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Managing Sustainable E-Waste Resilient Infrastructure with Smart Bin

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ABSTRACT

Innovation has become an essential and inevitable factor that profoundly influences globalization and supports the prosperity of economies worldwide. Over the past few decades, one of the most common forms of innovation has been the development of electronic goods and gadgets, particularly components of the Internet of Things. These electronic goods have become indispensable in various industries, such as manufacturing, medical, telecommunication, food and beverages, and service sectors, significantly enhancing operational processes. With the increasing demand for electronic goods globally, both businesses and end users have embraced their usage extensively. However, this widespread reliance on electronic equipment has also led to a surge in electronic waste generation, posing a significant environmental challenge. Estimated that approximately 44.7 million tonnes of e-waste have been generated annually since 2016, a figure projected to rise steadily with the continuous advancement of new technologies. Malaysia produces about 365,000 tonnes of e-waste each year, prompting the need for effective e-waste management solutions. One such solution has been implemented by ERTH, a non-governmental organization (NGO), that offers convenient collection services for e-waste around the Klang Valley. As the demand for electronic goods continues to escalate, stakeholders must recognize the environmental impact of e-waste and actively engage in sustainable e-waste management practices. The integration of innovative approaches such as ERTH's e-waste collection services can significantly contribute to minimizing the detrimental effects of e-waste on the environment hence fostering a more environmentally responsible approach towards electronic goods consumption. By promoting responsible disposal practices and embracing recycling initiatives, societies can work together to create a greener and more sustainable future.

1. Introduction

In today's industrial revolution 4.0 era, nations are rapidly embracing information technology (IT) innovation across various sectors, using high-tech machinery and equipment to develop innovative products and enhance services. Electronic devices have become an integral part of modern life, with

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varying lifespans based on usage. When these devices malfunction and cannot be easily repaired due to resource limitations, consumers often dispose of them, leading to the accumulation of e-waste in dumping areas [1]. E-waste, consisting of faulty electronic products, can contain hazardous materials including Sulphur, Mercury, Beryllium oxide, and other heavy metals that harm the environment and human health. Environmentalists and non-governmental organizations are increasingly concerned about the proper management of e-waste to address these environmental challenges and protect living beings.

In Malaysia, waste management companies handle various waste products by collecting and sending them to designated disposal areas. However, this approach has not effectively addressed environmental issues, and awareness among users remains insufficient [2-4]. Despite the implementation of recycling bins for paper, glass, plastic, and metal materials, waste volumes and pollution continue to be major concerns, particularly evident in coastal areas where ocean currents deposit plastics and waste materials on shorelines. Malaysia faces the challenge of managing e-waste, generated by both the industrial sector and households due to the rapid growth of the technological industry. Improper e-waste management can lead to environmental and health issues, as it contains hazardous substances harmful to living beings. To tackle this problem, the Malaysian government has introduced the MyEwaste mobile application in alignment with the United Nations Sustainability Development Goals (SDG) under the 6th goal: Clean Water & Sanitation [2-4]. Despite these efforts, there is still a lack of awareness among Malaysians regarding proper e-waste disposal. Introducing Smart-Bin technology could be a solution to improve e-waste management and bring benefits to individuals, industries, and the environment.

Smart-Bin is an innovative smart waste bin designed to incentivize residents within Klang Valley to dispose of their e-waste responsibly. By using Smart-Bin, residents can receive monetary rewards based on the weight and usability of the electronic gadgets they dispose of, especially batteries. The primary goal of Smart-Bin is to collect smaller gadgets including batteries for recycling purposes. Based on recent studies by [5,6] have shown that reusing and reprocessing batteries can significantly reduce the number of batteries ending up in landfills, preventing the contamination of water and soil by toxic components and metals. The need for sufficient and effective e-waste disposal bins in residential areas, especially around Klang Valley, is crucial in fostering awareness and encouraging proper e-waste management to protect the natural ecosystem. The i-Bin project represents a promising solution to address these challenges and promote responsible e-waste disposal practices.

1.1 Background Study

The advancements in technology have undoubtedly brought about positive changes worldwide. However, they have also led to a concerning increase in electronic waste, which is now accumulating in landfills across the globe. Most of the E-Waste that has been disposed of contains hazardous chemicals such as cadmium, mercury, beryllium, and other substances that can cause severe damage to people and the environment [5-7]. The use of mobile devices has experienced rapid growth, particularly in Malaysia, with the advent of internet technology. As of 2020, Malaysia recorded 29.3 million internet users, projected to reach 30.77 million by 2025 [8]. Unfortunately, the rapid development of new technology has resulted in equipment with shorter lifespans. Coupled with the lack of proper electronic waste recycling facilities, this has contributed significantly to the mounting e-waste issue in Malaysia [6]. According to a report, mobile phone rechargeable batteries and cell phones are among the highest-disposed waste items [5,6]. Studies justify that the key factors that cause the impact of e-waste are inconvenient processes, lack of awareness, and poor regulations on e-waste disposals [9,10]. In another statement by the World Health Organization, a study conducted by the Global Environmental Sustainability Programme (GESP) has reported that 17.4% of E-Waste was properly recycled in the recycling facilities has created a positive outcome by withholding approximately 15 million tonnes of carbon dioxide being released to the environment [9]. On the other hand, an innovative method for the development of intelligent E-waste bins, incorporating machine learning algorithms to recognize and classify objects [10-12]. The study emphasized the importance of precisely identifying different types of e-waste, such as batteries, circuit boards, and electronic devices. The research showcased how machine learning techniques have the potential to improve the sorting and recycling processes of e-waste.

1.2 Problem Statement

E-waste, which includes discarded electronic devices and electrical equipment, has become a significant global issue due to the rapid growth of technology and the short lifespan of many electronic products. Improper disposal of e-waste can lead to environmental and health hazards, as it contains hazardous substances like heavy metals and toxic chemicals. The research aims to investigate the implementation of E-Waste Kiosks designed specifically for battery and small IT equipment disposal [5,6]. By focusing on these items, the study seeks to address the unique challenges associated with their proper disposal. The investigation aims to raise awareness among individuals, businesses, and communities about the importance of responsible e-waste management. Currently, inadequate waste collection facilities and low recycling rates contribute to the improper disposal of e-waste. The research seeks to develop sustainable solutions to minimize environmental impact and health risks associated with e-waste while also identifying strategies for effective e-waste management.

The E-Waste Kiosk with AI integration offers a promising and innovative solution to address the challenges of battery and small IT gadget disposal. By utilizing AI and Machine Learning, the kiosk efficiently evaluates the functionality and weight of the discarded items, enabling users to receive cash back based on usability and weight. Many countries and organizations have implemented e-waste collection and recycling programs to promote responsible disposal. Some have even established dedicated drop-off centers for convenient e-waste disposal [13,14]. Additionally, electronic manufacturers and retailers are initiating voluntary take-back programs, encouraging customers to return faulty products while reducing transportation costs [9]. On the other hand, in line with the Sustainable Development Goals (SDGs) outlined by the United Nations, Private E-Waste Recycling Companies are also playing a role in collecting e-waste products from various sources, including households, businesses, and institutions [15,16].

Despite government-established E-Waste collection centers, accessibility remains a challenge in remote areas with limited transportation options. The lack of standardized procedures confuses individuals about what can be deposited, leading to illegal disposal. Cash-back E-Waste Kiosks like ecoATM are limited [9]. Insufficient knowledge among the public results in improper e-waste disposal, leading to environmental concerns. Improving accessibility, providing clear guidelines, and enhancing public education are essential to address these challenges effectively.

The proposed solution for managing e-waste involves intelligent bins or kiosks in residential areas, integrated with IoT technology. These kiosks provide precise information about deposited e-waste, including weight, type, condition, and usability. Thermal imaging cameras detect battery temperature variations, and weighing sensors measure battery weight. Image recognition and barcode scanning technologies identify battery types and retrieve data. Implementing a price/usability metric categorizes batteries based on their remaining capacity and internal resistance, allowing for distinct pricing tiers.

