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Education and awareness: keys to solid waste reduction

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ABSTRACT

In the research, education, and awareness were focused on as essential pillars to successfully address the problem of reducing solid waste. The objective is to implement educational and awareness solutions within the community to encourage a substantial change in behavior toward the reduction of solid waste. The design thinking methodology was applied to develop effective solutions. To measure the level of public awareness, we conducted interviews using the Atlas ti22 which allowed us to triangulate with the surveys that revealed that 60% of those surveyed agreed with the policies regarding environmental impact, 55% agreed that the authorities take preventive measures regarding public health and 58% stated that the participation of the citizens in recycling programs. Then, innovative prototypes were developed that satisfied the real needs of users and experts in their evaluation, thus laying a solid foundation. It was concluded that citizens as well as authorities must be aware that by working collaboratively, we can contribute to society.

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1. INTRODUCTION

Solid waste management has become a pressing challenge in the contemporary world. As urban populations grow and consumption patterns evolve, the waste we generate increases exponentially. In turn, the way we manage this waste has a significant impact on the environment, public health and long-term sustainability. From plastics polluting our oceans to the growing need to find solutions for reusing and recycling materials, solid waste has moved to the forefront of the global agenda. This introduction will explore the complexity of this issue, highlighting the importance of addressing waste management in a responsible and sustainable manner to ensure a cleaner and healthier future for generations to come.

Co-fermentation of solid residues and wastewater from citrus processing has great potential for obtaining biofuels. However, more research is needed to determine the process variables that should be evaluated to maximize H2 production. In this study, the Plackett-Burman experimental design was used to evaluate the effect of different variables, such as pH, citrus peel residue concentration, citrus processing wastewater concentration, yeast extract, particle size, and autochthonous bioaugmentation inoculum. Concentrations of citrus peel residues and citrus processing wastewater, as well as particle size, were found to have a significant effect on H2 production and organic acid production. These results demonstrate the technical feasibility of co-fermentation of citrus production chain residues and suggest that adjusting substrate concentration variables can increase energy recovery from H2 production [1].

Hard water is a major problem worldwide due to its contamination. Adsorption is presented as a promising method to treat hard water due to its low cost, ease of use and maintenance. In this study, we used silicon/aluminum functionalized zeolite (Ze-Si/Al) as an adsorbent material to treat hard water. We modified the concentration of the solid waste source (pumice and cans) to obtain ten different Si/Al ratios in the zeolite. Then, we tested the optimal sample with different parameters such as contact time, dye concentration and isotherm models. We characterized the Ze-Si/Al adsorbent by scanning electron microscopy (SEM), X-ray diffraction (XRD) and X-ray fluorescence (XRF). The results showed that the zeolite functionalized with a Si/Al ratio of 0.67 had the highest sorption capacity. Equilibrium was reached after 300 min of contact time. In addition, we found that the dye concentration influences the contaminant removal. We used the Langmuir isotherm model for Ze-Si/Al. We also discuss the potential development and future research directions [2]. In summary, this study is crucial to expand the knowledge on the use of waste as a source of Si/Al to improve zeolite quality.

In developing countries, such as Ethiopia, an increase in musculoskeletal disorders has been observed among street cleaners due to the lack of a standardized work environment. This study aims to determine the burden and factors associated with these disorders in the city of Gondar. A cross-sectional study design was used and 422 street cleaners with at least one year of work experience were randomly selected. Data were collected through face-to-face interviews and questionnaires. The results showed a high prevalence of musculoskeletal disorders, especially in the lower back region. Factors such as overweight, age, job dissatisfaction and cleaning distance were significantly associated with these disorders. It is concluded that ergonomic measures need to be implemented to reduce the burden of musculoskeletal disorders in street cleaners [3].

The objective of this research was to evaluate the impact of the inclusion of Citrus sinensis solid residues (SWC) in the diet of common carp (Cyprinus carpio) on the flesh quality of the fish, as well as the possible mechanisms underlying these effects. Four different diets, each containing different levels of SWC (0%, 5%, 10% and 15%), were formulated and fed to common carp weighing approximately 48.83 ± 5.59 g for a period of 60 days. The results revealed that the diet with SWC had a significant positive effect on specific growth rate, muscle sweetness (through sweet amino acids and sweet molecules) and the nutritional value of the fish flesh (with higher levels of protein, α-vitamin E and allopurinol). Chromatography-mass spectrometry analysis showed that inclusion of SWC in the diet resulted in higher levels of essential amino acids. In addition, the diet with SWC facilitated the synthesis of non-essential amino acids in muscle by enhancing glycolysis and the tricarboxylic acid cycle [4].

