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MEMORIAS: EXPOTECH UNAD 2025 "Hacia un futuro sostenible y sustentable: Ciencia abierta y tecnología al servicio de la humanidad"

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Analyzing the digital divide using open data: an approach to the techniques and methodologies used

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Abstract. The digital divide is a multidimensional phenomenon that must be analyzed so that everyone can take advantage of the benefits of ICTs. Although multiple analyses have been conducted on this phenomenon, no analysis has been made of the data analysis techniques used to address it. Therefore, this document analyzes various scientific articles that address the digital divide to assess the techniques and methodologies used. To this end, a literature review and critical analysis of this bibliographic material were conducted. The results show that there are different data analysis techniques that allow us to understand the phenomenon and subsequently address it. In practical terms, this work will help those interested in studying the digital divide choose a technique that connects with the process they wish to develop.

Keywords: Digital Divide, Open Data, Data Science, Data Analysis Methodologies.

1 Introduction

In the current digital age, data science has emerged as a multidisciplinary field that utilizes algorithms, processes, and methods. Scientific systems extract meaningful knowledge and patterns from large volumes of structured and unstructured data. The open data ecosystem, on the other hand, refers to the digital infrastructure that facilitates open and open access, use, and redistribution of data. In this context, the digital divide is presented as a complex and multifaceted phenomenon that reflects the disparity in access, use, and mastery of information and communication technologies (ICTs) among a given population. In the case of Colombia, this gap represents a significant challenge to inclusive and sustainable development, despite the efforts made by the government and other stakeholders.

In the contemporary digital age, characterized by the growing adoption of information and communications technologies (ICTs), a phenomenon known as the "digital divide" persists. This term refers to the disparity between individuals, groups, and regions in terms of access to, use of, and effective utilization of ICTs. The digital divide has profound implications for social inclusion, economic development, and equity, as those lacking digital access or skills are at a disadvantage when it comes to fully participating in the knowledge society. In the particular case of Colombia, a country with geographical, cultural, and socioeconomic diversity, the digital divide represents a significant challenge. Despite efforts by the government and other stakeholders to promote digital inclusion, substantial differences in internet access, digital skills, and technology use remain among different regions and population groups.

In this context, data science has emerged as a multidisciplinary field that combines statistical methods, machine learning, data mining, and visualization techniques to extract meaningful insights and patterns from large volumes of structured and unstructured data. At the same time, the open data ecosystem, which facilitates open access, use, and redistribution of data, has gained importance as a key enabler for innovation and social problem-solving.

This paper reviews the data science methodologies being applied to analyze the digital divide and understand this multidimensional phenomenon.

2 Background and Related Work

It is important for this proposal to relate what is understood by data science and open data, data science is defined as:

Data Science is a new interdisciplinary field that synthesizes and draws on statistics, computer science, computing, communication, management, and sociology to study data and its environments (domains and other contextual aspects, such as organizational and social aspects) to transform data into insights and decisions following a thinking and methodology (D. Donoho, 2017)

On the other hand, open data refers to:

Data are characteristics or information, usually numerical, collected through observation. In a more technical sense, they are a set of values for qualitative or quantitative variables about one or more people or objects, while a datum is a single value for a single variable. Data are transformed into information when they are created, extracted, processed, and used for predetermined purposes (Atenas et al., 2021).

Now, in the current digital age, data science has emerged as a multidisciplinary field that uses scientific methods, processes, algorithms, and systems to extract knowledge and uncover meaningful patterns, providing us with actionable insights from large volumes of structured and unstructured data. With the advent of advanced digital technologies and the proliferation of data in all walks of life, data science has become a fundamental pillar for informed decision-making in a variety of sectors, including business, science, government, and healthcare. From data collection and cleansing to analysis and interpretation of results, data science offers powerful tools for understanding and addressing complex and dynamic problems in contemporary society. By employing statistical methods such as machine learning, data mining, data visualization, and other techniques, it helps drive innovation, process optimization, and ultimately improve decision-making.

On the other hand, the open data ecosystem refers to the digital infrastructure that facilitates open and open access, use, and redistribution of data. Open data is data that is available for anyone to use, modify, and share, without restrictions imposed by copyright, patents, or other control mechanisms. Open data can be found on platforms such as Datos.gov.co, Dane, and MinTIC. These are examples of initiatives that promote open and transparent data in Colombia, fostering collaboration, citizen participation, and innovation.

Now, there is a phenomenon known as the digital divide, which is a complex and multifaceted phenomenon that reflects the disparity in access, use, and mastery of information and communication technologies (ICTs) among a given population. This gap can manifest itself in different dimensions, such as internet access, ownership of digital devices, digital skills, among others, and can have profound implications for social inclusion, economic development, and equity.

Today, equitable access to digital technology and information has become a determining factor for the economic, social, and cultural development of countries. However, despite significant advances in technological infrastructure, inequalities in access to and use of information and communications technologies (ICTs) persist, a phenomenon known as the digital divide.

In the case of Colombia, a country characterized by its geographic, cultural, and socioeconomic diversity, the digital divide represents a significant challenge to inclusive and sustainable development. Despite efforts by the government and other stakeholders to close this gap, there are still disparities in internet access, digital skills, and technology use among different regions and population groups. The World Bank illustrates the following:

The digital divide hinders growth and limits opportunities. About one-third of the world's population, or 2.6 billion people, will remain offline in 2023. While more than 90% of the population in high-income countries used the internet in 2022, only 1 in 4 people in low-income countries have access to it, 850 million people lack any form of identification, and many of them lack the basic skills to use the internet effectively (World Bank, 2023).