Thermal imaging cameras or infrared cameras play a vital role in identifying temperature variations across the surface of batteries. By monitoring heat distribution, these sensors can detect irregular temperature patterns or higher temperatures, indicating internal flaws or issues within the batteries. Weighing sensors, typically employing load cells or other mechanisms, are integrated into the platform or container of the kiosks. When a battery is placed on the kiosk, the load cell measures its weight and transmits the information to the kiosk's software.

Two methods are employed for battery identification. Firstly, image recognition technology is utilized, where cameras or scanners integrated into the e-waste kiosk capture images of the disposed batteries. Machine learning algorithms, configured with a dataset of battery images, analyze the captured images to identify the battery type.

Secondly, barcode scanners are employed as batteries commonly come with barcode labels containing manufacturer information and other relevant details. By equipping the kiosk with scanners capable of reading these codes, the system can compare the scanned code with a database or employ machine learning algorithms to identify the battery type and retrieve associated data.

To determine the usability of batteries, data collected from the Battery Usability sensor is used. A scale or grading system can be established, considering factors such as remaining capacity, internal resistance, voltage levels, and other relevant parameters. Based on the assessed usability, different price tiers are assigned, enabling batteries with higher usability to command a higher price, while those with lower usability are assigned a lower price. The Research Questions, Research Objective, and Hypothesis are summarized below and in Figure 1.

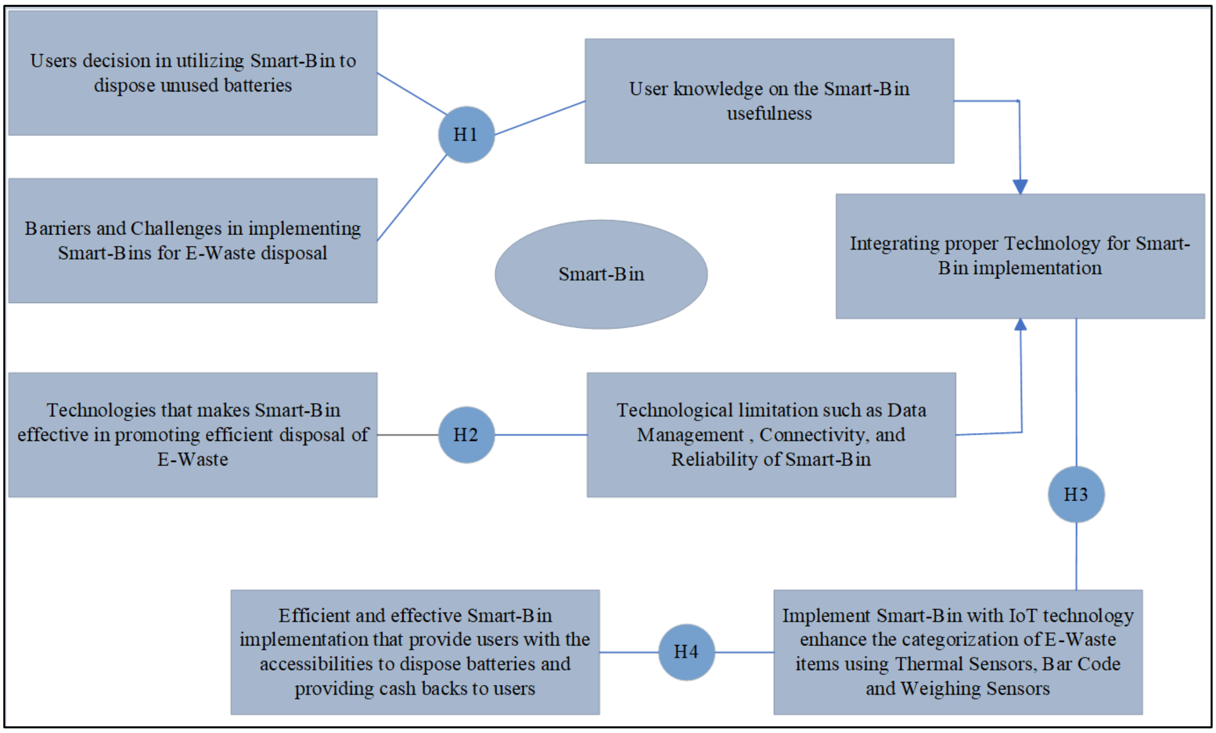

Fig. 1. Research Framework Diagram

1.3 Research Questions

RQ1: What are the factors influencing consumers' decision to use e-waste kiosks for disposing of batteries?

RQ2: What are the key features and technologies that make smart bins effective in promoting the proper disposal of e-waste?

RQ3: How can the implementation of intelligent bins or kiosks with IoT technology enhance the monitoring and categorization of e-waste items, including batteries?

RQ4: What are the potential barriers and challenges in implementing smart bins for e-waste disposal, and how can they be addressed?

1.4 Research Objectives

RO1: To explore factors, that shape consumers' behaviors and choices in utilizing e-waste kiosks for battery and small IT equipment disposal.

RO2: Identify and analyze the various features incorporated in smart bins for e-waste disposal.

RO3: The research aims to identify the features, functionalities, and capabilities of intelligent bins that contribute to improving the categorization of e-waste items, including the ability to identify and differentiate various types of batteries.

RO4: Identify the key barriers and challenges faced in the implementation of smart bins for e-waste disposal.

1.5 Research Hypotheses

H1: The availability of e-waste kiosks, including their convenient location near residential areas or workplaces, has a positive impact on consumers' inclination to utilize them for battery disposal. When disposal options are easily accessible, individuals are more likely to engage in proper disposal practices. Furthermore, the provision of incentives or rewards by e-waste kiosks, such as cash-back offers, discounts, or loyalty programs, plays a significant role in influencing consumers' decisions to use the kiosks for battery disposal. Tangible benefits provided through these incentives motivate individuals to actively participate in recycling initiatives.

H2: The integration of smart bin features and technologies enhances user engagement and encourages individuals to participate in e-waste disposal, leading to increased recycling rates and reduced environmental impact.

H3: IoT-enabled intelligent bins can enhance the categorization of e-waste items, including batteries, by leveraging image recognition, barcode scanning, or other IoT-driven technologies to accurately identify and differentiate various types of batteries.

H4: Technological limitations, including issues with data management, connectivity, and reliability, present challenges in the implementation and effectiveness of smart bins.

1.6 Value Creation

The synthesis of advanced technologies and thoughtful hypothesis exploration in this study generate substantial value by paving the way for an improved e-waste management paradigm. By dissecting intricate interrelationships, this research enhances understanding of sensor integration and user-centric considerations, ultimately contributing to a more efficient, sustainable, and user-friendly approach to e-waste management. Additionally, meticulously dissecting the connections between hypotheses, reveals the optimal utilization of sensors like thermal and weighing sensors, enabling a more precise and efficient sorting and categorization of electronic waste items. This technological enhancement not only streamlines the waste management process but also significantly minimizes the environmental impact through targeted recycling practices.

1.7 Scope

The research primarily focused on investigating and understanding the factors that influence consumers' behaviors and decision-making when it comes to using e-waste kiosks for the disposal of batteries and small IT equipment within Condominiums in Klang Valley. It delved into the underlying motivations and determinants that shape consumer behavior in the context of e-waste management practices [16]. The study pursued to gain insights into why consumers choose to utilize Smart-Bin, examining the various factors that contribute to their decisions. By exploring these factors, the research aimed to uncover the key drivers and influences that shape consumer behaviors related to e-waste disposal through kiosks. Ultimately, the goal was to enhance our understanding of consumer perspectives and preferences to inform the development of effective strategies and interventions to encourage responsible e-waste management practices. On the other hand, in this research, the current value of disposable batteries is not included. The mobile application providers are not discussed in this research.

The survey focuses mainly on residents, foreigners, and students who are residing in condominiums within Klang Valley. The targeted age group of residents in this survey is between 18 and 65 years old. The survey forms will be distributed to a minimum of 60 residents who possess good literacy skills. Meanwhile, the oral questioning technique will be employed on those who have a lower level of literacy skills or those who require additional assistance in terms of explanation and addressing their doubts such as senior citizens and foreigners.

