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PAPER

Mobile Application to Improve the Follow-up and Control Process in Patients with Tuberculosis

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ABSTRACT

Tuberculosis is a severe and life-threatening illness that affects numerous individuals worldwide every day. The key objective of this study was to create a system that could enhance the monitoring and management of tuberculosis patients. To achieve this goal, the Mobile D methodology was utilized because of its effectiveness in project management. This methodology emphasizes test-driven development, continuous integration, and optimization to enhance software processes. The outcome of this research was a prototype of a mobile application specifically designed for individuals with tuberculosis. Professionals and people affected by the disease assessed the quality of the prototype. They evaluated its effectiveness, user-friendliness, design, and functionality and gave ratings of 4.77 and 4.69 on a Likert scale, respectively. These figures indicate that the prototype meets high-quality criteria. In conclusion, this research successfully created an efficient prototype that enhances the monitoring and control of tuberculosis patients. The prototype includes features such as real-time consultations for immediate interaction between physicians and patients, clinical history visualization, and medication reminders, all of which improve the user's experience.

KEYWORDS

tuberculosis, mobile application, patient management, monitoring

1 INTRODUCTION

Tuberculosis is the most lethal infectious disease in the world. The Pan American Health Organization (PAHO) indicates that tuberculosis claims the lives of 4400 people per day and affects 30,000 people daily, despite being a preventable and curable disease [1]. The COVID-19 pandemic and socioeconomic inequalities have reversed years of progress in the fight against tuberculosis, increasing the burden and especially affecting the most vulnerable groups [2]. According to the World Health Organization (WHO) [3] in 2021, an estimated 10.6 million people worldwide contracted tuberculosis, including 6 million men, 3.4 million women, and 1.2 million children. In addition, a 3% increase in the burden of drug-resistant tuberculosis

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was observed, with the detection of 450,000 new cases of rifampicin-resistant tuberculosis [4], this increase represents the first time in years that growth in the number of people infected with drug-resistant bacilli has been recorded. The COVID-19 pandemic caused disruptions in tuberculosis control services in 2021 and particularly affected activities aimed at controlling the disease. There are two types of tuberculosis, latent tuberculosis and active tuberculosis [3]. Latent tuberculosis shows no symptoms and is not contagious, but may develop in some cases, risk factors include diabetes, weakened immune system, malnutrition, and smoking. Active tuberculosis has symptoms that may vary, but generally include chronic cough, chest pain, weight loss, fever, and night sweats.

The eradication of tuberculosis is included in the United Nations' Sustainable Development Goals. The WHO's "End TB" strategy aims to reduce deaths from TB by 90% and reduce the incidence of new cases by 80% by 2030 [5]. In September 2015, the SDGs were established, among which is SDG 3, also known as "good health and well-being." This goal has as its main purpose to ensure a healthy lifestyle and promote well-being at all stages of life, which is fundamental for sustainable development [6, 7]. Each SDG is composed of several targets that expand and detail the goals. An example is SDG target 3.3, which has as one of its goals for 2030 the eradication of tuberculosis [8]. To achieve this goal, it is crucial to improve the process of monitoring and controlling patients with tuberculosis. Because of this, research has been conducted that explores the use of technology, as described in the research [9], in which the Scrum methodology was used for the development of a web application that solves the problem of slowness in the process of diagnosing tuberculosis. Through the collection of qualitative and quantitative data in 45 medical centers of the Regional Health Directorate (DIRESA) of Callao, it was shown that the web application managed to reduce 120 hours of monthly validation and avoided the generation of 8,700 duplicate data, thus improving the efficiency of the diagnostic process. On the other hand, [10] proposes to build a web platform using the web engineering (IWeb) methodology to optimize the delivery of test results so that they can be consulted by any entity authorized by the Secretariat of Health of the State of Hidalgo in real-time, immediately, and without intermediaries to reduce bureaucratic procedures that are time-consuming and unreliable. To finish with the prototype, validation, registration, and log-in tests were carried out, and all the observations and usability contributions made by the end users were attended to, resolving the areas of opportunity. [11] proposes to improve the diagnosis of tuberculosis in marginalized and resource-poor communities using deep learning and mobile health technologies, a dataset provided by Dr. Peinado from Peru was used. This dataset includes 4701 X-ray images, of which 453 are normal (from patients without TB) and 4248 are abnormal (from patients with different types of TB manifestations). The second research activity focused on the development of effective and efficient computational models (in particular, models based on convolutional neural networks (CNN)) to classify the image into different categories of TB manifestations. To this end, a mobile phone-based cloud computing system is designed and deployed that achieves 89.6% pre-accuracy in binary image classification. The approach aims to accelerate TB diagnosis in these communities through affordable and efficient technologies.