According to the text provided, the water balance of solid waste landfills in Ohio, USA was conducted using precipitation, evapotranspiration, waste tonnage, landfill gas and leachate data. Contributions from three water sources were estimated: precipitation, incoming waste, and leachate recycling. It was found that entrained water is the main source of moisture in landfills, followed by precipitation infiltration. Leachate recirculation did not significantly affect moisture content. However, poor stormwater management could lead to unfavorable conditions. The calculated landfill moisture content was affected by the assumed runoff coefficient [5].

2. LITERATURE REVIEW

A study was carried out on the different effects with respect to solid waste and also the impacts that would occur if it materializes. The consequences that arise from large national and transnational companies for not considering the awareness that must be raised in order to counteract putting into practice the awareness that will generate the impact if we do not take into account [6]. The prediction of soil contaminants using artificial intelligence (AI) is not necessary for estimating geospatial sources and achieving a balance between interpretability and precision. This results in poor spatial extrapolation and generalization. In a recent study, a geographically interpretable four-dimensional AI prediction model for soil heavy metal (Cd) content was developed and tested in Shaoguan City, China [7].

Clean City Valdivia is a web and mobile application that seeks to address the waste collection problems of the municipality of Valdivia in Chile. The tool is in the final phase of prototyping and is based on open-source software. Its aim is to improve communication between users and service providers by providing educational materials on waste management and related environmental issues. This will help users minimize waste production and optimize waste management before collection. The app features several key features, such as a dynamic map viewer that shows the location of the waste collection trucks and estimated routes for the future. The potential impact of this tool was assessed through a survey of residents of a pilot city, demonstrating positive effects on service coordination. To estimate the future routes of trucks, machine learning algorithms or computer intelligence will be used. The integration of open-source technologies has been critical to addressing development challenges and adapting the tool to new scenarios. The valuable contribution of the municipality and the community has played an important role in defining a concrete solution [8]. These days, several applications of deep neural networks have been developed, one of which focuses on solid waste classification. In densely populated countries such as India, large amounts of waste are generated, much of which could be recycled for new uses. Recyclable waste is usually separated at treatment plants and sent to recycling units, but sometimes it is also dumped in water bodies or landfills. This paper presents a viable solution to categorize waste into different categories at the root of the problem [9]. The project uses a methodology that combines convolutional neural networks (CNNs) with image recognition concepts. It was found that accuracy improved significantly with increasing input data. When integrated with front-end applications, the proposed system can be used at the community level to separate household waste, which will help reduce the generation of unused waste.

No city can be considered smart without an intelligent waste management system, and in this document, we have developed an integrated waste management platform. The aim of this study is to create an efficient waste management system based on the internet of things (IoT) for mobile applications. We have examined the traditional waste management system in India and identified several problems with current systems, such as non-hygienic landfills, overloaded waste taps, limited collection, lack of storage in collection vehicles and lack of awareness about selective waste collection, recycling and reuse. This study therefore proposes a solution to address the above-mentioned problems. It provides a platform for domestic users, collection vehicle drivers and waste management authorities to interact with the country's solid waste management. The main idea of our project is to alert the competent authorities when the container in a given region is full and needs to be reviewed [10].

Measurement accuracy is crucial in the current era of the industrial revolution, where the rise in living standards has led to a significant increase in municipal solid waste (MSW). Current industry 4.0 standards require precise and efficient edge computing sensors for the classification of solid waste. If waste is not properly managed, this can have a negative impact on global health, the economy and the environment. All stakeholders must understand their role and responsibility in the generation and recycling of solid waste. To ensure the success of recycling, it is essential to separate and manage waste efficiently and properly. Computational complexity in the classification of non-organic waste is directly related to the performance of peripheral computing devices [11]. Existing research in waste classification has been carried out using CNN architectures, such as AlexNet, which contains a large number of parameters and requires a great many operations to classify a single image. This makes it too heavy for computing applications that require low computing complexity. The proposed model surpasses existing similar models, achieving an accuracy of 82.48% and 83.46% with the Softmax and support vector machine (SVM) classifiers, respectively. Although MobileNetV2 may have slightly lower accuracy compared to larger, heavier CNN architectures, it remains comparable and more practical for edge computing devices and mobile applications.

Despite multiple policies and regulations, efforts to control household waste in Malaysia have been inadequate. However, with technological advances, community participation can be increased. This study examines the e-waste management technology currently used in Malaysia, particularly the use of mobile applications. It also investigates the factors influencing the adoption and use of this technology by Malaysians to promote recycling in communities. A survey of recycling professionals in Kuala Lumpur was conducted to identify their interests, challenges and opinions on e-waste management service [12]. Based on these findings, a design framework was proposed to increase participation and awareness in Malaysian communities. Therefore, it is recommended to use technologies such as e-waste management to direct recyclable waste to the right place and prevent inappropriate disposal, with the aim of reducing household waste.

