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Development of a Mobile App to Inspire Environmental Education in a Scholar Community

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Abstract

Information technologies (IT) can significantly improve environmental awareness. Mobile Applications (Apps) can increase environmental education and motivate people to develop actions to mitigate climatic changes like recycling. This research project was carried out in an academic context to improve ecological literacy by promoting positive habits when managing data on recycling. Based on environmental Eco-Schools program requirements and user needs, an Android mobile App was developed that allows individuals to register and monitor their collected waste for recycling. User tests were conducted with 30 participants to evaluate the App usefulness and usability. The results reveal that the App is usable and offers a proper user experience. Participants realized the App benefits because they were willing and motivated to use it in the future which can contribute to the improvement of the environmental awareness and literacy of the academic population.

Keywords: environment awareness and literacy; recycling; mobile application development; Android; usability.

1. INTRODUCTION

Climate Action is one of the great challenges of the current century and is also one of 17 goals of Sustainable Development Goal (SDG) (United Nations, 2024). Studying, understanding, addressing, and mitigating the impact of climate change must bring together research from multiple disciplines. Despite this, environmental education also plays an important role in changing habits and behavior. So, promoting environmental education, adopting practices targeted at sustainability, and reducing the impact the activities may have on the ecosystem and resources are essential (Barreiros et al., 2023). Sustainability doesn't have to be a separate topic and a business objective (Mendonza et al., 2019), it can be integrated into research, in several activities carried out either at the company level or at the level of the academic or the community in general. As stated by dos Santos et al (2022) the need to be more sustainable has become a current challenge and the time is coming when action cannot be postponed.

Nowadays, technologies are essential and can be a fundamental tool as a social practice for raising awareness and promoting environmental education (Franco, Moreira, Cleumar Lima, Silva, Nascimento & Miranda, 2023). Technologies are increasingly present in the lives of children, young

ISSN 2183-489X

people, and adults, contributing to cognitive stimuli and facilitating the learning process through educational games, video games, and the use of cell phones (Marcandali et al., 2019). Also, the use of information technologies (IT) can facilitate a better understanding of environmental awareness and, in addition, promote the acquisition of environmental literacy. Higher education institutions are large consumers of resources and waste producers that impact the environment. There is work about using mobile apps to create environmental awareness. Shan, Ang & Yang (2020) developed a Mobile Application to educate Singapore citizens, Calitz, Cullen & Odendaal (2020) developed an eco-feedback application to create environmental awareness in students from a University, and Sozoniuk, Park & Lumby (2022) developed a study suggesting the effectiveness of using mobile applications as tools to promote recycling habits and encourage sustainable waste management practices.

Eco-Schools is one of the largest global sustainable schools program implemented actually in 99 countries (FEE, 2023), coordinated at the international level by the Foundation for Environmental Education since 1981 and implemented in Portugal by the European Blue Flag Association since 1996 (ABAAE, 2018). It aims to encourage action, recognize, and reward the work carried out by the school in improving its environmental performance, school space management, and community awareness (ABAAE, 2018). It promotes generation after generation of sustainably minded, environmentally conscious people, teaching the next generation the habits to make a difference (FEE, 2023). The implementation of Eco-School program has specific goals defined each year, where each participating school, in addition to prioritizing and defining its objectives, must comply with appropriate methodology. Therefore, the initiatives carried out must be communicated, monitored, and evaluated, and it is also important to involve all stakeholders through updated and reliable data about project actions and results. The four schools that are part of the Institute Polytechnic of Beja (IPBeja) were awarded individually the green flag in the academic year 2018/19 (ABAAE, 2020) because of the work done.

One initiative of this program is to monitor data on the recycling collected (e.g., plastic, glass, paper, and batteries). These needs led us to search for a solution to automate data collection as far as possible, involving all the stakeholders in the institution. The motivation to develop this work was related to the need to achieve environmental objectives and good practices of IPBeja members to maintain the Green Flag award. In this way, the research problem was to understand IPBeja members' awareness of environmental issues through their recycling collection practices. The starting question for this research was: can self-registration and recycling monitoring awaken people to environmental literacy and its protection?

To respond to the problem and research question, we developed a mobile application (App). Contrary to the previous studies, our app allows users to self-register waste for recycling, giving them from our point of view more accurate feedback on their environmental footprint and motivating

the academic community to become more informed and active citizens through their understanding of users' contribution to reducing greenhouse gas emissions and their environmental and digital literacy.

This paper reports the development process of a mobile App titled "IPBeja Recicla" which aims (1) to help users in the academic community encourage the selective disposal of waste materials according to Eco-Schools goals; (2) to inform and promote environmental literacy, as each user can check the individual impact of each type of waste disposed of (glass, plastic, plastic) selectively; and (3) to measure the collective impact of the academic community. Another contribution of this study is the validation of the App usability and usefulness for users' environmental awareness and motivation to manage their recycling data.

This project was developed by students and teachers in the "Integrated Project" subject of a Computer Science degree program. According to Chen, Kolmos & Du (2020), this work was developed in the Project Based Learning (PBL) approach, where students can acquire technical and non-technical skills through the resolution and active exploration of real-world challenges and problems. The App development has been running for the last 3 years developed for different student groups and follows the principles of the software engineering field.

The App was developed for the Android operating system (Meike & Schiefer, 2021) and programmed first in Java (Smyth, 2023) and after in Kotlin (Laurence, Hinchman-Dominguez & Meike, 2022). The data is supported in a cloud NoSQL database. Automatic learning models were also developed in this project to create image classifiers of possible recyclable objects. Some encouraging results were obtained from these models, but the recognition of objects using barcodes was revealed to be more promising.

The "Background in Environmental Education and Digital Transition" section describes the theoretical concepts that support this work and presents other similar research works. The "Methodology" section describes the used research approach, the software project development process, and the data analysis methods applied. The "App Development" section describes the system analysis (requirements and use cases), the system design (data model, the graphical user interfaces, and the system programming structure), and the implementation details. The "App Evaluation - Results and Discussion" section describes the user test procedures and results and their findings and discussion. Finally, the "Conclusions and Future Work" section summarizes the main contributions and points for future work.