3 Research Methodology

The methodological approach for the project will be mixed; initially, a quantitative process will be carried out by conducting a systematic literature review. A qualitative approach will then be implemented by implementing the Benchmarking methodology, which allows us to discover how and in what ways the organization can improve its performance by knowing and understanding what others do, including its own, and in this way, improve processes, as well as strengthen what it has, look at its mistakes and learn from them (Marciniak, 2017).

Additionally, it can be indicated that Benchmarking "Allows for a critical attitude towards what the company has been doing, encourages self-assessment or internal analysis, taking into account the outside, that is, it makes management and the people involved in the process alert to possible improvements, based on what happens in other external organizations, improving this and other processes, the quality of service" (Brio-nes-Veliz et al., 2021, p. 2020).

Based on the above, Benchmarking will be implemented in the following phases: the first phase aligns with one of the main purposes of benchmarking, which is to discover how and in what ways performance can be improved by understanding and understanding what others are doing. In this case, the methodological approaches used in previous research will be analyzed, which will allow for identifying strengths, weaknesses, and areas for improvement.

4 Results

As part of the literature review, a bibliometric analysis was implemented. For this purpose, the Biblioshiny tool, based on the Bibliometrix R library, was used. The most significant results derived from this analysis are presented below.
In Figure 1, some general characteristics of the research are evident, on which we can highlight the years of searching that were carried out over a period of 8 years (2016-2024). The review has covered 53 different sources, which indicates diversity in the resources used. A total of 59 documents have been analyzed, although it is not an extremely high number, it allows in-depth critical conclusions to be drawn. The topic shows an accelerated growth of 26.36% annually, which means a growing interest in these studies since 2016.

Fig. 1. Overview of scientific articles.

In Figure 2. Scientific production has shown significant growth since 2020, reaching its peak in 2023. This growth coincides with greater adoption of technologies such as Data Science, made up of different areas such as artificial intelligence, data mining and statistics, which in turn provides tools to employ digital inclusion, the rise of digital transformation and the impact of the COVID-19 pandemic could have accelerated this interest

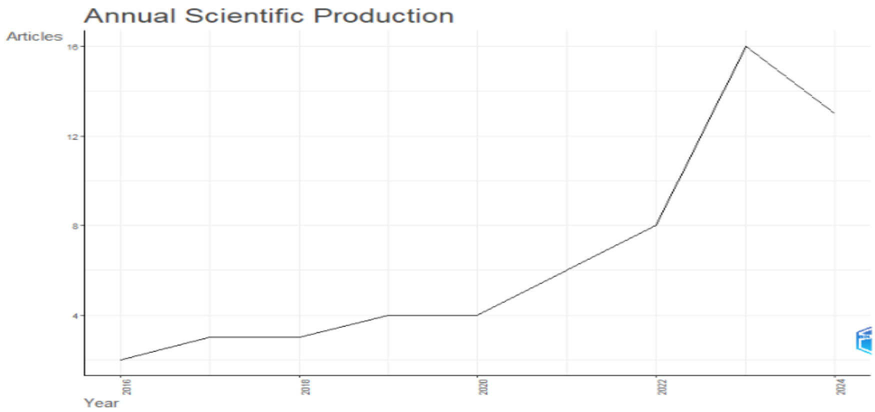

Fig. 2. Scientific articles per year

Now, to carry out a more in-depth analysis of the 59 articles initially identified, a detailed classification was made, selecting the 22 most relevant articles that established a clear and significant relationship between the digital divide and data science. The list of documents can be seen in the Table 1.

Table 1. Selected documents

No. Article	Tittle	Author	Year
1	Research on the Impact of Information Literacy on the Creativity of Foreign Language Teachers in Chinese Universities Under the Background of Big Data	Zhou Guoxiang, Yuncheng University, China Mambetova Elnura, Shaanxi Normal University, China, Wang Guihua, Yuncheng University, China	2024
2	Analysis of Learning Behavior Characteristics and Prediction of Learning Effect for Improving College Students' Information Literacy Based on Machine Learning	YONG SHI, FANG SUN, HONGKUN ZUO, AND FEI PENGy	2023

3	Mapping the geodemographics of digital inequality in Great Britain: An integration of machine learning into small area estimation	ALEX SINGLETON, ALEXANDROS ALEXIOU, RAHUL SAVANI	2020
4	Deep Learning Influences on Higher Education Students' Digital Literacy: The Meditating Role of Higher-order Thinking	Xiaoxia Tian, Kyung Hee Park, Qi Liu	2023
5	The convergence of Artificial Intelligence and Digital Skills: a necessary space for Digital Education and Education 4.0	Miguel Ángel Marzal, Maurizio Vivarelli	2024
6	A New Reciprocal Teaching Approach for Information Literacy Education under the Background of Big Data	Fei Liu, Qian Zhang	2021
7	The digital divide in light of sustainable development: An approach through advanced machine learning techniques	Antonio Hidalgo, Samuel Gabalyb, Gustavo Morales-Alonso, Alberto Urueña	2019
8	Awareness of Artificial Intelligence as an Essential Digital Literacy: ChatGPT and Gen-AI in the Classroom	Stuart Marshall Bender	2024
9	Development and Validation of a Digital Literacy Scale in the Artificial Intelligence Era for College Students	Ha Sung Hwang, Liu Cun Zhu and Qin Cui	2023
10	Trajectory tracking of changes digital divide prediction factors in the elderly through machine learningHUANG	Jung Ryeol Park1, Yituo Feng	2023
11	Big Data and Business Intelligence on Twitter and Instagram for digital inclusion	Carlos Barroso-Moreno, Laura Rayon-Rumayor, Antonio Bautista García-Vera	2022
12	Information literacy for use of open data: trends and perspectives	Patrick Cunha I, Marieta Marks Low, Andrey Anderson dos Santos, Ana Clara Cândido	2024