2. Literature Review

Technology has become an integral part of our lives today and most of our day-to-day activities are heavily dependent on electronic gadgets to facilitate most of our errands. Technological advancements have indeed brought not only positive changes to the world, but it has also caused an adverse impact due to the surging electronic waste in many landfills around the world. The usage of mobile users has grown rapidly over the years with the advancement of internet technology especially in Malaysia recorded 28.8 million internet users in 2020 [8]. Thus, according to Shad, Ling, and Karim (2020), new technology equipment with a shorter life span and the lack of proper electronic waste recycling facilities has significantly surged the amount of e-waste in Malaysia [17]. E-waste is known as Electronic and Electrical equipment (EEE) that is broken, unusable, and products that reach their end of life. In most cases, E-Waste contains hazardous chemicals such as cadmium, mercury, beryllium, and other substances that can cause serious damage to the environment and people. Having said that, Morita (2021) stated that the frequent replacement of mobile devices due to the rapid production by mobile device manufacturers has caused e-waste from the telecommunication sector to increase substantially [5]. On the other hand, the lack of awareness and management strategies also can be considered for the recent increase of e-waste in Malaysia. Therefore, according to the Department of Environment Water Malaysia (DOE), recycling e-waste appropriately by disposing of it in the e-waste bin or sending the faulty device to the nearest recycling center will contribute to a huge reduction in the e-waste system in the country.

Inappropriate disposal of e-waste in landfills leads to hazardous materials being exposed to the environment which leads to serious damage to the soil and people’s health [5,6]. The key factor that causes the impact of e-waste is lack of awareness, inconvenient processes, and poor regulations on e-waste disposals [17]. Other factors including inadequate government policies, and lack of e-waste laws and management strategies have caused environmental and social issues in Malaysia, Indonesia, and Singapore [8]. However, the report from the World Health Organization (WHO) shown the study by the Global Environmental Sustainability Program (GESP) reported that 17.4% was properly recycled in the recycling facilities has reduced approximately 15 million tons of carbon dioxide from being released into the environment. World Health Organization (WHO) reported that the hazardous content from e-waste will create a detrimental effect on overall human health particularly in vulnerable populations such as children, senior citizens, and expectant mothers in which some prognosis includes decreased function of vital organs, damage to their DNA, stillbirth and premature births [15].

Many countries are striving to pursue an effective way of managing e-waste efficiently. Thus, there are many solutions identified and available and the key solution is recycling and raising awareness of the impact of e-waste among citizens. Similarly, Shad, Ling, and Karim (2020) recommended that Malaysia establish an effective law on recycling e-waste due to that the recycling system currently in place only focuses on valuable items, arduous collection transportation because of scattered household e-waste, and most importantly the recovery and recycling process can be costly [17]. However, recycling only will not reduce the soaring e-waste in the world as electronic device manufacturers should consider producing environmentally friendly devices that are durable, recyclable, and repairable to reduce the emerging e-waste that is discarded in landfills [7]. Additionally, with more smart technologies such as smart E-waste Kiosks, a bin that allows consumers to dispose of their unrepairable devices or batteries in selected locations will create a seamless approach for users to recycle their e-waste [6].

As a result of the above discussion, the proposed system in this project fundamentally concentrates on a device that improves the convenience of citizens to dispose of their e-waste whilst receiving a certain amount of rewards in terms of cash or points according to the size and usability of the e-waste items that has been disposed of in the Smart-Bin. Figure 2 shows how the existing E-Waste management process can be integrated with new technologies such as Thermal sensors.

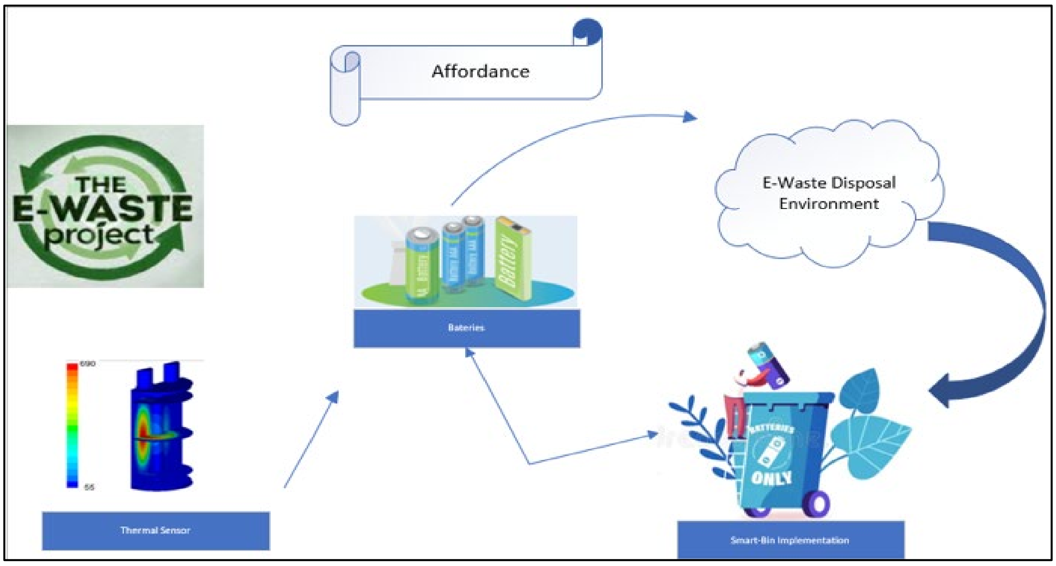

Fig. 2. Overview Flowchart

2.1 Background Study

The advancements in technology have undoubtedly brought about positive changes worldwide. However, they have also led to a concerning increase in electronic waste, which is now accumulating in landfills across the globe [18]. Most of the E-Waste that has been disposed of contains hazardous chemicals such as cadmium, mercury, beryllium, and other substances that can cause severe damage to people and the environment [19]. The use of mobile devices has experienced rapid growth, particularly in Malaysia, with the advent of internet technology. As of 2021, Malaysia recorded 29.3 million internet users, this number is projected to reach 30.77 million by 2025 [8]. Unfortunately, the rapid development of new technology has resulted in equipment with shorter lifespans. Coupled with the lack of proper electronic waste recycling facilities, this has contributed significantly to the mounting e-waste issue in Malaysia [5,6]. According to a report, mobile phone rechargeable batteries and cell phones are among the highest-disposed waste items [5,6]. The key factor that causes the impact of e-waste are inconvenient processes, lack of awareness, and poor regulations on e-waste disposals [15]. In another statement by the World Health Organization, a study conducted by the Global Environmental Sustainability Programme (GESP) has reported that 17.4% of E-Waste was properly recycled in the recycling facilities has created a positive outcome by withholding approximately 15 million tonnes of carbon dioxide being released to the environment. On the other hand, an innovative method for the development of intelligent E-waste bins, incorporating machine learning algorithms to recognize and classify objects [19]. The study emphasized the importance of precisely identifying different types of e-waste, such as batteries, circuit boards, and electronic devices. The research showcased how machine learning techniques have the potential to improve the sorting and recycling processes of e-waste.

