

PAPER

Mobile Application for Energy Efficiency Management in Manufacturing

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ABSTRACT

Energy efficiency in industrial sectors consumes 40% of global energy and generates more than 30% of greenhouse gas emissions, contributing to air pollution that affects more than 90% of the world's population. The research focused on developing a mobile application for energy efficiency management in manufacturing companies. Using the Mobile D methodology, recognized for its effectiveness in project management and its focus on test-driven development, continuous integration, and optimization of software processes, a prototype application was created. This prototype was evaluated by former experts and company staff, such as managers and supervisors, who rated its usability, design, security, efficiency, effectiveness, and functionality with high scores, ranging from 4.58 to 4.91 on a Likert scale. The mobile application includes functions such as equipment registration, allowing users to enter devices and their energy consumption; real-time monitoring and control with alerts if any machine exceeds its normal consumption; and detailed visualizations of energy efficiency, with monthly, quarterly, or annual analysis according to the corresponding areas.

KEYWORDS

energy, efficiency, manufacturing, mobile application

1 INTRODUCTION

Lack of access to electricity is a critical concern, with an estimated 733 million people without access to this essential service and close to two billion people relying on polluting technologies for cooking; this energy access deficit underscores the urgency of accelerating electrification, increasing investments in renewable energy, and improving energy efficiency [1]. On the other hand, the industrial sectors are responsible for approximately 40% of global energy consumption and contribute more than 30% of global greenhouse gas emissions [2]. According to the World Bank, energy consumption accounts for more than three quarters of greenhouse gas emissions; financing energy efficiency initiatives and large-scale implementation of renewable energy, while phasing out fossil fuels, is necessary to accelerate the energy transition [3].

León-Trejo, L., Cabanillas-Carbonell, M. (2025). Mobile Application for Energy Efficiency Management in Manufacturing. *International Journal of Interactive Mobile Technologies (IJIM)*, 19(7), pp. 58–69. <https://doi.org/10.3991/ijim.v19i07.52849>

Article submitted 2024-10-14. Revision uploaded 2025-02-18. Final acceptance 2025-02-19.

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The energy sector plays a major role in air pollution, affecting more than 90% of people around the world and linked to over six million premature deaths each year; this highlights the urgent need for cleaner energy solutions to protect public health and the environment [4]. As stated by the United Nations (UN) [5], a large part of the greenhouse gases that surround the Earth and retain the Sun's heat comes from energy production, which is based on the burning of fossil fuels to generate electricity and heat. The International Energy Agency (IEA) also mentions that annual investment in energy efficiency has increased by 45% since 2020, with strong growth in key sectors such as electric vehicles and heat pumps [6]. In the industrial field, the ISO 50001 standard is an indispensable tool for energy management. This international standard establishes a management system that allows companies to continuously improve their energy efficiency, optimizing their performance and reducing costs [7]. However, in Latin America and the Caribbean, there are several barriers that hinder the adoption of energy efficiency; among the most significant is the lack of consumer education (73%), followed by the absence of adequate standards and regulation (54%) and insufficient information on final energy consumption (52%); furthermore, (41%) identify insufficient training of human capital as an additional obstacle to greater penetration of energy-efficient practices in the region [8]. Within this framework, energy efficiency becomes an essential strategy not only to mitigate the environmental impact of energy consumption but also to meet the United Nations Sustainable Development Goal 7 (SDG 7), which sets specific targets to improve energy efficiency (target 7.3), being crucial to reduce greenhouse gas emissions and promote sustainable development [9]. To achieve this goal, improving energy efficiency in manufacturing companies is crucial, which has led to research that looks at the use of technology, as detailed in the study [10], which is an application of digital twin technology in the energy efficiency management system of intelligent buildings. After its implementation, the energy-saving rate reached 21.524%, exceeding the target of 1.524%; this demonstrates a significant reduction in energy consumption and the effectiveness of the technology in optimizing energy efficiency. On the other hand, [11] proposes a sensor-based recurrence analysis of energy efficiency in machining processes. The app allows real-time monitoring of energy consumption, identifying inefficiencies and improving energy efficiency; experimental results indicate that the energy efficiency prediction error of the sensor-based models is less than 5%, demonstrating great potential for implementation in industry. In [12], a comprehensive and flexible architecture is proposed to enhance energy efficiency and optimize decision-making in the management of energy consumption and production in Panama, utilizing the Scrum methodology. This architecture integrates technological components such as the Internet of Things (IoT), artificial intelligence (AI), cloud computing, and mobile applications, effectively addressing the challenges related to electricity consumption and production; experiments demonstrated the functionality of the proposed platform, evidenced by a score of 90 on the System Usability Scale (SUS), indicating an excellent level of satisfaction among users. In addition, [13] the study focused on implementing an intelligent agent (IA) to improve incident management (IM), reducing the number of unresolved incidents and the resolution time and increasing user satisfaction; the development was based on the Scrum framework and technologies such as Dialogflow, Webhook, and PostgreSQL; the results showed a 14% reduction in unresolved issues, a 63% decrease in resolution time, and an improvement in satisfaction, with 43.3% of users "satisfied" and 57.7% "very satisfied." Research [14] indicates that in Serbia, in order to improve energy efficiency in the industrial sector, a regulatory framework established by the Energy Efficiency Law is implemented; this law promotes local and industrial measures, including the appointment of trained energy managers and companies. Serbia has a potential of 5.65 Mtoe in renewable energy, of which 1.054 Mtoe is biomass and 0.909 Mtoe is