13	Beyond the digital divide: Towards a situated approach to open data	Louise M. Bezuidenhout, Sabina Leonelli, Ann H. Kelly and Brian Rappert	2017
14	Exploring the Determinants of Artificial Intelligence (AI) Literacy: Digital Divide, Computational Thinking, Cognitive Absorption	Ismail Celik	2023
15	Research on college students' information literacy based on big data	Yao Ying	2018
16	Relationship between teachers' digital competence and attitudes towards artificial intelligence in education	Hector Galindo-Dominguez, Nahia Delgado, Lucia Campo, Daniel Losada	
17	Information literacy of college students from library education in Smart classrooms: based on big data exploring data mining patterns using Apriori algorithm	Si Chen1 • Ying Xue1 • Xiangzhe Cui	2024
18	Research on the influence mechanism and governance mechanism of digital divide for the elderly on wisdom healthcare: The role of artificial intelligence and big data	Jian Zhou, Zeyu Wang, YangLiu* andJian Yang	2022
19	Digital competence and human development in the age of Artificial Intelligence	Oscar-Yecid Aparicio-Gómez1Olga-Lucía Ostos-Ortiz	2023
20	The interplay between teachers' trust in artificial intelligence and digital competence	Margarida Lucas · Yidi Zhang · Pedro Bem - haja · Paulo Nuno Vicente	2024
21	Digital Literacy, Media Literacy and Open Data	Felipe Gértrudix Barrio, Maria del Carmen Gálvez de la Cuesta, Elias Said Hung and Jose Francisco Duran Medina Mail	2016
22	A Deep Learning-Based National Digital Literacy Assessment Framework Using Mobile Big Data and Survey Data	XINGYU CHEN, ZHIYI CHEN, LIN LIN, HONGYAN YAN, ZHIYONG HUANG, AND ZHI HUANG	2023

The digital divide is not limited solely to a lack of access to technology, but encompasses inequalities in digital skills, attitudes toward ICTs, and demographic and socioeconomic differences. Studies like Alex's (Singleton et al., 2020)demonstrate how machine learning, specifically techniques like "gradient boosting regression trees," can map geographic inequalities, underscoring the need for holistic approaches to describing and mitigating these disparities.

The work of Yong Shi et al. (2023) and others highlights that the use of supervised learning algorithms allows for the analysis and prediction of digital literacy behaviors in students. This highlights the potential of data science to design adaptive educational strategies that promote greater digital inclusion.

Various studies, such as those by Miguel Ángel Marzal and Maurizio Vivarelli (2024), show how AI can enhance digital skills and act as a bridge in educational contexts. However, the importance of addressing the ethical and equity challenges that AI could exacerbate, especially in contexts of inequality, is highlighted.

The work of Louise M. Bezuidenhout et al. (2017) and Patrick Cunha et al. (2024) highlights that access to open data can empower communities and reduce informational barriers. However, they emphasize that information literacy training is essential to fully utilize these resources.

Jung Ryeol Park and Yituo Feng's (2023) research focuses on older adults, identifying critical variables affecting their access to ICTs using neural networks and machine learning algorithms. This highlights the need for targeted approaches for vulnerable populations, ensuring that digital policies are inclusive and tailored.

Studies such as those by Ha Sung Hwang et al. (2023) and Xiaoxia Tian et al. (2023) show how digital literacy must evolve to address the complexities introduced by AI. The creation of specific theoretical frameworks and assessment scales reflects the importance of preparing students and teachers to face the technological demands of the digital age.

The integration of advanced techniques such as data mining, deep learning, and small area estimation (Alex Singleton et al., 2020) allows for precise analysis of digital inequalities, offering novel insights into how to intervene more effectively.

Table 2 below lists the data and techniques used by the authors of the articles to analyze the phenomenon of the digital divide.

Table 2. Comparison of data and techniques used

N	Data Used	Data analysis techniques used
1	Structured questionnaires were used to measure the dimensions of information literacy (knowledge, awareness, skill, and ethics) and their relationship to creativity.	**Big data:** the hypothesis was verified using descriptive statistics, validity and reliability tests, correlation analysis and regression analysis
2	A questionnaire is used to collect data on the information literacy learning behavior and course performance of 320 university students.	**Machine learning:** Pearson's algorithm, Supervised classification algorithms such as Decision Tree, KNN, Naive Bayes, Neural Network and Random Forest, It is determined that the Random Forest prediction model has the best performance in predicting the classification of the learning effect.
3	**Use of Open Data** : The importance of using open data, such as that provided by Ofcom, to obtain relevant information on Internet access and use in different areas is emphasized.	**Machine Learning:** Predictive Models, an alternative approach to machine learning, specifically a "gradient boosting regression tree" (GBRT)
4	Data selected from 687 university and higher education students using a convenient sampling technique	**Deep Learning:** Multi-group structural equation modeling to test the applicability of the research model to various groups.
5	Analysis of the state of the art	**Big Data and Artificial Intelligence:** State of the Art
6	Survey	Assessing library information literacy based on **fuzzy mathematics and data mining**
7	The survey sample size used for this study is over 17,000 people, an equal proportion of whom are digitally skilled and non-digitally skilled.	The research approach uses a Innovative **data analysis methodology based on an artificial intelligence technique: classification and regression trees**
8	Does not inform	The approach of the article is **analytical and critical,** examining both the advantages and disadvantages of using Gen AI in the classroom.

