JCTA Journal of Computing Theories and Applications ISSN:3024-9104

Research Article

A Mobile App Development for E-Waste Management in Bahrain (Athar)

Ehab Adwan, Noor Mohamed, Hayat Bureshaid, and Batool Mohamed

Department of IS, College of IT, University of Bahrain, Sakhir, Bahrain; e-mail: eadwan@uob.edu.bh; nooralqasaaim@gmail.com; hayatbureshaid@gmail.com; batolalbelady@gmail.com
* Corresponding Author: Ehab Adwan

Abstract: Bahrain still suffers from electronic solid waste annually due to ineffective waste disposal management. Compared to other Gulf Cooperation Council (GCC) countries, Bahrain generates the largest waste quantity per person, approximately 1.2 to 1.8 million tons of hazardous waste annually. Therefore, the present research article aims to manage the e-waste discarding mitigation by arranging the waste collection, presenting it for sale/purchase/donation (C2C, C2B, B2G), and organizing the waste recycling process. Derived from this aim, the article explores the e-waste phenomena and proposes the development of an e-waste mobile application named "Athar". The significance of "Athar" lies in firstly, enabling citizens to live in a clean environment with limited diseases. Secondly, assisting the Ministry of Tourism attract more tourists. The research article embraces a seven-phased Agile-based SDLC method to analyze, design, implement, test, and evaluate Athar through the utilization of several research techniques, including questionnaires to collect user and system requirements, other techniques such as data flow diagrams, entity relationship diagram, database schema, etc. for the system design, OutSystems programming language to implement the mobile app, and one questionnaire based on Nielsen heuristics for usability evaluation. Findings demonstrate the adequacy of the Athar application with an outstanding usability score of 89.1%.

Keywords: Agile-based SDLC model; Bahrain; E-waste; Managing Mobile application; OutSystems; Recyclizing.

1. Introduction

On the one hand, the whole world has witnessed a dramatic increase in the use of technology, including the generated quantity of electronic solid waste. On the other side, Bahrain still suffers from an increase in electronic solid waste because of the weak disposal management considering its small and limited size of 786.5 KM² and 1,493,654 population[1], [2]. Bahrain has the greatest population density in the whole Gulf Cooperation Council (GCC) and is considered one of the world's top trash producers. This phenomenon has become a significant topic of discussion in solid waste field in the last few years.

Several literature analysis methods, including systematic literature review (SLR), web content analysis (CA), questionnaires, and interviews, have been used throughout this research project. The SLR reduces the likelihood of making inaccurate or deceptive findings due to biases in original research or biases resulting from the review process, which makes them so strong[3]. Using content analysis, researchers may quantify and examine the occurrence, significance, and relationships of certain words, themes, or concepts. Using a range of qualitative and quantitative research techniques, researchers in the discipline of information science test hypotheses and identify solutions to several research difficulties [4], at which the usage of content analysis (CA) is growing [5]. Moreover, with respect to interviews, study [6] believe that they enhance the quality of the information being gathered, while w.r.t questionnaires, two questionnaires were conducted to collect User and System requirements. In order to create Data Flow Diagrams (DFD) and entity relationship diagrams (ERD), the information collected through questionnaires and interviews were analyzed and integrated with the

Received: June, 19th 2024
Revised: August, 18th 2024
Accepted: August, 20th 2024
Published: August, 26th 2024

second and third stages of a seven-stage based Agile-based system development life cycle technique (Agile-SDLC)[7].

According to [8], Bahrain still faces disposal management deficiencies of electronic solid waste, as, despite its small proportions, Bahrain produces the highest garbage per person among the GCC, with an annual production of 1.2 million tons of hazardous waste. Furthermore, the lack of communication between electronic waste donors and recipients further complicates recycling.

To overcome this challenge, this research paper proposes the development of a mobile-based application (i.e. Athar) that mitigates e-waste disposal management. Aiming to mitigate e-waste in Bahrain, two objectives were set accordingly: 1) exploring the e-waste phenomena and 2) developing and evaluating a mobile-based e-waste application. Both objectives were addressed by using the Agile-SDLC technique, which comprises two stages: 1) the exploratory stage and 2) the development and evaluation of the Athar app stage. In the prior, an interview was conducted with the Supreme Council of Environment and Crown Industries factory to investigate the matter and use SLR and CA techniques. During that, a 1st questionnaire collected user requirements. Later, the 2nd and 3rd questionnaires (System requirements and evaluation) were conducted along as DFD, ERD, Dialog diagram, Outsystems for coding the application, a second survey for gathering system requirements, and a third survey for measuring the app's usability.

The research project contributed to investigating the phenomenon of electronic waste, designing the Athar mobile application based on user and system requirements, building the Athar app to support both iOS and Android operating systems, and measuring the application's usability.

The research paper is composed of 5 sections. Section 1 serves as the introduction to this research project. Section 2 includes the literature review divided into several subsections, whereas section 3 discusses the methodologies and techniques used in this research project. Section 4 analyzes and discusses the findings and results of the methodologies mentioned in the previous section and section 5 concludes the paper and discusses future work.

2. Literature Review

Conducting state-of-the-art research to explore the phenomenon of e-waste management necessitates searching for several e-waste-related papers and relevant technologies. We have employed the SLR and CA.

2.1. Literature review techniques

As depicted in Table 1. the SLR is an independent scholarly methodology that seeks and evaluates all relevant information about a topic to reach conclusions about the matter [9]. The SLR is divided into five steps. As part of stage 1, data sources, such as Google Scholar, were selected. In stage 2, searching formulas were applied, which narrowed the number of articles to 50. Moreover, stage 3 refined the collected documents, and during stage 4, documents were manually reviewed and selected. Conversely, [5] defines CA as a method for analyzing qualitative data, such as text, to find the presence of specific words, themes, or concepts.

2.2 The e-waste disposal phenomena

2.2.1 Definition and Categories of the E-waste Disposal

As per the findings of state of the art, [10] the phrase "e-waste," or electronic waste, is a broad term used to describe the outcome for end-of-life electric and electronic equipment (EEE). The rapidly expanding volume and threat of e-waste have drawn attention worldwide. They further state that disposing of e-waste causes serious pollution because it includes over a thousand compounds, many of which are dangerous. Furthermore, it is detrimental to public health and the environment [11]. Table 2 depicts the electrical and electronic equipment categories as mentioned by [12].

2.2.2 Pros and Cons of the E-waste Disposal

As per the state-of-the-art findings, the process of recovering valuable components from e-waste is known as e-waste recycling or e-waste management lifecycle lifespan[13]. Nonetheless, because printed circuit boards contain valuable metals like gold, silver, and other metals, recycling e-waste with the right equipment is profitable. However, the recycling prices in

rich countries are too high now, and a lot of e-waste is sent to developing countries like China, India, Brazil, and elsewhere[14], [15]. Furthermore, advocated by [16], it is predicted that 50 million tons of electronic trash are produced annually, of which only 20% are recycled properly. The remaining electronic debris is either improperly disposed of informally or in landfills, putting workers at risk of exposure to dangerous elements. Mourya [17] advocates that improper e-waste disposal might cause flame retardants and heavy metals to leak into the ground. Moreover, eating these plants puts the animals' internal health in jeopardy. Similarly, toxins produced by e-waste that seep into ponds, streams, rivers, and lakes pose a hazard to aquatic life and should be taken seriously[18].

Table 1. The SLR method and research findings

Keywords / Phases	Thematic subject	Article
Keyword 1	Electronic waste; Disposal; Mobile application	368
Keyword 2	E-waste; GCC; Application	480
Keyword 3	E-waste Management; Arab countries; Application	51
Keyword 4	Recycling process; E-Waste; Mobile application	121
Keyword 5	Bahrain; Disposal; E-waste	320
Phase 1: Selection of data source	Google Scholar (paper, article, website)	1340
Phase 2: Applying searching formula	AND / OR/ NOT	96
Phase 3: Refining document items	AND / OR/ NOT	75
Phase 4: Manual review and exclusion	AND / OR/ NOT	61
Phase 5: Selection and review of articles	AND / OR/ NOT	**50**

Table 2. Categories of electrical and electronic equipment

Categories of electrical equipment	Examples
Large household appliances	Refrigerator, Freezer, Microwave oven, Oven, Dishwasher
Small household appliance	Coffee maker, Toaster, waffle iron, food processor
IT and telecommunications equipment	Telephones, Satellites, Fiber optics
Consumer equipment	Audio equipment, televisions, calculators, home appliances
Lighting equipment	LEDs, Fluorescent, Flashbulbs
Electrical and electronic tools	Electrical pumps, power generators, compressors
Toys, leisure, and sports equipment	Video games, Modern interactive toys, Treadmill
Medical devices	Infusion pumps, blood transfusion kits, catheters, scanners
Monitoring and control instruments	Heating regulator, smoke detector, thermostat
Automatic dispensers	Automatic soap dispenser

2.2.3 Frameworks and Methods of the E-waste Disposal

As per state-of-the-art findings, Chinese electronic garbage is ultimately recycled and recycled or disposed of in landfills or incinerators. Nonetheless, [19] noted that while there may be some variances, the procedure of getting rid of e-waste varies little among nations. Also, [20] states that recycling e-plastic, a component of e-waste follows one of the three recycling processes and yields various results. Furthermore, Table 3 illustrates respondents' preferences for recycling e-waste in Bahrain, as reported by [21], with "drop-in" recycle containers being the most favored option.