2. BACKGROUND IN ENVIRONMENTAL EDUCATION AND DIGITAL TRANSITION

Releases of greenhouse gases (GHG) from human activities contribute to the disruption of the natural balance, causing an increase in temperature (APA, 2021). The planet has warmed about 1°C above pre-industrial levels, mainly due to increased activities such as burning fossil fuels, deforestation, and livestock, which generate gases that aggravate the greenhouse effect (APA, 2021).

Portugal is among the European countries most vulnerable to climate change, due to its geographical characteristics. The main target in Portugal, is the commitment to carbon neutrality between 85% to 90% by 2050, that is, to nullify the balance between emissions and removals of carbon and other greenhouse from the atmosphere, to contribute to limiting global warming to 1.5ºC compared to the pre-industrial period (APA, 2021).

Urban waste contributes directly to GHG emissions through the generation of methane from the anaerobic decay of waste in landfills, and the emission of nitrous oxide from solid waste combustion facilities (UE, 2023). The GHG emitted contributes to global warming, so all emission reductions can contribute to slowing down the global warming process.

UE (2023) argues that carbon dioxide (CO2) emissions must reach net zero worldwide. Reducing emissions of other GHGs, such as methane, plays a key role, especially in the short term. However, the United States Environment Protection Agency (EPA) states that both have high global warming potential, namely methane has 21 times and nitrous oxide has 310 times the warming potential of carbon dioxide. The separation importance and selective disposal of the urban waste solid is essential to promote recycling in a circular economy perspective (Hopewell, Dvorak & Kosior, 2009).

Information and Communication Technologies (ICTs) play a crucial role in environmental management and waste management by providing tools and resources for collecting, processing, analyzing, and communicating relevant information. Hilty & Aebischer (2015) and Ullo & Sinha (2020) point out some of ICT's main roles that can be highlighted for: Environmental Management: 1) Data Collection and Monitoring: ICTs enable real-time collection and monitoring of environmental data. Sensors, mobile devices, and monitoring networks can gather information about air quality, water quality, biodiversity, noise pollution, and other environmental indicators. This data provides valuable insights to assess environmental health and take appropriate management measures; 2) Modelling and Simulation: ICTs allow for the development of computational models and simulations to understand the behavior of environmental systems. These models can be used to predict the effects of different scenarios and interventions, enabling a more informed and strategic approach to environmental management; 3) Information and Education: ICTs play a crucial role in disseminating information and promoting environmental education. Online platforms, mobile apps, and social media are used to provide information about environmental issues, conservation best

practices, and tips for sustainable living. This helps raise awareness among the public about the importance of environmental protection and promotes the adoption of more sustainable behaviors; 4) Communication and Public Engagement: ICTs facilitate communication and public involvement in environmental management. Social media, websites, and mobile apps allow people to express their environmental concerns, share ideas, and participate in discussions. ICTs also facilitate participation in crowdsourcing initiatives and data collection, involving the public in generating information and making decisions.

Regarding Waste Management, ICTs also contribute at various levels (Son & Van, 2023): 1) Optimization of Collection and Recycling: ICTs are used to optimize waste collection and recycling processes. Geographic Information Systems (GIS) and routing algorithms were employed to optimize waste collection routes, reducing time and resources required. Additionally, mobile apps can provide information about collection points, schedules, and instructions for proper waste separation. For example, Gonçalves (2014) aimed to optimize the selection of collection points and minimize the total distance travelled for waste collection. It involved installing ultrasonic sensors in the collection points, allowing real-time monitoring of their fill levels. A model was applied to optimize the collection process of recyclable waste; 2) According to Hannan, Arebey, Begum & Basri (2011) monitoring and tracking: ICTs enable the monitoring and tracking of waste flows. Through Radio-Frequency Identification (RFID) and barcode systems, it is possible to track the waste movement from collection to destination. This helps improve waste management efficiency, reduce losses, and identify opportunities for recycling and resource recovery; 3) Awareness and Engagement: ICTs play an important role in raising awareness and engaging people in waste management, Helmefalk & Rosenlund (2020). Mobile apps, games (e.g., "Praia Ambiente", and “Recycle Bingo!”), and online platforms can provide information about waste reduction practices, recycling, and composting. They can also encourage the public to participate in recycling programs by offering rewards, progress tracking, and the opportunity to share achievements with the community; 4) Data Analysis and Decision-Making: ICTs enable the collection and analysis of large volumes of data related to waste management. This includes data on waste quantity and composition, recycling rates, environmental impacts, and costs. Such information is essential for evaluating the performance of waste management programs, identifying areas for improvement, and supporting strategic decision-making, Gutierrez-Lopez, McGarvey, Costello & Hall (2023), Hussain, Elomri, Kerbache & Omri (2024).

The continuous advancement of ICTs offers additional opportunities to enhance environmental and waste management. Emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics can provide even more precise and detailed insights into the state of the environment and management practices. These technologies have the potential to drive innovative solutions and improve global sustainability.