9	Developed 23 preliminary research questions and used a quantitative approach to survey 318 college students.	**Factor Analysis, Hierarchical Regression Analysis**
10	This study used data from the 2020 Digital Information Gap Survey Report published by the National Information Society Agency of Korea.	**Prediction model**
11	48,991 publications in Spanish and English were analyzed	**Web Scraping, Text Analytics**
12	Systematic literature review, Web of Science	Systematic literature review
13	integrated visits to four university departments in Kenya and South Africa.	**Data analysis,** this study employed a qualitative approach, including semi-structured interviews and participant observations.
14	Building a model of previous research	**Relationship Analysis**
15	The research approach is analytical and descriptive, using methods such as surveys and interviews to collect data on the current state of information literacy.	**Data analysis,** this study employed a qualitative approach, including semi-structured interviews and participant observations.
16	A sample of 445 Spanish teachers from different educational levels (primary, secondary and higher education) is selected	Quantitative approach, Sampling method
17	It combines university libraries based on big data to carry out information literacy education for university students through full use of library resources, software and hardware facilities.	**Data Mining, Apriori algorithm**
18	Based on data from 1,052 elderly people in China	**Confirmatory factor analysis, Descriptive statistical analysis**
19	Surveys	Quantitative analysis

20	Sample of 211 primary and secondary school teachers.	Quantitative methodological approach
21	1,126 surveys of Internet users aged 16 or over, residing throughout Spain	Quantitative Approach, Sampling Method
22	A national digital literacy assessment framework (survey)	**Deep Learning Model**

Patrick Cunha et al. (2024) emphasize that information literacy is essential for empowering citizens to use open data. The lack of skills in this area contributes significantly to the digital divide, limiting the ability of certain groups to access and leverage information available on digital platforms.

Jian Zhou et al. (2022) highlight how AI can contribute to improving digital literacy among older adults, specifically in the field of smart healthcare. Through factor analysis and predictive models, this study identifies key factors affecting access to and use of technologies in vulnerable populations.

Chen et al. (2024) propose an educational model based on the use of university library resources and data mining algorithms, such as Apriori, to improve students' information literacy. This approach underscores the importance of integrating advanced technologies into educational environments to bridge the digital divide.

Xingyu Chen et al. (2023) introduce a national digital literacy assessment framework based on deep learning and mobile data. This approach enables accurate, large-scale assessment of digital skills, offering practical tools for designing inclusive policies.

Margarida Lucas et al. (2024) analyze how teachers' digital competencies influence their trust in artificial intelligence in education. Their findings emphasize the importance of training educators not only in technical skills but also in the critical integration of technological tools into teaching.

Carlos Barroso-Moreno et al. (2022) investigate how analyzing large volumes of social media data can reveal patterns of digital inclusion and exclusion. This approach offers an innovative perspective on how to use data science to address technological inequalities.

5 Discussion and Conclusions

Data science offers advanced tools that allow us to analyze and mitigate the digital divide, such as information literacy and equitable access to digital technologies. However, its effectiveness is limited by persistent inequalities in access to technological and educational resources, as well as by the lack of inclusion of sociocultural factors. It is evident that, although quantitative methods are useful for identifying patterns and inequalities, they lack a comprehensive approach that incorporates qualitative aspects, which could enrich the understanding of these dynamics.

Traditional statistical techniques, such as descriptive and regression analysis, are essential for describing and modeling phenomena related to the digital divide. However, advanced methods, such as machine learning (k-means, decision trees, neural networks), provide greater predictive and analytical capabilities, particularly in data segmentation and the identification of hidden patterns. This demonstrates the need to complement traditional approaches with modern algorithms to address complex problems in an efficient and scalable manner.

A recurring theme in the analysis is the dependence on high-quality and representative data. Predictive models, such as deep neural networks and decision trees, require accurate data to minimize bias and improve the generalizability of results. This limitation highlights the importance of establishing robust policies for data collection, cleaning, and storage, as well as the need to ensure that data sources are inclusive and ethically managed.

Although advances in data science have led to the development of useful theoretical and practical models for understanding the digital divide, many of these models suffer from limitations in their generalizability. This is due to unrepresentative samples, approaches focused exclusively on quantitative data, and a lack of consideration of structural and cultural factors. This finding underscores the need to design more holistic studies that include contextual and qualitative variables.

The integration of advanced technologies into educational settings has proven effective in fostering critical and reflective skills in students. However, these initiatives also face barriers, such as a lack of teacher training and a mismatch between available technological tools and the actual needs of educational contexts. This suggests that interventions should be accompanied by teacher training programs and local adaptations.

Data mining and artificial intelligence offer a proactive approach to identifying inequalities in digital access, designing intervention strategies, and evaluating public policies. These techniques allow for the analysis of large volumes of data, identifying critical factors, and implementing customized solutions. However, challenges related to interpreting the results and the complexity of the models require decision-makers to be trained to understand and act on these analyses.

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Analysis of Calls to Emergency Line 123 in Bogotá Using K-Modes Clustering

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Abstract. The Bogotá 123 emergency line receives thousands of calls daily for various types of emergencies. Without efficient management, responding to them in a timely manner can be challenging. To better understand these patterns and optimize the response, the K-Modes algorithm was applied, a clustering technique that allowed the classification of calls into different groups.

Data from the year 2023 was analyzed, and five main clusters were identified, organized according to the type of incident, priority, location, and characteristics of the callers. The results showed that certain emergencies are more frequent in specific areas and at certain times, facilitating better resource distribution planning and a faster, more effective response.

This study demonstrates that segmenting calls based on common characteristics is key to improving the efficiency of emergency services. With this information, responsible entities can make more informed decisions, prioritize the most urgent incidents, and reduce response times.