Table 3. Methods of E-waste Recycling

Methods of applying e-waste recycling	Percentage
Call e-waste collection center and get it collected from my house.	34.8%
I will drop it in e-waste recycling bins if available nearby.	53.0%
I will give it to e-waste collectors if neighborhood collection is set for certain days.	12.2%

2.3 E-waste management in the GCC countries

As per state-of-the-art findings, the GCC (KSA, UAE, Oman, Kuwait, Qatar, and Bahrain) is considered one of the markets for electronic goods with the fastest growth rates globally.

According to [21], KSA's statistics show that it produces approximately 3M tons of annual e-waste annually, which is expected to increase five times over the next ten years. International Computer Company, the leading Saudi Arabian IT solutions provider, has teamed up with German company EXITCOM, specializing in electrical and electronic device recycling. Alternatively, the UAE is currently home to the world's first recycling and reuse facility. Sims started its IT asset management and end-of-life electronics recycling facility in Jebel Ali in November 2012. With the facility's opening, businesses can decide between software destruction and some of the most advanced data management and security software solutions. In addition to protecting and destroying physical assets, they can recycle or resell their used IT assets.

For Oman, [21], [22] advocates that the Oman Environmental Services Holding Company (OESHC) research revealed that over 38000 tons of e-waste were disposed of. However, for Kuwait, the e-waste recycling program is set to be established by Kuwaiti environmental solutions company Istidamah. Alternatively, for Qatar, recycling is a top priority, where the government supports initiatives to expand the availability of recycling services. Companies and associations set up stores and drop boxes at their locations so employees and customers can eliminate unwanted items. Verizon In Qatar, a program called "Hand It On" offers a 10% discount on a new phone in exchange for dropping an old one. As part of Q-Tel's e-waste recycling program, monthly lottery prizes are given to contributors of e-waste [21], [22].

Bahrain, as advocated by [22], at just 758 square kilometers, it is the smallest sovereign Arab country and the third-smallest country in Asia by land. Bahrain is ranked 23rd out of all the minor countries in the world. The Central Informatics Organization performed the official 2010 census, which yielded 1234571 residents overall in Bahrain, according to [23]. In 2014, the population was estimated to be 1.316 million. Forecasts indicate that with a growing rate of 7.4%, the population will rise dramatically to 2.128 million in 2030. Therefore, Bahrain will continue to produce an increasing amount of electronic trash which will impact the environmental system unless considerable actions are taken to eradicate it. Therefore, the government started gathering e-waste informally through Recycle IT Bahrain, Zain Bahrain, Bahrain Computer Repair Centre, and Universe Environment. The annual e-waste amounts are 15,500 tons, with each individual producing 12.9 kg of it [24].

2.4 Mobile and web applications

In the web content analysis process, four general and six specialized features are used to compare the widely used e-waste mobile and online applications, as shown in Table 4. Listed in Table 4, the applications [25]–[36] were carefully selected based on four criterians, including, 1) focus on e-waste management, 2) application technology type whether mobile applications or websites, to ensure accessibility and suitability for a diverse user demographics, 3) the geographical scope of the applications which aimed to choose solutions that address e-waste on a global scale and catering to various regions, and 4) each application's features were scrutinized against specific user and system prerequisites to ascertain that they offer requisite tools and functionalities for efficient e-waste management. Almost all mobile apps contain capabilities for managing user accounts and facilitating user registration and login. Only a small percentage of websites have these two elements, though. With the exception of one mobile application, every website and mobile application has a customer support communication feature, demonstrating how crucial the feature is. In a similar vein, every mobile app and website—aside from GreenE—has an About Us feature. Regarding the features themselves, the ability to take a picture of the equipment for the purposes of donation and sale is exclusive to one website and one application. Moreover, E-waste blogs and information are available on half of the most well-known websites and mobile apps, keeping consumers up to date on the most recent e-waste occurrences. Additionally, eight of the twelve apps offer purchasing and selling services to their subscribers. Giving electronics to manufacturers or other users is an additional third way to handle them. With the exception of Eco Weee, all websites and mobile apps offer a donation facility. Out of the websites/mobile apps, seven have a pickup scheduling feature, while five do not.

Table 4. Comparative analysis based on common features

App_N	Ref	App_T	App_L	General Features				Specific Features				
				User reg & login	Managing user Acct	Comm with cust Svs	About Us Page	E-photo capturing	E-waste info & blogs	Selling & buying Svs	Donation Svs	Schedule Pickup
My WM	[25]	Website	USA	X	X	X	X		X	X	X	X
Bekia	[26]	Mobile App	Egypt	X	X	X	X			X	X	X
E-Tadweer	[29]	Mobile App	Egypt	X	X	X	X	X			X	X
Pakam	[30]	Mobile App	Nigeria	X	X	X	X			X	X	X
WasteBazaar	[31]	Website	Nigeria	X	X	X	X			X	X	X
E-Scrappy recyclers	[32]	Website	India			X	X		X		X	X
GreenE	[33]	Mobile App	India			X			X		X	
Eco weee	[28]	Mobile App	Singapore	X	X		X		X	X		
ERF	[34]]	Mobile App	Qatar	X	X	X	X		X		X	X
Ecyclex	[35]	Website	UAE			X	X	X		X	X	
Madenat Al-Nokhba	[36]	Website	UAE			X	X		X	X	X	
Crown Industries	[27]	Website	Bahrain			X	X			X	X	
Athar		**Mobile App**	**Bahrain**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**

While applying for the CA, certain applications and websites appeared to lack login and registration features. We firmly ascertain the significance of incorporating these features to maintain applicant records, formalize the application process, facilitate transactions, enable seamless communication with applicants through stored details, and pave the way for forthcoming functionalities like rewards, loyalty programs, and points accumulation. Furthermore, the user will be able to control his account by altering the password, phone number, email, and a few other settings. Additionally, customer support will be accessible to offer users assistance and direction. The "about us" page aims to provide people with information about who we are, what we do, and how to get in touch with us as customers. To provide a more thorough experience, users will also be able to take pictures of gadgets, sell, purchase, or donate electronic waste to various people and organizations, and repair and recycle electronics. Users will be able to arrange for a pickup of the electronics they have donated, repaired, recycled, or sold. Lastly, an area dedicated to e-waste blogs and information is offered to disseminate knowledge regarding electronic trash.

Several reasons arise for the combination of e-waste, Selling & Buying, and Donation Service features. First, this project advocates for a shared responsibility approach among individuals to mitigate the financial strain often shouldered by nations and governments. This involves engaging in commercial activities such as buying and selling to effectively manage and dispose of electronic waste. Second, providing selling, buying, and donation services will help us achieve our aim of mitigating the e-waste amount in Bahrain through exchanging benefits between Bahraini citizens. Lastly, using these services, we will implement the circular economy effectively by utilizing products, equipment, and infrastructure for a longer period, thereby improving the productivity of these resources.

3. Proposed Method

3.1 The research design model

This research project uses the Agile based System Development Life Cycle (SDLC). Advocated by [7], the selection of this model has the potential to create an even better system

that ensures security is integrated at every stage. The two phases of the agile-based SDLC are the development and assessment of mobile applications and the exploratory phase. According to [7], [37], this methodology's core elements include regular updates to the implementation process and the production of smaller project implementation iterations based on results, lessons gained, and innovative ideas. In Figure 3, the seven phases include Identifying problems, Opportunities, and objectives, determining human information requirements, analyzing system needs, Designing the recommended system, Developing and documenting software, Testing and maintaining the system, and implementing and evaluating the system.