Some studies have been developed to assess the impact of ICTs and mobile App technologies in promoting recycling and environmental education. Shan, Ang & Yang (2020) developed a Mobile Application to educate Singapore citizens on recycling based on risks, attitudes, norms, abilities, and self-regulation model. Based on the App authors tracked their user's actions and recycling behavioral changes. Through the App users received stickers with QR codes that identified them and put over their bags with the recyclables. In this way, researchers could analyze and record the contents to recycle and quantify the individual impact on the environment. The App granted points to users from the respective recycling records that they could exchange for vouchers or monetary rewards. This work shows an increase in recycling rates of around 20 to 40 percent. However, this study has a drawback in collecting recycling records because it needs human intervention. The process could be automated and more productive if users could directly record their recycling data in the application. A recycling audit developed by Recycle Coach (2021) in Newark/USA supported by an App and an educational campaign reduced plastic bag contamination by 82 percent in one month. This suggests Apps can have a positive effect on user's environmental education and recycling good practices. In an exploratory study, Calitz, Cullen & Odendaal (2020) developed an eco-feedback application to create environmental awareness among postgraduate students at Nelson Mandela University. The results indicated that participants became more aware of their impact on the environment after being exposed to an eco-feedback app and that the functionality provided proved useful. The provided functionalities offer dynamic information about the positive environmental impact of each recycling motivating more users to use the App in these actions. In another work, Sozoniuk, Park & Lumby (2022) conducted an online survey to 1215 App users in the New Jersey/USA area to investigate residents' acceptance of mobile recycling apps. They tried to understand the effect of key factors such as performance expectancy, facilitating conditions, hedonic motivation, and habit on the intention to use recycling apps and recycle household waste. A positive and significant effect on residents' intention to use recycling apps was found from those factors. In addition, the effectiveness of using mobile applications as tools to promote recycling habits and encourage sustainable waste management practices and involvement in recycling activities among residents was suggested. These results for residents in terms of household recycling allow us to hope that the same positive results can be achieved for recycling in academic contexts.

3. METHODOLOGY

This chapter describes the methodologies related to the research approach, the App development process, and the data analysis methods used.

3.1. Research Method

It should be emphasized that the research method was the Design Science Research (DSR). According to Brocke, Hevner & Maedche (2020) DSR has its roots in engineering and the sciences being a problem-solving paradigm. It seeks to enhance human knowledge by creating innovative artifacts and generating design knowledge (DK) via innovative solutions to real-world problems. In this way, we chose this paradigm because those principles are aligned with our engineering research project. Our research process follows the following six phases, according to Peffers, Tuunanen, Rothenberger & Chatterjee (2007):

1. Identifying the problem and motivation. The "Introduction" section states the research problem and the motivation to develop this work.
2. Defining the objectives for a solution. The "Introduction" section describes the objectives of this research work involving the App development and the user feedback to determine the acceptance and impact of that solution.
3. Determine the desired properties and functionalities of the artifact. The System Analysis" subsection of the "App Development" section describes the App requirements and their use cases.
4. Design and development of the App. The "System Solution Design" subsection describes the architecture of the solution and the main decisions about the data model, the user interface proposals, and the programming structure decisions. In the subsection "App Implementation" we can see the decisions and results of the concretization of the functional App.
5. Demonstration of mobile App software as a pilot project that can be used and assessed. The different App prototypes were in the preliminary stages and were shown and experimented with by specific users.
6. Evaluation of the mobile App related to its usability and acceptance to motivate and develop recycling actions. The evaluation was supported by a user test method and a questionnaire survey.
7. The communication of this research has been done through seminars presenting the results to the academic community where the work has been developed and through this paper describing the research the research process, design, and findings.

3.2. Software Development

The App development needed to interrelate the DSR paradigm with software development methodologies, project management, and learning methodology for students. The Waterfall Model was chosen for software development because the project with students required a systematic sequential path from the requirements eliciting and specification, through planning, designing,

modeling, implementing, testing, and deploying the completed software" (Pressman, 2005). The Waterfall model in Figure 1 shows the sequential development process that flowed through all phases and wrapped up before the next phase began.

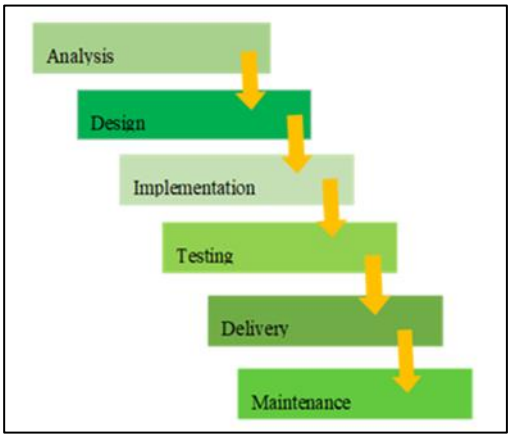


Figure 1- The waterfall model (adaptation from Pressman, 2005)

In turn, it was necessary to define the learning methodology applied to students who took part in the project. Bearing in mind that the aim is for students to be builders of their knowledge in a simulated context as close as possible to the labor market, and they work in teams involved in the teaching-learning process we chose the Project Based Learning (PBL) approach. The project management was supported with the Microsoft Teams tool that facilitates collaboration and communication in an agile way between all the project members. This allows students and teachers to discuss the project details as necessary in the PBL approach.

This project has been developed over the last three academic years (2021/22, 2022/23, 2023/24) by three groups of students and supervised by the 3 teachers in the 'Integrated Project' subject of the Computer Engineering program. The group of teachers have different skills, two from the area of Computer Science and another from the area of Environmental Engineering. The latter worked as a consultant on the recycling problem and was very important in providing the students with effective information for the system analysis.

The first group of 3 students worked mainly on researching similar systems and validating the research ideas relative to the impacts of selective recycling for different types of waste. They also conducted the system analysis phase to elicit and specify the requirements, target users, and use cases. This group also proposed the database model, and the graphical user interfaces and programmed a preliminary functional prototype in a very embryonic state.

The second group of 2 students validated and refined the previous work done by the first group. After that, they focused mainly on developing mechanisms to recognize automatically recyclable objects. One is based on barcode optical recognition and the other is object image recognition

supported in an image classifier from a deep learning model. Another functional prototype version of the App was also deployed based on the project updates.

The third group of 2 students focused on the user validation of the usability and usefulness of the functional App prototype. From these results, a new App version was incremented. The graphical user interfaces were refined, and the programming code was improved for the most important App functions.

Finally, a new round of tests was carried out with users to check the system's functional state and the suitability of the interfaces to the user tasks. An opinion survey based on a questionnaire was applied to the users after they had undertaken and finished their App experience. According to Hill & Hill (2008), the researcher can construct a questionnaire that falls into one of three distinct types depending on the type of question and answer it establishes. Hill & Hill (2008) state that it is "useful when the researcher intends to obtain qualitative information that would serve, for example, as a complement or indicator of the context of the quantitative information obtained".