In today’s era, finding a parking space has become a challenge for those living in urban areas, resulting in wasted time and resources. In addition, the carbon emissions generated by the search for parking damage the environment and contribute to fuel wastage. Fortunately, thanks to the use of smartphones, app-based solutions have been developed to address this problem. After careful evaluation of all criteria, we have implemented a comprehensive solution using a mobile application [13]. This application will allow users to easily find nearby parking spaces using various customizable filters.

The search for a renewable source of phosphorus (P) for agriculture globally is a major challenge due to the depletion of phosphate resources and the risk of environmental problems caused by excessive phosphorus mobility. A study analyzed phosphorus transformation in MSW compost at different stages of maturity and evaluated its effect on soil phosphorus status. It was found that the application of MSW to the soil increased the available phosphorus content and potentially mobile forms of phosphorus. However, it is noted that the use of MSW as a phosphorus source does not represent a serious environmental risk and could be a viable option, provided that the material is mature [14]. It is recommended to assess phosphorus availability and potential environmental risks when using compost as a phosphorus source rather than relying solely on total phosphorus content.

One of the most important industries in the world is waste disposal. If not properly maintained, it would cause damage to the environment. Poor waste segregation, insufficient garbage collection techniques and lack of public support for waste management are some of the key reasons for Sri Lanka's major problem with improper waste disposal. We propose an IoT based solid waste management system that allows monitoring of garbage cans, directing collection trucks, creating a predictive model and a point reward system. As a result of this research, the following prototypes were created: a smart bin model with the ability to open and close itself and detect the level of waste in the bin; a prototype mobile application for garbage collectors that provides analyzed data on truck position and ensures punctuality; a prototype mobile application for the general public that accepts the weight and type of discarded solid waste as input data and calculates reward points [15]. This is a low-cost IoT-based system that manages the huge volumes of garbage collected every day using existing resources.

The accumulation of solid waste on campus is a common problem in several public universities and colleges in the Philippines. Using the 3Rs (Reuse, Recycle, Reduce) is a popular strategy to minimize this problem. The main campus of Cebu University of Technology, in the Philippine city of Cebu, uses these 3Rs to foster green technology and build a circular economy. Given that some classrooms still lack comprehensive teaching equipment and technologies to strengthen teaching delivery, the implementation of the 3R is very timely. Consequently, the ultimate objective of this article is to use 3Rs to create low-cost, portable and environmentally friendly teaching equipment. This study uses reusable solid residue from the campus, such as glass, wooden pallets, tree branches and rotating wheels, to create teaching equipment. This equipment contains all the didactic material and tools necessary for the teaching-learning process. Thanks to their mobility, teachers can move quickly between classes with their educational loads. Several tests were carried out during the functionality assessment, such as the voltage analysis test, the fall test and the system quality assessment [16]. According to the test results, this teaching equipment is useful for teaching classes in the developing SUCs of the Philippines. In addition, the equipment can be used not only for face-to-face teaching, but also for online classes.

The disposal and collection of garbage is a continuing global challenge, aggravated by the world's growing population, lack of funding and public awareness, and, more recently, the outbreak of COVID-19. Since there is no uniform and coherent system that covers all parties involved in the production and collection of waste, information technology can be used to replace outdated, time-consuming and energy-intensive systems. To address the above-mentioned concerns, a mobile-based garbage collection system has been developed, which includes route and time optimization, an AI chatbot and efficient GPS surveillance. The vehicle routing problem with time windows (VRPTW) with synchronization and priority was optimized using LNS, and the total travel time was reduced from 172 minutes to 144 minutes. The AI chatbot function makes it easier to report concerns and complaints related to garbage collection, as well as asking about waste management suggestions (reducing, recycling and reusing) for home use. The primary purpose of the creation of an AI chatbot is to replace the manual procedure of reporting trash collection difficulties in Sri Lanka with a more efficient and attractive method. The chatbot provides Q&A trash management. The user of optimized GPS Tracking can use the map to find the nearest waste disposal site based on the type of garbage it creates. The truck driver can use the map to locate the best route to the nearest garbage disposal centers and public landfills, as well as see the location of homeowners [17]. The main purpose of the component is to indicate the location of the garbage deposits, as well as the best routes for truck drivers using linear regression and Node2vec technique.

Solid food waste is gradually increasing in landfills around the world. When this garbage decomposes, it releases greenhouse gases like CO2 and methane into the atmosphere, endangering human health and the ecosystem. Active composting of household garbage can make good use of food lost to generate cultivable soil, thereby helping to alleviate the waste problem caused by climate change. However, the general population currently has difficulties in managing and distinguishing which items are biodegradable and which are not. In addition, there is a lack of desire, incentives and community support to actively compost the garbage. CompostAI is a unique mobile application based on deep learning proposed in this study to make communal compostage easy and socially attractive. This application classifies garbage into seven categories using Xception's CNN model: compost, paper, cardboard, glass, metal, garbages, and plastic. Of the six CNN models trained, verified and evaluated, the Xception model achieved the best results, with an accuracy of 78.43% and a F1-score of 81.22. In addition, CompostAI allows users to announce local sustainability events, locate nearby compostage services and discover new skills for sustainable living [18]. CompostAI effectively facilitates and socializes community participation in compostage, boosting compostage rates and minimizing the harmful waste dilemma that contributes to climate change.