In the study [12], the implementation of an efficient image processing platform to extract the images of plasmonic ELISAs for TB antigen-specific antibodies and analyze their characteristics is presented. Supervised machine learning techniques are used to obtain a binary classification from eighteen lower-order color moments. The proposed system is trained off-line, followed by testing and validation using a separate set of real-time images. Using a conjoint classifier, Random Forest, we demonstrated 98.4% accuracy in detecting TB antigen-specific antibodies on the mobile platform. According to the research [16], it is known that people in a medical center prefer to use mobile devices (88%) followed by tablets (38%) and finally computers to access medical learning sessions.

The objective of the present research was to identify various perspectives and alternatives to develop new interventions to improve the health and quality of life of patients and thus develop a system capable of optimizing the process of monitoring and controlling patients with tuberculosis.

This research article is divided into four sections. The second section describes the methodology used, including the concepts considered, the program design, and the target population. The third section details the application development process, including the architecture. Finally, the results and conclusions of the study are presented.

2 METHODOLOGY

The research of the existing agile methodologies was carried out, and for the choice, the amount of information used, the knowledge of each methodology, the adaptation, and flexibility for the implementation are taken into account (Table 1).

Table 1. Choice of methodology

Methodologies/ Criteria	Information Management	Knowledge	Adaptation	Flexibility	Points
Design Thinking	4	3	4	3	14
XP	3	4	3	3	13
Mobile D	4	5	4	5	18
Scrum	3	3	4	3	13
Kanban	3	2	3	3	11

In accordance with the theoretical support found in the research for the choice of a methodology, the winner was Mobile D, as shown in Figure 1. This is why it will be used in the project.

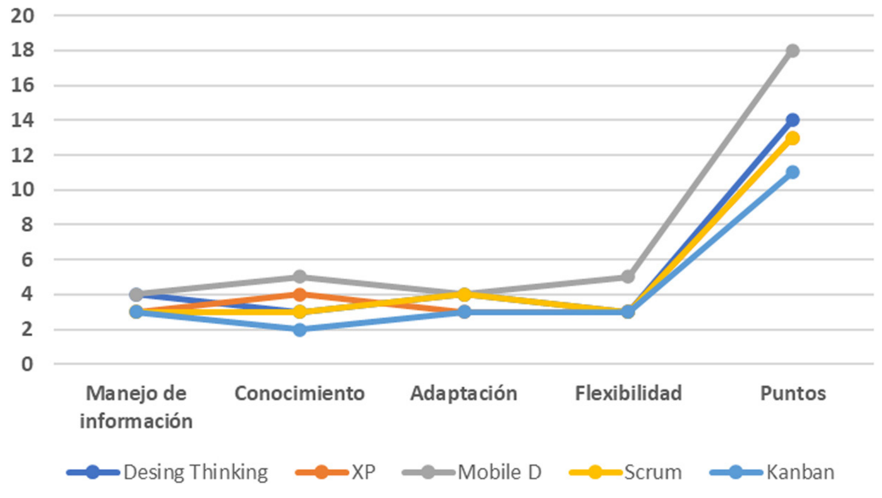

Fig. 1. Methodology chart

The Mobile-D methodology is used to deliver a finished product in a maximum of ten weeks, with a team of no more than ten developers. It focuses on test-driven development, continuous integration, and refactoring, as well as improving software processes [13]. As shown in Figure 2, Mobile-D consists of five phases to carry out the project efficiently.

