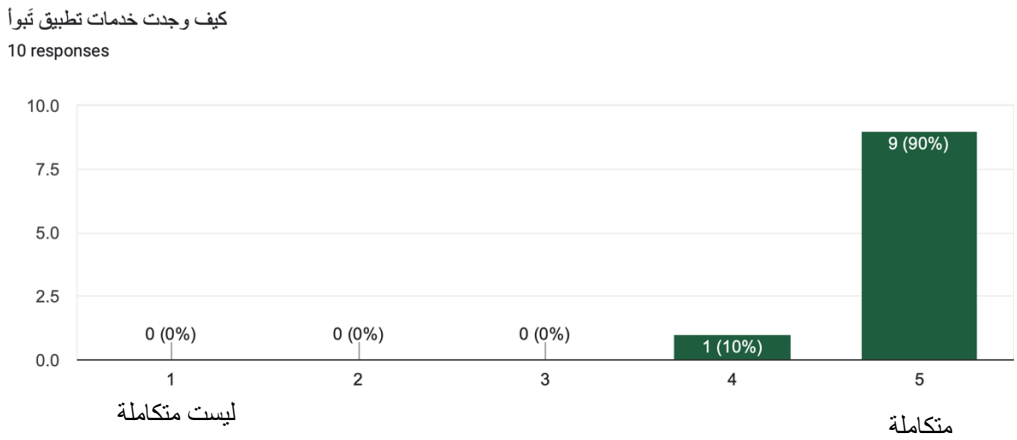
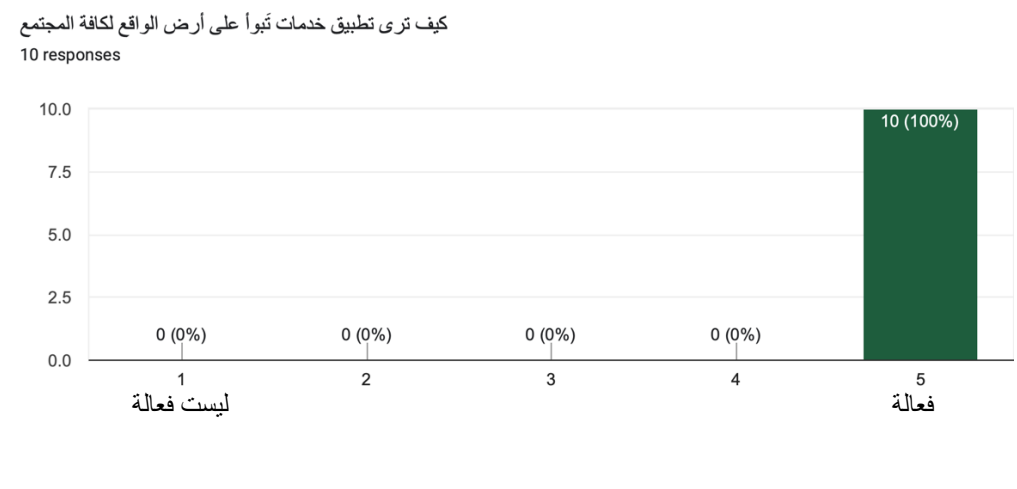
How did you find Taboua messages that appear when an error occurred like not filling all the required data	90% of participants strongly agreed that the Taboua error messages are sufficiently clear. While 10% of participants unbiased.	
How did you find Taboua system services	90% of participants strongly agreed that the Taboua app services are comprehensive and complete. While 10% of participants agreed.	
What are your thoughts on the potential application of Taboua services in a real-world setting?	All of the participants strongly agreed that Taboua services would be efficient and applicable in the real world.	

Table 13: UAT Questionnaire Results (Taboua Mobile Application)

The last two questionnaire questions were open-ended to ascertain their overall experience with the system and any desired future features refer to (Appendix C. Testing Data). The participants expressed overwhelming satisfaction with the Taboua mobile application, noting that it is user-friendly, consistent, and simplifies daily lives. As shown in (Figure 67) B2 participant described it as innovative, unique, and easy to use:

Figure 67:User Acceptance Testing - B2 participant Feedback for Mobile Application

Furthermore, all participants agreed that the Taboua is applicable to a real-world setting. As shown in (Figure 68), the B5 participant's description of the experience was highly positive, resulting in a positive outlook for the future and an aspiration to extend the Taboua globally.

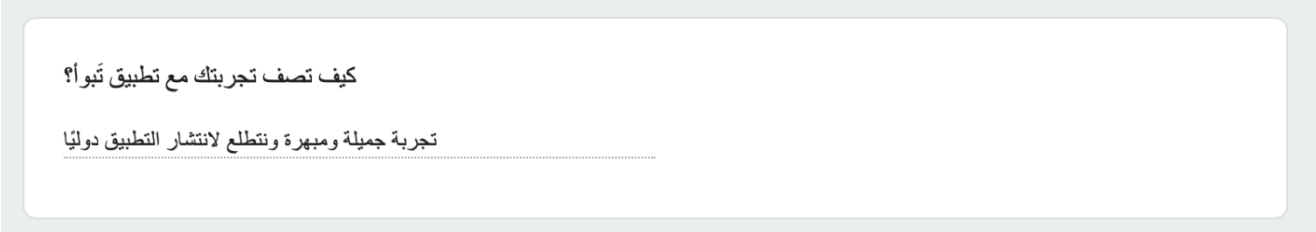


Figure 68:User Acceptance Testing - B5 participant Feedback for Mobile Application

For future developments, participants proposed the addition of a service that would collect recyclable waste from their homes and deliver it to recycling centers. Furthermore, they suggested the provision of information regarding the garbage collection times for each area.

5.4 Quality Attributes (NFR testing)

The quality attribute table, shown in Table 14, presents the non-functional system requirements for Taboua. It details the specific quality attributes associated with each user story, systematically linking them to the relevant measures and results.

User Story	Quality Attribute	Measure	Result
As a new Taboua User (Guest + Registered), I want to learn how to use each feature in the system within three minutes, so I can save time and not get frustrated and find another application to use.	Learnability: How fast is it for users to complete the main actions once they see the interface?	Measure the time it takes for a new user to complete specific tasks successfully. Users need 3 minutes to complete each action.	To assess the learnability of the Taboua app, we evaluated 10 different users in terms of their completion time for each feature. • User 1: 40 sec to 2 min • User 2: 40 sec to 2 min • User 3: 30 sec to 1 min • User 4: 30 sec to 2 min • User 5: 45 sec to 2 min • User 6: 30 sec to 1 min • User 7: 40 sec to 2 min • User 8: 50 sec to 2 min • User 9: 35 sec to 1 min • User 10: 55 sec to 2 min The results showed that the average completion time ranged from a minimum of 39.5 seconds to a maximum of 1 minute and 42 seconds. This performance is considered successful as it meets our acceptance criteria.
As a Taboua User (Guest + Registered), I want the recycling item model to be available 90% of the time I try to scan the waste item so that I can find the nearest recycling centers.	Availability: How readily is the system operational and accessible when required for use?	Availability = (Total Operating Time −Downtime)/Total Operating Time×100%. The Taboua Recycling Item Model need to be available 90% of the time.	To measure the availability of the Taboua model, we recorded the operating time and downtime for 10 users during the testing sessions. The recorded times were: • User 1: 3 min • User 2: 4 min