2.2 Current Process

The current e-waste management system in Malaysia involves various essential elements to encourage responsible disposal practices and reduce environmental consequences [2-4]. A major factor involves creating public awareness regarding the dangers of e-waste and the significance of appropriate disposal methods. To achieve this objective, educational campaigns and initiatives are implemented to educate individuals about the potential environmental and health risks linked to the inappropriate handling and disposal of e-waste. To streamline the process of discarding defective electronic devices, dedicated collection centers and drop-off points have been strategically set up across Malaysia. These designated sites offer a convenient and easily accessible solution for individuals to responsibly dispose of their e-waste. Equipped with appropriate facilities, these centers are capable of effectively managing and storing e-waste until it is ready to be transported to recycling facilities. Various recycling companies that specialize in e-waste management such as ERTH and Cenviro Malaysia play a crucial role in ensuring that e-waste is processed in an environmentally responsible manner. Through partnerships with these companies, the recovery of valuable materials from faulty electronic devices is maximized, reducing the need for raw material extraction and minimizing the environmental impact. There are multiple initiatives have been employed to overcome the e-waste challenges including the E-waste take-back program which encourages the return and proper disposal of electronic waste. However, there are some limitations to the current e-waste management system. The availability of dedicated collection points in rural areas for e-waste disposal is often scarce or non-existent [16]. The lack of nearby drop-off locations creates inconvenience for residents when it comes to appropriately disposing of their electronic devices. Furthermore, transportation and logistical issues pose significant challenges in rural areas [17]. The limited transportation services to the nearest recycling facilities create obstacles for residents in transporting their e-waste to proper disposal centers. Consequently, e-waste tends to accumulate and be stored in households, raising the potential for environmental contamination and associated risks. Figure 3 shows the current method of disposing of e-waste in cities and urban areas in Malaysia.

Fig. 3. Current method to dispose of e-waste in Malaysia (Source: MAMPU)

2.3 Technology Innovation

Previous studies primarily emphasize the integration of heat sensors for monitoring the temperature of e-waste bins [18]. Additionally, another researcher [19] has directed their attention towards ultrasonic sensors for detecting the fill levels of the bins. In this paper, I propose the integration of a Thermal Imaging Camera with an Arduino board to assess the usability and quality of batteries. This innovative approach aims to enhance the e-waste management process by providing a more comprehensive understanding of battery conditions. Even though a heat sensor such as DS18B20 may detect the accurate heat of the entire bin, it still lacks detection of individual items such as batteries [5]. Moreover, through the implementation of the suggested system in the smart bin, it becomes possible to identify the distinct heat profiles and thermal characteristics associated with various electronic devices, including batteries. This integration offers a valuable tool for effectively analyzing and understanding the thermal behavior of e-waste, aiding in the appropriate sorting and disposal of electronic devices. Another researcher [6] discussed the Fibre Optic sensor in identifying battery quality, however, the process requires physical contact with the disposed of items. By this, the incorporation of the proposed Thermal Imaging Camera into an e-waste bin enables the non-intrusive testing of batteries without the need for physical contact or disassembly. Additionally, this advanced system eliminates the downsides and potential hazards related to conventional battery testing techniques. The integration of the Thermal Imaging Camera enables quick and efficient evaluation of battery performance and quality, ultimately enhancing the overall effectiveness of e-waste management processes. This capability allows for a swift and efficient evaluation of the battery's thermal characteristics, reducing the risk of damage or interference during the scanning process. Furthermore, by integrating a Thermal Imaging Camera with the Arduino platform, the system enables real-time temperature measurements and analysis, allowing for immediate feedback on battery quality. This immediate assessment provides valuable information about the battery's condition and helps in making prompt decisions regarding its usability and further handling. In conclusion, by incorporating these technologies, especially when combined with platforms like Arduino, the sorting of e-waste, including batteries, can be enhanced, resulting in improved efficiency and effectiveness of e-waste management processes as a whole.

2.4 Framework Literature

The literature framework delves into the intricacies of thermal sensors, emphasizing their capability to detect temperature variations associated with different electronic waste items. When harnessed within the e-waste context, thermal sensors enable a highly efficient sorting process, distinguishing materials based on their heat signatures. This innovation not only enhances the accuracy of sorting but also optimizes resource utilization through targeted recycling practices. Moreover, the framework also underscores the empowerment of AI technologies in refining decision-making processes. By analyzing data patterns and trends, AI technologies can enable predictive models for optimal waste management strategies. This, in turn, fosters more sustainable practices, reduces environmental impact, and enhances operational efficiency as shown in Table 1

Table 1
Framework Literature Summary

Framework	Problem Statement	Objective	Methodology	Contribution	Limitation	Perspective
Abd-Mulalib (2021). A Review of Modern Thermal Imaging Sensor Technology and Applications for Autonomous Aerial Navigation. Journal of Imaging, 7(10), 217.	Inaccurate thermal imagery, such as edges and textures in navigation purposes, particularly in natural scenes and unmanned aerial vehicles (UAVs).	To examine and analyze the various levels of challenges and concerns related to thermal sensors within a navigation system	Collecting relevant research papers for the study by conducting a systematic search using specific keywords in platforms including the university library database and Google Scholar platform. The identified keywords include "long-wave infrared," navigation", "thermal imaging", "GPS denied, "deep learning," and "vision-based techniques.	Theoretical: By exploring the fundamental physics of operation, sensor configurations, and computational aspects, the study aims to enhance our understanding of the theoretical foundations behind the integration of thermal sensors in navigation applications. Managerial: By categorizing relevant papers based on the type of algorithms used and discussing sensor specifications and configuration aspects, the study offers valuable insights for managers and decision-makers involved in the development and implementation of thermal sensor-based navigation systems.	limited availability of compact and powerful onboard processing hardware, the initial design of navigation algorithms was primarily focused on unmanned ground vehicles (UGVs) rather than unmanned aerial vehicles (UAVs).	These sensors enable the detection and interpretation of thermal signatures, allowing for enhanced situational awareness and improved navigation capabilities.
Andeobu (2021). On-site research with a thermal camera on industrial heating. IOP Conference Series: Materials Science and Engineering, 1031(1), 012082.	Heating problems, thermal bridges, heat loss in industrial buildings	To identify key factors that influence the performance and efficiency of heating systems in industrial settings.	capturing thermal images of various locations within each industrial building, specifically targeting areas with heating challenges by using thermal imaging technology.	Theoretical: By applying thermal imaging technology as a non-invasive tool for investigating the practices of heating technologies in industrial premises, the researcher will be able to capture and analyze thermal patterns and	The presence of high ceilings in industrial buildings poses a challenge for heating and ventilation systems. Due to the working processes and	The studies provide valuable recommendations and insights that can assist architects, engineers, and facility managers in making well-informed decisions

temperature variations Managerial: valuable and practical insights can be utilized to enhance the design and optimization of heating systems in industrial buildings Societal: By optimizing the heating systems in industrial buildings, it is possible to minimize energy consumption, resulting in reduced carbon emissions and overall energy savings Managerial: By evaluating and comparing the effectiveness and accuracy of the thermal cameras in various applications, as well as taking into account cost factors, managers are empowered to make well-informed decisions that align with their specific requirements and budgetary limitations Societal: The availability of affordable thermal camera systems expands the accessibility of this technology, potentially benefiting farmers, researchers, and other stakeholders involved in crop monitoring and resource management	heavy load cranes or the need for storage capacity, hot air tends to rise while the ground level, where the workstations are located, remains colder. This obstacle hinders the effectiveness and energy efficiency of many heating technologies.	regarding the design and implementation of heating systems in industrial buildings
Managerial: The research provides a feasible and cost-effective answer for regular screening of dairy products, allowing for prompt identification of melamine contamination and mitigating the negative impacts on the overall healthcare system. Societal: By implementing the sensors in the dairy industry, better	2. Highly depending on complex metrics for melamine detection in dairy products	

				quality control, enhancing consumer trust, and minimizing economic losses associated with melamine contamination incidents can be eliminated.		
Chen (2021). Thermal Sensors for Contactless Temperature Measurements, Occupancy Detection, and Automatic Operation of Appliances during the COVID-19 Pandemic: A Review. Microm achines, 12(2), 148	Lack of contactless body temperature identification technologies during the COVID-19 pandemic.	To identify the type of Thermal sensors and how thermal sensors can be utilized in contactless applications, which have become increasingly important during the pandemic.	reviewing and analyzing the different types of thermal sensors proposed during the last ten years, with a focus on their potential employment in COVID-19-related applications	Theoretical: The research contributes to the field of sensor technology by reviewing the theory behind thermal sensors and their various types Managerial: The research emphasizes the importance of technology in supporting the necessary changes to public life, such as social distancing and contactless operations Societal: By enabling contactless temperature measurements and automating processes to reduce physical contact, thermal sensors contribute to public health and safety	The cost of the sensors is expensive. The accuracy and efficiency depend on the quality of the various sensors available in the market.	Thermal sensors are described as versatile devices capable of contactless temperature measurements, presence detection, people counting, and automation of appliances and systems, thereby reducing the need for physical touch.