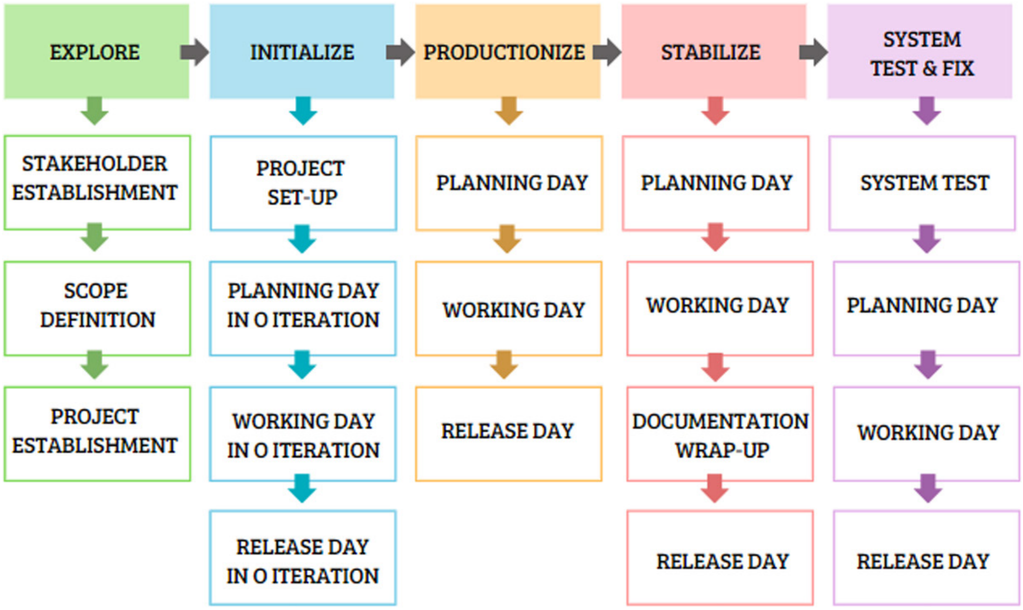

Fig. 2. Mobile-D development cycle

2.1 Exploration

In this phase, the following stakeholders were established: **Stakeholders:** Health centers; **Users of the application:** People suffering from tuberculosis; and **Developers:** Researchers of this project.

2.2 Initiation

At this stage of the study, the technological resources (both hardware and software) necessary to carry out the research project have been defined and secured.

Hardware:
1 laptop with at least a 4-core processor and 8 GB RAM.
A mobile device is compatible with Android and iOS.

Software:
Flutter: Google's open-source framework for creating cross-platform applications with a single code base, compiled in native cross-platform applications with a single code base, compiled in native code for fast performance. It offers development tools, automated testing, and an active community [14].
MySQL: It offers ease of use and administration, high reliability, and scale-ability for large databases. Its superior performance, high availability, and robust security make it ideal for a variety of applications [15].

2.3 Production

In this phase, the ideas and functions of the application are organized. Figure 3 shows the architecture of the proposed application, which shows the users who will use it, which would be patients and physicians specializing in tuberculosis. On the other hand, it also shows the database process and how they relate to the application.