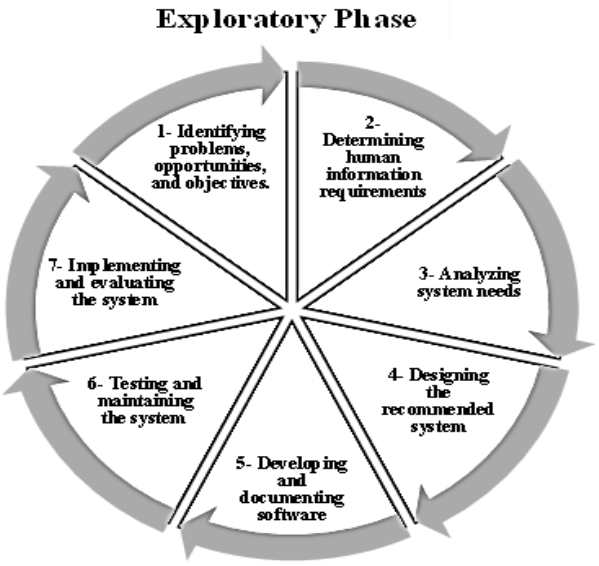

Figure 1. The Agile based SDLC (Source: [7])

The first stage of the agile-based system development life cycle determines the outcome of research projects. It focuses on identifying and defining the primary issue, which in our case is the ineffective management of e-waste disposal and determining the most effective ways to address it through proposing, investigating, and assessing solutions. We are developing a mobile app to handle Bahrain's e-waste disposal in order to address this issue [7]. The second stage focuses on determining the requirements of people to develop the application based on their preferences. At the end of this phase, the user needs and requirements are gathered by questionnaires and interviews and are listed below.

The third phase is about data flow diagrams (DFD) that show the sequence in which events happened and illustrate an organized version of the system. At the fourth stage, the data gathered from the earlier stages will be used to design the logical portion of the system. System users will be guided toward the proper method of inputting data that the system accepts, entailing preparing program packets for programmers, which comprise the specifications file, input/output layout, and processing details [7].

The fifth phase will see the creation of the necessary software and associated documentation, entailing designing, coding, and fixing any possible mistakes. Testing the system is crucial in the sixth stage to lower the cost of problem identification prior to the system being utilized by actual users. The documentation and system maintenance phases, which span the entire cycle, start at this stage. Verifying the system is performing as planned is the goal of this process [7]. The implementation phase starts once system testing using different testing techniques is completed. The application of information system development, divided into smaller processes like database construction, equipment installation, and new system manufacturing, takes place during this seventh and final phase of the SDLC [7].

3.2 Requirements collection techniques

Requirements were collected through 2 interviews and questionnaires. The two interviews were conducted with The Supreme Council of Environment and the Crown Industries. To satisfy the user requirements, two questionnaires (1st and 2nd Questionnaires) were utilized to gather user and system requirements and prepare for analysis [38]. The questionnaires were

distributed in November 2023 with a sample size of 127 of population size of 1,494,044 according to [2], with a margin of error 5.7% and 80% confidence level where N = population size, e = margin of error, p = Percentage of population, z = z-score (the number of standard deviations a given proportion is away from the mean) as depicted in Equation (1)[39].

$$\text{Sample size} = \left(\frac{\frac{\left(z^2 \times p(1-p)\right)}{e^2}}{\left(1 + \left(\frac{\left(z^2 \times p(1-p)\right)}{(e^2 N)}\right)\right)} \right) \quad (1)$$

Both of the 1st and 2nd questionnaires received 127 responses. The questionnaires consist of multiple sections. Each questionnaire was divided into many sections based on its intended usage. The 1st questionnaire was divided into three separate sections based on the three kinds of Athar users: givers, mediators, and recipients. The questions assess users' knowledge of the phenomenon of electronic waste and their preferences as individual user types. The second questionnaire's questions cover functional and non-functional system needs and center on the proposed mobile application Athar.

Furthermore, the second questionnaire is distributed to collect system requirements. The core system is crucial because it establishes the framework for all other needs and the architecture flow [40]. Both questions were designed and analyzed using the Microsoft Forms tool.

3.3 Application development techniques

The Athar application's models will be developed and defined via diverse system methodologies. Creating multiple-level DFD, process specifications, entity relationship diagrams (ERD), data dictionaries, and dialog diagrams are all included in this part. As a process-oriented description, the systems model emphasizes the effects, or flow, of information between modules[41]. IT and business systems are conceptualized and created through research in this broad field. According to [42], DFD is a systematic analytical and design methodology. It provides details about the kinds of data introduced into the system, the data that is already there from the system, the entities that are a part of the system, and the processes that are a part of the system. The context level (0 DFD) displays the system's boundaries, the entities interacting with it, and the information flows that pass through them [43], while Level 1 DFD illustrates the input and output data flows that are present across the system and summarizes the processes.

The process definition contains a list of the system's formal procedures as well as the logic behind which inputs would be handled to generate which outputs. The main goal is to explain and summarize the procedures and requirements of the regulations. To provide a clearer image, consistent and high-quality data must meet the process requirements [44]. Alternatively, the database schema is a design made to show the database structure. The database schema's core components—the record tables, their attributes, and the connections between them—can be found within, along with a variety of other features such as views, types, tables, relationships, and more. A data dictionary lays the foundation for a database system by analyzing the requirements and the database's evolution. Moreover, a dialog diagram is a tool that shows the next steps a user might take to look into different interfaces.

3.4 Application implementation and testing techniques

Based on the functional and non-functional requirements, the implementation phase is meant to provide the Athar's coding, through which the Outsystems platform is utilized exclusively for the Athar system's implementation, development, Testing, and installation.

According to [45], OutSystems is given preference over other platforms, i. e. (Mendix, Appian), as it caters to citizen developers, offers a clean design with drag-and-drop elements, and contributes to automatic integration and one-click deployment, while the other two were Less-Code platforms. Also, Apache Cordova enables HTML5, CSS3, and JavaScript to enable cross-platform development of mobile applications for Android 8 to 13 and iOS 13 to 16, which is used in constructing OutSystems applications [46]. As stated by [47], the OutSystems architecture is composed of a platform server, service studio, service center, lifetime, and integration studio, so the developed apps are implemented, generated, managed, optimized,

and deployed; online applications are compiled to C#/Java, and mobile applications are deployed to iOS and Android, and it lets developing programs using drag and drop.

However, to confirm that all of the application's units function as intended and approve the I/P data types entered, validation and unit testing/mocking mechanism techniques were used, as stated by [48]. According to [47]–[49], unit testing is a sort of software testing in which individual software units are examined to ensure that each one operates as intended. This is accomplished by isolating a portion of the program code and evaluating its functionality during the application development.

3.5 Application evaluation technique

A 3rd questionnaire was distributed to users to determine their usability of Athar using Nielsen's heuristics [50]. 25 of Likert scale questions were provided based on eight major and 22 subcategories of Nielsen's criteria. A Likert scale questionnaire was preferred over other techniques (i.e. t-tests) as the former is a tool to measure attitudes, opinions, or perceptions on a multi-point scale, typically capturing ordinal data through respondents' levels of agreement with statements. In contrast, a t-test is a statistical method used to compare the means of two groups to determine if there is a significant difference between them, requiring continuous data. While the Likert scale is used for survey data collection, the t-test is employed during data analysis to test hypotheses about differences between groups [50].

With a sample size of 35, 33 respondents responded to the questionnaire, developed using Microsoft Forms and distributed online in April 2024. Based on Eq.1 and with a sample size=1,494,044 [2], margin of error= 5.7% and confidence level= 90%, where a certain proportion of the standard deviation from the mean is defined as the number of standard deviations of a certain proportion [39].

The Usability of Athar could have been calculated based on the formulated Eq. 2 where each Nielsen criterion (%) = the average of the summation of sub_criterians (%). Consequently, the total usability rate (%) = the average of the summation of criterians (%).

$$\text{Usability (\%)} = \left[\sum Satisfaction \left(\sum \frac{subcriterian}{No.\ of\ subsriterian}\right) \times 100\%\right] /8 \quad (2)$$

4. Results and Discussion

4.1 Requirements analysis

In the 1st questionnaire, users were asked to identify themselves. The findings revealed that 40% of respondents were electronics buyers, 10% were sellers or donors, 3% were mediators, and the remaining respondents were not classified as any user type. The majority of respondents were aware of the seriousness of electronic waste and its effects, according to the results of additional questions designed to evaluate respondents' understanding of these matters. Among the respondents, 93% have not used e-waste management applications, while most liked to start using one. Furthermore, the results of the second questionnaire indicated that 62% of participants preferred having an application, while 38% preferred having a website. This information prompted us to develop a mobile application.

The remaining questions concern the system's technical aspect, including the functional and non-functional requirements. According to the questionnaire's findings, most respondents are interested in having all the features and functions specified. The functional requirements are depicted in Table 5.