2.4.1 Theoretical (Technical)

According to the works of literature studied, there are many Theoretical methodologies identified in enhancing e-waste management especially batteries through various sensor and software integration. Furthermore, the literature contributes to the knowledge of effective approaches for managing e-waste and highlights the potential benefits of incorporating advanced sensors in waste management systems.

2.4.2 Practical

The literature indicates that the integration of Thermal Sensors in e-waste bins lies in the ability to facilitate non-intrusive and efficient testing of batteries which offers numerous societal benefits such as providing a quick and accurate assessment of battery performance and quality without the need for physical contact with the devices.

2.4.3 Managerial (Business)

Based on the literature, integrating Thermal Sensors in e-waste bins contributes to informed decision-making in e-waste management. Moreover, the real-time temperature measurements and analysis provided by these sensors empower quality, recycling, sorting, and disposal decisions for e-waste, including batteries.

2.4.4 Societal (Convenience of disposing of e-waste)

The literature highlights several societal benefits associated with the integration of Thermal Sensors in the e-waste bin. By accurately assessing battery quality and identifying potentially hazardous batteries, this technology ensures that only suitable batteries are processed and recycled. This minimizes the risk of environmental contamination and contributes to a cleaner and healthier environment for communities and future generations.

2.5 Change Management

In the context of addressing critical environmental concerns like e-waste management, change emerges as an ever-present force, signifying the need for transformative actions. This shift seeks to reform disposal practices within residential areas through strategic change management strategies. Additionally, this analysis covers what, where, why, and how of this change, highlighting its potential to enhance both environmental preservation and convenience. The proposed change management initiative aims to introduce dedicated e-waste bins tailored for small electronic items. By saying this, the change is set to revolutionize disposal practices within residential areas by offering tailored solutions for responsible e-waste disposal. Moreover, by strategically situating bins in convenient locations and emphasizing convenience and environmental responsibility, this initiative demonstrates the transformative potential of change management in fostering positive behaviors and environmental preservation within local communities.

2.6. Summary of Literature

The study focuses on the incorporation of smart technologies into e-waste kiosks to enhance the effectiveness and efficiency of the system. Furthermore, the study analyses the implementation of real-time monitoring systems using various heat sensors to track the quality and usability of the disposed items including batteries. By saying this, the integration of new technologies enables improved planning of sorting of e-waste items and prevents the kiosks from overflowing, ensuring smooth and timely disposal of e-waste. By leveraging IoT technologies, such as sensors and real-time data, the studies aim to optimize the operation of e-waste kiosks and improve their inclusive performance. This approach helps address the challenges associated with e-waste management by providing a more systematic and efficient solution. The findings of the research suggest that the integration of smart technologies in e-waste kiosks has the potential to enhance their functionality, resulting in better management and disposal of electronic waste.

3. Methodology

This research aims to address the current difficulties faced by individuals residing in the Klang Valley area and propose viable solutions. Specifically, the study focuses on addressing challenges related to small electronic devices like batteries and suggests the implementation of Smart-Bin kiosks. confronts a pressing issue of generating 365,000 tonnes of e-waste annually, and this number is steadily growing [21]. While licensed recycling vendors are involved in the formal recycling process, the informal method of e-waste disposal involves harmful practices such as burning and dismantling

items in landfills. The exponential growth of companies in the ICT sector has contributed significantly to the mounting e-waste problem. In the context of the Klang Valley region, residents residing in condominiums encounter several obstacles when it comes to effectively disposing of their e-waste. These challenges may include limited access to suitable disposal facilities, a lack of awareness regarding proper e-waste management, and the absence of convenient recycling options within their residential communities. By saying this, a comprehensive review of existing literature, reports, and studies related to e-waste management, recycling processes, and the implementation of similar initiatives has been conducted to identify the solutions.
To carry out the research, a variety of techniques and procedures are employed in categorizing, selecting, processing, and assessing the information. This entire process is commonly referred to as research methodology. Qualitative, quantitative, and mixed-method methodologies are the three primary research approaches widely utilized by researchers [22-25].
Qualitative research involves observing and analyzing individuals' actions and words to collect and interpret data. It is a subjective approach that utilizes various methods, such as in-depth interviews and focus group discussions, to gather information [26-27]. This type of research is exploratory and allows for open-ended exploration of the topic. Then again, quantitative research aims to explain phenomena by gathering numerical data and analyzing them using mathematically based methods, primarily statistics.
Conversely, mixed methods research is an inclusive approach where the researcher collects, analyses, and interprets both quantitative and qualitative data. This method integrates the two approaches in diverse ways and encompasses a specific design framework for the study.

3.1 Research Design

The research design for the e-waste management study in the Klang Valley area consists of a mixed-methods approach, combining quantitative and qualitative research methods to gather comprehensive data and insights [28-32]. Additionally, a well-structured questionnaire has been created to gather numerical data regarding the disposal practices of residents, the difficulties they encounter, and their level of awareness regarding the responsible management of e-waste. The survey will include multiple-choice questions and open-ended and Likert-scale item questions to capture a range of responses. Furthermore, the survey will be administered electronically through online platforms to residents in the Klang Valley area.

3.2 Research Method Type

In this project, a mixed methods research approach was utilized, employing a questionnaire and survey as the data collection technique to gather accurate information. The mixed method was used in this research study as these techniques save time and the data can be practically gathered from any subject [20-23]. The quantitative and qualitative technique is the most suitable method for the resident sample that has been pre-selected at a particular time or in other words is a single point in time even though the collection of data takes more than a few weeks. To understand the challenges faced by Klang Valley residents, a survey was conducted to gather relevant information about the current situation. The questionnaire method was chosen for this research as it offers time efficiency and allows data to be collected practically from any participants. A specific collection of survey questions was absorbed and improved upon, drawing from multiple research sources. These questions were utilized to collect valuable information regarding the level of awareness among residents about the process of handling electronic waste (e-waste), their opinions on managing e-waste items, and their current behaviors about e-waste management in high-rise condominiums. The participants in the study were individuals aged between 18 and 65 years. To ensure a representative sample, 60 residents with proficient literacy skills were carefully selected to receive the survey forms. To accommodate individuals with lower literacy levels or those who needed additional support, such as senior citizens and foreigners, an oral questioning technique was employed. This approach aimed to enhance their comprehension, address any uncertainties, and provide a fair opportunity for their participation in the study.

3.3 Target Population

All users of social media platforms are included in the study's target population. The purpose of the study is to investigate how this diverse population views the use of encryption in social media and its significance [24-26]. The study aims to gather a thorough and inclusive understanding of people's attitudes toward encryption features and techniques by focusing on social media users from various backgrounds, demographics, and ages. The knowledge gained from this diverse target audience will aid in the creation of encryption techniques that take social media users' needs and preferences into account, ultimately enhancing data security and user experience in the digital sphere.

3.4 Convenient Sampling

The mixed method was deemed appropriate for sampling residents at a specific time, even though the data collection spanned several weeks. In this research, it has been concluded that all participants in the sample should encompass individuals from all demographic groups and be residents of high-rise buildings around Klang Valley. These locations have been selected as the main research area due to the significant presence of both local and foreign residents, who primarily work in the ICT sector or students. Taking into consideration the high number of condominiums with ICT sector residents and students, Klang Valley was identified as a suitable location for e-waste management studies. The utilization of Google Forms for data collection has been chosen due to its convenience and accessibility for respondents, thereby enhancing the likelihood of their active participation in the survey [27-31]. Furthermore, to analyze the data, quantitative and qualitative data analysis will be used as the fundamental measure for summarizing and measuring the collected information [32-33]. This will involve applying a range of descriptive statistics which involve calculating measures such as frequencies, percentages, means, and standard deviations to summarize and describe the characteristics of the collected data. Microsoft Excel is utilized to gather and analyze the data, facilitating the organization of data into tables and eventually transforming it into meaningful graphs and charts for visualization purposes.