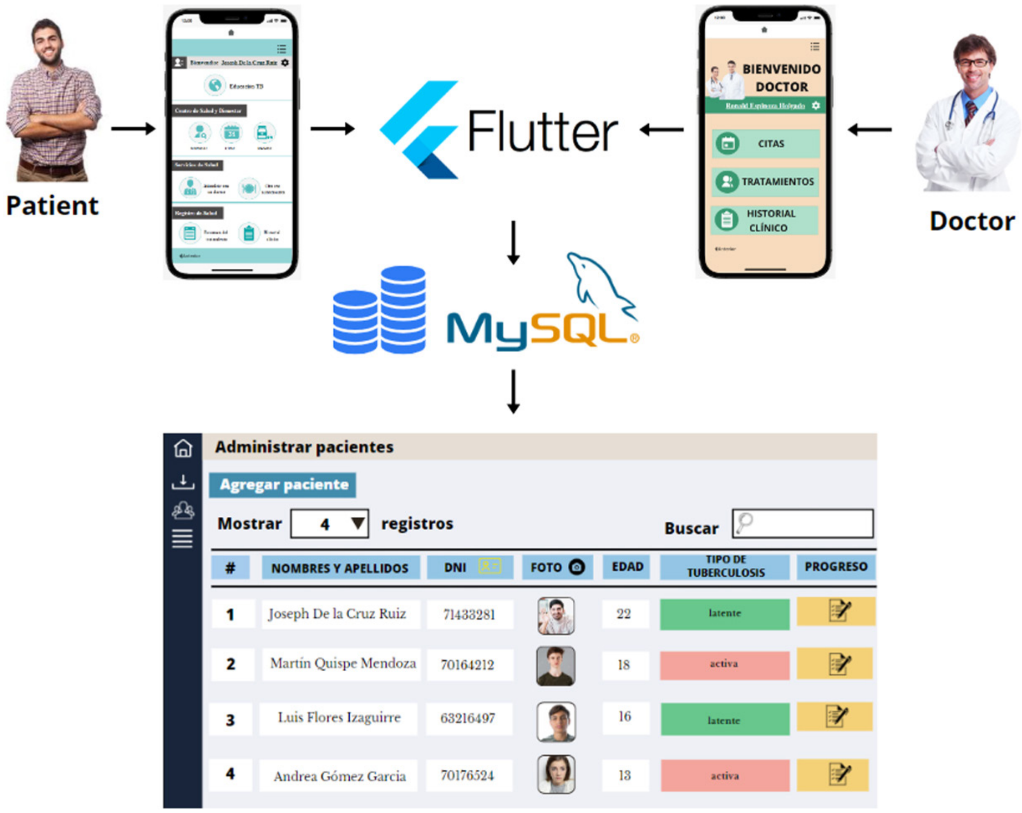

Fig. 3. Project architecture

Both the specialist physician and the patient will have access to the "Tuberculosis Tamer" application. When logging in, they will be able to select their role (doctor or patient). The application, developed in Flutter, will connect to a MySQL database to store and manage patient data.

2.4 Stabilization

During this stage, the application is prototyped. Figure 4 shows the possible interfaces. In Figure 4a, the user is presented with the option to choose between two types of logins: physician or patient. Once the user has selected their role in the case of a patient, they enter the application and are presented with Figure 4b, where they access the main menu that offers a variety of functionalities. Figure 4c shows a section with access to online content related to the disease.

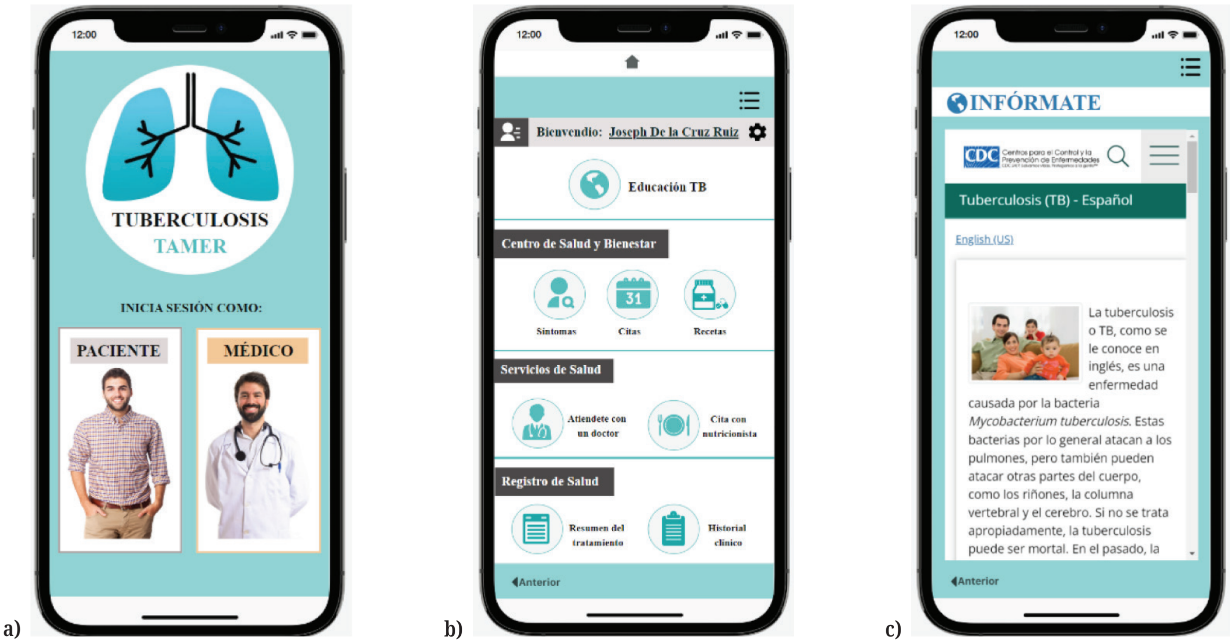

Fig. 4. Session start interfaces: (a) welcome interface (b) patient options (c) online information

The interface register is shown in Figure 5. Figure 5a highlights the daily symptom log and additional observations on their health status. In Figure 5b, there are both face-to-face and virtual appointment bookings. Also, in Figure 5c, the application offers the ability to interact with a tuberculosis physician through scheduled video calls or online messages.

Fig. 5. Registration interfaces: (a) symptom registration interface (b) appointment booking (c) live consultations

Figure 6 illustrates doctor menu interfaces. Figure 6a shows the doctor's main menu. Figure 6b shows the doctor's scheduled, canceled, and completed appointments.