4.2 Application development analysis

The context level DFD of Athar's system is demonstrated in Figure 3. Moreover, Figure 4 illustrates how the context level diagram is broken down into sub-processes in level 1 DFD. The entity relationship diagram (ERD) as depicted in Figure 5 is composed of 11 entities, each of which is represented in a table. As for the database schema, Tables 6 and 7 depict the data dictionaries for donors, sales, repairs, and recycling services in addition to the giver and payment data dictionary. Table 8 additionally displays the process specification. Conversely, Figure 6 illustrates the dialogue diagram, highlighting each user type's many dashboards and interfaces, ranging from the giver to the receiver.

Table 5. Athar application functional requirements

Function No.	Functions
F01	**Giver, Admin, Receiver, and Mediator Registration**
Description	All user types register on the application so they access Athar's services.
Activities	1-Users will create new accounts by filling in the required information. 2-Check if all user requirements are fulfilled and valid. 3-Create accounts and store user information in the database.
F02	**User Login**
Description	Users access the application after creating an account by entering their credentials.
Activities	1-Users will enter their ID/Email and Password. 2-Check the database for authentication. 3-Allow users to access the application.
F03	**Buying Service**
Description	Receivers buy electronics from givers through the application.
Activities	1-Choose desired electronics from the lists. 2-Review electronics details & fill in required information. 3-Place buying order.
F04	**Selling Service**
Description	Givers sell electronics to receivers through the application.
Activities	1-Givers will click on the sell button. 2-Fill in required electronics details. 3-Place electronics for sale.
F05	**Donating Service**
Description	Givers donate to any available charity through the application.
Activities	1-Click on the donate button. 2-Choose a specific charity. 3-Fill in required donation information & submit.
F06	**Repairing Service**
Description	Givers repair their damaged electronics in repair shops through the application.
Activities	1-Click on the e repair button. 2-Choose a specific repair shop. 3-Fill in electronic information & submit.
F07	**Recycling Service**
Description	Givers (individuals or businesses) can connect with recycling companies.
Activities	1-Individuals select mediator & recycle company. Businesses select recycling company. 2-Fill in the required information & submit.
F08	**Capture a Photo of Electronics**
Description	Givers attach photo of the electronics for selling/repairing/recycling/donating purposes.
Activities	1-Select a service 2-Capture a photo of electronics or upload from device.
F09	**Schedule a Pickup**
Description	Users schedule pickup time for recycled/repaired/donated/bought electronics.
Activities	1-Select a service 2-Choose a specific date after filling in the required information.
F10	**Track Service**
Description	Users can track the location and status of their recycled/repaired/donated electronics.
Activities	1-After submitting the order, click on the tracking button.
F11	**View E-waste Blogs**
Description	Users view and read all blogs related to electronic waste on the application.

Activities	1-Users click on the blogs button. 2-Display all blogs. 3-Users click on a specific blog to view it.