Keywords: Emergencies, analysis, data, trends, patterns, K-Modes.

1. Introduction

Effective emergency response is crucial for maintaining public safety and mitigating the impacts of critical incidents. In urban areas like Bogotá, the management of emergency calls plays a pivotal role in ensuring timely and adequate responses to emergencies. However, the emergency response system in Bogotá faces significant challenges due to inefficiencies in resource allocation, lack of effective mitigation strategies, and the misuse of the emergency line (123). These issues often result in delayed responses, particularly when the volume and nature of incoming calls vary significantly.

Throughout 2023, the Bogotá 123 emergency line experienced considerable fluctuations in the number and types of calls received, creating difficulties in optimizing the distribution of available resources. These challenges have led to delays in addressing high-priority incidents, impacting the overall effectiveness of the emergency response system.

To address these challenges, the present study applies advanced data science techniques, including descriptive statistics and clustering methods such as the K-Modes algorithm. The goal is to uncover underlying patterns and trends in the emergency call data, which can inform strategies for improving resource allocation and response times. This analysis represents a first step in systematically examining the data from the 123 emergency line, with the ultimate aim of enhancing resource planning, optimizing emergency response, and improving the overall efficiency of the system.

This paper, therefore, aims to contribute to a better understanding of the operational challenges within Bogotá's emergency response system, offering a data-driven approach to support improvements in the effectiveness and responsiveness of emergency services.

2. Background and Related Work

The analysis of emergency calls is a useful tool to improve the response of emergency services and optimize the allocation of resources. This theoretical framework is based on previous studies that have used various methodologies to analyze emergency call data, aiming to extract patterns, predict demand, and improve incident management.

Data analysis is used in the classification of the severity of patient emergencies. "Emergency operators receive calls from people requesting services such as firefighters, emergency medical services, and rescues through the emergency phone number. However, understanding all situations and determining the appropriate services needed to respond is difficult under critical time conditions" [15]. This improves the accuracy of the response and also optimizes the use of available resources, ensuring an appropriate and timely response for each type of emergency.

In the article by [29], an analysis of 911 call data from nine cities revealed that, in most of them, less than 3% of the calls involved a violent crime, highlighting the need for timely responses from unarmed personnel and reducing dependence on the police. The study emphasizes that many of the incidents currently handled by police forces could be managed by civilian response teams, specialized in mental health, neighborhood disputes, and other community concerns, thereby reducing the burden on police and improving emergency system efficiency. National 911 statistics in Mexico [12] also show that most calls are related to medical and security emergencies, which is crucial for understanding trends and planning resource allocation.

The use of prediction models and resource planning enables more efficient and effective management of emergency services, improving the response capacity to incidents [8]. These models help emergency managers anticipate future needs and plan resource distribution more strategically. Similar to what [14] state, the study of temporal patterns in medical emergency calls highlights the importance of understanding trends to improve response and resource allocation in emergency services. By analyzing call data over time, it is possible to identify peak demand periods and adjust operations to ensure an appropriate and timely response.

According to [28], telecommunications are a fundamental pillar in emergency management in Colombia, as they enable effective coordination between the various entities responsible for disaster response. Thanks to these technologies, early warnings can be disseminated more quickly, and critical information can be transmitted in a timely manner, which helps minimize the impact of adverse events and optimize decision-making in crisis situations. The analysis of the National Telecommunications System in Bogotá and Medellín highlights the importance of interoperability between different emergency services to improve efficiency and reduce response times [23]. Moreover, as stated in the same analysis, the integration of advanced technology and improved communication infrastructure between emergency agencies enables more effective coordination, facilitates the management of complex incidents, and enhances the response capacity to critical situations.

Although these analyses have contributed to transforming emergency systems, they still face some challenges. For example, many models depend on historical data that may not reflect unexpected situations, such as natural disasters or pandemics. In addition, the quality and quantity of available data vary between regions, which may limit the applicability of the models. However, these limitations also represent an opportunity to continue innovating and creating more adaptable and effective systems. With technological advances such as artificial intelligence and spatiotemporal analysis, it is possible to design more flexible tools that better respond to changing needs. This will help build emergency systems that are better prepared to face future challenges and ensure quick and appropriate care for those who need it most.

3. Research Methodology

3.1 Data Source

The data used in this study comes from open records of calls made to the 123 emergency line in Bogotá during the year 2023. These records were obtained through the Bogotá Mayor's Office open data platform, ensuring that the information was reliable, representative, and suitable for analyzing reported incidents in the city.

3.2 Data Preprocessing

Before applying data analysis techniques, a cleaning and transformation phase was carried out. This process included the removal of null values, correction of inconsistencies in incident categorization, and standardization of categorical variable labels. Additionally, the localities were grouped into five zones of the city (north, west, center, east, and south), and callers were classified into five age ranges (childhood, adolescence, young adulthood, middle adulthood, and elderly).

3.3 Clustering Method

To identify patterns in the data, the K-Modes algorithm was used a variation of the K-Means method specifically designed for categorical data. The K-Modes algorithm works very similarly to K-Means, but instead of using the mean to calculate the centroid, it uses the mode. In other words, clusters will be defined based on the number of matching categories among data points, meaning the most frequent values are used to form the clusters [16]. To determine the optimal number of clusters, the elbow method was applied, establishing that five groups represented the most suitable segmentation of the data.