Cutting-edge mobile computing (MEC) is seen as an essential technology to cope with time-critical, computing-intensive applications on the internet of vehicles (IoV). IoV vehicles with MEC reduce their processing load by outsourcing work to edge servers. However, task downloading is difficult due to the high speed of vehicle mobility and the network environment that varies over time. Furthermore, restricted stock units (RSUs) or cars as discharge objects wastes computing resources and increases the latency of the task process. To this end, we address the reduction of delay in task processing and the improvement of service reliability as a matter of maximizing utility and present a method of distributed cooperative discharge from vehicle to road task with task migration. MEC is seen as an essential technology to cope with time-critical, computing-intensive applications on the IoV. IoV vehicles with MEC reduce their processing load by outsourcing work to edge servers. However, task downloading is difficult due to the high speed of vehicle mobility and the network environment that varies over time. Furthermore, RSUs or cars as discharge objects wastes computing resources and increases the latency of the task process [19]. To this end, we address the reduction of delay in task processing and the improvement of service reliability as a matter of maximizing utility and present a method of distributed cooperative discharge from vehicle to road task with task migration.

Increasing urbanization has led to a serious problem: the disappearance of waste in the global environment. Therefore, proper management of these will become essential to guaranteeing a healthy and clean habitat. Although governmental bodies in many countries propose different solutions in waste management, solid waste has a considerable impact on the environment, due to its slow destruction. This study focuses on an intelligent waste container based on AI, capable of categorizing the most common materials such as metal, glass and plastic. Through image processing and machine learning algorithms, the smart cube segments waste, while ultrasonic sensors constantly monitor the filling level. A specific app will generate the optimal routes for collectors to take the full containers. This innovative system overcomes the challenge of identifying each type of design using visual data, thus preventing the use of expensive sensors and filtering techniques. The smart container categorizes solid waste, deposits it in its corresponding compartment and communicates the load level. In short, it presents itself as a portable solution for waste control. deposits them in their corresponding compartment and communicates the load level. In short, it presents itself as a portable solution for waste control. it deposits them in its corresponding compartment and reports the load level [20]. In short, it presents itself as a portable solution for waste control. Technical planning and coordination are crucial in urban solid waste management (GRSU) to promote the sustainable development of cities in social, physical, territorial and legal-political terms. Over the past two decades, Chiclayo has faced a serious pollution problem as the most affected city in northern Peru due to poor management of its urban solid waste. Therefore, the aim of this research is to assess the urban impact caused by solid waste on the configuration of public spaces in the districts of José Leonardo Ortiz, La Victoria and Chiclayo. The actors involved in management were analyzed through a territorial diagnosis, using a methodological approach to calculating efficiency indices. Management progress over the past decade was evaluated using the Fisher-Davies method and Leopold diagrams, whose results were compared to the perception of the local population. The results revealed that urban solid waste management has had a negative impact on the layout of public spaces. This impact is negatively reflected in the biotic, abiotic and sociocultural aspects of the urban environment [21]. This study provides evidence of how city governance affects territorial sustainability. This, in turn, will serve as a basis for developing thematic approaches addressing urban, environmental, socio-economic and technological policies in response to changing territorial dynamics.

In the locality of los Olivos, located in Lima, Peru, a considerable amount of solid waste is generated which is one of the main reasons behind environmental pollution. In order to reduce pollution, the design of a mobile application with specific activities of simple and accessible use was conceived. The creation of this application was carried out using Balsamiq Mockup and was implemented on the Android operating system. The main objective of this mobile application is to provide real-time information about the proximity of solid waste collection services. The intention behind this is to raise awareness among people about the benefits that this initiative brings to their health, considering that in everyday life solid waste and other types of necessary waste are generated. Additionally, it is planned to install specific waste collection points, which would bring significant benefits to the population of the Los Olivos district [22]. The purpose is to abandon the harmful habit of pollution and take an important step towards the solution: recycling. The community would also become an essential component of this crucial change, contributing to the creation of a healthier district free of environmental pollution.

3. METHOD

This method section describes in detail the steps to be followed for the implementation of the mobile application development. In addition, in the development part, the creation of the prototype designs was carried out using the Figma technological tool. Therefore, the design thinking methodology was also implemented, as well as its solid waste flowchart.

3.1. Method design thinking

This method allows for a holistic analysis of the different processes that an organization may have. In addition, the activities to be carried out are analyzed through its 5 phases that comprise it as you can see in Figure 1 [23]. Regarding the empathize phase, the problem under study is known by applying different techniques such as the interview. The most outstanding and priority activities that emerge from the interviews are defined; and then through the idea phase, activities can be grouped, eliminated and emerged. Then the prototypes are made based on the previous phase; ending with the last phase the evaluation by experts.