4. Findings and Discussion

The findings and discussion of the e-waste management study in the Klang Valley area present a comprehensive analysis of the challenges faced by residents in effectively disposing of small electronic gadgets, with a particular focus on batteries. The study aimed to identify and propose effective solutions to address these challenges and promote responsible e-waste management practices within the region. In this section, we present the key findings derived from the structured questionnaire and in-depth interviews conducted with relevant stakeholders. The structured questionnaire gathered quantitative data on the e-waste disposal practices of residents, the obstacles they encountered, and their level of awareness regarding responsible e-waste management.

4.1 Demographic

In the age of technological advancement and growing environmental concerns, the integration of smart bins into electronic waste (e-waste) management presents a progressive approach to addressing the challenges of waste disposal. However, the success of such implementations goes beyond the realm of technology, it hinges on a profound understanding of human behaviors, preferences, and demographics. Among the crucial components of this understanding lies the demographic section, encompassing variables such as age, gender, locality, and occupation. This survey explores the pivotal role of these demographic factors in the implementation of smart bins in e-waste studies. By investigating how various demographic groups engage with and react to smart bins, valuable insights are obtained as shown in Figure 4. These insights not only enhance the efficient utilization of these advanced waste management systems but also promote the development of customized strategies, inclusivity, and overall effectiveness.

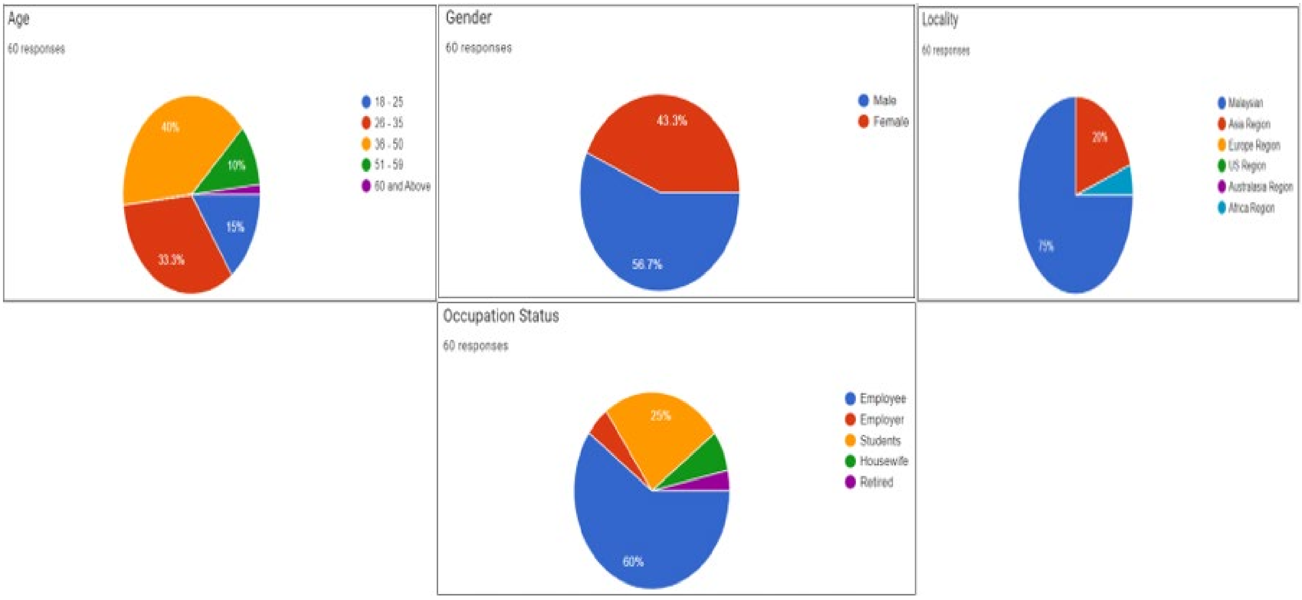

Fig. 4. Demographics Section

4.2 Quantitative Results

The data presented in Figure 5 highlights how the location of e-waste bins can significantly impact respondents' decisions when disposing of unused batteries. According to the feedback received, 50 percent of respondents agreed that the proximity of the bin's location influenced their disposal choices. This indicates that having easily accessible e-waste bins can positively influence responsible battery disposal behaviors. Additionally, 28 percent strongly agreed with the statement, reinforcing the importance of convenient bin placement. However, there were some neutral responses which are 20 percent and a small percentage of respondents (1.7 percent) disagreed, suggesting that while location proximity is influential for many, there may be other factors affecting disposal decisions for some participants. These findings emphasize the significance of strategic e-waste bin placement to promote responsible battery disposal practices.

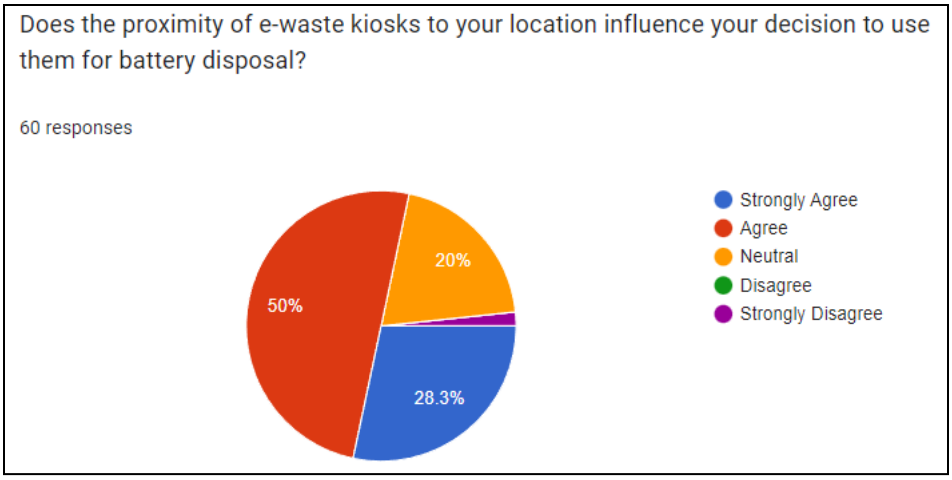

Fig. 5. Respondents' decision-making in disposing of the waste

The data from Figure 6 provides insights into respondents' convenience levels when disposing of batteries using the traditional method. While a significant proportion of 43.3 percent of respondents find the current method to be convenient, a smaller percentage (3.33%) strongly agrees with this statement. A notable proportion (33.3%) remains neutral regarding the convenience of the traditional method. On the other hand, 15% of respondents disagree with the current method's convenience, and a minority (5%) strongly disagree. These findings highlight a diversity of perspectives on the convenience of the traditional disposal method and underscore the importance of exploring more efficient and eco-friendly alternatives to meet users' preferences and environmental needs