Fig. 6. Doctor menu interfaces: (a) welcome screen (b) appointment booking

Figure 7 shows the story interfaces. In Figure 7a, a summary of the patient's treatment that the doctor considers seeking is displayed. In relation, Figure 7b shows the patient's medical history.

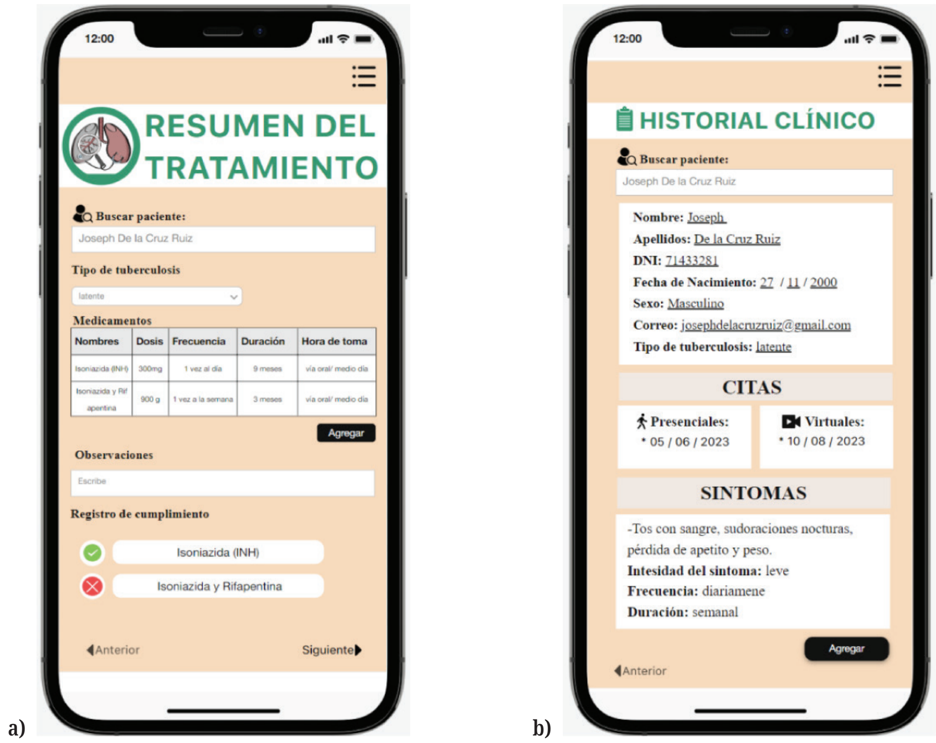

Fig. 7. Patient history interfaces: (a) treatment summary (b) clinical history

Figure 8 shows the doctor's computer database of registered patients and the entire process.

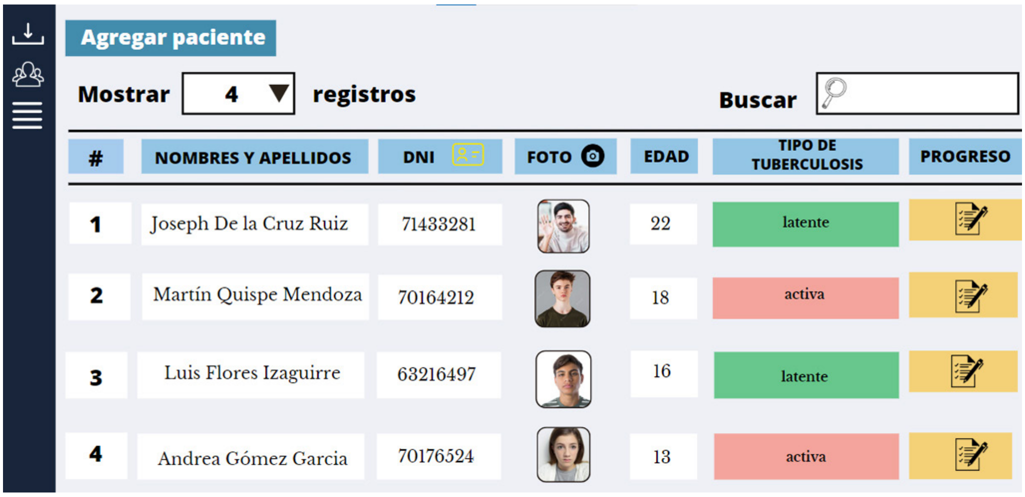

Fig. 8. Patient database

2.5 Text

For the evaluation of the system, 20 experts from different universities in Peru and 15 people involved with the disease from Lima, Peru, between the ages of 13 and 22, participated. Likert-scale questionnaires were used for the evaluation. The evaluation criteria are shown in Table 2.