hydropower; despite lagging behind the EU, it is estimated that the implementation of these measures could generate energy savings of 20% in key sectors such as industry.

The purpose of this study was to analyze various perspectives and alternatives to facilitate the implementation of interventions aimed at improving energy efficiency in manufacturing companies. As a result, a mobile application capable of managing and optimizing energy use in industrial environments was developed.

2 METHODOLOGY

For this study, the Mobile D methodology will be applied (see Figure 1). The advantages of this methodology are the following: a low cost to make a change in the project; it delivers results quickly and ensures the right software at the right time [15].

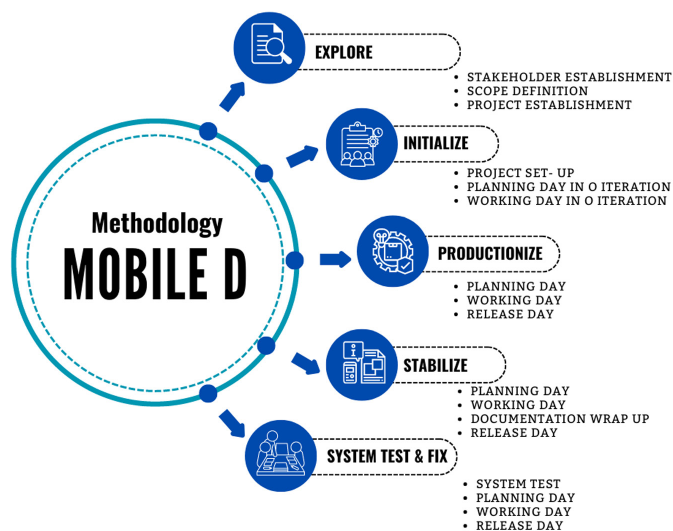


Fig. 1. Phases of the mobile-D methodology

2.1 Explore

In the project exploration phase, the focus is on establishing the project plan and basic concepts. Although this phase is slightly different from the main production process and can be separated from it, it is crucial not to omit it, and the importance of client involvement during this stage is emphasized [16].

In this phase, the stakeholder groups were established:

- **Target group:** Manufacturing companies
- **Users of the application:** Managers, supervisors of a given company
- **Developers:** Researchers of the present project.

2.2 Initialize

At this stage of the study, the technological resources, both hardware and software, required for the implementation of the research project have been identified and secured.

Hardware: A laptop with at least a 4-core processor and 8 GB of RAM will be used for development and programming.

Software:

React Native—It is a framework that allows you to create native mobile applications for iOS and Android using JavaScript and React, reusing components that are translated into native elements of each platform [17].

iOS—It is Apple’s mobile operating system, renowned for its intuitive interface and strong security features [18].

Android—It is an operating system designed for mobile devices, such as phones and tablets, which generally have touch screens [19].

PostgreSQL—It is an open-source relational database, noted for its reliability and extensive feature set, and is ideal for managing complex and scalable data [20].

2.3 Productionize

During this phase, previously organized ideas and functions are developed and codified. Figure 2 shows the architecture created for the development of the application.