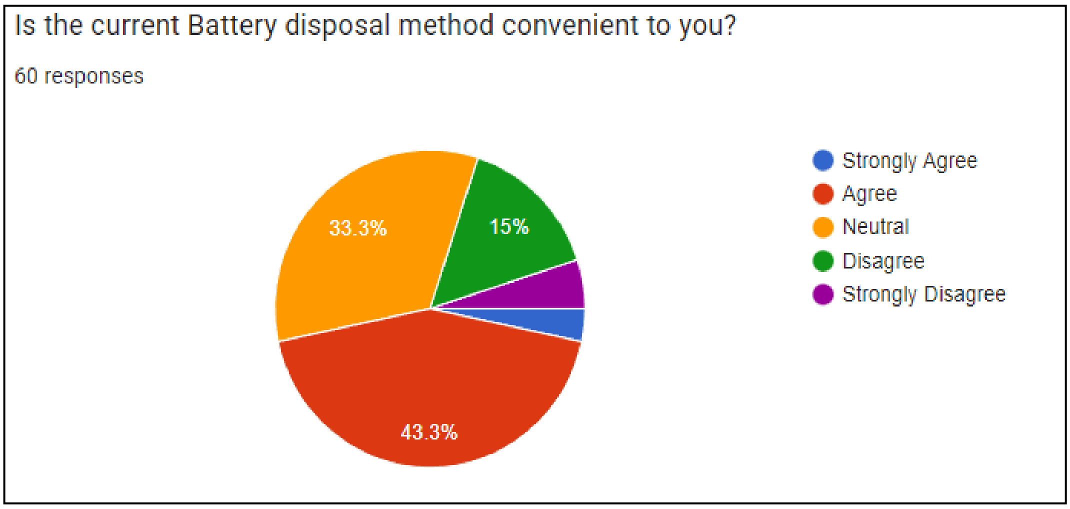

Fig. 6. Respondents' convenience in disposing of batteries

The data presented in Figure 7 offers valuable insights into users' preferences regarding the installation of e-waste kiosks in their vicinity. A significant proportion of respondents (66.7%) agree that having e-waste kiosks nearby is desirable, while an additional 30% strongly agree with this statement. Only a small percentage of respondents (3.3%) remained neutral on the matter. These findings indicate a positive receptiveness among the participants towards the idea of having accessible e-waste kiosks, which reflects the potential success of implementing such facilities in various locations to promote responsible e-waste disposal and environmental sustainability.

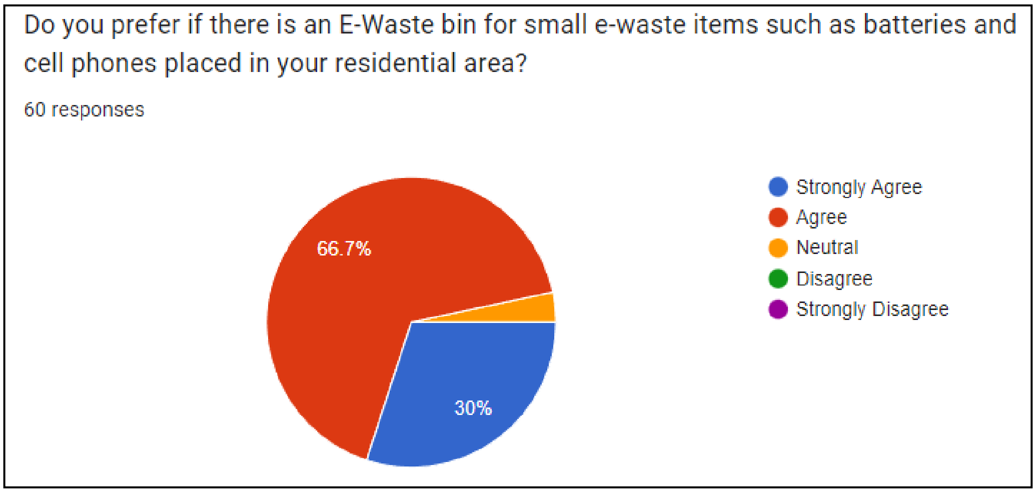

Fig. 7. Respondent's acceptance of E-Waste Kiosk for battery disposal

Figure 8 illustrates the various methods used by respondents to dispose of their unused batteries. The statistics indicate that the highest proportion, at 12.3 percent, disposes of batteries in regular rubbish bins. The second most common method is placing batteries in recycling bins, accounting for 10.5 percent of the respondents. Additionally, the survey revealed a mixed response among participants regarding the disposal of batteries in general bins. Some respondents used descriptions like dustbins, trash bins, and mixed with general waste. This suggests that certain participants may lack access to designated battery recycling bins or may not be fully aware of appropriate disposal methods. The findings highlight the need for increased awareness and accessibility to proper e-waste disposal options to promote more environmentally responsible practices.

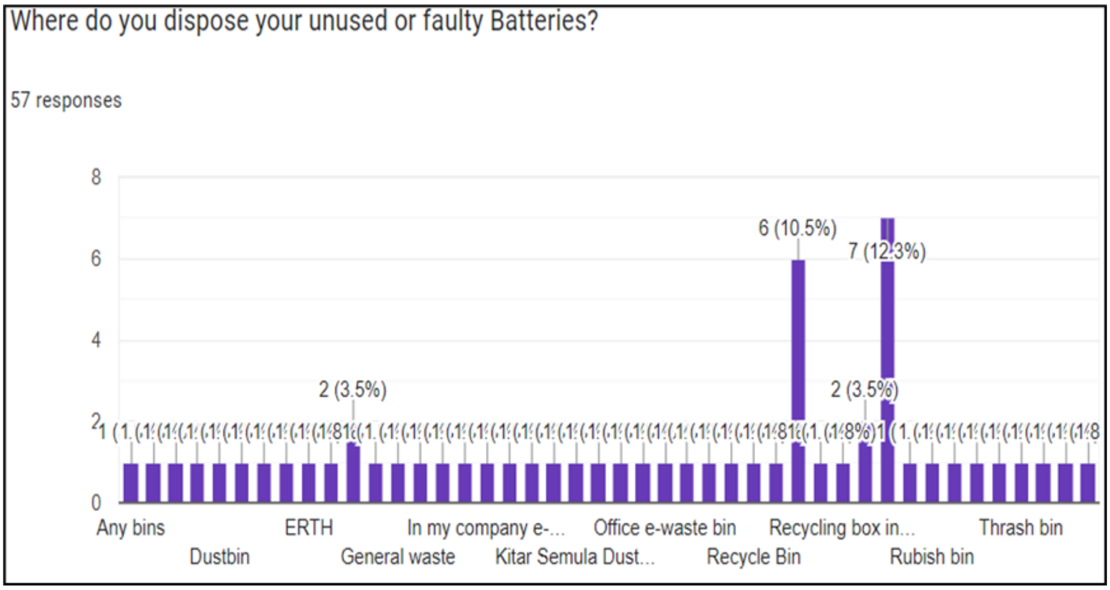

Fig. 8. Location of disposing of unused batteries by the respondents

4.3 Qualitative Results

Figure 9 presents the respondents' awareness of the environmental dangers associated with inadequate battery disposal. According to the feedback, a significant majority of participants, amounting to 71.7 percent, are aware of the environmental impact resulting from improper battery disposal. However, 28.3 percent of respondents indicated that they are not fully aware of the consequences. The data indicates a positive trend, with the majority of participants demonstrating awareness of the potential environmental harm resulting from improper battery disposal.