Table 2. Evaluation criteria

Criteria	Aspects
Usability	Easy to use
	Intuitive, simple, and fast
	Easy access and navigation
Design	Understandable colors and fonts
	Attractive visual elements
	Graphics according to the design
Functionality	Readable
	Facilitates interaction
	Suitability
Efficiency	Optimize resources
	Displays accurate results
	Provide fast response time

3 RESULTS

3.1 Validation of the design model with experts

This section shows the results of the validation of the design quality level, based on 20 experts from different universities in Peru. In the validation, different criteria were applied (usability, design, functionality, and efficiency), from which questions based on the Likert scale were established. The purpose of this means of validation was to measure the degree of acceptance by the experts. Table 3 shows the criteria used in this validation, as well as the different questions used in each criterion and the level of quality obtained by calculating the mean and standard deviation (S.D.). It also shows that the total mean is 4.59, so the final quality level is very good.

Table 3. Validación por expertos

Criteria	Aspects	Media	S. D	Quality
Usability	Is the application easy to use?	4.60	0.50	Very Good
	Is the application intuitive, simple, and fast?	4.95	0.22	Very Good
	Is the application easy to access and navigate?	4.85	0.37	Very Good
Design	Are the colors and fonts understandable?	4.60	0.50	Very Good
	Does the application present attractive visual elements?	4.85	0.37	Very Good
	Does it present graphics according to what the application wants to convey?	4.85	0.37	Very Good
Functionality	Is the application readable?	4.85	0.37	Very Good
	Does it facilitate user interaction?	4.70	0.47	Very Good
	Does the application present suitability?	4.55	0.51	Very Good
Efficiency	Are resources optimized in the application?	4.85	0.37	Very Good
	Does it show accurate results?	4.65	0.49	Very Good
	Does it provide a fast response time?	4.90	0.31	Very Good
Total average and final quality level		**4.77**		**Very Good**

Figure 9 shows the graph summarizing the criteria, where efficiency has the highest percentage (97%), followed by functionality and usability (96%), and design (95%).

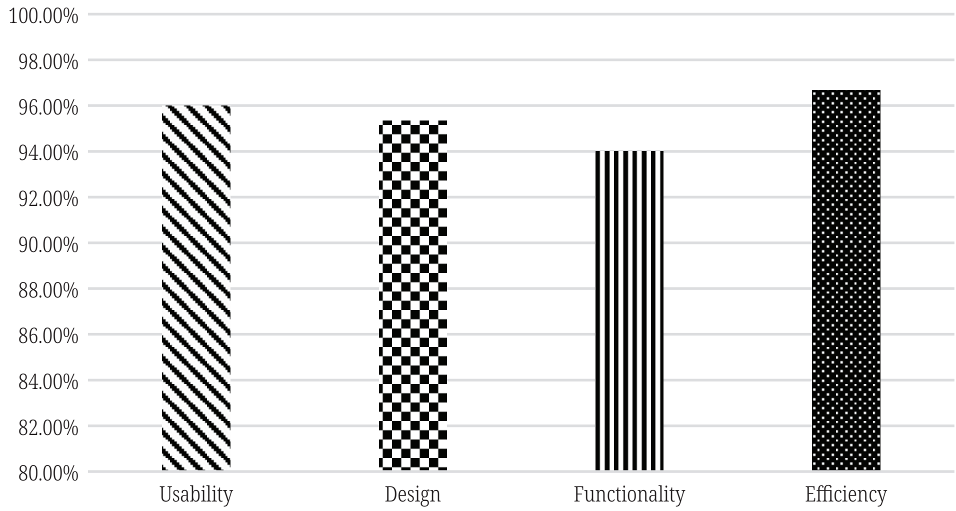

Fig. 9. Summary of criteria

Figure 10 clearly shows that the "very good" category on the Likert scale represents the highest percentage. In particular, the aspects of usability and efficiency reached 80%, followed by design at 77%, and functionality at 70%.