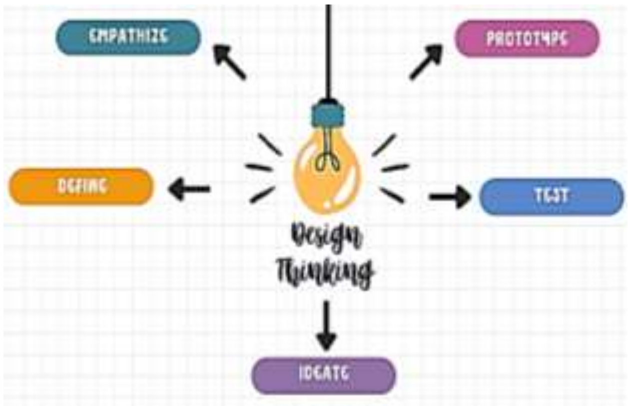

Figure 1. Design thinking

3.2. Solid waste management flowchart

The process initiates with "waste generation," where solid waste is generated from various sources. Subsequently, the collected waste undergoes a "collection" phase, where it is gathered from different locations. Next, in the "separation process," the waste is sorted into distinct categories such as paper, plastic, glass, and organic materials. After separation, the "transformation of waste solid" phase prepares recyclable materials for recycling, while organic waste can be converted into compost or utilized for energy generation. Finally, the non-recyclable or non-reusable waste is subjected to "elimination," involving disposal in landfills or controlled incineration, aiming to manage waste that cannot be recovered and minimize environmental impact. This process sequence represents a typical approach to solid waste management, emphasizing resource recovery and environmental sustainability see Figure 2.

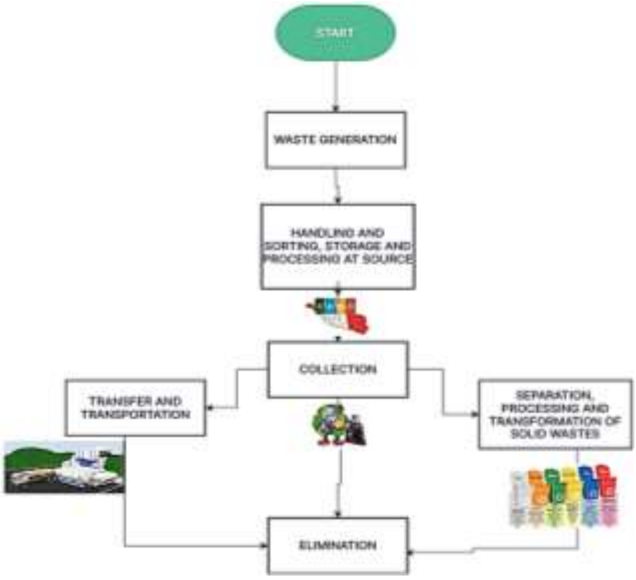

Figure 2. Solid waste management flowchart

3.3. Technological tools

Figma is a tool that allows you to create designs and prototypes, where it can be applied in companies, as well as in theses and research articles, among others [24], [25]. In addition, it is a collaborative tool that also has established templates. In that sense, it is very useful for all types of design that can be carried out according to the objective to be carried out.

4. RESULTS

4.1. About the interview

In this subsection, we conducted brief interviews with 100 different people, such as officials, and regional professors. Besides, will present the results of the interview, prototypes' development, expert validation, and the proposed model regarding the subject. Also, personnel in charge and environmental specialists, among others see in Table 1.

Table 1. About the interview

Dimensions	Questions
Educational	P1: What is the role of formal education in raising awareness of solid waste management? P2: How can educational institutions promote the teaching of sustainable waste management practices? P3: What effective strategies exist for including solid waste education in the school curriculum?
Community	P4: How can community education contribute to solid waste reduction in local areas? P5: What are the most effective methods for engaging the community in waste reduction initiatives? P6: What are the challenges and opportunities in encouraging community involvement in solid waste management programs?
Communication	P7: What communication strategies are effective in raising public awareness of the importance of reducing solid waste? P8: How can the media play a key role in disseminating messages about waste management? P9: What is the impact of awareness campaigns on people's attitudes and behavior towards solid waste?

P1: Emphasized the vital role of formal education in raising awareness about solid waste management. They pointed out that education provides a strong foundation for understanding waste management and its impact on the environment. This response highlights that schools and educational institutions are essential platforms for instilling awareness and knowledge about sustainable waste practices. The interviewees recognized that formal education is a fundamental channel to reach younger generations, helping them comprehend the significance of proper waste disposal and reduction see in Figure 3.