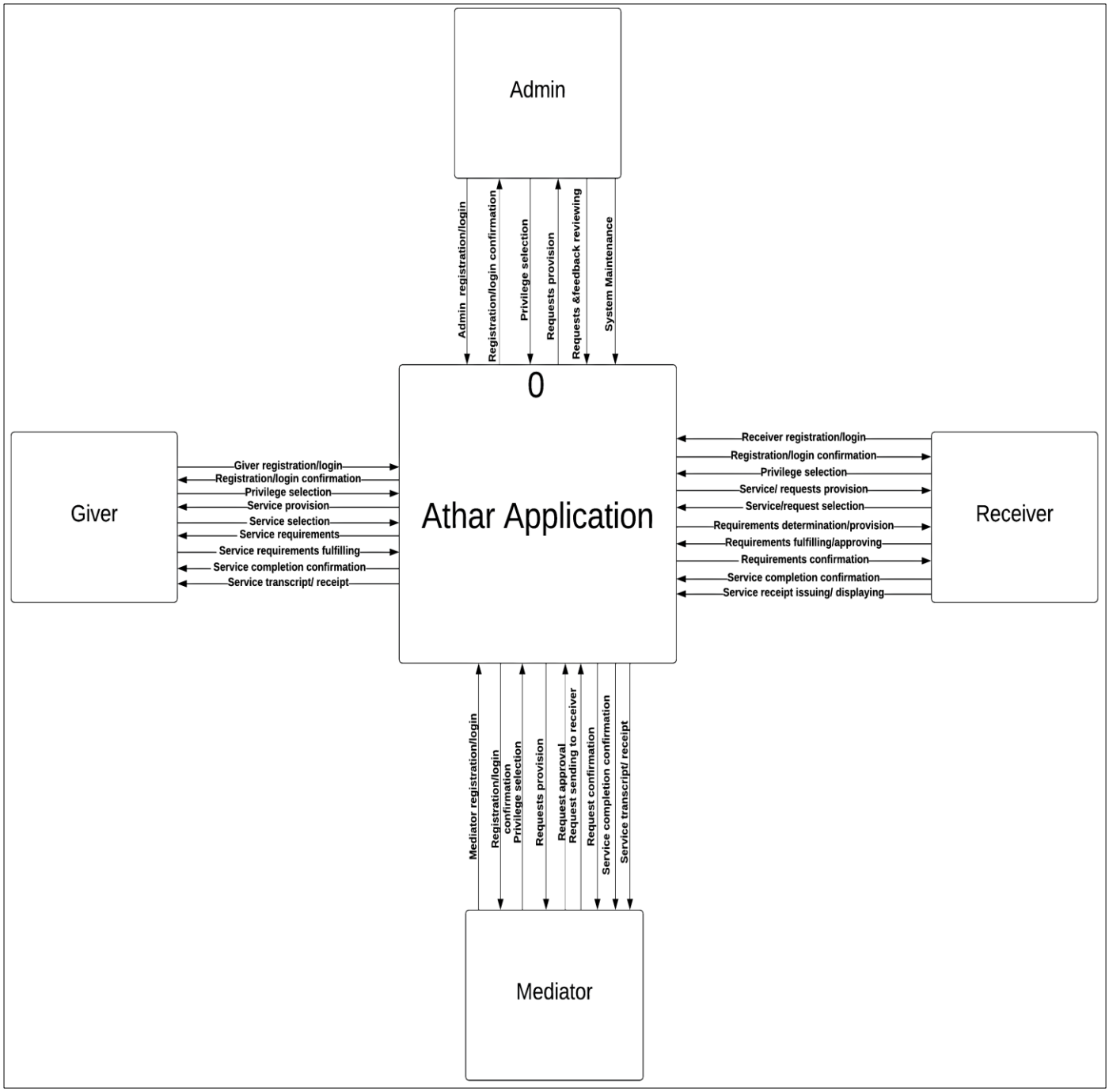

Figure 3. The Context Diagram of the Athar app

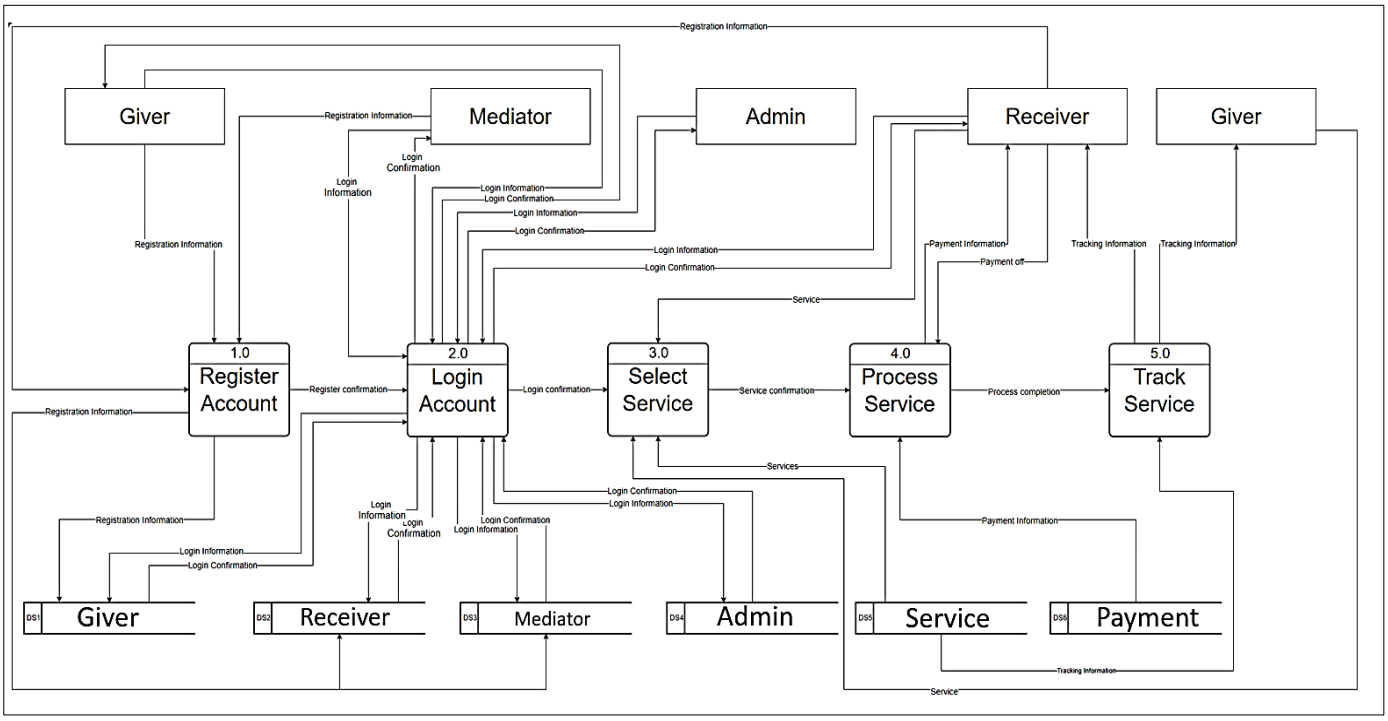

Figure 4. Level 1 DFD of the Athar app

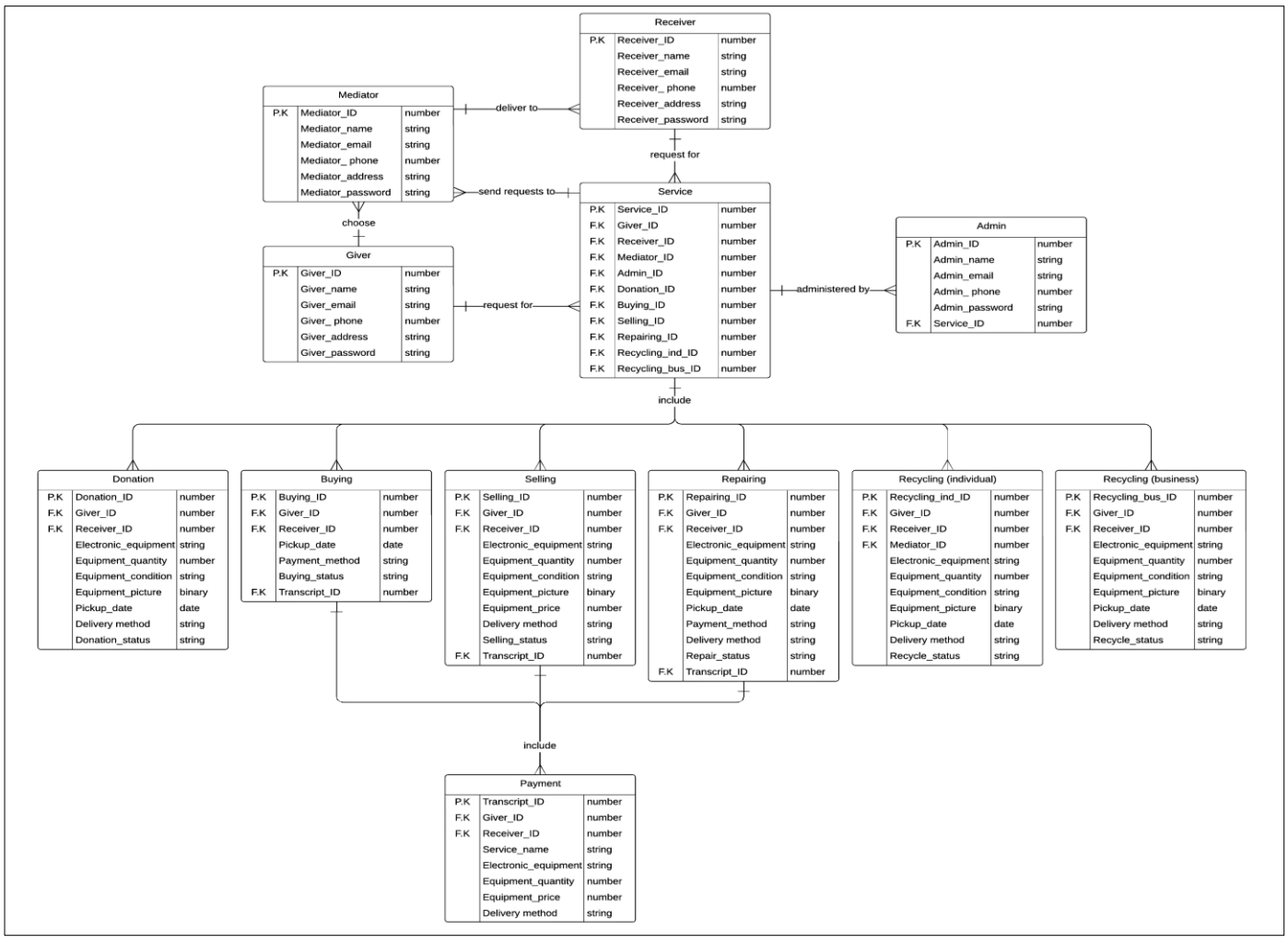

Figure 5. Entity Relationship Diagram (ERD) of the Athar app

Table 6. Giver table data dictionary

Attribute name	Data type	P. K	F. K	NULL	Unique	Other constraints
Giver_ID	Number	Yes	-	-	Yes	-
Giver_name	String	-	-	-	-	-
Giver_email	String	-	-	-	Yes	-
Giver_phone	Number	-	-	-	Yes	-
Giver_address	String	-	-	-	-	-
Giver_pass-word	String	-	-	-	-	-

Table 7. Donation table data dictionary

Attribute name	Data type	P. K	F. K	NULL	Unique	Other constraints
Donation_ID	Number	Yes	-	-	Yes	-
Giver_ID	Number	-	Yes	-	Yes	-
Receiver_ID	Number	-	Yes	-	Yes	-
Electronic_equipment	String	-	-	-	-	-
Equipment_quantity	Number	-	-	-	-	-
Equipment_condition	String	-	-	-	-	-
Equipment_picture	BLOB	-	-	-	-	-
Pickup_date	date	-	-	-	-	-

Table 8. Process Specification of Athar app

Process ID	**Process 1.0**
Process Name	Privilege Selection
Description	Users select type of users for registration privilege selection.
Process ID	**Process 2.0**
Process Name	Registration
Description	The user will sign up for a new account or enter their credentials.
Process ID	**Process 3.0**
Process Name	Login
Description	Users can log in using the credentials he used in the registration page.
Process ID	**Process 4.0**
Process Name	Service Selection
Description	Users can choose any of the services displayed.
Process ID	**Process 5.0**
Process Name	Service Processing
Description	Selected services will be processed and approved.
Process ID	**Process 6.0**
Process Name	Service Tracking
Description	Users can track service status and electronics location.

4.3 Application Implementation, Testing, and Evaluation Analysis

The main page of Athar prompts the user to select how they want to enter the application: either by creating a new registration for those who are without an existing account, as depicted in Figure 10, or by entering their email and password if they have a previously created account. During the registration, the user must choose which type of account he is creating, whether it was a giver, receiver, mediator, or admin account. Creating an admin account will require confirmation from current application administrators before the user can log into his account. As illustrated in Figure 11, the user will be prompted to select the preferred service (donation, sale, recycling, or repair) after becoming a giver. Upon selecting recycling, repair,

or donation, the customer is presented with a page from which they can select their preferred company. After selecting a company, the giver must fill up and submit a form regarding the given electronics.