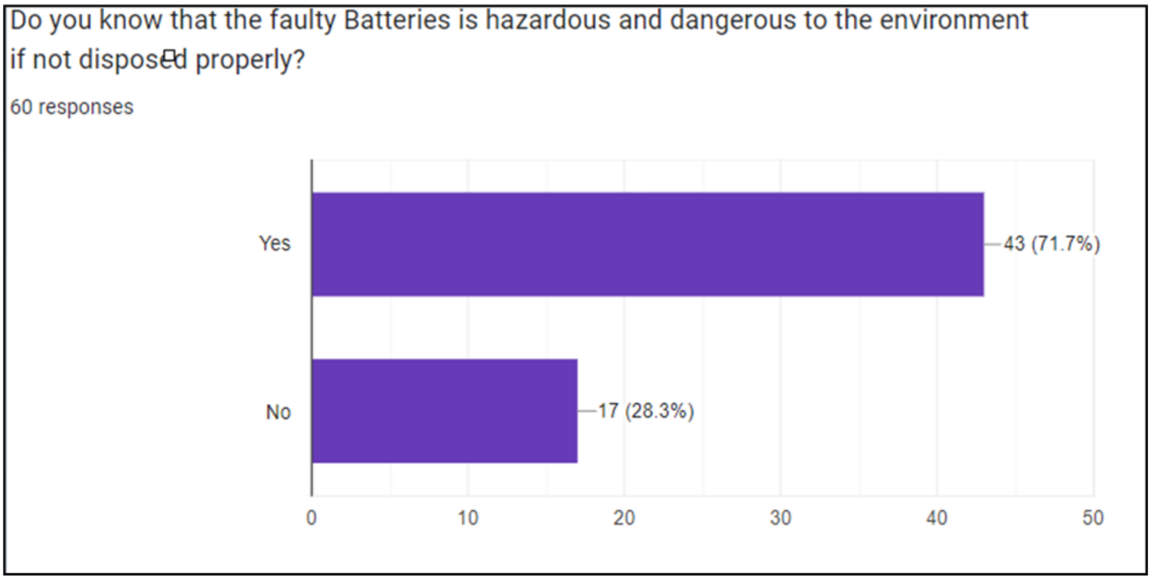

Fig. 9. Respondents' awareness level of the danger of disposing of batteries

4.4 Value Creation

The research's noteworthy impacts across practical, managerial, theoretical, and societal spheres converge to create considerable value. The study imparts valuable understandings of user perspectives and sentiments regarding the amalgamation of modern technologies, particularly thermal sensors, with smart bins, aiming to amplify the effectiveness of E-Waste management. Practically, the integration of Thermal Sensors in e-waste bins lies in the ability to facilitate non-intrusive and efficient testing of batteries which offers numerous societal benefits such as providing a quick and accurate assessment of battery performance and quality without the need for physical contact with the devices.

In a Managerial context, the incorporation of Thermal Sensors into e-waste bins enriches the process of informed decision-making within e-waste management strategies. Furthermore, these sensors furnish real-time temperature data and analysis, thereby bolstering the quality of decisions related to recycling, sorting, and disposal of e-waste, encompassing items such as batteries. This contribution enhances the precision and effectiveness of the overall e-waste management framework.

The theoretical contributions of this study encompass the exploration of strategies for advancing e-waste management, particularly concerning batteries, by integrating a range of sensors and software solutions. Additionally, the literature extends our comprehension of efficacious methodologies in e-waste management, while emphasizing the potential advantages linked to the integration of advanced sensor technologies within waste management systems. This body of work enhances our theoretical understanding of optimal e-waste management practices and underscores the potential merits derived from the incorporation of state-of-the-art sensor systems.

Societally, the incorporation of Thermal Sensors in e-waste bins offers notable advantages, primarily centered around the ease of e-waste disposal. The literature underscores numerous societal gains linked to this integration. By precisely evaluating battery conditions and recognizing potentially unsafe batteries, this technology guarantees that only appropriate batteries undergo processing and recycling. As a result, the risk of environmental pollution is mitigated, leading to a more pristine and healthier environment for communities and posterity.

In conclusion, this study offers a multifaceted spectrum of contributions that collectively enhance the landscape of e-waste management. On a practical level, the integration of Thermal Sensors brings real-time data insights, revolutionizing decision-making for recycling and disposal strategies. The theoretical dimension advances through innovative integration methods, reshaping the e-waste management paradigm. From a managerial standpoint, informed decision-making is highlighted, with sensors elevating sorting, recycling, and quality assessment, particularly for batteries. Societally, the study emphasizes the convenience of e-waste disposal, risk mitigation, and the creation of cleaner environments for current and future generations. Altogether, these contributions weave a comprehensive narrative of the transformative potential when advanced technologies are harnessed for sustainable and efficient e-waste management.

4.4.1 Practical contribution

The integration of Thermal Sensors in e-waste bins, as evidenced by the literature, holds the potential to revolutionize battery testing processes in a non-intrusive and efficient manner. This innovation carries significant societal advantages, notably enabling rapid and precise evaluation of battery performance and quality without necessitating direct physical contact with the devices. This capability aligns with the growing demand for sustainable and effective e-waste management practices, streamlining assessment procedures, and minimizing resource consumption. By eliminating the need for invasive testing methods, this integration contributes to a cleaner environment and safer handling of electronic waste, paving the way for enhanced battery recycling and disposal practices.

4.4.2 Managerial contribution

Integrating Thermal Sensors in e-waste bins, as indicated by the literature, plays a pivotal role in bolstering informed decision-making within e-waste management. The sensors' real-time temperature measurements and analysis are instrumental in enhancing the quality, recycling, sorting, and disposal processes for various e-waste items, batteries included. By continuously monitoring temperature changes, these sensors provide invaluable insights into the condition of disposed items, enabling swift identification of reusable components, hazardous materials, and appropriate sorting categories. This data-driven approach not only streamlines processes but also aligns with sustainability goals, optimizing resource allocation and minimizing environmental risks associated with e-waste disposal.

4.4.3 Theoretical contribution

The review of the literature highlights a plethora of theoretical methodologies aimed at advancing e-waste management, with a particular focus on batteries, through the integration of diverse sensor and software solutions. These theoretical frameworks offer a blueprint for optimizing the handling of electronic waste, enhancing efficiency, and minimizing environmental impact. Moreover, the literature extends our understanding of effective approaches to e-waste management, shedding light on strategies that encompass the incorporation of advanced sensors into waste management systems. This scholarly contribution not only enriches our comprehension of optimal e-waste management practices but also underscores the potential advantages derived from harnessing cutting-edge sensor technologies to address the pressing challenges of electronic waste disposal.

4.4.4 Societal contribution

The literature underscores a range of societal advantages linked to the integration of Thermal Sensors within e-waste bins. This technology brings forth significant benefits by precisely evaluating battery quality and promptly identifying potentially hazardous batteries. By enabling the segregation of appropriate batteries for processing and recycling, this integration effectively mitigates the risk of environmental contamination. Consequently, it contributes to cultivating a cleaner and healthier environment, not only for present communities but also for generations to come. The integration of Thermal Sensors aligns with the imperative of sustainable practices, enhancing responsible e-waste management and safeguarding the well-being of both local populations and the broader ecosystem.

4.4.5 Integration and Value creation

The integration of Thermal Sensors into e-waste bins represents a significant step toward improved e-waste management, offering a range of valuable outcomes. Combining theoretical foundations with practical implications, this integration reshapes the landscape of electronic waste disposal comprehensively. The theoretical alignment of Thermal Sensors with advanced methodologies, particularly for battery management, ensures precision in evaluating battery quality and identifying hazardous units. This informs practical strategies for sorting, recycling, and disposal, paving the way for more effective and sustainable practices. Moreover, the integration contributes to societal well-being by mitigating environmental risks. By exclusively processing suitable batteries, these sensors reduce the potential for contamination, resulting in a healthier environment for present and future generations. The holistic fusion of theoretical insights, practical applications, and societal benefits underscores a value-creation process that goes beyond technology, empowering informed decision-making, environmental conservation, and responsible waste management. In essence, the integration exemplifies a forward-looking approach to addressing e-waste challenges, fostering sustainability and a secure future.

5. Conclusions and Limitations

Despite its potential, the integration of Thermal Sensors may face challenges in scalability, cost, and sensor accuracy. Implementing the technology on a large scale could prove complex and resource-intensive. Moreover, the initial investment and maintenance costs might hinder widespread adoption. Ensuring the precision and reliability of sensor readings could also be a limitation, impacting the effectiveness of informed decision-making in e-waste management.

In conclusion, this study focuses on the incorporation of smart technologies into e-waste kiosks to enhance the effectiveness and efficiency of the system. Furthermore, the study analyses the implementation of real-time monitoring systems using various heat sensors to track the quality and usability of the disposed items including batteries. By saying this, the integration of new technologies enables improved planning of sorting of e-waste items and prevents the kiosks from overflowing, ensuring smooth and timely disposal of e-waste. By leveraging IoT technologies, such as sensors and real-time data, the studies aim to optimize the operation of e-waste kiosks and improve their inclusive performance. This approach helps address the challenges associated with e-waste management by providing a more systematic and efficient solution. The findings of the research suggest that the integration of smart technologies in e-waste kiosks has the potential to enhance their functionality, resulting in better management and disposal of electronic waste.

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