			• User 3: 2 min • User 4: 3 min • User 5: 3 min • User 6: 2 min • User 7: 3 min • User 8: 3 min • User 9: 2 min and 30 sec • User 10: 2 min As there was no downtime reported during these periods, the model was available for the entire operating time, which totals 27 minutes and 30 seconds. This means that the availability of the model is 100%, exceeding our target of 90% and confirming its availability and effectiveness in serving users consistently.
As a Taboua User (Guest + Registered), I want the recycling item model to have a high accuracy of at least 90% in waste categorization so that I can rely on the system to correctly identify and classify the waste types.	Accuracy: How precisely does the system's outputs or results match the expected outcomes?	Accuracy = (Number of correct predictions / Total number of predictions) ×100%. The Taboua Recycling Item Model needs to achieve at least 90% accuracy.	The accuracy of the 'Taboua' Recycling Item Model was evaluated across 10 users, with varying numbers of predictions made by each. The total number of correct predictions summed up to 27 out of 30 possible predictions. This results in an accuracy rate of 90%,

			exactly meeting our target of at least 90% accuracy. This confirms the model's reliability in correctly identifying and classifying waste types, ensuring users can depend on the system for accurate waste categorization.
As a Taboua User (Guest + Registered), I want the system to have an intuitive and consistent user interface layout, so that I can easily locate and access different functionalities across the system.	Recognizability: How quickly and accurately can users identify and understand the interface elements and functions based on common conventions or prior experience?	Measure the time it takes for users to locate and identify key interface elements necessary to complete specific tasks. Users should be able to recognize and understand the purpose of key interface elements within 1 minute for each critical action.	In evaluating the recognizability of the Taboua app's user interface, we tracked the time it took for the 10 participants to locate and identify essential interface elements needed to complete specific tasks. The times recorded were as follows: • User 1: 30 secs • User 2: 20 secs • User 3: 40 secs • User 4: 30 secs to 2 mins • User 5: 15 secs • User 6: 30 secs • User 7: 20 secs • User 8: 30 secs • User 9: 25 secs • User 10: 42 secs The average time across all users was 32.7 seconds. These results confirm that the system typically allows users to

			recognize critical interface elements in less than a minute, effectively demonstrating the simplicity and consistency of the interface.
As a Taboua User (Guest + Registered), I want the system to have descriptive and user-friendly error messages, so that I can understand and resolve any issues that may occur during system interactions.	User-Error Protection: How effectively does the system prevent user errors and provide clear feedback to help users recover from mistakes easily and accurately?	Measure the time it takes for users to successfully resolve errors on their own after receiving the error message. Users should understand and resolve errors within 1 minute of encountering the error message.	To evaluate the Taboua app's user error protection, we measured the time it took users to understand and resolve errors on their own after encountering an error message. the results are as follows: • User 1: 3 secs • User 2: 3 secs • User 3: No errors • User 4: 20 secs • User 5: 4 secs • User 6: 5 secs • User 7: 4 secs • User 8: 5 secs • User 9: No error • User 10: 40 secs Among the 8 users who encountered errors, the average time taken to resolve them was approximately 10.5 seconds. This indicates that the system effectively prevents user errors and provides clear feedback to help users recover from errors quickly and efficiently.

As a new Taboua Staff, I want to learn how to use each feature in the system within three minutes, so I can save time and not get frustrated and find another application to use.	Learnability: How fast is it for staff to complete the main actions once they see the interface?	Measure the time it takes for a new staff to complete specific tasks successfully. Staff need 5 minutes to complete each action.	To assess the learnability of the Taboua website we recorded the time it took each staff member to successfully complete key actions after first encountering the interface. The times recorded were as follows: • Staff 1: 30 sec to 2 min • Staff 2: 1 min to 3 min • Staff 3: 1 min to 4 min • Staff 4: 1 min to 5 min • Staff 5: 1 min to 6 min • Staff 6: 1 min to 2 min • Staff 7: 1 min to 4 min • Staff 8: 1 min to 3 min • Staff 9: 2 min to 3 min • Staff 10: 2 min to 5 min The results showed that the average completion time ranged from a minimum of 1 minutes and 15 seconds to a maximum of 4 minute and 70 seconds. This performance is considered successful as it meets our acceptance criteria.
As a Taboua Staff, I want the system to have descriptive and user-friendly error messages, so that I can understand and resolve any issues	User-Error Protection: How effectively does the system prevent staff errors and provide clear feedback to help users	Measure the time it takes for staff to successfully resolve errors on their own after receiving the error message.	To evaluate the effectiveness of the Taboua website's user error protection, we measured the time it took staff to understand and

that may occur during system interactions.	recover from mistakes easily and accurately?	Staff should understand and resolve errors within 1 minute of encountering the error message.	resolve errors on their own after receiving error messages. the results are as follows: • Staff 1: 5 secs • Staff 2: 3 secs • Staff 3: 5 secs • Staff 4: 5 secs • Staff 5: 30 secs • Staff 6: 10 secs • Staff 7: No errors • Staff 8: 5 secs • Staff 9: 7 secs • Staff 10: No errors Among the 8 staff members who encountered errors, the average time taken to resolve them was approximately 8.75 seconds. This indicates that the system effectively prevents user errors and provides clear feedback to help users recover from errors quickly and efficiently.
As a Taboua Staff, I want the system to have an intuitive and consistent user interface layout, so that I can easily locate and access different functionalities across the system.	Recognizability: How quickly and accurately can staff identify and understand the interface elements and functions based on common conventions or prior experience?	Measure the time it takes for staff to locate and identify key interface elements necessary to complete specific tasks. Staff should be able to recognize and understand the	To evaluate the recognizability of the Taboua website interface, we recorded the time it took 10 staff members to locate and identify key interface elements needed to perform specific tasks.

		purpose of key interface elements within 1 minute for each critical action.	The times recorded were as follows: Staff 1: 40 secs Staff 2: 45 secs Staff 3: 35 secs Staff 4: 50 secs Staff 5: 30 secs Staff 6: 50 secs Staff 7: 1 min Staff 8: 40 secs Staff 9: 35 secs Staff 10: 1 min The average time for all staff was 44.5 seconds. These results confirm that the system typically allows staff to identify critical interface elements in less than a minute, effectively demonstrating the simplicity and consistency of the interface.

Table 14: Quality Attributes (NFR testing)

5.5 Discussion

In this section, we conduct a detailed discussion of user experiences in both the Taboua mobile and web applications. It provides insights into users' satisfaction, feedback, and the ongoing efforts by the Taboua team to make improvements to the challenges to ensure user satisfaction and the continuous enhancement of Taboua system.

Taboua Mobile Application

After analyzing the interviews, questionnaire, and quality attributes (NFR) for the Taboua mobile application, we found that the participants were all satisfied with their experience, highlighting its user-friendly and consistent interfaces, responded rapidly, have clear messages, and comprehensive services. These outcomes underscore a successful and high level of user satisfaction.

The Taboua mobile app has successfully met its non-functional requirements (NFR) criteria successfully. For Learnability, participants effectively completed tasks within the specified time frame (3 minutes at most), indicating that the system's design facilitates quick learning. In terms of Availability and Accuracy, the recycling item model was fully operational with no downtime during testing, achieving 100% availability and maintaining 90% accuracy. Regarding Recognizability and User-Error Protection, except for one participant, all participants were able to recognize crucial interface elements within one minute, while all participants were able to resolve errors within one minute.

However, there is an opportunity for further improvement in the mobile application, particularly in areas where participants faced challenges, such as in garbage bin requests, one participant highlighted the need for a clearer instructing message to assist in accurately locating the requested bin.

Furthermore, regarding the Taboua recycle item model, participants praised the integration of AI in classifying waste materials, but some participants noted that sometimes the model mispredicted certain images and took a long time to predict, which led to recommendations for enhancing the model's accuracy and reducing prediction time. Also make the model predict more than one item on the same image.