P2: Suggested several strategies to promote sustainable waste management in educational institutions. They recommended organizing conferences and workshops with waste management experts as a way to train teachers and empower students. Integrating ecological projects into the curriculum was also seen as an effective approach to making students more proactive and environmentally conscious. The responses indicate that involving teachers, students, and experts can foster a culture of responsible waste management within educational settings.

P3: Interviewees acknowledged that integrating solid waste education into the school curriculum is an effective strategy. They highlighted the importance of incorporating waste management into existing subjects such as science and geography. Furthermore, they emphasized that interdisciplinary projects addressing waste management can inspire students to take action. These responses underscore the importance of making waste management an integral part of education, ensuring that students learn about sustainable practices from a young age see in Figure 3.

P4: Recognized the significance of community education in reducing solid waste in local areas. They emphasized that community education is essential for creating awareness about recycling, waste reduction, and responsible waste disposal in everyday life. The responses highlight that community education can bridge the gap between theoretical knowledge and practical implementation, making the community an active participant in waste reduction efforts.

P5: Provided insights into engaging the community in waste reduction initiatives. They pointed out that collaboration with community leaders and civic groups can mobilize the community toward taking action. Additionally, tangible incentives, such as waste segregation programs, were seen as motivational tools for encouraging active community participation. These responses stress the importance of involving the community in decision-making and providing practical incentives to drive positive change.

P6: In response to this question, the interviewees provided insights into the challenges and opportunities associated with encouraging community involvement in solid waste management programs. They identified several challenges, such as the potential resistance to change within the community and the need to overcome cultural and behavioral barriers. The interviewees acknowledged that motivating community members to actively participate in waste management efforts can be complex and require a well-thought-out strategy.

However, they also pointed out the numerous opportunities that exist. Collaboration with community leaders and civic groups was recognized as a means to mobilize the community toward action. The interviewees highlighted that providing tangible incentives, such as waste segregation programs, can motivate active participation see in Figure 3.

P7: Interviewees discussed the importance of effective communication strategies in raising public awareness of solid waste reduction. They emphasized the need for online awareness campaigns and outreach through traditional media to reach a diverse audience. Success stories and real-life examples of people reducing waste were highlighted as inspirational tools. These responses underscore the role of communication in translating knowledge into action and in reaching a wide and diverse audience.

P8: The interviewees recognized the crucial role of the media in disseminating messages about waste management. They mentioned that the media can provide a platform for discussing waste management issues and raising public awareness. Additionally, interviews and reports with waste management experts were seen as valuable in educating the audience. These responses emphasize the media's power to inform and educate the public about the importance of proper waste disposal.

P9: Discussed the impact of awareness campaigns on people's attitudes and behaviors toward solid waste. They pointed out that campaigns can change people's attitudes and lead to positive behavior changes, such as increased recycling. Measuring indicators, like the rise in recycling rates, can demonstrate the positive impact of campaigns. These responses highlight that well-executed awareness campaigns can lead to tangible behavioral changes in communities and individuals see in Figure 3.

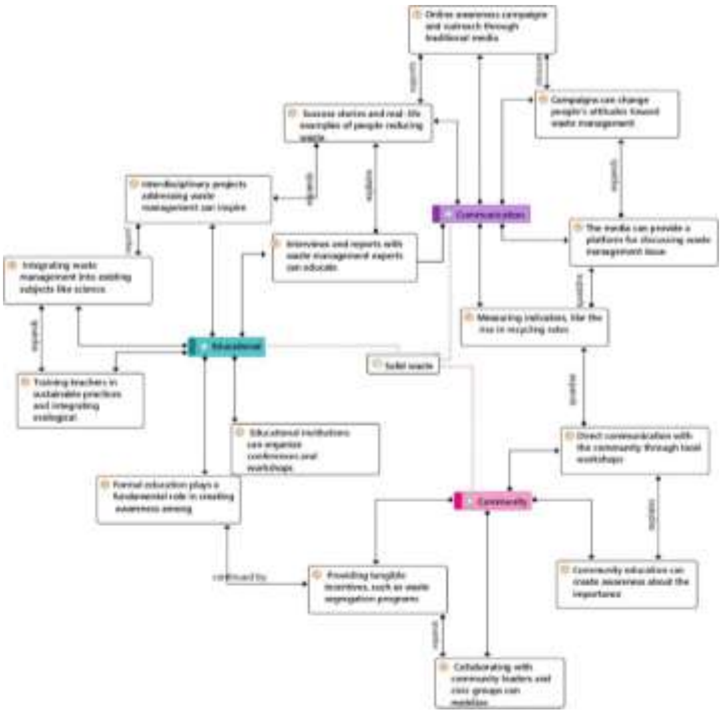

Figure 3. Education and awareness networks on solid waste (Atlas Ti22)

4.2. Population survey

A survey of the population of a local community was conducted as a pilot on satisfaction in the dimensions of environmental impact, public health and citizen participation. The questions were designed so that the answers were dichotomous, i.e., to answer yes or no. 3 questions were asked in the 3 dimensions in total:

- Environmental impact
  Question 1: Do you agree with the policies implemented to promote solid waste recycling?
- Public Health
  Question 2: Do authorities carry out preventive measures to reduce risks that affect public health?
- Citizen Participation
  Question 3: Are citizens involved in programs carried out by organizations, in waste and recycling?