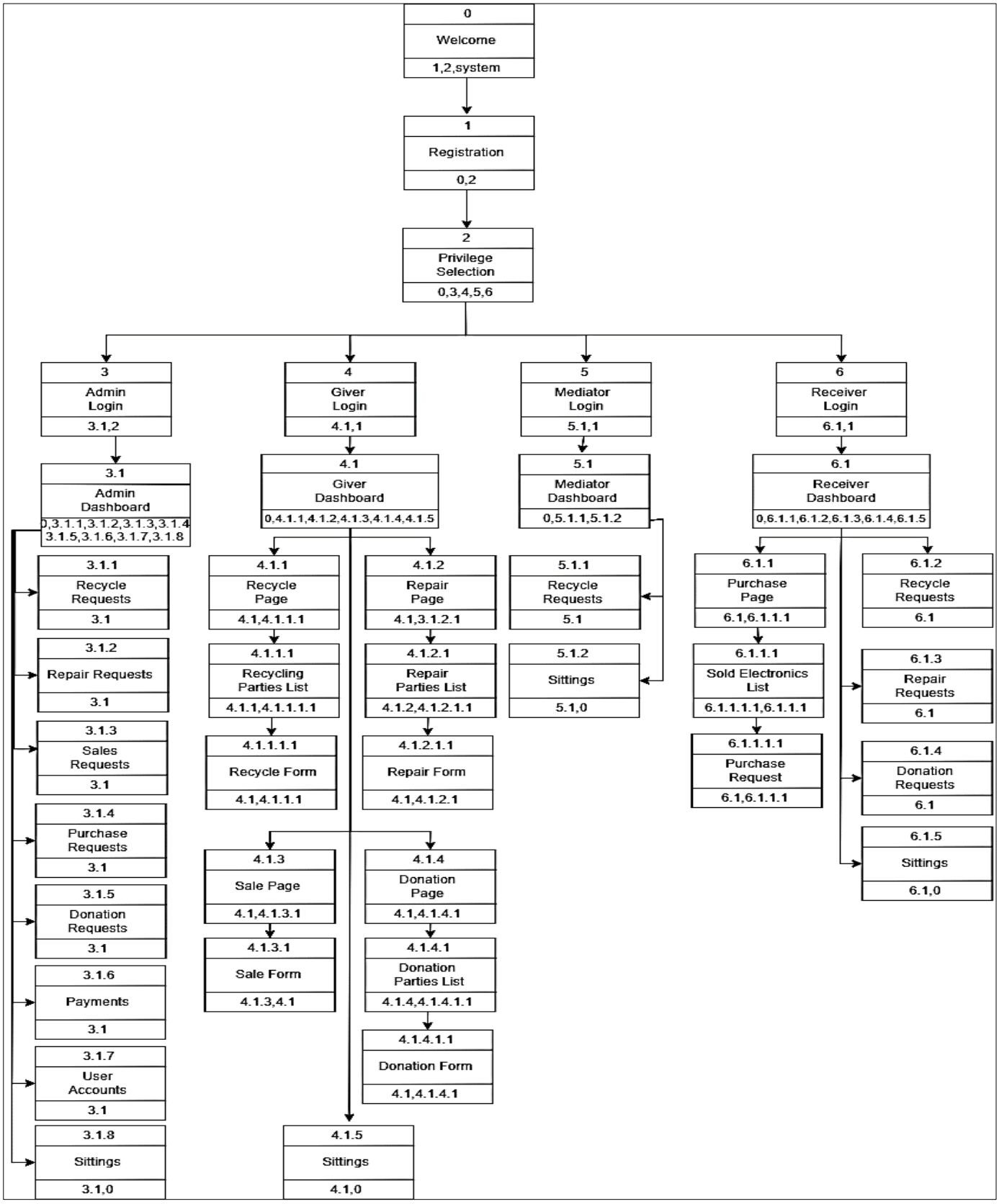

Figure 6. Dialog Diagram of Athar app

Furthermore, we wrote a section of code that verified Athar functions in accordance with the insights of [47], and we separated those functions to identify unneeded dependencies between the tested functions and other units. In the introduction to the application, the Welcome page will appear, and the user will choose to register or log in. If the user chooses to register, the registration page will appear for him to enter his information. If the user completes entering his information, the privilege selection page will appear to him, which will also appear to the user when he chooses to log in to the page. Finally, after the user chooses the privilege, the login page will appear for him to enter his information and verify it, after which the user can log in as shown in Figure 7.

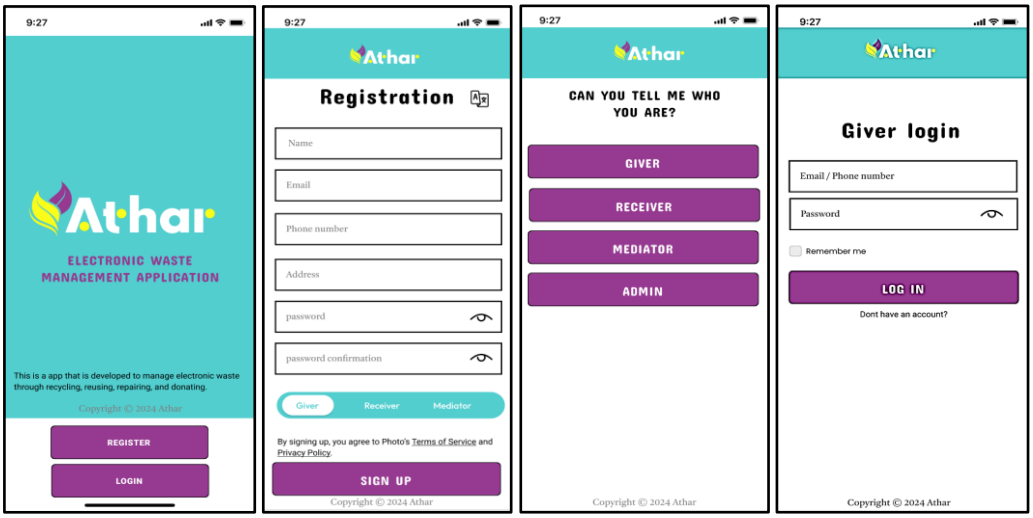

Figure 7. Welcome, registration, select privilege, and login I/O interfaces.

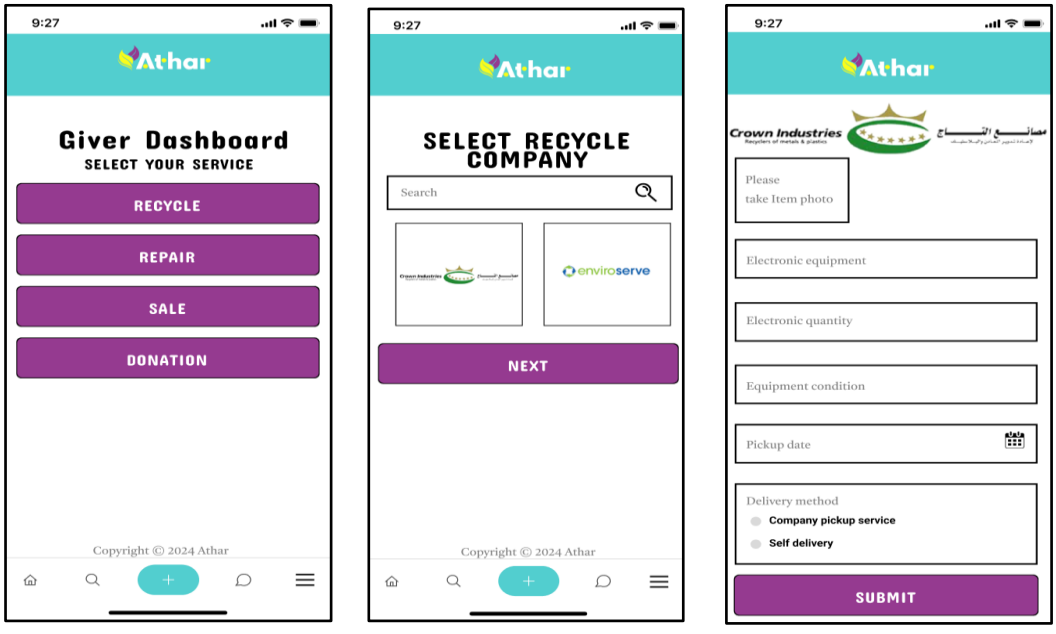

Figure 8. Giver dashboard, select company, form I/O interfaces.

If the user is a giver, four services will appear on the dashboard from which he can choose: recycling, repair, sell, and donation. If the user chooses either recycling, repair, or donation, a second page will appear to him through which he must choose the company he wants, and after that, he must fill in the data in the form as shown in Figure 8. If the user chooses the sell service, the form for the sale will appear to him, and after filling in the data, a page will appear to the user to ask whether he wants to sell a second product. If he chooses yes, the form will appear to him a second time, as shown in Figure 9.

For the user's privilege as a receiver, a dashboard will appear to him containing the services our application provides to the receiver. If the receiver chooses to purchase, a page will appear to him through which he can see the products offered for sale. Using the search bar, he can search for a specific thing, and after selecting something, he can see its details, as shown in Figure 10.