Finally, the participants shared additional recommendations such as in recycling center placements, some participants suggested adding more recycling centers. Also, implementing a service to collect recyclable waste directly from homes and transport it to recycling centers. Additionally, they recommended providing information about garbage collection schedules for each area. The Taboua team will consider these recommendations to enhance service accessibility and user convenience.

Taboua Website Application

After analyzing the interviews, questionnaire, and quality attributes (NFR) for the Taboua web application, we deduce an overall positive and satisfactory user experience, describing it as user-friendly and have consistent interfaces, responded rapidly, have clear messages, and comprehensive services. These outcomes underscore a successful and high level of user satisfaction.

The Taboua web app has successfully met its non-functional requirements (NFR) criteria successfully. For Learnability, except for one participant, all participants effectively completed tasks within the specified time frame (5 minutes at most). Regarding Recognizability and User-Error Protection, all participants were able to recognize crucial interface elements and resolve errors within one minute, reflecting the system's user-friendly and intuitive design.

However, there is an opportunity for further improvement in the web application, particularly in areas where participants faced challenges, such as in garbage bin management, participants suggested clarifying the user interface by changing the design of the help messages (tooltips) to distinguish them from buttons, and by displaying bin information in a pop-up window rather than a sliding sidebar, incorporating postal code search for easy tracking, and displaying the quantity of bins available by size.

Furthermore, regarding the recycling center management, improvements suggested including adding an image loader indicator, ensuring that links to center websites open in new windows, and providing the ability to write a new waste type if not listed with the already specified types of waste when adding new center. Also enhancing the opening hours feature to be more direct, incorporating direct communication options like WhatsApp or calls with centers. Regarding complaints management, participants requested the ability to edit the status of a complaint after rejection to correct any mistakes and advocated for adding the response date to the complaints list.

Finally, the participants shared additional recommendations such as for bin requests management and complaints management, suggestions include date-based filtering for complaints and requests, adding more detailed tracking statuses for better control. And to have information about the employee who handled the request or complaint. As for staff management, they suggested adding more specified permissions and controls for each service on the web, enhancing security and administrative functionality. Lastly, they hope for the system to cover all regions of Saudi Arabia.

In summary, the discussions highlight a positive overall user experience for both the Taboua web and mobile applications. User feedback has been acknowledged, and decisions to implement improvements are currently in progress. In response, for the mobile application, the Taboua team is committed to enhance recognizability by making the interfaces more easily identifiable and understandable. Also improving the recycling item model accuracy, efficiency, and explore more recycling centers across Riyadh city. While for the web application, the Taboua team will work on enhancing enhance the learnability by having a straightforward and more consistent interface. Also plans to modify the bin requests and complaints management system to accommodate the participants' changes, improving flexibility and providing essential information. Also review and refine the staff management permission settings to ensure robust security and operational efficiency.

Chapter 6: Conclusions and Future Work

6 Conclusions and Future Work

Taboua waste management system emerges as a pivotal initiative in addressing the pressing challenges faced by Riyadh in its quest for enhanced waste management and environmental sustainability. The importance of effective waste management cannot be overstated, particularly in the context of Saudi Arabia's Vision 2030, which envisions sustainable cities and communities for future generations.

We have successfully implemented all the functionalities and features planned for the first and second releases of the Taboua project, as outlined in our roadmap. For the mobile application, this includes a number of features: users can view waste bins and recycling centers, request new bins, manage their accounts through registration, login, logout, guest user access, account deletion and profile editing functions, submit complaints and utilize the Recycling Item Classification Model. We also reached the milestone of submitting the Taboua mobile application for release on the Apple App Store. On the website side, this includes the management of garbage bins and recycling centers, staff registration, user account management (login and logout), and managing garbage bin requests. The website also facilitates complaints management and a heat map to visualize complaints Lastly, our website has been successfully hosted, making these services accessible online.

As we reflect on the journey of developing Taboua, several key aspects come to light:

Global and Local Impact:
The impact of Taboua extends beyond local boundaries, it is positioned to contribute significantly to Riyadh's operational efficiency and environmental sustainability. Its potential to foster a heightened sense of responsibility within local communities aligns seamlessly with broader global goals of promoting eco-friendly practices.

Challenges Encountered:
The development of Taboua was not without its challenges. A primary obstacle lay in the initial difficulty of engaging with a society largely unaware and disinterested in waste management. Communication hurdles with the Riyadh Municipality added complexity, and the shortage of data posed a significant setback, leading to manual data collection as detailed in the data collection section.

Limitations of the System:
Due to the lack of available data related to waste management in Riyadh, we could not include certain features in our Taboua system. Specifically, we were unable to incorporate the waste collection time feature, which would have given detailed information about when waste is collected in each district of Riyadh. For more information on how we gathered our data, refer to (4.4.2: Data Collection and Preparation).

Main Contribution of the Project:

The primary contribution of Taboua lies in its holistic approach to waste management. Through its user-friendly interfaces, web, and mobile applications, Taboua not only simplifies current waste management processes but also encourages individuals to actively participate in sustainable practices. The envisioned streamlined waste disposal and recycling processes align harmoniously with the 2030 vision for a more sustainable future. Additionally, Taboua promotes increased awareness about recycling items and the availability of recycling centers, further encouraging informed and active participation in sustainable waste disposal practices.

Future Work:

In the next phase of Taboua project, we intend to improve the Taboua system by adding sensors to the bins. These sensors will be able to determine both the location of the bins and the fullness level. This development aims to increase Taboua' s efficiency and recognition as a leading waste management system in Riyadh and across Saudi Arabia. Additionally, a significant step forward will be the incorporation of نفاذ | Nafath, for secure and convenient login processes on both the website and the mobile application. This move aims to streamline user access while ensuring the highest levels of security and user experience. Another important step forward will be adding the English language on both the website and the mobile application, making Taboua accessible to all non-Arabic speakers. The ongoing collaboration between technology, user interaction, and forward-thinking objectives forms the essence of Taboua.

In conclusion, Taboua serves as a guide for making Riyadh's waste management better. It not only addresses current challenges but also leads the way for a significant change in how we handle waste. When we think about all the things Taboua does making it easy for people to use, giving power to individuals, and spreading awareness it's not just a fix for now; it's starting something important for a healthier and more eco-friendly future.

Chapter 7: Acknowledgements

7 Acknowledgements

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Appendices

Appendix A. Requirements Elicitation Data

Interview raw data file: Access here

Questionnaire raw data file: Access here

Questionnaire Data:

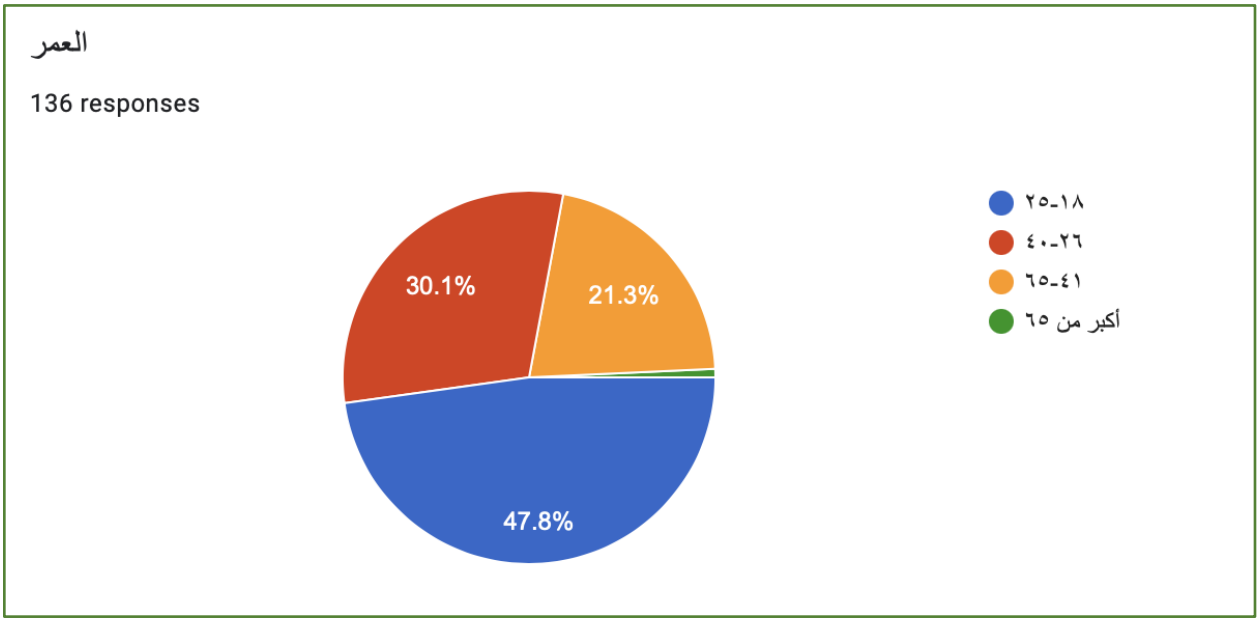
Number of questionnaire responses received from each neighborhood in Riyadh city:

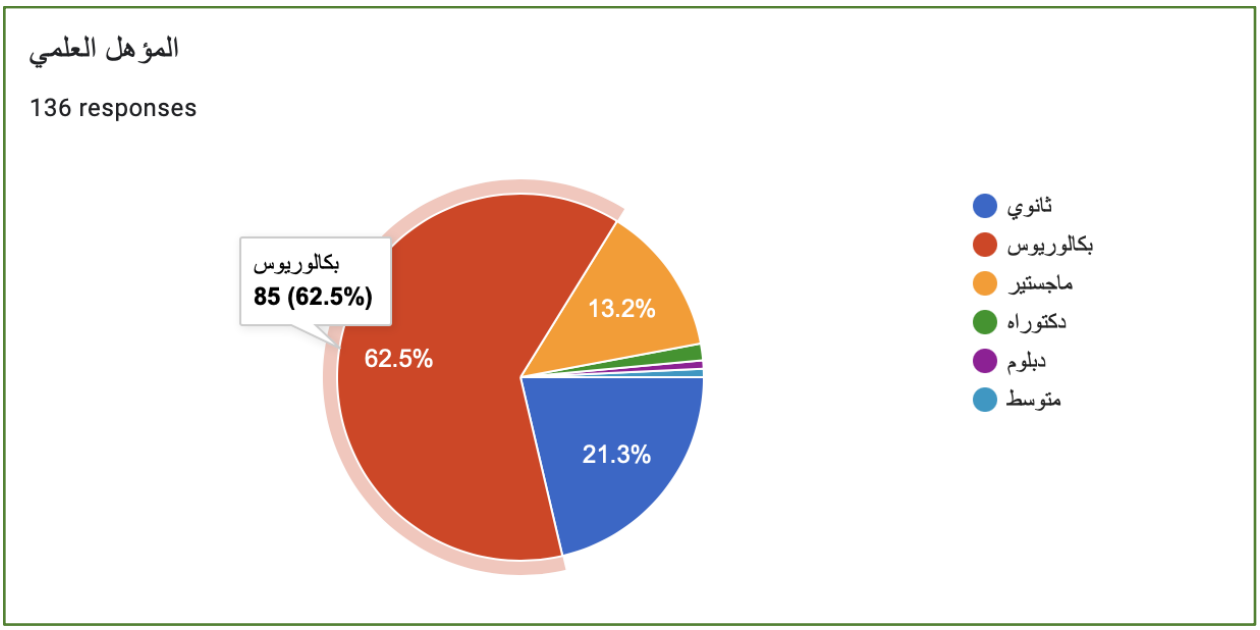
Region / Number of districts in the region	Districts	Number of Responses
North of Riyadh / 28	Alwaha	1
	Almasif	1
	Almohammadiyyah	1
	King Fahad	2
	Alsahafuh	2
	Alnakheel	1
	Altaeawun	3
	Alqirawan	1
	Alolaya	3
	Alwurud	1
	Almilqa	12
	Aleaqiq	1
	Alaizdihar	3
	Alearid	3
	Alfalah	3
	Alwadi	1
	Faculty housing for King Saud University	2
	Alkhuzamaa	2
	Alrabie	1
	Alnarjis	7
	Alyasamin	7
	Alghadir	3
	Diriyah	4
	Almaghrizat	1
	Alnuzha	7
	Hatayn	2
	Alnafl	5
East of Riyadh / 13	Qurtuba	1
	Alquds	1

	Alrawda	2
	Jarir	1
	Alsueaduh	1
	Aljaziruh	1
	Alrayaan	1
	Khashm Al-Aan, Alharas housing	1
	Alrawabib	1
	Ashbilia	3
	Alnahdah	1
	Almanar	1
	Alrawabi	1
South of Riyadh / 4	Alhazm	4
	Alsiwidiu	10
	Alshafa	1
	Almansourah	1
West of Riyadh / 8	Am alhamaam algharbii	1
	Alzuhra	2
	Albadiea	7
	Laban	2
	Alhada	1
	Alawali	1
	Irqah	4
	Almahdiyah	1

Table 15: Number of Responses from Each Neighborhood in Riyadh City

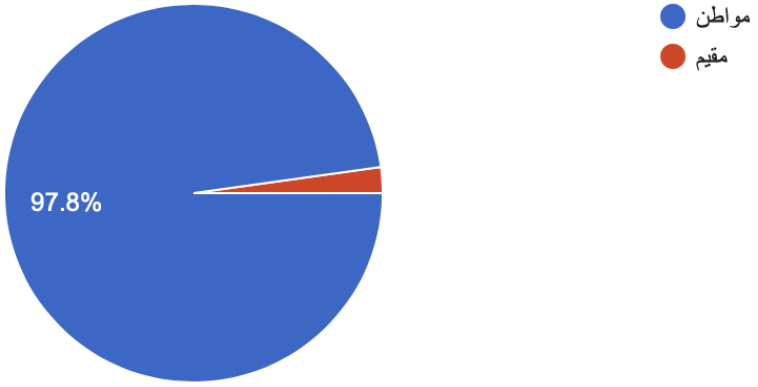
Questionnaire Data Charts:





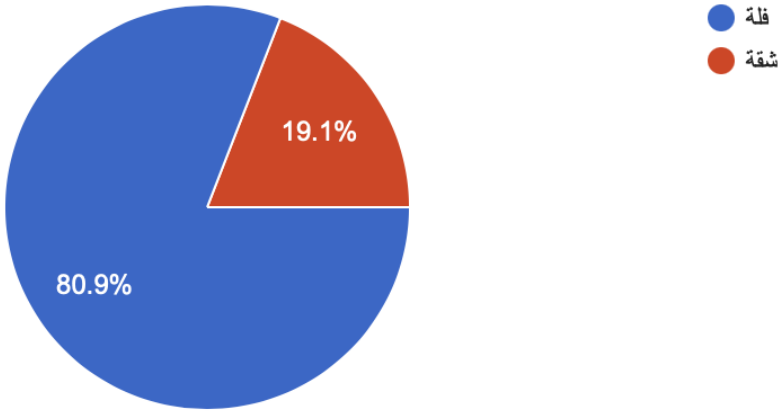
نوع الهوية

136 responses



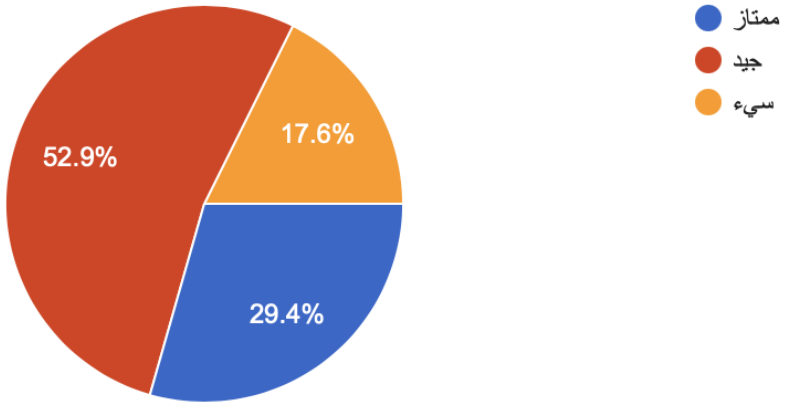
نوع السكن

136 responses



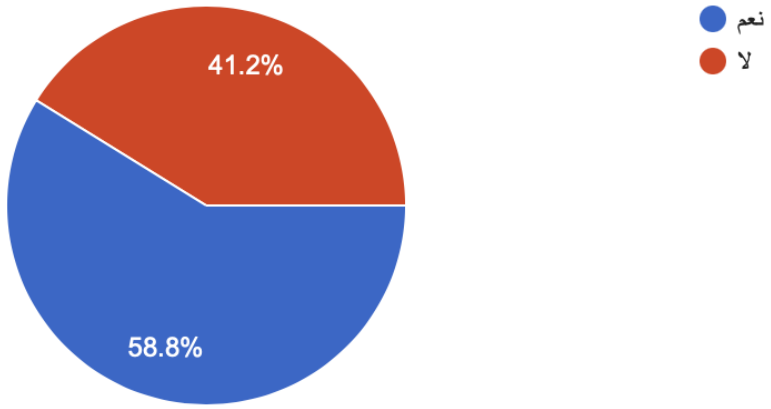
ما هو مستوى رضاك عن حاويات القمامة والنظافة في الحي؟

136 responses



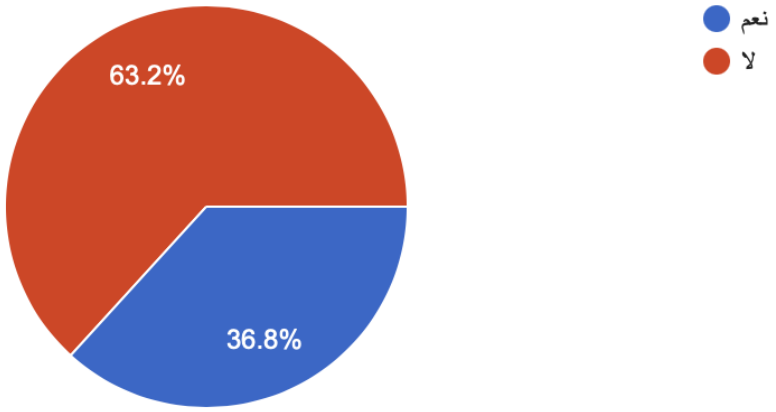
هل عدد حاويات النفايات في نطاق منزلك كافية لاحتياجك؟

136 responses



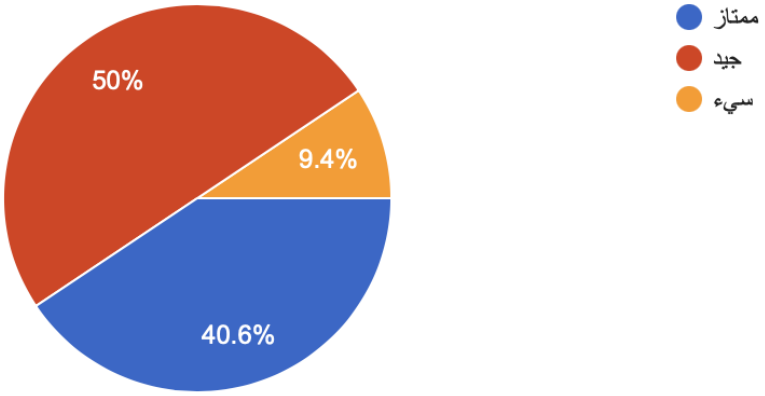
هل ترى أن حجم حاوية النفايات مناسبة لكمية النفايات؟

136 responses



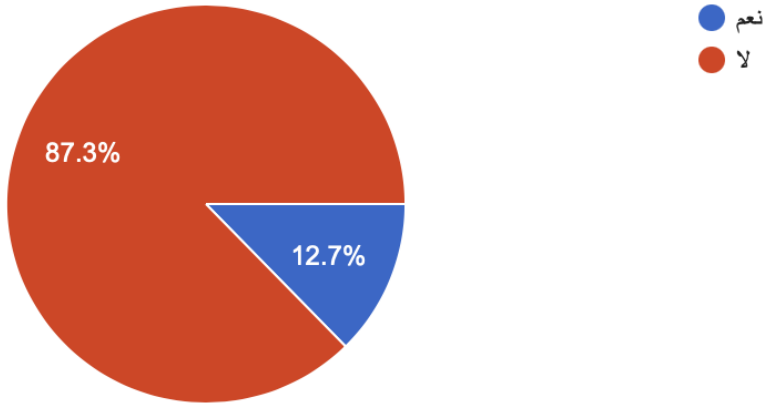
إن كنت قد قدمت طلب حاوية نفايات كيف تصنف جودة الخدمة المقدمة؟

64 responses



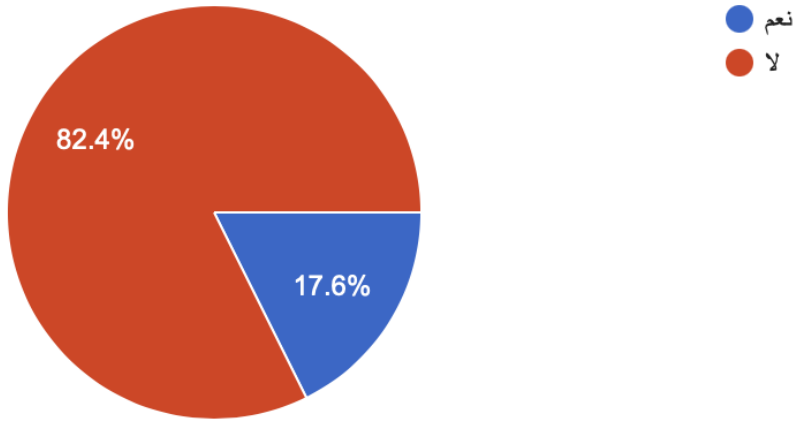
هل تواجه مشاكل في التواصل مع الجهة المسؤولة عن النفايات؟