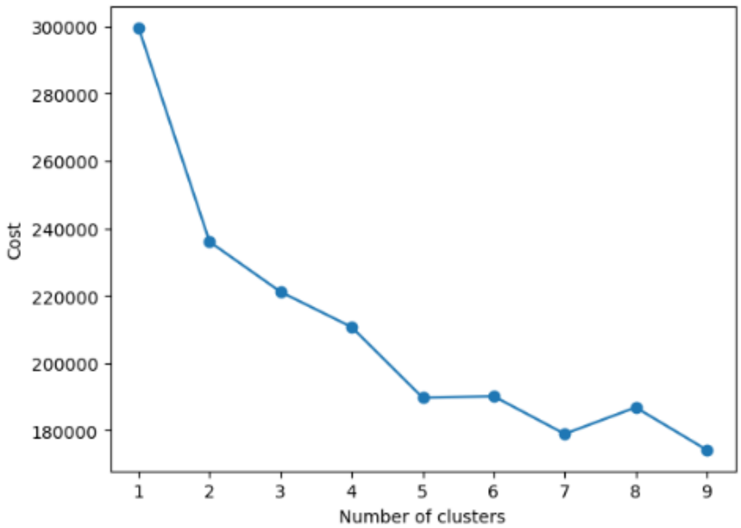

Fig. 1. Elbow Method for selecting the optimal number of clusters

Figure 1 shows a significant decrease in the cost function up to the optimal point at k=5, indicating that this number of clusters is the most representative for segmenting the data.

3.4 Tools Used

The analysis was carried out using the Python programming language and various specialized libraries. Pandas and NumPy were used for data processing and cleaning, while the kmodes library was used for clustering. The results were visualized using Matplotlib and Seaborn.

3.5 Model Evaluation

The resulting clusters were analyzed based on their main characteristics, such as the type of incident, priority level, geographic location, and demographics of the callers.

This comprehensive approach allowed for detailed insights into the distribution and characteristics of calls to the 123 emergency line in Bogotá during 2023, providing a solid foundation for optimizing resource allocation and improving emergency response management in the city.

4. Results and Discussion

The analysis of calls to the 123 emergency line in Bogotá made it possible to identify five distinct clusters using the K-Modes algorithm. Segmenting the incidents helps to better understand the characteristics of emergencies and to plan resource allocation with greater accuracy.

4.1 Cluster Identification

Five main clusters with well-defined characteristics were identified:

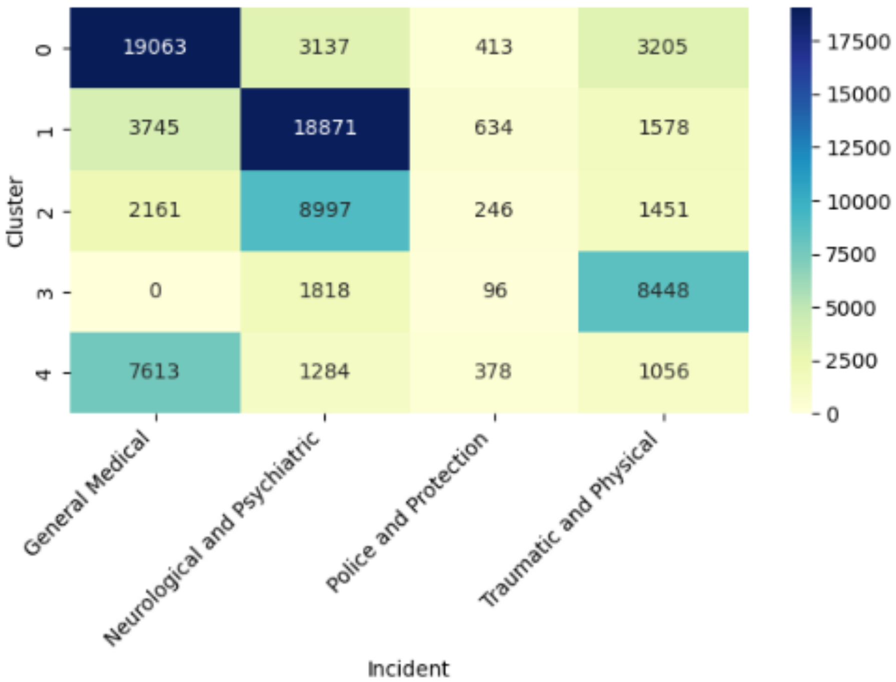

Fig. 2. Frequency table of incidents

Figure 2 shows that clusters 0 and 1 contain the highest concentration of data. The most frequent incidents are generally medical or neurological, while the least frequent are police or protection related incidents likely because the police have their own dedicated emergency line.

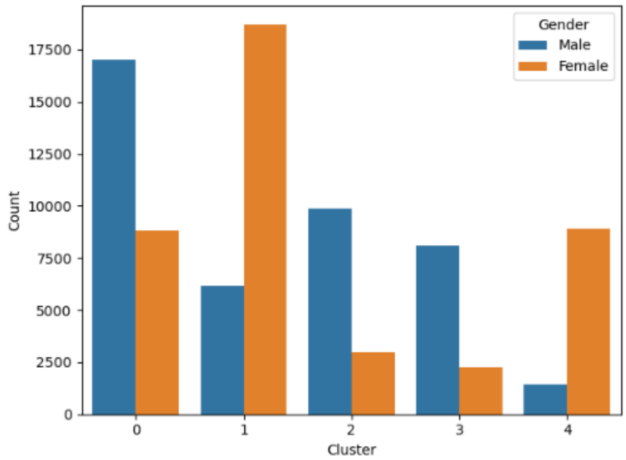

Fig. 3. Clusters by gender

In Figure 3, a clear predominance of the female gender is evident in clusters 1 and 4, while clusters 0, 2, and 3 are mainly composed of male callers. When cross-referenced with Figure 2, we can infer that general medical emergencies are more associated with men, while neurological and psychiatric emergencies are more commonly reported by women.