3.3 Data Analysis

Data collection from the usability assessment of the App was performed to detect the system's functional state and the suitability of the interfaces to the user tasks regarding the last version of the App prototype (see 5.1 section). The intentional non-probabilistic sampling was carried out on those who have shown immediate availability to be part of this study, with a total sample of 30 participants (students, teachers, and staff of IPBeja).

A mixed questionnaire in Google Forms was created to assess the App's satisfaction and usability, including open and closed questions. The participants previously approved the questionnaire, including a free informed consent form, and checked that the data collected would be treated anonymously and confidentially.

The questions were divided into 5 groups: 1) sampling characterization (gender, age, and position at IPBeja, in the case of students it was asked the name of course they attended); 2) How often do you use mobile apps? 3) How often and what type of separated waste: 3.1 How regularly do you separate your waste? 3.2) What types of materials do you separate; 4) Feedback based on App usage experience (4.1 Ease of registering separated materials; 4.2. Importance of the information provided on the environmental benefits of recycling; 4.3 General ease of use of the application; 4.4 Convenience in registering the various objects in series; 4.5 Would you be willing to use this App daily to manage your contribution to recycling; 4.6 General level of satisfaction with the user experience?); and 5) Do you have any suggestions or comments that could improve this application?

Groups 1, 2, and 3 have closed questions; the group 4, regarding the feedback based on their experience of using the App the respondents were asked to rate their opinion on a scale of 1 to 5,

where 1 is the worst-case and 5 the best, and the group 5 of questions is an open question. The results were analyzed using descriptive statistics, performed by Excel function (count if) to calculate the fraction of a specific category (scale 1 to 5). For a better perception, the results of the questionnaire regarding the feedback respondents were grouped into 3 levels (from 1 to 3) regarding the categories previously defined. The considered levels are the following: 1- less important (it was considered scale 1- worst case and scale 2); 2- important (it was considered scale 3), and 3- very important (it was grouped the scale 4 and scale 5- the best case).

The success of the user tasks was verified by visual observation of the user actions and using a record sheet as shown in Table 1.

USER	**DAY**	**START**	**END**	**TASK**					**QUESTIONNAIRE CONCLUDED?**	**OBSERVATIONS**
				4.1	**4.2**	**4.3**	**4.4**	**4.5**		
Number	**Day/ Month**	**Hour: Minute**		**Successful Concluded? (yes/no)**					**Concluded? (yes/no)**	

Table 1 – Task Record Sheet

For open-ended questions, the qualitative data were analyzed using information extraction techniques from syntactically analyzed pieces of text by applying a set of patterns (Benli & Ismailova, 2018).

4. APP DEVELOPMENT

This section describes the analysis, design, and implementation phases of the App software development.

4.1. System Analysis

This phase is the first part of the waterfall development model defined in the methodology section and was crucial to achieving the intended project goals. The tasks were to get needs, functional requirements, target users, and use cases following the software engineering principles, Vliet (2008). The sources of the elicitation and specification requirements were the documentation survey about the environmental impacts of the selective waste disposed of for recycling. The survey was based on the field of Environmental Engineering. The Eco-Schools program provided knowledge and goals about the type of material to be recycled: plastic, metal, paper, glass, and batteries. The characteristics and qualitative and quantitative impacts on the environment were identified for each material type. To better raise the impact awareness of recycling on members of the academic

community, a study was made to determine for each type of material what are savings on the environmental resources. For example, in the case of paper, how many trees are saved when a specified paper quantity is recycled? And in the case of plastic, what are the savings of CO2 to the atmosphere due to less petroleum burned?

The target users of this system were profiled based on the functions performed in the academic community and their participation in the Eco-Schools program. The actors addressed in the system were: students, teachers, staff, and system managers. These users regularly attend the four schools. Some of the students also live in the academic residences of IPBeja. The main use cases assigned to each type of user were identified from the performed survey. In the matrix represented in Table 2, it is possible to see the relationships between user types and their use cases. From this it is possible to verify that students, teachers, and staff have a similar functional profile, being able to register recycling, to retrieve information about their environmental impacts on the community, and to get literacy in this field. The system manager has administrative tasks such as managing user profiles, recycling materials in the database, and usage and recycling analytics.

USER TYPE	USE CASES
Students, Teachers, and Staff	Sign-up, Sign-in, Register for Recycling, Analyze Recycling Impacts, Search for Recycling Literacy
System Manager	Manage Users, Manage Recycling Materials, Manage Usage Stats

Table 2 – Matrix of relationships between user types and their use cases

All the use cases were specified through a Unified Modelling Language (UML) diagram (James, Jacobson & Booch, 2004), and its specification tables were recorded with the following data: user and system action flow and the pre-conditions and post-conditions. The functional and non-functional requirements were also recorded. The non-functional elements were recorded around the usability, security, and privacy areas. The initial technical requirements of the system pointed out that the system should run on the Android operating system and be programmed in Java programming language on Android Studio (Smyth, 2023). Some of the decisions made in this analysis phase were improved and based on iterative validation developed by the analysts of the different project teams. For example, the initial version of the recycling record task had just one manual method to register the materials for recycling. After the first round of tests, the method was boring for users to insert all the data. To overcome this last issue two automatic methods were proposed: (1) One based on optical barcodes and (2) another based on image object recognition.

4.2. System Solution Design

The solution design process for the system development focused on three stages: (i) a data model that supports the database; (ii) graphical user interfaces and (iii) a classes model to support the application programming.

In the first iteration of the system's data structure design, it was modeled the entity-relationship model that supported the data entities (the main ones: material, material type, recycling, impact, and user) and the respective relationships involved in its business domain. This model served as a communication facilitator between the team members and supported the creation of the physical model of a relational database. Later, due to technical requirements arising from the App programming on Android and because the data do not have a rigid structure, it was decided to use a non-relational database model (NoSQL) supported in the Firebase (Google Firebase, 2024) database management system. The previous relational model was used to transpose the structure of the tables into the data collections to be created in this new model.