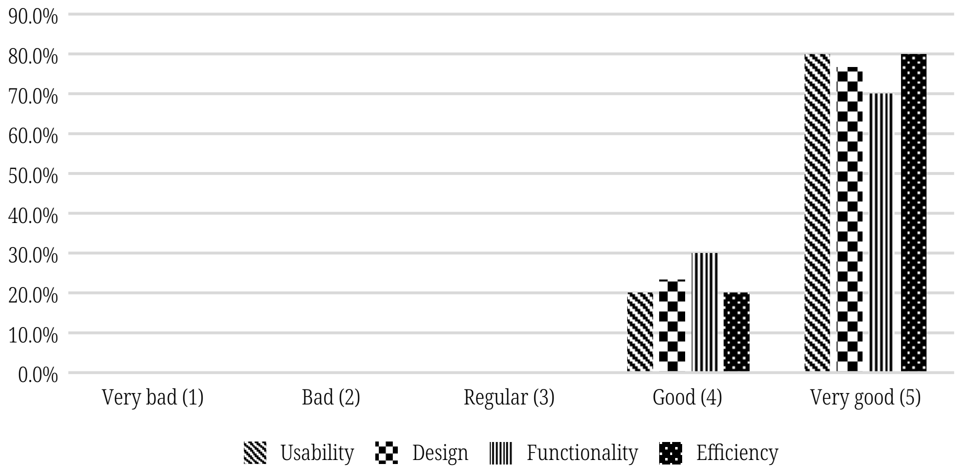

Fig. 10. Likert scale analysis in criteria evaluation

3.2 Validation of the design model with users

In addition to the validation of the application by experts in the field, a usability study (SUS) was also carried out, through this validation, possible errors based on the operation of the system were mitigated, as well as the acceptance of the application by the users. For this purpose, 15 people involved with the disease collaborated in the study. As shown in Table 4, the measurement of performance and acceptance was performed for each sprint, for the validation of performance, the Likert scale was used, having as an answer the option 1 = very bad, 2 = bad, 3 = regular, 4 = good, 5 = very good.

Table 4. Validation by users involved with the disease

Criteria	Aspects	Media	S. D	Quality
Usability	Is the application easy to use?	4.60	0.51	Very Good
	Is the application intuitive, simple, and fast?	4.73	0.46	Very Good
	Is the application easy to access and navigate?	4.80	0.41	Very Good
Design	Are the colors and typeface understandable?	4.80	0.41	Very Good
	Does the application present attractive visual elements?	4.67	0.49	Very Good
	Does it present graphics according to what the application wants to convey?	4.53	0.52	Very Good
Functionality	Is the application readable?	4.67	0.49	Very Good
	Does it facilitate user interaction?	4.67	0.49	Very Good
	Does the application present suitability?	4.60	0.51	Very Good
Efficiency	Are resources optimized in the application?	4.60	0.51	Very Good
	Does it show accurate results?	4.80	0.41	Very Good
	Does it provide a fast response time?	4.80	0.41	Very Good
Total average and final quality level		**4.69**		Very Good

Figure 11 shows the graph summarizing the criteria, where efficiency and usability have the highest percentage at 94%, followed by functionality and design at 93%.

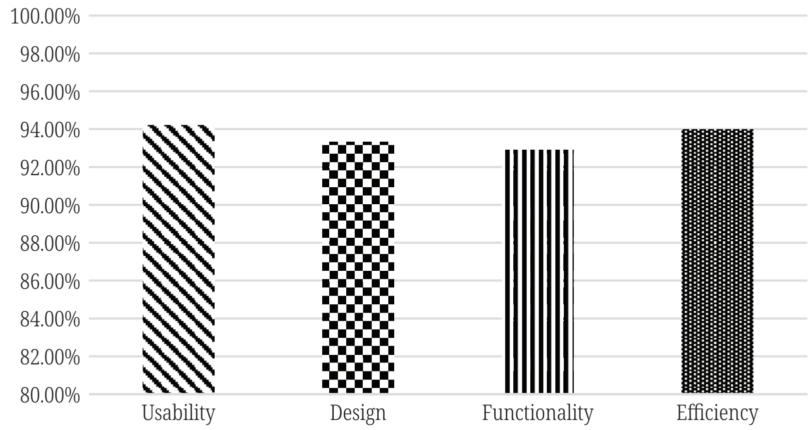

Fig. 11. Summary of criteria

Figure 12 clearly shows that the "very good" category on the Likert scale represents the highest percentage. In particular, efficiency is at 73%, followed by usability at 71%, design at 67%, and functionality at 64%.