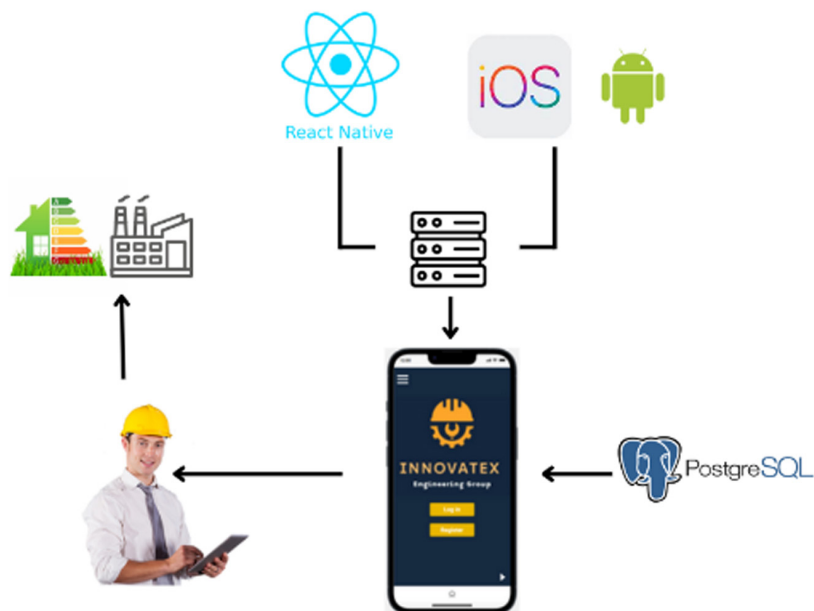


Fig. 2. Project architecture

The project consists of a mobile application designed to improve energy efficiency in an industrial plant. The application is developed in React Native, which allows it to work on both iOS and Android devices. The database used is PostgreSQL, which stores and manages relevant data on the energy consumption of various machines and processes in the plant. Company representatives can use this application to access real-time information, make informed decisions, and optimize energy use, contributing to greater operational efficiency and reduced energy costs in the manufacturing environment.

2.4 Stabilize

During this stage, prototypes of the application were developed. Figure 3 illustrates the initial phase, such as login, menu options, and web information. In Figure 3a, the home screen is shown, where the user can log in or register. Once the user has logged

in, he or she accesses the main menu, illustrated in Figure 3b, which offers a variety of functionalities. In Figure 3c, the information screen is presented, where a description of the energy efficiency concept is provided, among other relevant details.