Subsequently, the graphical user interfaces for all use cases were designed by sketching the screens that support the user's tasks in the system. This was an iterative process supported by a cycle of assessment and improvements. Two medium-fidelity non-functional prototyped versions were sketched. In Figure 2 it is possible to visualize two iterative design proposals for the App landing page one for the end users and the other for the system manager.

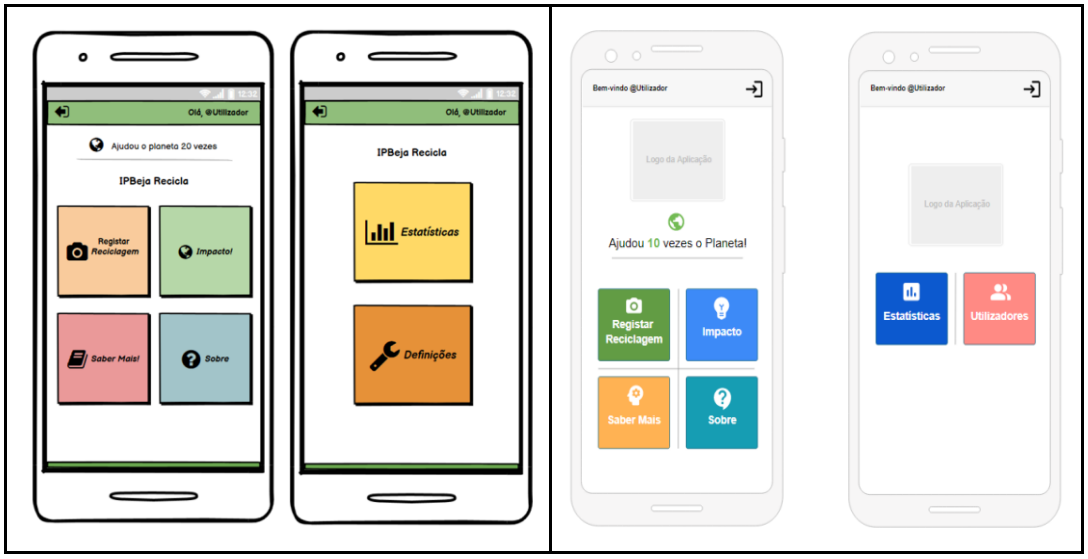


Figure 2 - Comparing two iterative versions of landing page design.

To optimize the user's experience the design of the graphical interfaces was supported by the usability principles "10 Nielsen Heuristics" (Nielsen, 1994). In particular, the following points were considered when designing the interfaces: "User control and freedom", "Error prevention",

"Flexibility and efficiency of use" and "Help users recognize, diagnose, and recover from errors". In this design phase, the interfaces were evaluated based on the "Expert Review" method (Harley, 2018).

When designing the system programming, the UML class diagram was modelled. This allowed a better system's object abstraction. The classes identified and related to each other reflected the business rules and the functionality of each system use case. So, some of them were mapped from the data entities defined in the data model step and some others were added due to their specific functionality role. After these design decisions and their consolidated outcomes, the project moved to the next phase.

4.3. Implementation of the App

The first version of the functional prototype was programmed in Java language. To better integrate and ensure greater data security it was decided to use the Firebase Cloud (Google Firebase, 2024) to access two data services: Cloud Storage to store files from object images to be recycled and Cloud Firestore to support a NoSQL database that was mentioned before. All the foreseen use cases were implemented. It served to preliminarily test the project objectives and check the technical feasibility of the project. On this prototype, an empirical test was conducted with informal users that demonstrated that there are still many improvements. This was the case with the registering tasks of materials for recycling to make the system more attractive for the users' recycling habits.

The development of the second version of the project was based on the gaps identified in the previous version and on a list of other improvement proposals. One shortcoming was the manual recycling registration method which requested the user to fill in all form fields. This process becomes boring for the user. To automate the process other registration methods were designed. One is supported in optical barcode recognition and the other in object recognition from a photographic image.

The first implementation of the barcode recognition method was supported by Google Machine Learning (ML) Kit (Google for developers, 2024) which offers image analysis from a Programming Application Interfaces (API) to label images and detect barcodes, text, faces, and objects in real-time. The barcode scanning API can read data encoded using the most standard barcode formats as needed. In this implementation, the barcode was detected from a photo taken by the user. This solution has a drawback when the recognized barcode is not registered in the system database. In this case, the user must fill in all object’s data to be validated by the system manager. After that, the object's data will be fully available to future users using the barcode as recognized.

In this second version of the project, several solutions were researched for the recognition characteristics of object images from a photographic picture captured from the mobile camera. Several object recognition models based on artificial intelligence were used. The first one was

supported in the "object detection and tracking API" from ML Kit (Google for developers, 2024). After one implementation, the tests showed accuracy rates close to zero because the models were not trained specifically for these types of recycling objects (water bottles with different capacities).

A survey was developed to identify datasets of recyclable objects classified as waste materials. Two datasets were found suitable for this purpose: the Garbage Classification and the Bottles and Cans Images dataset. Each one has hundreds of images from these types: cardboard, plastic bottles, glass bottles, tin bottles of different capacities among other various kinds of waste. The two datasets were merged into one called "bottledata".

On this merged dataset three image classifiers of recyclable objects and their properties were developed based on different deep-learning models. The first one was based on the Keras system (Keras, 2024) that, together with TensorFlow (Google TensorFlow, 2024), trained a classification model based on a convolutive neural network. It presented acceptable results in training but low accuracy values (less than 50%) in the execution mode.

The same dataset was then trained and tested with the convolutional neural network ResNet50 (Ibrahim, 2024). Testing the model, we found an accuracy reasonable (about 85%) in training, but not in a real environment where it recognized almost all glass bottles. Finally, the mentioned dataset was trained on the convolutional neural network architecture aInceptionV3. The generated model offered the best accuracy in recognizing a batch of recyclable (plastic and glass bottles) object images with an accuracy of around 96%. So, it was decided to integrate this classifier into the App as one of the recycling registration methods. From previous experiences, it was understood that image dataset size is critical to get an accurate processed model. However, it is virtually impossible in this project to generate a dataset of all the images of objects to be recycled. Another restriction is related to the distance and angle at which the images are photographed, which can bias object recognition.