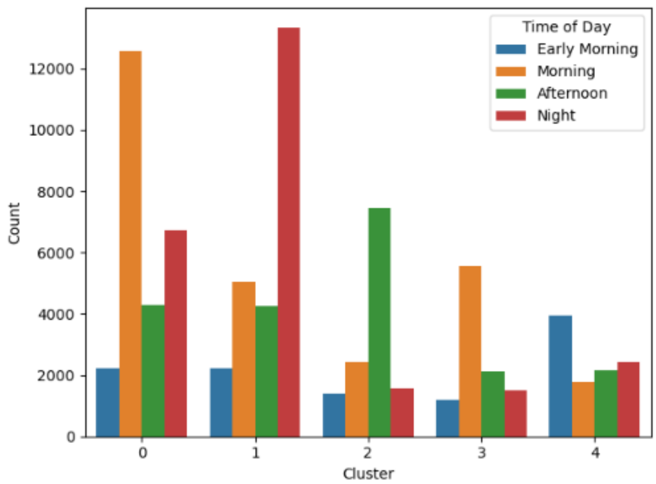

Fig. 4. Clusters by time of day

Data from Figure 4 shows that the morning and nighttime periods are the most active for the emergency line. Clusters 0 and 3 are dominated by morning activity, suggesting that men tend to experience more incidents at this time, whereas women are more active in the nighttime and early morning hours.

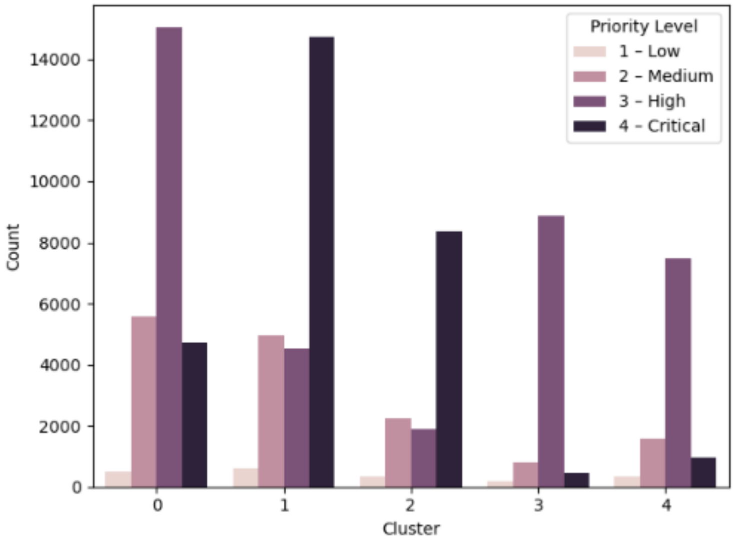

Fig. 5. Clusters by priority

Figure 5 shows that most emergencies are classified as high or critical priority, which reinforces the need to optimize time and resources in emergency response.

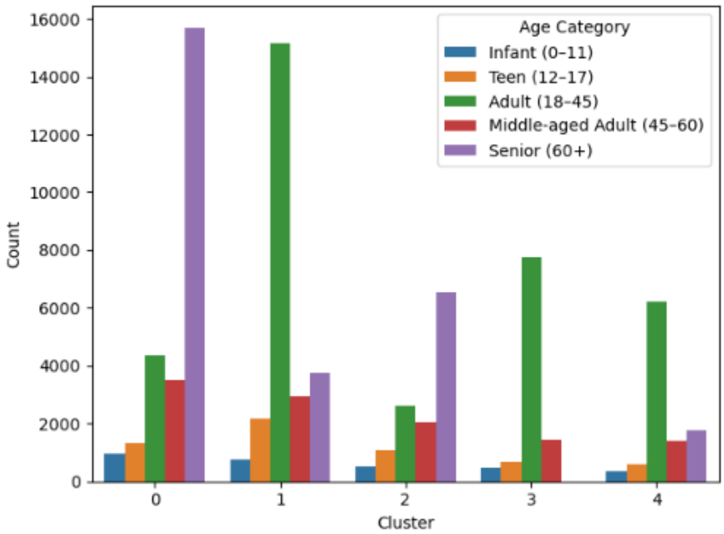

Fig. 6. Clusters by age

Figure 6 reveals a clear predominance of adults aged 18 to 45 and seniors over 60 as the primary callers. Clusters 1 and 4 are mostly composed of women aged 18 to 45, typically during nighttime hours, while clusters 0, 2, and 3 are mostly composed of men over 60, particularly in the morning.

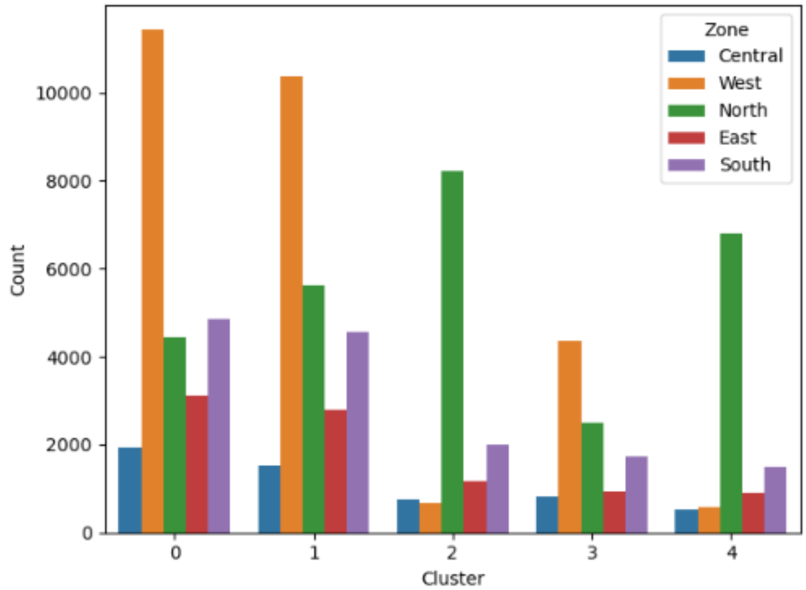

Fig. 7. Clusters by city zone

Figure 7 shows a noticeable distribution of emergencies across the northern and western areas of the city. However, these zones do not show a clear dominance when analyzed in combination with other variables.