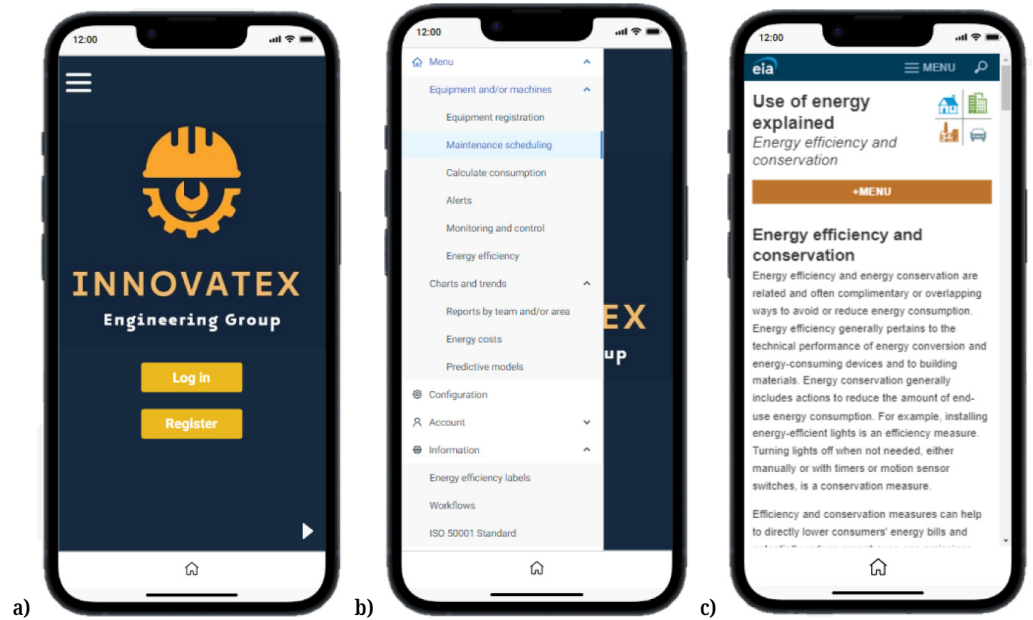


Fig. 3. Login interfaces: (a) Home, (b) Menu, (c) Information

Figure 4 shows equipment management and energy monitoring interfaces. Figure 4a shows the equipment registration screen, where the area manager or supervisor enters the relevant details of each machine or piece of equipment. Figure 4b illustrates the energy performance of each piece of equipment, specifying the daily consumption in kWh and other important characteristics. Finally, Figure 4c highlights the equipment monitoring and control screen, which shows specific data according to the selected area and date.

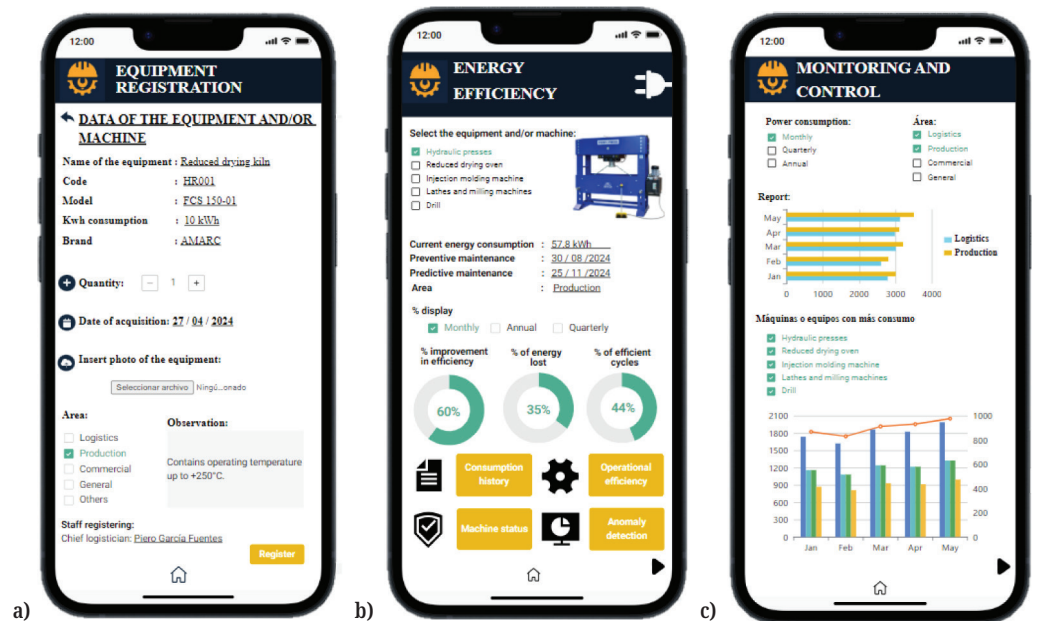


Fig. 4. Energy management and monitoring interfaces: (a) Equipment registration, (b) Energy performance, (c) Equipment monitoring and control

Figure 5 visualizes the alert and consumption calculation interfaces. Figure 5a shows the alert screen, where automatic notifications are generated when the energy consumption of a piece of equipment exceeds the usual levels, allowing supervisors to take preventive or corrective actions. On the other hand, Figure 5b presents the energy consumption calculation screen, which allows users to visualize and calculate the energy consumption of different equipment in the company, facilitating detailed monitoring of energy use and the identification of opportunities to improve efficiency.