After a new round of tests, several functional and usability issues were detected that led to the redesign and implementation. It was decided the migration of the programming code from Java to Kotlin language using a converter available in Android Studio. The reason to this decision was the need to structure better the project code, clean up unnecessary classes, split up the logical data model and user interface views, and ensure greater scalability in the future. Another reason was that the Kotlin language offers better performance for Android applications than Java.

In these tests, the barcode recognition method regularly failed for certain objects, which made the user experience less fluid and more comfortable. In that sense, the barcode recognition method was changed from one photograph capture to a sequential analysis of frames whose image processing can better map the intended pattern. So, the ML Kit Scan barcodes API was implemented with the CameraView API (Iavarone, 2024) which allows various possibilities of transformation and

processing images or frames through the camera. The recognition results increased substantially related to the previous version making the App more robust for this use case.

Another relevant issue was the addition of the new barcodes to the database. It was impossible to have a complete dataset with all the barcodes from the recyclable objects. So, the system must be enriched by users through their registrations of new objects, as shown in the pictures from Figure 3. In this way, these registrations require a system manager validation because they may contain inconsistencies and errors caused by users that would be propagated in subsequent records. When a barcode is recorded for the first time (see the middle screen of Figure 3) a new record is inserted in the database with the non-active state. Only after approval by the system manager does it become active and available so that all its data will be visible to other users when reading that barcode as exhibited in the right screen of Figure 3.

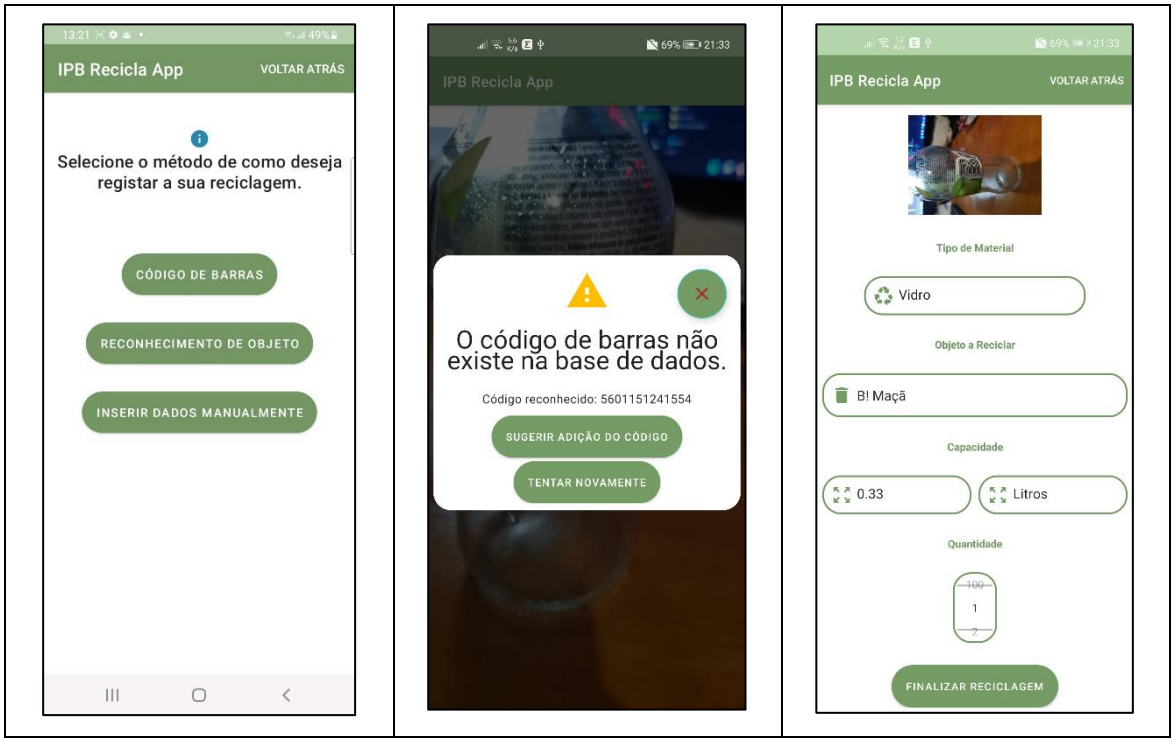


Figure 3 – Screens sequence to register object data

On the left screen in Figure 3 the main menu allows users to start registering recycling waste materials. There it is possible to choose one of the three available methods (barcodes, image object recognition, and manual). Although the right screen in that Figure has resulted from a barcode registration the layout of the manual registration has a similar appearance. The differences are in fields “Tipo Material” and “Objeto a Reciclar” which are dropdown boxes instead of text fields allowing users to choose the appropriate properties.

Other implementations were made regarding the responsiveness of the interface for different screen sizes. The App was tested for various screen sizes and resolutions and some issues were detected for screen sizes of 5.15 inches or lower. Graphical objects like the menu, buttons, and texts may not be fully and correctly displayed. On the left image of Figure 4 is visible the landing page interface of the previous version with those problems and on the right screen is the current version with the issue fixed.