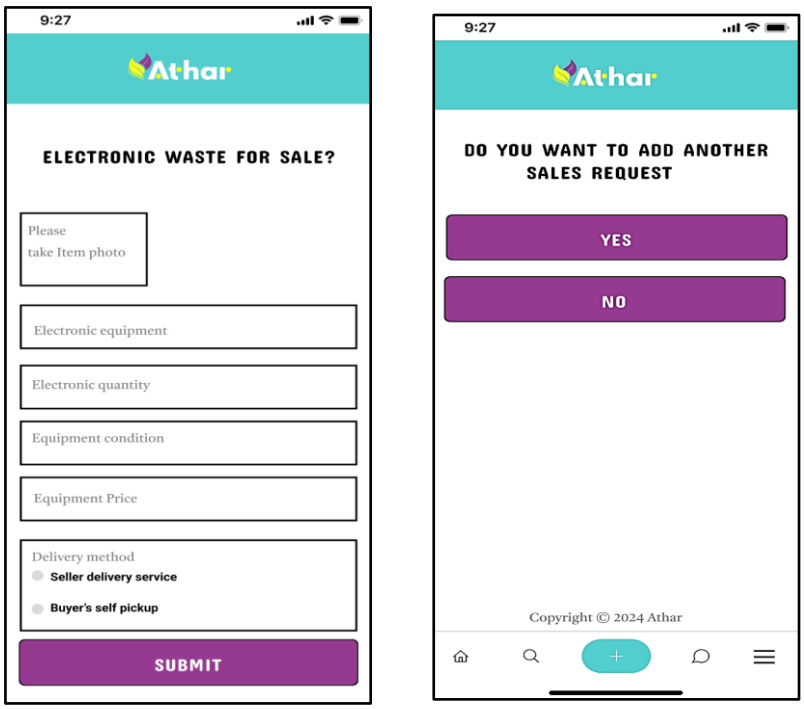

Figure 9. Sale request I/O interfaces

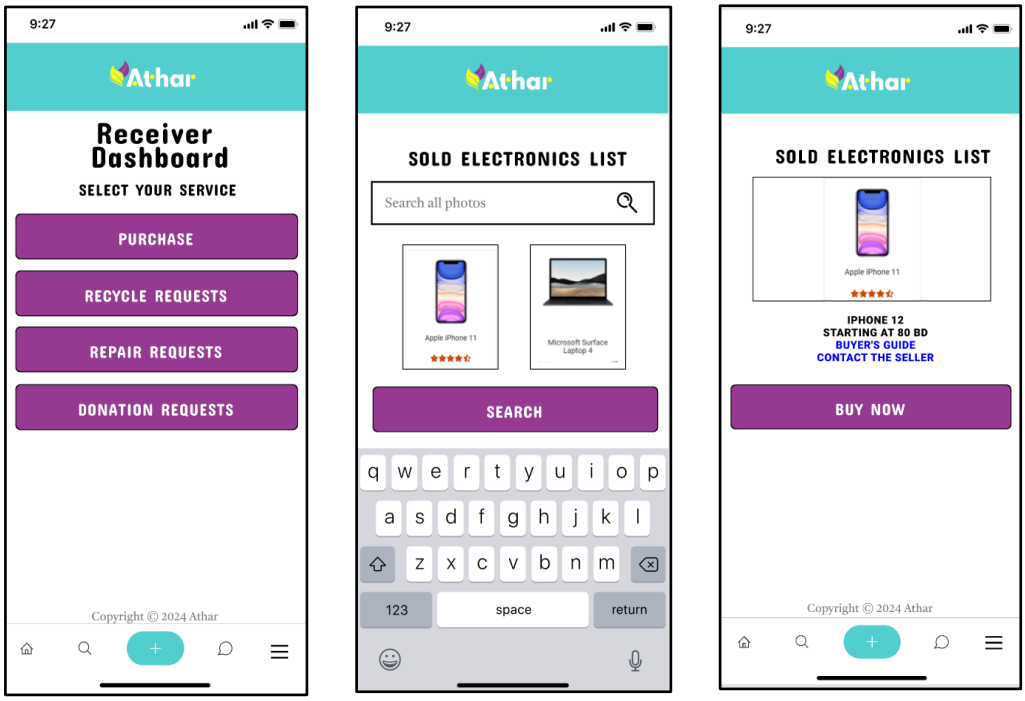

Figure 10. Receiver dashboard, sold list, e-details pages

4.4 Application Evaluation Analysis

Based on Nielsen criteria, Table 9 presents the statistical results of the 3rd questionnaire and indicates an overall usability rate of 89.1%. Visibility shows how obvious the system is to

users from various service perspectives. The average score for highly satisfied individuals is 13.53, for satisfied individuals is 15.87, for neutral individuals is 3.47, for unsatisfied individuals is 0.03, and for highly unsatisfied individuals is 0. Three primary heuristics were utilized to build the model accuracy, as indicated by the model accuracy. While the application's simplicity and menus received scores between 35% and 55% satisfaction, the application's navigation received scores above 55%. The satisfaction level for the user control assessment, which was based on Athar's simplicity and, navigation and menus, ranged from 40% to 50%. Sixty-five percent of users enjoyed the Athar mobile application's consistency, stylish and well-designed user interface, and the other media it uses. In contrast, Athar received scores between 25% and 55% for error recognition & prevention, 35% and 50% for privacy, and 30% and 50% for security.

Table 9. The 3rd Questionnaire findings are based on Nielsen's heuristics.

Heuristics	H. Satisfied	Satisfied	Neutral	Unsatisfied	H. Unsatisfied
Visibility					
Location of information	36%	58%	6%	0%	0%
Response time	39%	55%	6%	0%	0%
Selection input of data	49%	42%	6%	3%	0%
Model Accuracy					
Navigation structure	55%	33%	12%	0%	0%
Menus	36%	55%	9%	0%	0%
Simplicity	49%	48%	3%	0%	0%
User Control					
Explorable interface	43%	48%	9%	0%	0%
Menus control	43%	48%	6%	3%	0%
Process confirmation	43%	48%	9%	0%	0%
Consistency					
Design consistency	43%	42%	15%	0%	0%
Naming convention	42%	47%	13%	0%	0%
Application response	30%	52%	18%	0%	0%
Aesthetic and Minimalist Design					
Multimedia content	37%	45%	18%	0%	0%
Icons	52%	39%	9%	0%	0%
Menus	39%	58%	3%	0%	0%
Error Recognition & Prevention					
Error recognition	27%	55%	18%	0%	0%
Error prevention	40%	45%	15%	0%	0%
Privacy					
Clear warnings	36%	52%	12%	0%	0%
Privacy protection	36%	48%	16%	0%	0%
Security					
Timely information display	46%	48%	6%	0%	0%
Simple interface	49%	48%	3%	0%	0%
Problem assistive platform	31%	45%	21%	3%	0%
Average	41%	48.1%	10.5%	0.4%	0%

5. Conclusions

In this research work, we successfully achieved two main objectives that ultimately contributed to mitigating e-waste in Bahrain: the exploration of the e-waste phenomenon, and the creation of a mobile-based e-waste application named "Athar" and its evaluation after completion. Nevertheless, we encountered some difficulties in achieving our goal due to some implications. Among these implications are the time spent collecting the data necessary to determine requirements and the difficulty in learning to use new software to develop the

proposed application. Despite these challenges, we could finish the project in the right timeframe even though it was time-consuming and slowed its progress. Furthermore, we intend to enhance the Athar application by adding additional features, including customization options, voice speaking, a reward system, and viewing the collection center's location features. Furthermore, we intend to expand the range of services available in Athar to operate internationally and make the application work offline. Finally, we will continue optimizing the database to accommodate future plans and increase satisfaction ratings.

Author Contributions: Conceptualization: All; methodology: All; software: All; validation: All; formal analysis: All; investigation: All; resources: All; data curation: All; writing—original draft preparation: All; writing—review and editing: All; visualization: E.A; Supervision: E.A; project administration: E.A; funding acquisition: this research is not funded.

Funding: This research received no external funding.