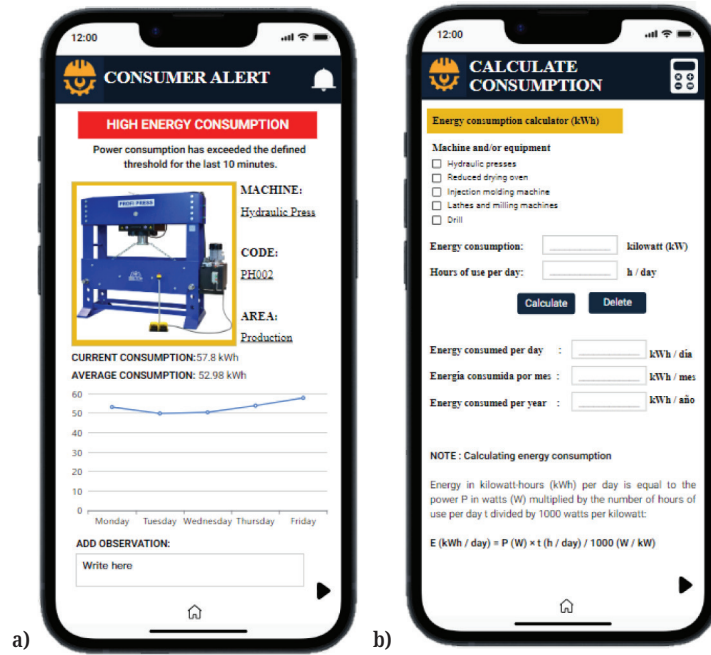


Fig. 5. Alerts and consumption calculation interfaces: (a) Alert for excess consumption, (b) Calculation of energy consumption

2.5 Text

The evaluation of the system involved 20 experts, together with 15 people related to the manufacturing industry, all from Peru, aged between 25 and 50 years old. The evaluation was carried out through the application of questionnaires based on the Likert scale. The criteria evaluated are shown in Table 1.

Table 1. Evaluation criteria

Criteria	Aspects
Usability	Is it intuitive for users to interact with the application?
	Is the workflow logical and efficient?
	Does the application adapt well to different devices and screen sizes?
Design	Is the appearance of the application visually appealing and professional?
	Is there visual and functional consistency across all screens?
	Does the visual design support the function without distracting the user?

(Continued)

Table 1. Evaluation criteria (*Continued*)

Criteria	Aspects
Security	Does the application allow granular access permissions to be configured, ensuring that users can only access information relevant to their role?
	Are there mechanisms for detecting intrusions or suspicious activity?
	Are there mechanisms in place to audit user access and actions within the system?
Efficiency	Does the application help to improve energy efficiency in the plant?
	Can the application handle an increasing number of users and data without losing efficiency?
	Does the application make optimal use of the device's hardware (processor, memory, sensors)?
Functionality	How useful and accurate are the analyses and reports generated by the application?
	Is the application compatible with a variety of manufacturing equipment?
	Does the application include all the necessary functionalities for energy efficiency management in a manufacturing plant?

3 RESULTS

Expert validation. This section presents the results of the design validation, carried out with the participation of 20 experts. For this validation, several criteria were used, including usability, design, safety, efficiency, and functionality. Based on these criteria, questions were formulated using a Likert scale to assess the level of acceptance of the design by the experts. Table 2 details the criteria evaluated, the questions corresponding to each criterion, and the results obtained, represented by the mean and standard deviation (S.D.). The overall mean achieved was 4.68, indicating that the level of quality of the design is considered very good.

An overall mean score of 4.68 was obtained, indicating that the quality level of the mobile application design is very high, as it is within the established range.

Table 2. Expert validation

Criteria	Aspects	Media	D.E	Quality
Usability	Is it intuitive for users to interact with the application?	4.60	0.50	Very high
	Is the workflow logical and efficient?	4.90	0.31	Very high
	Does the application adapt well to different devices and screen sizes?	4.80	0.41	Very high
Design	Is the appearance of the application visually appealing and professional?	4.85	0.37	Very high
	Is there visual and functional consistency across all screens?	4.80	0.41	Very high
	Does the visual design support the function without distracting the user?	4.80	0.41	Very high

(*Continued*)

Table 2. Expert validation (Continued)

Criteria	Aspects	Media	D.E	Quality
Security	Does the application allow granular access permissions to be configured, ensuring that users can only access information relevant to their role?	4.50	0.69	Very high
	Are there mechanisms for detecting intrusions or suspicious activity?	4.80	0.41	Very high
	Are there mechanisms in place to audit user access and actions within the system?	4.50	0.51	Very high
Efficiency	Does the application help to improve energy efficiency in the plant?	4.70	0.47	Very high
	Can the application handle an increasing number of users and data without losing efficiency?	4.60	0.60	Very high
	Does the application make optimal use of the device's hardware (processor, memory, sensors)?	4.55	0.60	Very high
Functionality	How useful and accurate are the analyses and reports generated by the application?	4.50	0.61	Very high
	Is the application compatible with a variety of manufacturing equipment?	4.55	0.51	Very high
	Does the application include all the necessary functionalities for energy efficiency management in a manufacturing plant?	4.70	0.47	Very high
Total		4.68	0.49	Very high