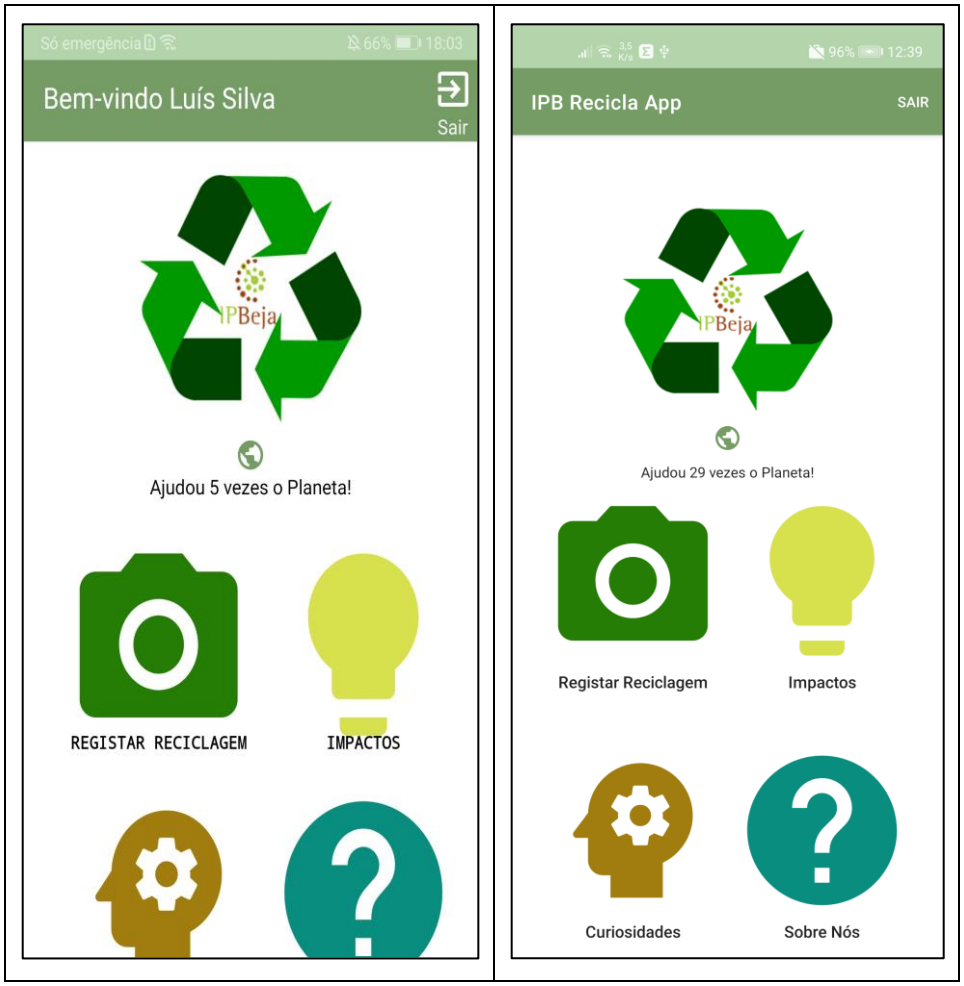


Figure 4 – Responsive screen between versions

Another example is related to the informative page about the positive impacts each user and each school community has on the environment. Also, some problems of responsiveness and clarity of information were detected and corrected as is evident in the left (first version) and right images (last version) of Figure 5.



Figure 5 - Responsive impact screen between versions

Several other improvements were implemented to make the App more robust and usable for users. Thus, this last version can now be evaluated by a representative group of users in usability tests.

5. APP EVALUATION - RESULTS AND DISCUSSION

This section describes the experimental conditions and the sample characterization of the developed user tests. The results obtained in the test and post-test questionnaire are also presented and the discussion of the results and their findings.

5.1. User tasks

This evaluation was supported in user tests to understand the usability and usefulness level of the App. The tests were developed individually with 30 participants. The tests were carried out by a moderator who managed the test procedure and recorded relevant participant's actions. After a brief explanation of the project and a small usage adaptation session participants carried out 5 tasks asked by the moderator. The procedures can be seen in Table 3. The first 4 tasks are registering recycling

objects of 4 different materials (glass bottle using barcode; plastic bottle using barcode but not yet registered in the database; paper ream (500g) inserting manually and 5 plastic bottles using barcode). Finally, the fifth task was to search the CO_2 savings impact of the recycling done for each school. After each test session, one opinion questionnaire was applied to each participant in the experience.

INSTRUCTIONS
1. Explain to the user the aim of the APP IPBeja Recicla
2. Show how the main options work 2.1 register the separated materials, using the barcode 2.2 CO_2 impact of recycling done
3. The user can get used to the application in about 2 minutes
4. Tasks to be asked to user in this order 4.1 Could you please register one glass bottle *"Águas das Pedras"* using the barcode; 4.2 Could you please register one plastic bottle of yogurt *"Pingo doce"* using the barcode; 4.3 Could you please register one paper ream (500 g) inserting the data manually; 4.4 Could you please register 5 unities of natural water bottles using barcode; 4.5 What is the amount of CO_2 saved by the recycling done for the schools.
5. Ask the participant to fulfill the questionnaire. End by thanking the participant for their contribution to the study and expressing willingness to provide latter further information on the APP. **Note**: The experiment moderator must record the main results.

Table 3 – Procedures used by the moderator to test the usability of the proposed App

5.2. Sample characterization

The App's usage test and satisfaction questionnaire were applied to 30 people from the IPBeja academic community, of whom 47% are students, 37% are teachers and 17% are staff. Regarding gender, 60% are men and 40% female. Of the total students (14) respondents, 57% and 43% belong to Computer Science and Environmental Engineering courses respectively.

5.3. Results and Discussion

During the test, all users completed the registration tasks (from 4.1 to 4.4) and the task of consulting information (4.5). The success of these tasks was assessed based on the observation of the moderator and the user feedback.

The results obtained from the questionnaire regarding participants' background digital literacy (use of mobile applications) showed that 90% of all respondents use mobile Apps daily.

Concerning participant's environmental literacy, 77% of the total respondents' separate waste daily, in opposite 23% do it a few days per week; 100% separate, plastic, paper, and glass, batteries being the 2nd most selectively deposited materials (57%), followed by oils (33%).

Figure 6 depicts the respondent's feedback for 6 relevant questions based on their experience after using the App. The results are distributed by the 3 classification levels (Very important, Important, and Less important) grouped as mentioned in the "Methodology" section. The results show that: 1) it is easy for most participants (80%) to register the separated material; 2) regarding the importance of the information provided on the environmental benefits of waste recycling about 87% consider it very important; 3) for the facility of using the App, most respondents consider it easy (77%); 4) regarding the convenience felt in recording the various objects in series, about 80% consider it very important; 5) when was asked about the availability of respondents to using this App daily to manage their contribution to recycling, circa of 67% said yes!; 6) in general 87% of the respondents considered the level of satisfaction using the App is very important.