In the satisfaction survey conducted in a local community regarding the dimensions of environmental impact, public health, and citizen participation. The results indicate that 60% of the respondents agree with the policies implemented to promote solid waste recycling, 55% perceive those authorities undertake preventive measures to reduce public health risks, and 58% believe that citizens are involved in programs related to waste and recycling. These results reflect a level of satisfaction and support in these three dimensions among the surveyed population, although they do not provide details regarding the reasons behind these perceptions or potential areas for improvement see in Figure 4.

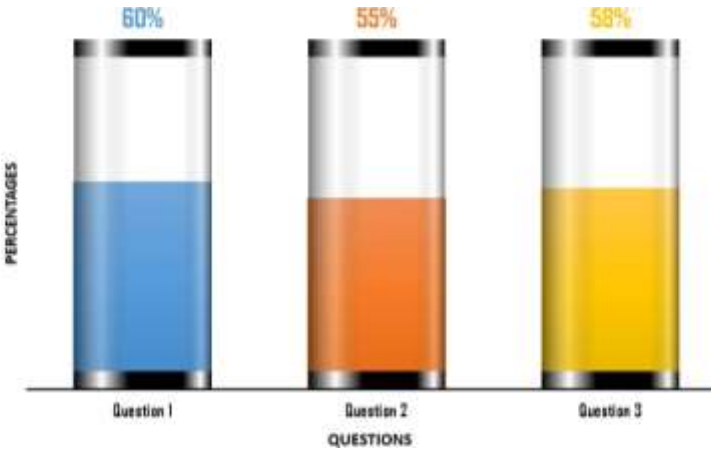

Figure 4. About the interview

4.3. Prototype development

In this section, we will be developing the prototypes of the mobile application which will have several prototypes so that the user can access and perform the appropriate recycling. Also, at the moment we have 10 prototypes in which in each figure two prototypes will be implemented where they will have their respective description and a brief explanation of their functionality. Also, as a prototype development, we have Figure 5 where we can see the start of the application, which has buttons to start and go to the next screen. You can also see the login where you will have the username and password, in turn, if you forgot your password. So, you also have the option of user registration.

Figure 5. Starting the application with login

In addition, we have the development of the prototype in Figure 6, where the user has the option of user registration with the registration of name, email, user, and password. The next screen would be the start of the application. So, it would explain how to recycle waste from the comfort of your home, in addition to what types of classification would be. In the development of Figure 7, the user after logging in has the option to see on the map the places of recycling of solid waste and in turn on the next screen the calendar that users would observe that days would pass the waste collector, to have a clean planet without pollution. In the development of the prototypes in Figure 8, it can be seen that after the user has access to the waste map and the calendar. Also, after clicking on the next button, another screen will appear with an explanation of the types of waste, and such as hazardous waste. So, on the next screen, the user will see the images of the waste that can be recycled at home and those that cannot be recycled at home. Finally, we have the development of the last prototype in Figure 9, which would be the adjustment of the page plus editing the user profile in case you made a mistake in placing your name or surname correctly. Also, in the edit profile screen you have the option to modify your name, your email, your password, your birthday and your country or region.

Figure 6. User registration plus home

Figure 7. Waste maps more calendar

Figure 8. Types of recycling most sought after

Figure 9. App settings plus y edit user profile

4.4. Expert validation

The expert review has been conducted in the context of waste management education and awareness, assessing four key criteria. In terms of usability, a score of 86/100 has been assigned, indicating that the interface or system in question is easy to use and user-friendly. Quality receives an even higher score of 87/100, suggesting that the content and information related to solid waste management are of high quality and meet expected standards, see in Table 2.

Table 2. About the interview

Criterion	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	MEAN
Usability	90	90	80	90	80	90	90	80	90	80	86
Quality	90	90	80	80	80	90	90	90	90	90	87
Integration	80	80	90	90	90	90	80	80	90	90	86
Interface	80	80	80	90	90	80	90	90	80	90	85

4.5. Proposed model

Figure 10, illustrates the proposed model for this research, encompassing solid waste generation, source separation, and selective collection of both usable and non-usable waste. Additionally, the model incorporates joint collection, which utilizes waste for organic waste and thermal fuels, among others. Non-usable waste is classified as packaging and inorganic waste. This proposed model aims to increase public awareness on environmental preservation and the harmful impact pollution has on our health.