The summary graph in Figure 6 shows that design is the highest rated criterion, with 81.7% of evaluations as “Very Good.” Usability follows closely with 76.7%, while efficiency scores 65%. Security scored 63.3% and functionality 60%. These scores clearly reflect the strengths of the prototype in each of the evaluated criteria and point to the areas with the greatest potential for improvement.

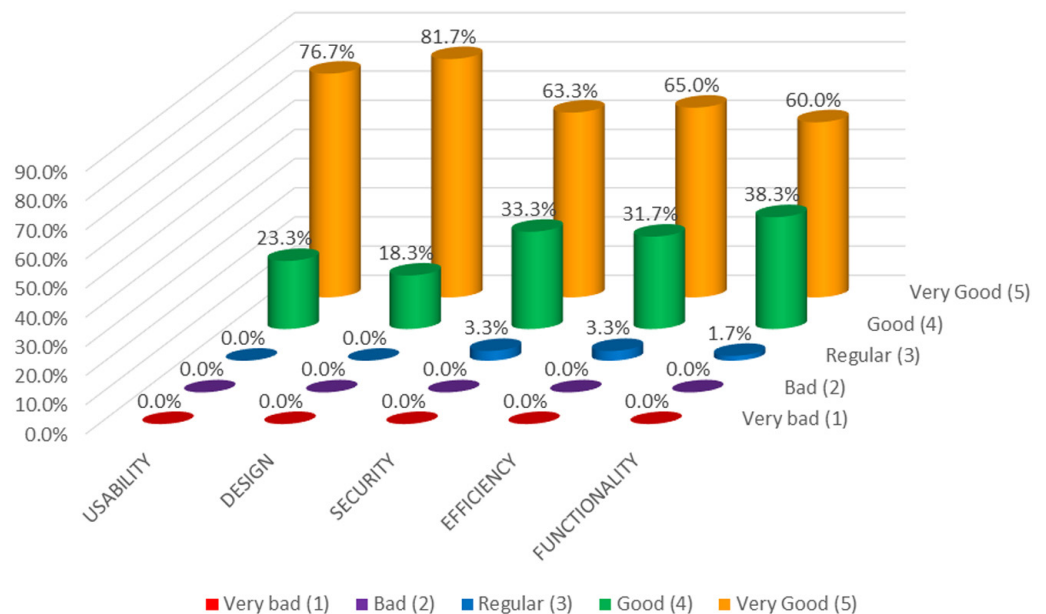


Fig. 6. Summary of criteria

Validation by users. Usability studies of users such as managers and supervisors of manufacturing companies were carried out. This study made it possible to identify and correct possible errors related to the operation of the system, as well as to evaluate the acceptance of the application by the users (see Table 3). Fifteen people from the manufacturing sector participated in the study. Performance and acceptance were evaluated at each sprint using a Likert scale.

Table 3. Validation by users

Criteria	Aspects	Media	D.E	Quality
Usability	Is it intuitive for users to interact with the application?	4.60	0.51	Very high
	Is the workflow logical and efficient?	4.93	0.26	Very high
	Does the application adapt well to different devices and screen sizes?	4.73	0.46	Very high
Design	Is the appearance of the application visually appealing and professional?	4.93	0.26	Very high
	Is there visual and functional consistency across all screens?	4.93	0.26	Very high
	Does the visual design support the function without distracting the user?	4.87	0.35	Very high
Security	Does the application allow granular access permissions to be configured, ensuring that users can only access information relevant to their role?	4.53	0.64	Very high
	Are there mechanisms for detecting intrusions or suspicious activity?	4.80	0.41	Very high
	Are there mechanisms in place to audit user access and actions within the system?	4.53	0.52	Very high
Efficiency	Does the application help to improve energy efficiency in the plant?	4.67	0.49	Very high
	Can the application handle an increasing number of users and data without losing efficiency?	4.67	0.49	Very high
	Does the application make optimal use of the device's hardware (processor, memory, sensors)?	4.73	0.46	Very high
Functionality	How useful and accurate are the analyses and reports generated by the application?	4.67	0.62	Very high
	Is the application compatible with a variety of manufacturing equipment?	4.40	0.51	Very high
	Does the application include all the necessary functionalities for energy efficiency management in a manufacturing plant?	4.60	0.51	Very high
Total		4.71	0.45	Very high