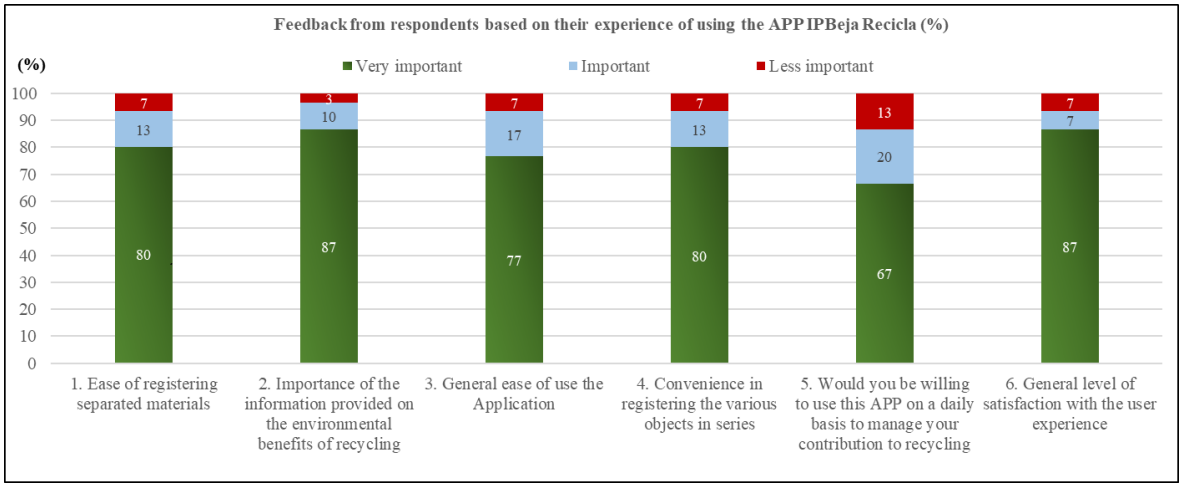


Figure 6 - Feedback from respondents based on their experience of using the App (%)

The participants rated all the questions very positively. All have a percentage higher than 67% for the "Very important" level. Question 1 (80%) shows a high degree of ease in registering waste for recycling. However, we believe the barcode method still needs to be improved. Question 4 (80%) shows a high degree of convenience in registering various batch objects in one operation. This feature is important so as not to make of registering waste for recycling tedious, thus removing the motivation to use the App. Questions 3 (77%) and 6 (87%) suggest the App degree of usability and user experience is very positive.

The higher results of questions 2 (87%) and 5 (67%) seemed to confirm the results of Sozoniuk, Park, & Lumby (2022) related to the effectiveness of using mobile Apps as tools to promote recycling habits, encourage sustainable waste management practices and involvement in recycling activities among household recycling residents. This finding suggests the App can wake up

environmental awareness and motivate the academic population to develop actions to mitigate climatic changes like recycling.

The results from questions 2 and 5 suggest participants became more aware of their impact on the environment after being exposed to the App, which is aligned with the study of Calitz, Cullen, and Odendaal, 2020, who concluded the eco-feedback application created environmental awareness amongst postgraduate students. Contrary to this study, our app allows users to self-register their waste for recycling, giving them more accurate feedback on their environmental awareness.

Concerning the open question about any suggestions or comments that could improve the App, the respondents mentioned the following points to be improved: (1) reviewing the measurement units in the capabilities of the objects, as it is not very clear and makes the choice difficult; (2) “change the capacity of plastic bottles from litters (L) to milliliters (ml)”, which should appear first, followed by the type of object; (3) when inserting the object manually, the object type should appear instead of the recycling type.

Other participant comments were: in the question “How often do you separate waste (garbage)?”, “the options should be reviewed because there is no “weekly option”. “When selecting the material, if possible, do not have to click on the following fields to finalize the process”. “When you automatically identify the objects it's great and easy. However, “when manual recognition is carried out it takes more time”. For this case “it should have a tutorial to instruct users.” So, those comments are a helpful contribution to improving the App.

The respondents also mentioned that it would be “more reliable if the identification of objects were always through photographic recognition, without the need to introduce the barcode and name of the object, because more time is wasted, and it is not intuitive”. Respondents argue that “If this is not possible, then to remediate this situation”, the suggestion was tutorial to instruct users in the steps to follow”. These results are an important contribution to improving the App usability.

6. CONCLUSIONS AND FUTURE WORK

The project tried to respond to the specific need of Eco-schools program to the recycling problem and to motivate the academic population to protect the environment. The project involved the environmental and computer science fields to get a solution, and it was developed under the Project Based Learning approach creating new challenges to students and researchers with this specific development methodology.

To respond to the problem, an App was developed to offer environmental awareness and ecological literacy for the academic population at the same time, it allows users to self-register their waste for recycling. Some challenges were faced in implementation methods to recognize the recycling materials automatically like image classifiers and barcode recognizers.

User tests were conducted to measure the usability and usefulness of the App. The survey results obtained were useful to understand the viability of this concept. Most participants rated very positively all the questions. These results reveal that the App is usable and offers a positive user experience.

The results suggest this App can promote recycling habits and encourage sustainable waste management practices and environmental awareness. Participants realized their benefits because they were willing and motivated to use it in the future. These results are aligned with other studies that used this type of App. Contrary to those Apps, the developed in this study allows users to self-register waste for recycling and monitor their actions, giving them more accurate feedback on their environmental footprint. It suggests that the application can facilitate environmental awareness and literacy among the academic population in this field, promoting citizens who are more aware of ecological issues.

In the future, one intends to evaluate the App with a bigger user sample to check its viability more expressively and to research the viability and impact of applying one user's rewards mechanism and a gamified approach.

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