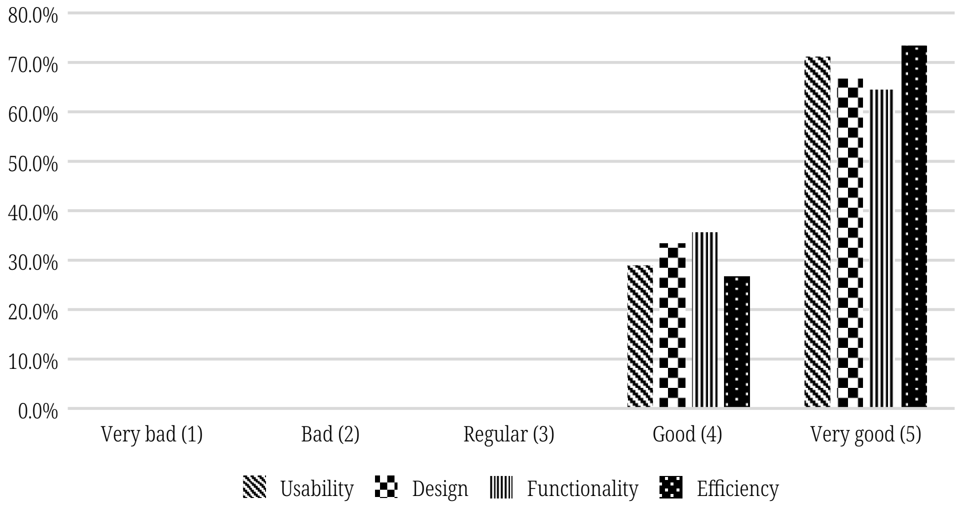

Fig. 12. Likert scale analysis in criteria evaluation

4 DISCUSSION

The design of a mobile application to improve the monitoring and control of patients with tuberculosis was carried out by applying the Mobile D methodology. On the other hand, in the research [11], deep learning and mobile health technologies are used to improve the diagnosis of tuberculosis. As for [9], the Scrum methodology was chosen to develop a web page that solves the problem of delay in the diagnostic process of the disease, while [10] uses web engineering methodology to streamline the delivery of medical test results. Research [17] uses the waterfall methodology for the care of patients with Alzheimer's disease.

The proposed mobile application includes live consultations for immediate interaction between physicians and patients. In addition, it offers clinical history viewing and medication reminders, thus improving the user experience. However, [9], [10], and [11] focus on streamlining medical examinations and having a more efficient diagnosis, thus limiting the capacity that the application or web page can have. The proposed research evaluates the criteria of usability, design, functionality, and efficiency to measure its quality. The mean was calculated through validation by experts, obtaining values of 4.80, 4.77, 4.70, and 4.80, respectively, using the Likert scale. These results indicate that the quality of the criteria evaluated in the application is very acceptable.

On the other hand, [12] achieved a high accuracy of 98.4% in the detection of tuberculosis antibodies using the Random Forest classifier. In [11], a mobile device-based cloud system is developed that achieves an accuracy of 89.6% in binary image classification. However, its accuracy decreases in multi-class classification by 62.07%, possibly due to the lack of pre-processing and intra-class and inter-class differences. Research [18] evaluates the effectiveness, usability, and safety of the prototype with an average score of 4.66 for health care in times of pandemic.

In the future, it is suggested to perform research following the Mobile D methodology for health improvement.

5 CONCLUSION

In conclusion, this research culminates in the development of a prototype mobile application aimed at improving the follow-up and control of patients with tuberculosis and facilitating fluid communication between patients and physicians. The prototype stands out for its functionality, efficiency, ease of use, and attractive design, benefiting the health care and management of those who need it. Its primary objective is to optimize the process of monitoring and controlling patients with tuberculosis, with the ultimate goal of improving their health and quality of life. To achieve this purpose, the Mobile D methodology was of vital importance, providing the structure and approach required to develop an effective solution focused on the needs of both patients and medical staff, and the evaluation of the prototype through expert judgments evidenced its acceptance and feasibility, as demonstrated by an overall average score of 4.77. In addition, those involved with the disease gave an average rating of 4.69 in aspects such as efficiency, usability, functionality, and design. A limitation found during prototyping is related to data management and information security, including user privacy. In addition, there is a possible limitation in the accessibility and availability of mobile devices in certain communities, which could affect their implementation in areas with limited resources. For future work, it is suggested that this project be complemented with emerging technologies, such as artificial intelligence, to support the diagnosis of patients' conditions. It is also proposed to expand the development of the mobile application to devices with the IOS operating system, with the aim of reaching a wider and more diverse audience.

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