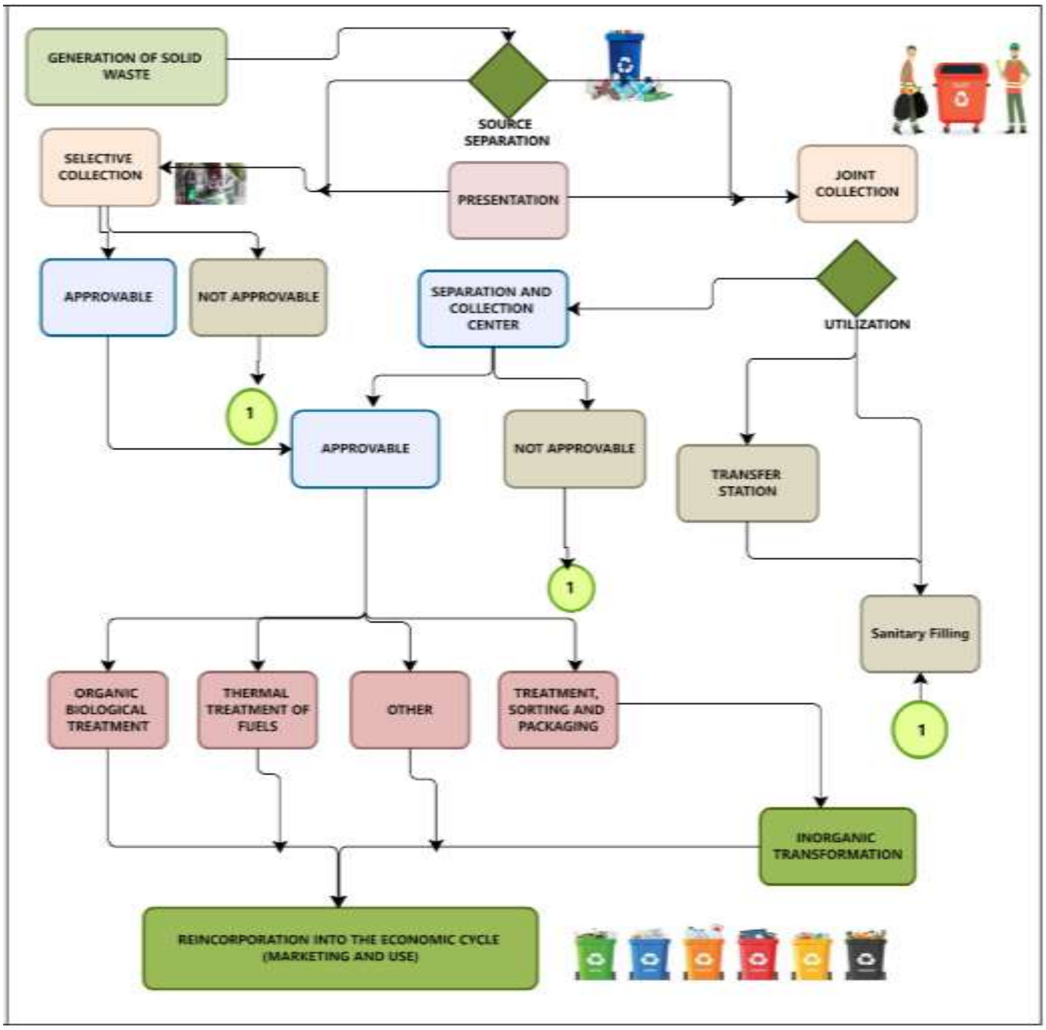

Figure 10. Proposed model

5. DISCUSSION

Sierra *et al.* [8] emphasize the significance and dedication to solid waste collection through the development of a web and mobile application to tackle waste collection issues in Valdivia, Chile. The purpose is to enhance communication between users and service providers, while also offering educational resources and highlighting environmental concerns in solid waste management. This approach aims to reduce waste production and optimize waste management processes before collection. This study builds upon previous research that highlights the role of mobile applications and solid waste in increasing engagement and knowledge in waste management [22]. Additionally, the use of mobile applications in waste management aims to decrease global environmental pollution. Therefore, this study presents the development of a mobile application with specific tasks and easy accessibility, aimed at raising awareness and reducing solid waste. The goal of this effort is to increase public awareness of the advantages of this initiative, thereby enhancing individual well-being.

6. CONCLUSION AND FUTURE WORK

The research carried out allowed for an exhaustive analysis of the education and awareness of solid waste by conducting interviews and surveys to get a broader picture. In addition, the design thinking methodology was used to carry out the stages in a systematized way, focusing more on the prototypes made appropriately. The validation was carried out by expert judgment in the field using criteria of usability, quality, integration and interface; being approved in all criteria. A model was proposed that serves as a guide to the proper use of a conscious way to have as a basis so that they can have a reference on the education and awareness related to solid waste. A limitation of the research was not to interview authorities representing the environmental area because of their busy agenda. In future work, it is suggested that the research be complemented with AI in a multidisciplinary and interdisciplinary way.

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