The quality of the prototype was assessed by calculating the average of the criteria considered. As shown in Figure 7, the average scores for each criterion are usability (4.76), design (4.91), security (4.62), efficiency (4.69), and functionality (4.56). Which points out that the quality of the mobile application is satisfactory, with an overall average of 4.71. It should be noted that, for the app to be considered viable, its overall average score must exceed a value of four.

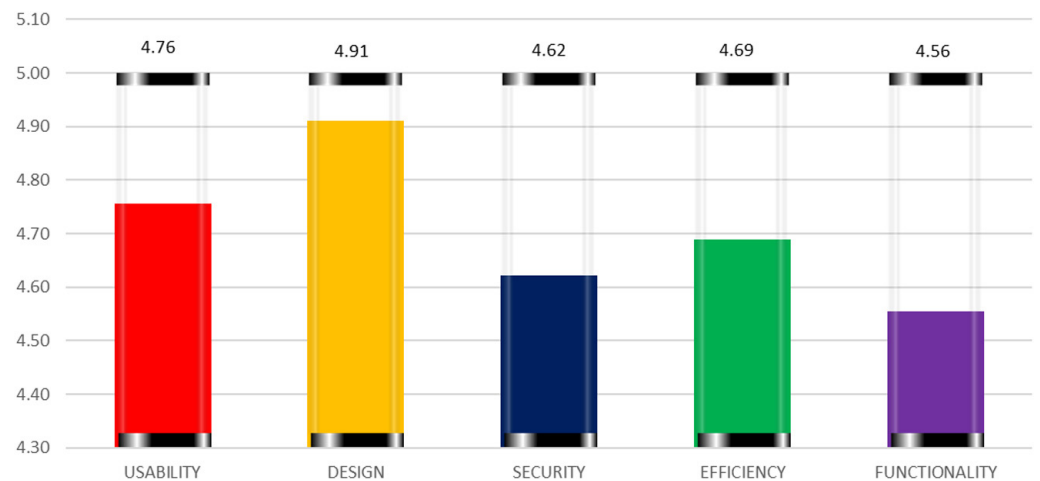


Fig. 7. Summary of criteria

4 DISCUSSION

The mobile application for energy efficiency management in manufacturing uses the Mobile D methodology, focused on agile mobile application development, which differentiates it from other approaches. In this study [12], the Scrum methodology is used to develop an architecture that integrates technologies such as IoT, AI, and cloud computing. In this study. On the other hand, another research [10] employs digital twins in smart buildings, achieving an energy savings rate of 21,524%, which exceeds the target of 1,524%. In addition, in [11], machining processes have been used, a sensor-based analysis that allows real-time monitoring of energy consumption with a prediction error of less than 5%. While all of this study aims to improve energy efficiency, the mobile application is focused on manufacturing, with a more limited focus on emerging technologies, but with the advantage of agile, user-centered development.

5 CONCLUSION

This study concludes with the creation of a prototype mobile application oriented to energy efficiency management in manufacturing companies. The prototype stands out for its usability, good design, security, efficiency, and functionality, benefiting both company managers and direct operatives. Its implementation facilitates the optimization of energy consumption, contributing to the reduction of operating costs and promoting greater sustainability and profitability in the manufacturing sector. The Mobile D methodology was applied, which is essential for its user focus and its ability to facilitate rapid adaptation to change and feedback. Evaluations were carried out through expert judgements evidencing its acceptability and feasibility, with a total score of 4.68. In addition, those involved in the company, including supervisors, bosses, and managers, gave the application an average score of 4.71 according to the criteria evaluated. Limitations of the study include the accessibility and connectivity of mobile devices, as well as the need to train staff and integrate the application with existing systems. For future projects, it is recommended to complement this work with the development of integration interfaces adaptable to various types of equipment and technologies.

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