79 responses



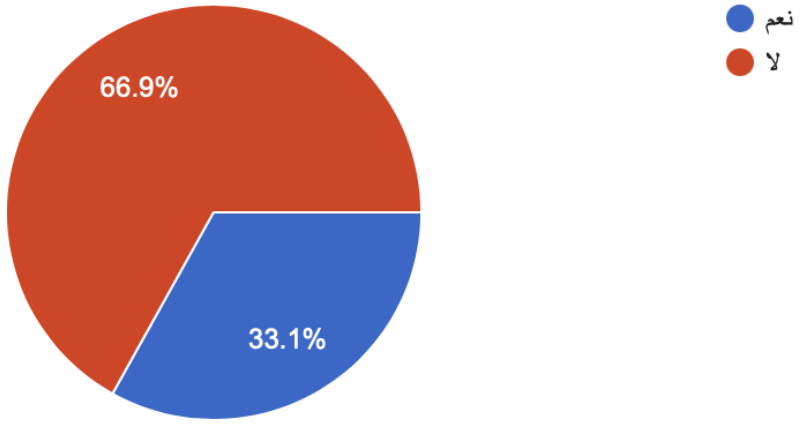
هل تطبق مفهوم إعادة التدوير قبل التخلص من النفايات؟

136 responses



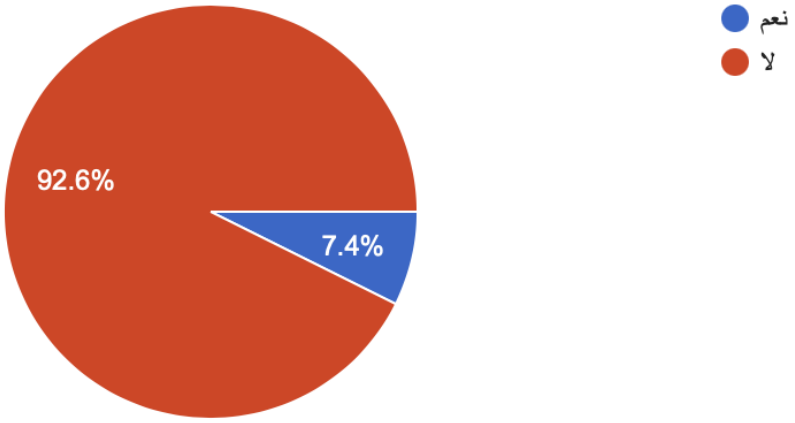
هل سبق لك وواجهت اي مشاكل متعلقة بحاويات النفايات في منطقتك؟

136 responses



هل سبق لك استخدام أي تطبيق لإدارة النفايات والتواصل مع الجهات المسؤولة؟

136 responses



Appendix B. Taboua System Demo

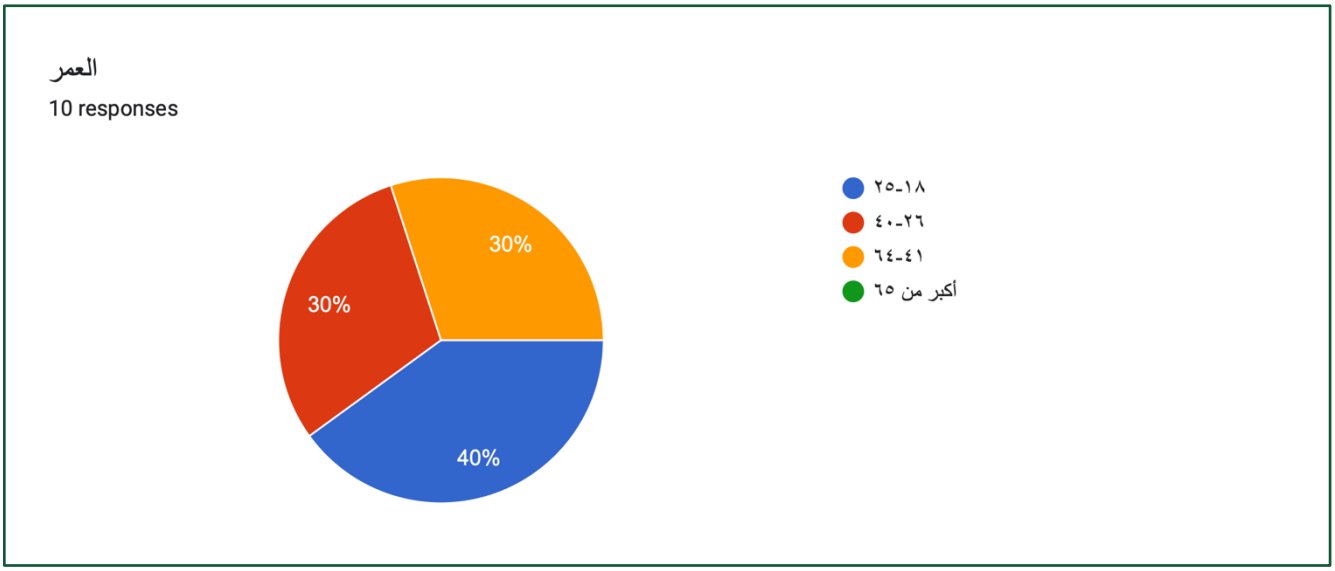
- **Taboua Mobile Application Demo: Access here**
- **Taboua Website Application Demo: Access here**

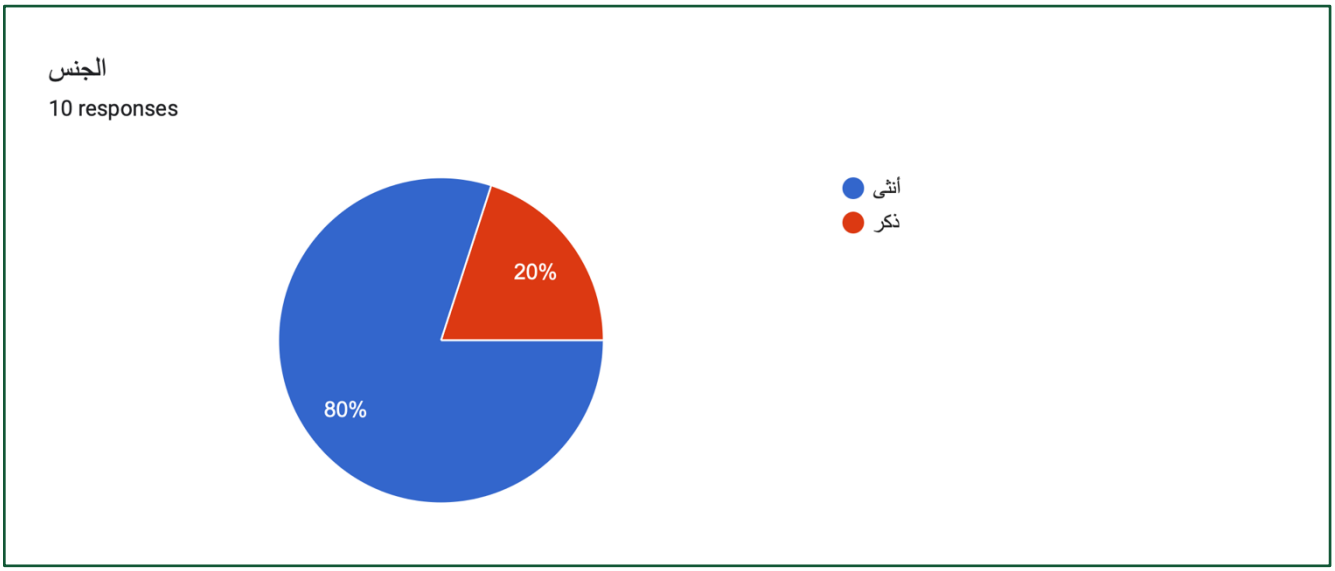
Appendix C. Testing Data

Testing Raw Data:

1. **Interview raw data file (Taboua Mobile Application): Access here**
2. **Interview raw data file (Taboua Web Application): Access here**
3. **Questionnaire raw data file (Taboua Mobile Application): Access here**
4. **Questionnaire raw data file (Taboua Web Application): Access here**

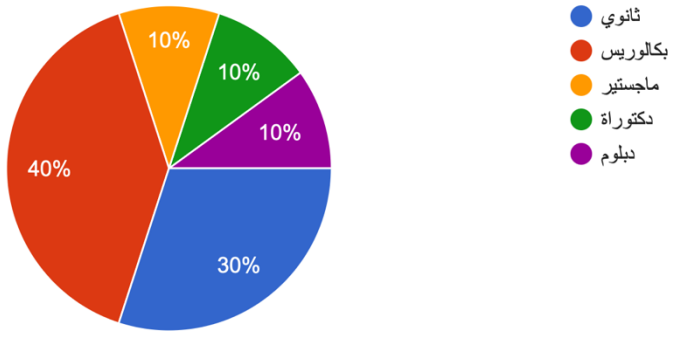
Demographics Chart of Participants (Taboua Mobile Application):





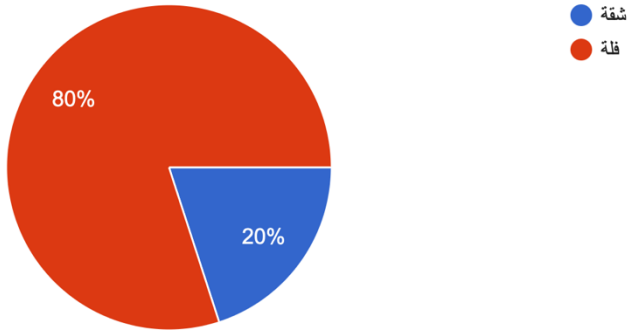
المؤهل التعليمي

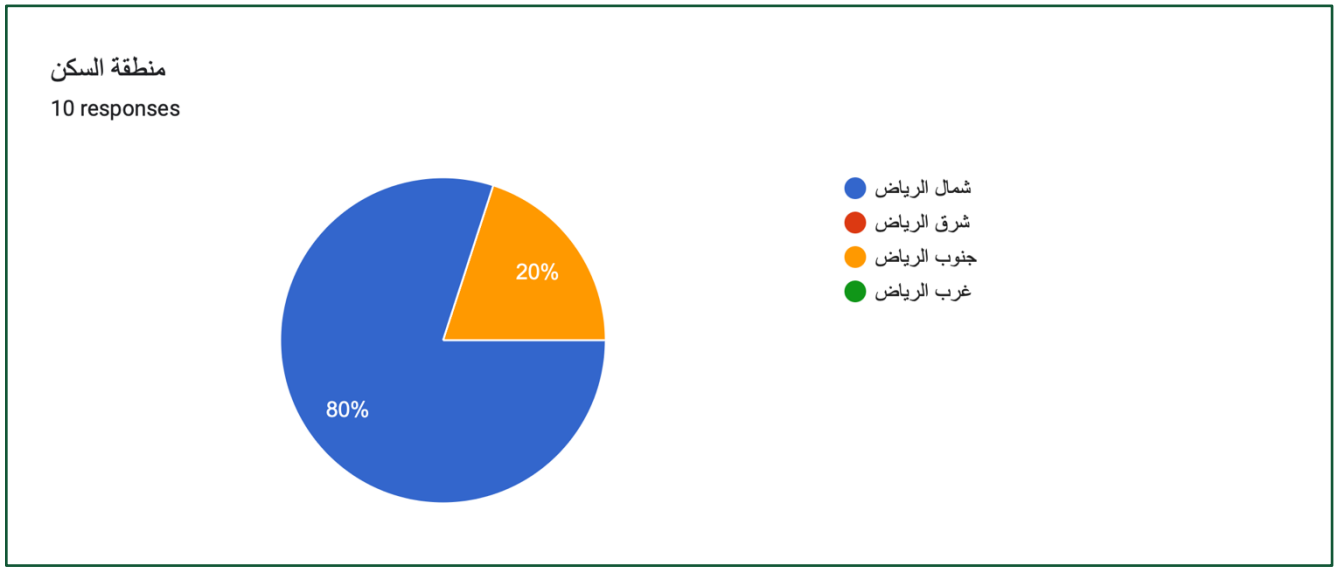
10 responses

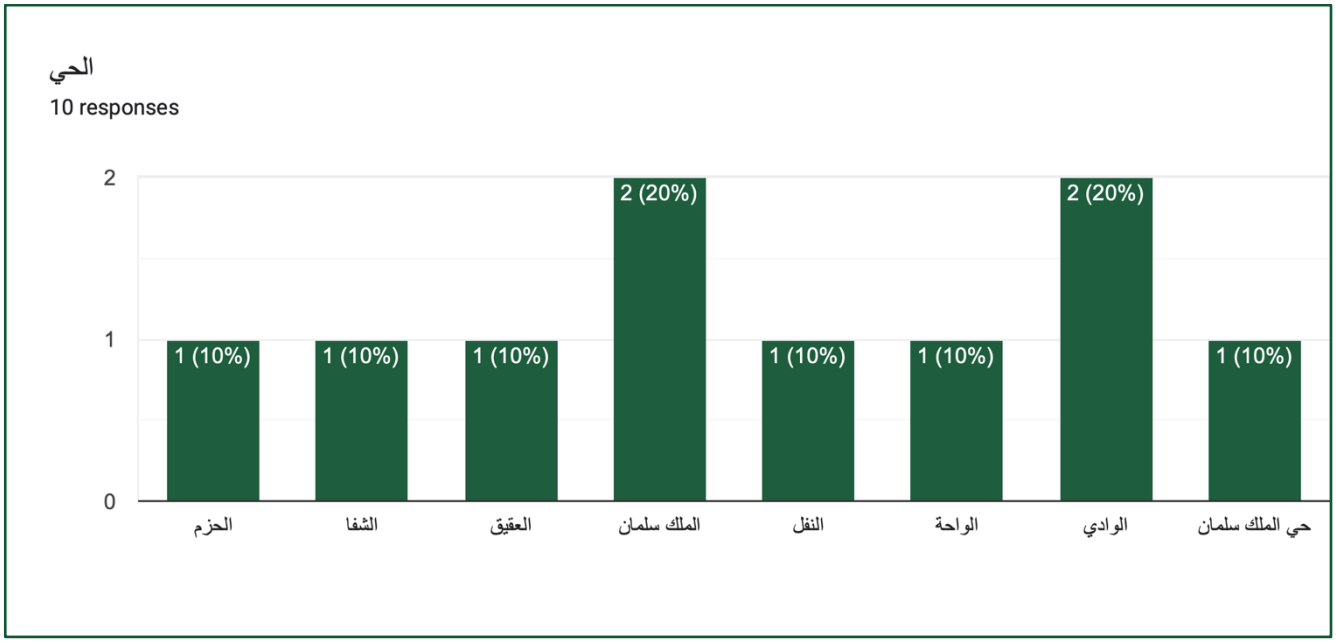


نوع السكن

10 responses

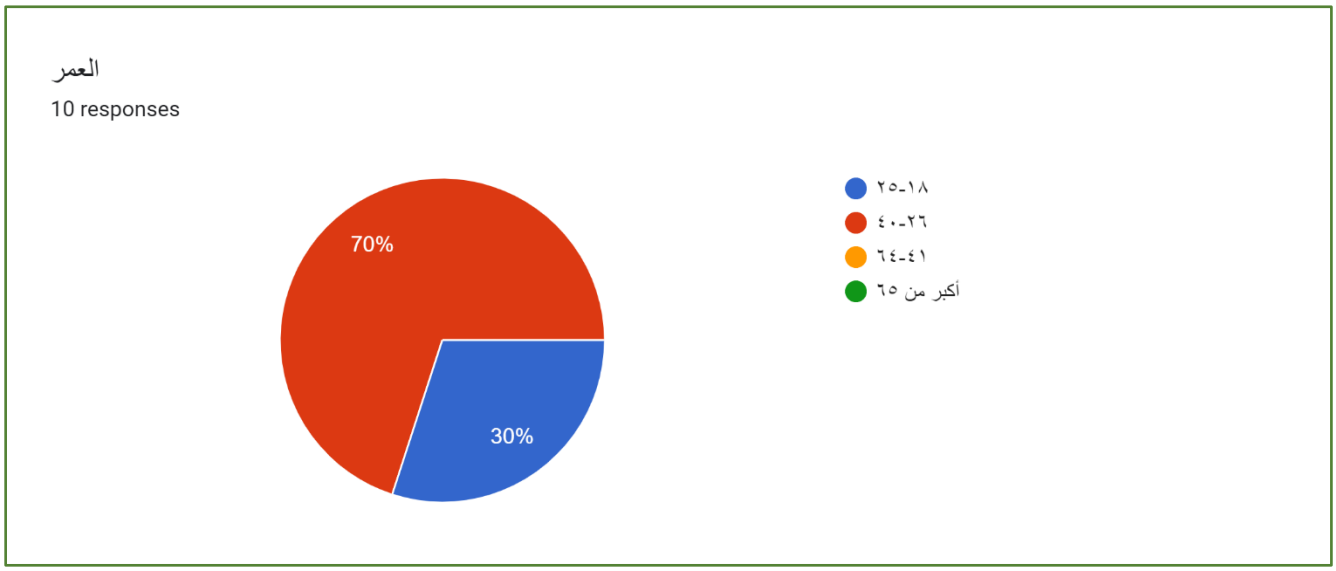


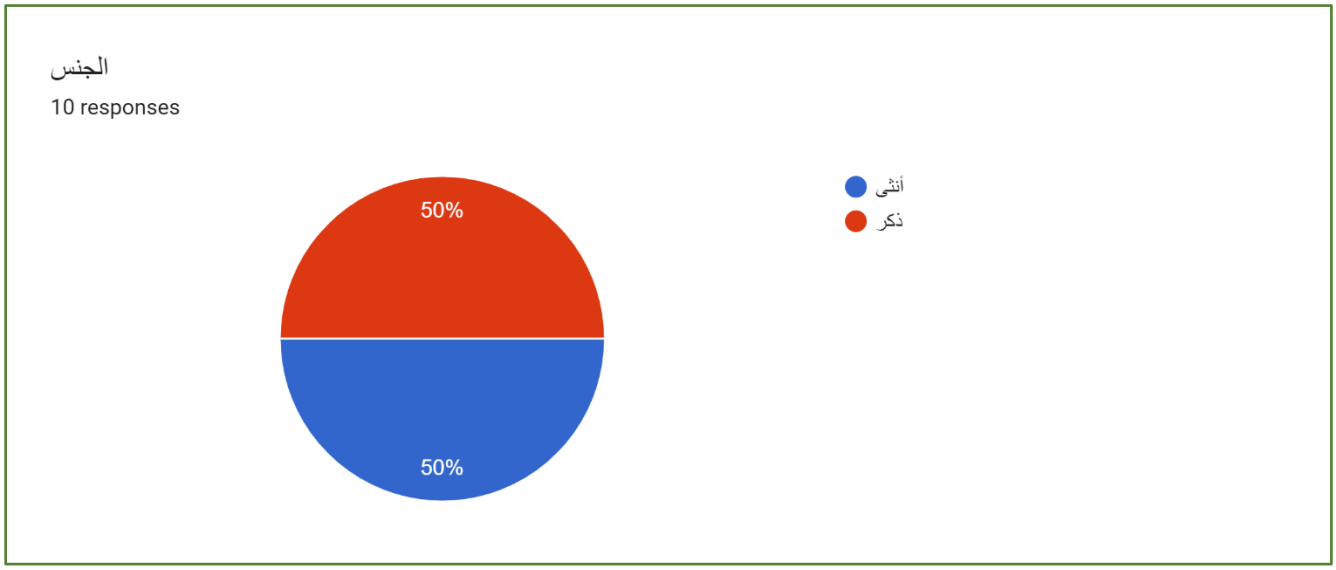

منطقة السكن
10 responses
20%
80%
شمال الرياض
شرق الرياض
جنوب الرياض
غرب الرياض


الحي
10 responses
2
1
0
1 (10%)
1 (10%)
1 (10%)
2 (20%)
1 (10%)
1 (10%)
2 (20%)
1 (10%)
الحزم
الشفا
العقيق
الملك سلمان
النفل
الواحة
الوادي
حي الملك سلمان

Questionnaire open-ended Questions (Taboua Mobile Application):

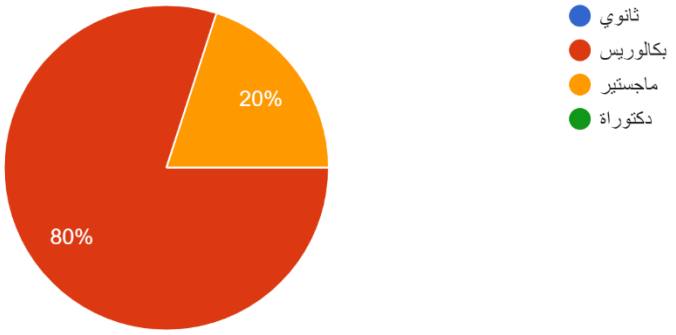
Demographics Chart of Participants (Taboua Web Application):