Data Availability Statement: The authors declare that all supporting research data is available.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] Government of Bahrain, "About Bahrain," 2024. https://bahrain.bh/wps/portal/en/BNP/ HomeNationalPortal%0A
[2] WorldometersInfo, "Bahrain Population 2024," 2024. https://www.worldometers.info/world-population/bahrain-population/%0A
[3] Z. Stapić, E. G. López, A. G. Cabot, L. de Marcos Ortega, and V. Strahonja, "Performing systematic literature reviews in software engineering," in *Central European Conference on Information and Intelligent Systems*, 2012, pp. 441–447.
[4] Columbia University Mailman School of Public Health, "Content analysis method and examples," 2023. https://www.publichealth.columbia.edu/research/population-health-methods/content-analysis
[5] V. Armann-Keown and L. Patterson, "Content analysis in library and information research: An analysis of trends," *Libr. Inf. Sci. Res.*, vol. 42, no. 4, p. 101048, Oct. 2020, doi: 10.1016/j.lisr.2020.101048.
[6] J. M. Addington-Hall, "Survey research: methods of data collection, questionnaire design and piloting," in *Research Methods in Palliative Care*, J. M. Addington-Hall, E. Bruera, I. J. Higginson, and S. Payne, Eds. London, England: Oxford University Press, 2007, pp. 61–82. doi: 10.1093/acprof:oso/9780198530251.003.0005.
[7] E. J. Adwan, J. Adwan, E. Alwedaei, and M. Mohsen, "A GCC Artificial Food Additives Management based Mobile Application Development," *J. Comput. Theor. Appl.*, vol. 1, no. 3, pp. 326–345, Feb. 2024, doi: 10.62411/jcta.9843.
[8] S. Zafar, "Solid Waste Management in Bahrain," 2023. https://www.ecomena.org/solid-waste-bahrain/%0A
[9] Technische Universität Berlin, "Description of the systematic liiterature review method," 2023. https://www.tu.berlin/en/wm/bibliothek/research-teaching/systematic-literature-reviews/description-of-the-systematic-literature-review-method
[10] G. Sotelo, "What Is E-Waste and Why Is It a Problem?," *Treehugger*, 2021. https://www.treehugger.com/what-is-e-waste-and-why-is-it-a-problem-5186270
[11] M. Ikhlayel, "Environmental impacts and benefits of state-of-the-art technologies for E-waste management," *Waste Manag.*, vol. 68, pp. 458–474, Oct. 2017, doi: 10.1016/j.wasman.2017.06.038.
[12] B. Ayvaz and A. Görener, "Reverse Logistics in the Electronics Waste Industry," in *Waste Management*, IGI Global, 2020, pp. 1664–1680. doi: 10.4018/978-1-7998-1210-4.ch077.
[13] T. L. Wu, "What Is E-Waste Recycling and How Is it Done?," *earth.org*, 20023. https://earth.org/what-is-e-waste-recycling/
[14] S. Chatterjee, "Sustainable Electronic Waste Management and Recycling Process," *Am. J. Environ. Eng.*, vol. 2, no. 1, pp. 23–33, Aug. 2012, doi: 10.5923/j.ajee.20120201.05.
[15] J. Hong, W. Shi, Y. Wang, W. Chen, and X. Li, "Life cycle assessment of electronic waste treatment," *Waste Manag.*, vol. 38, pp. 357–365, Apr. 2015, doi: 10.1016/j.wasman.2014.12.022.
[16] UN report, "UN report: Time to seize opportunity, tackle challenge of e-waste," 2019. [Online]. Available: https://www.unep.org/news-and-stories/press-release/un-report-time-seize-opportunity-tackle-challenge-e-waste
[17] B. Mourya, "An analytical study of e-waste and its impact on environmental pollution in India," *AD VALOREM- J. Law*, vol. 5, no. 3, pp. 34–39, 2018.
[18] P. Lein and D. A. Bruun, "The toxicological implications of e-waste," *Open Access Gov.*, vol. 40, no. 1, pp. 448–449, Oct. 2023, doi: 10.56367/OAG-039-9559.
[19] E. A. Omondi and A. A. Chepkoech, Gloria Koech Kegode, "E-plastic Waste: A Review of Waste Stream Management Challenges and Opportunities for Environmental Sustainability," *Int. J. Environ. Sci. Nat. Resour.*, vol. 32, no. 4, Aug. 2023, doi: 10.19080/IJESNR.2023.32.556343.
[20] H. Yang and S. Zhang, "Risk management of e-waste disposal in China: A life cycle perspective," *Energy Environ.*, vol. 35, no. 3, pp. 1235–1250, May 2024, doi: 10.1177/0958305X221140577.
[21] J. Indrupati and T. F. Henari, "Consumer behaviour in E-waste disposal-A case for setting up an E-waste collection and recycling facility in Bahrain," *2015 2nd Bahrain Int. Corp. Soc. Responsib. Conf.*, no. February 2015, pp. 1–16, 2015.

[22] Arabia Weather, "What is the smallest Arab country in terms of area?," *Arabia Weather*, 2022. https://www.arabiaweather.com/en/question/what-is-the-smallest-arab-country-in-terms-of-area#google_vignette
[23] Ministry of Information, "Population and Demographics," 2023. https://www.mia.gov.bh/kingdom-of-bahrain/population-and-demographics/?lang=en#:~:text=According to the official census for the year,in 2030%2C up from 621 thousand in 1999
[24] BTM, "BusinessE-Waste – How We Consume and Manage it," *bahrainthismonth*, 2021. https://www.bahrainthismonth.com/magazine/business/e-waste-how-we-consume-and-manage-it
[25] "Waste management & recycling services," 2023. https://www.wm.com/ (accessed Sep. 30, 2023).
[26] "Bekia," 2017. https://www.bekia-egypt.com/en/ (accessed Sep. 30, 2023).
[27] Crown Industries BSCC, "Crown Industries b.s.c.(c) – Recyclers of Metals & Plastics," 1997. https://www.crownbahrain.com/ (accessed Sep. 30, 2023).
[28] "Ecotrade Group," 2023. https://www.ecotradegroup.com/en/weee-pcb-catalogue (accessed Sep. 30, 2023).
[29] "Etadweer," 2021. https://www.etadweer.com/ (accessed Sep. 30, 2023).
[30] "Pakam," 2021. https://www.pakam.ng/ (accessed Sep. 30, 2023).
[31] "WasteBazaar," 2019. https://www.wastebazaar.com/ (accessed Sep. 30, 2023).
[32] "Escrappy Recyclers," 2021. http://escrappyrecyclers.com/ (accessed Sep. 30, 2023).
[33] GreenE, "eWaste," 2023. https://greene.gov.in/ (accessed Sep. 30, 2023).
[34] ERF, "Electronics Recycle Factory – erf," 2021. https://erf.com.qa/ (accessed Sep. 30, 2023).
[35] Ecyclex, "Certified Recycler in Dubai, Abu Dhabi and across UAE," 2012. https://www.ecyclex.com/ (accessed Sep. 30, 2023).
[36] Madenat Recycling, "Madenat Alnokhba Recycling, Best E-waste recycling in UAE - Madenat Al Nokhba." https://madenatrecycling.ae/ (accessed Sep. 30, 2023).
[37] E. J. Adwan, Y. Al-Aradi, M. Essa, and H. Malabari, "A Comprehensive Study and Development of Unified Mobile-Based Admission System for GCC Universities," *J. Comput. Theor. Appl.*, vol. 1, no. 2, pp. 212–230, Dec. 2023, doi: 10.62411/jcta.9793.
[38] A. Quatember, "A Standardization of Randomized Response Strategies," *Surv. Methodol.*, vol. 35, pp. 143–152, Jan. 2011.
[39] Survey Monkey, "Sample size calculator," 2023. https://www.surveymonkey.com/mp/sample-size-calculator/ (accessed Feb. 23, 2023).
[40] J. O. Grady, *System Requirements Analysis*. Elsevier, 2014. doi: 10.1016/C2012-0-06079-6.
[41] J. Semmlow, "Linear Systems Analysis in the Time Domain," in *Signals and Systems for Bioengineers*, Elsevier, 2012, pp. 261–316. doi: 10.1016/B978-0-12-384982-3.00007-9.
[42] Q. Li and Y.-L. Chen, "Data Flow Diagram," in *Modeling and Analysis of Enterprise and Information Systems*, Berlin, Heidelberg: Springer Berlin Heidelberg, 2009, pp. 85–97. doi: 10.1007/978-3-540-89556-5_4.
[43] R. Ibrahim and S. Y. Yen, "Formalization of the Data Flow Diagram Rules for Consistency Check," *Int. J. Softw. Eng. Appl.*, vol. 1, no. 4, pp. 95–111, Oct. 2010, doi: 10.5121/ijsea.2010.1406.
[44] M. Rouse, "Process Specification," *Techopedia*, 2012. https://www.techopedia.com/definition/28636/process-specification.
[45] R. Lichtenthaeler, S. Böhm, J. Manner, and S. Winzinger, *A Use Case-based Investigation of Low-Code Development Platforms*. 2022.
[46] B. Grácio, "I'm a Magic MABS: How the Mobile Apps Build Service Works," *OutSystem Blog*, 2018. https://www.outsystems.com/blog/posts/how-mobile-apps-build-service-works/ (accessed Mar. 07, 2023).
[47] A. Jacinto, M. Lourenço, and C. Ferreira, "Test mocks for low-code applications built with OutSystems," in Proceedings of the 23rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings, Oct. 2020, pp. 1–5. doi: 10.1145/3417990.3420209.
[48] N. Juristo, A. Moreno, S. Vegas, and M. Solari, "In Search of What We Experimentally Know about Unit Testing," *IEEE Softw.*, vol. 23, no. 6, pp. 72–80, Nov. 2006, doi: 10.1109/MS.2006.166.
[49] T. Hamilton, "What is Unit Testing?," *guru99*, 2024. https://www.guru99.com/unit-testing-guide.html
[50] J. Nielsen, "Enhancing the explanatory power of usability heuristics," in *Proceedings of the SIGCHI conference on Human factors in computing systems celebrating interdependence - CHI '94*, 1994, pp. 152–158. doi: 10.1145/191666.191729.