المؤهل التعليمي

10 responses



المسمى الوظيفي لاخر مهنة

10 responses

Accounting manager

مطور ويب

Projects manager

مدير مشروع

Senior awareness specialist

Business Developer

Learning and development specialists

Senior project manager

Senior digital experience specialist

Questionnaire open-ended Questions (Taboua Web Application):

كيف تصف تجربتك مع نظام تَبوأ؟

8 responses

رائعة وفوق توقعاتي

سهله و سلسة

ممتازه

ممتازة

رائعة و سلسلة

تجربة رائعة بهرت باتقان التطبيق وجمال تصميم الواجهات أتمنى ان نراه على أرض الواقع في أقرب وقت

عملي جدااا

تجربة رائعة تخدم البلديات خصيصًا والسكان عمومًا

ماهي المميزات التي تتطلع لوجودها في النظام مستقبلا؟

7 responses

ميزة إصدار التقارير وإرسالها بشكل فوري

ايضاً من الممكن متابعة امتلاء الحاويات عن طريق مستشعرات GPS تتبع مواقع الحاويات عن طريق ال

تعديل مراحل تتبع الطلب واضافه التصنيف بالتاريخ في البلاغات

طلب اضافة حاويات اعادة التدوير و حاويات حفظ النعمة

اراه نظام شامل من ناحية النفايات قد يكون في المستقبل هناك توسع خارج نطاق النفايات

ان يغطي كافة مناطق المملكة

معالجة البلاغات بطرق ابتكارية وتواجد حاويات بطرق متناسقة