4.2 Main Characteristics by Cluster

Cluster 0: General medical emergencies, mainly in Kennedy, Bosa, and Puente Aranda. Mostly occur in the morning and nighttime, with a predominance of male callers over 60 years old. Most frequent incidents include respiratory events and illnesses, with high priority (3).

Cluster 1: Neurological and psychiatric incidents in Kennedy and Bosa, mainly at night. Calls are primarily from women aged 18 to 45, involving unconscious persons or cardiac arrest. These incidents are classified as critical priority (4).

Cluster 2: Neurological and psychiatric emergencies in Suba and Engativá, with a high presence of elderly individuals over 60. Frequent incidents include unconscious persons and cardiac arrest, occurring mostly in the afternoon, with critical priority (4).

Cluster 3: Physical and traumatic incidents in Kennedy, mostly in the morning. Notable cases include injuries and falls from heights, with most calls made by adult men aged 18 to 45. These are generally high-priority incidents (3).

Cluster 4: General medical emergencies in Suba and Engativá, mostly during the early morning and night. The majority of calls come from women aged 18 to 45, and to a lesser extent, from individuals over 60. Common incidents include respiratory events and illnesses, with high priority (3).

Table 1. Grouped Analysis of Dominant Features in Each Cluster.

Parameter	Classification	Clusters
Type of Incident	General Medical	Cluster 0, 4
Type of Incident	Neurological/Psychiatric	Cluster 1, 2
Type of Incident	Traumatic/Physical	Cluster 3
Priority	High (3)	Cluster 0, 3, 4
Priority	Critical (4)	Cluster 1, 2
Geographic Zone	Western Zone (Kennedy, Bosa)	Cluster 0, 1, 3
Geographic Zone	Northern Zone (Suba, Engativá)	Cluster 2, 4
Time Frame	Morning	Cluster 0, 3
Time Frame	Night	Cluster 1
Time Frame	Early Morning and Night	Cluster 4
Time Frame	Afternoon	Cluster 2
Predominant Gender	Female	Cluster 1, 4
Predominant Gender	Male	Cluster 0, 2, 3
Predominant Age Group	Adults (18–45 years)	Cluster 1, 3, 4
Predominant Age Group	Elderly Adults (60+ years)	Cluster 0, 2

5. Discussion and Conclusions

5.2 Practical Implications

The clustering analysis conducted in this study revealed distinct patterns in the distribution of calls to the 123 emergency line in Bogotá, providing valuable insights into the structure and dynamics of the city's emergency response system. One of the key findings was the predominance of general medical emergencies and neurological/psychiatric incidents, which together constitute the majority of reported cases. This highlights a critical need to bolster response capacity in these particular areas, ensuring that resources are effectively allocated to address the most common and urgent types of incidents. Given the specialized nature of these emergencies, there is also an implication for further training and equipping emergency personnel to handle such cases with greater expertise.

Additionally, the analysis pinpointed specific localities—namely Kennedy, Engativá, Suba, and Bosa—as areas with a high concentration of emergency calls. This geographical concentration suggests that a more targeted and differentiated allocation of resources is necessary to ensure a timely and efficient response in these districts. It emphasizes the importance of adapting resource planning to the varying needs of different areas within the city, taking into account local demographics, infrastructure, and the historical trends of emergency incidents.

Another significant finding was the temporal variation in call demand, with call volumes peaking during the morning and nighttime hours. This pattern indicates that emergency response teams should consider implementing a more flexible staffing structure that can adjust to these peak periods, ensuring that personnel are adequately distributed across the day and night shifts. Such strategic redistribution would not only optimize the response capacity but also help in minimizing delays, particularly during periods of high demand when rapid response is most critical.

Moreover, the severity of incidents was found to have a direct impact on how resources are allocated. More severe emergencies, such as life-threatening cases, were prioritized for quicker response times, which is in line with standard emergency protocols. However, this finding also suggests that there may be room for further refinement in how resources are dispatched, particularly in cases where there is a high volume of calls. Improved decision-making algorithms that account for both the severity of incidents and available resources could further streamline operations and ensure that the most critical cases receive the attention they require without unnecessary delays.

5.2 Recommendations

Based on the findings obtained, it is recommended to optimize resource allocation in high-demand areas, particularly in Kennedy, Engativá, Suba, and Bosa. Additionally, it is suggested to adjust work shifts so that the periods of highest demand (morning and night) are staffed with sufficient personnel and emergency units.

It is also essential to reinforce the training of personnel in handling general medical and neurological/psychiatric incidents, ensuring that teams are prepared to respond to these cases efficiently. Public awareness strategies should also be implemented to reduce the number of improper or non-urgent calls, which would help improve the effectiveness of responses to actual emergencies.

Finally, it is advisable to continue data analysis in future research by incorporating information from previous years to evaluate the evolution of the identified patterns and enhance the predictive capability of clustering models applied to emergency management in Bogotá.

5.3 General Conclusions

This study provides a comprehensive analysis of the distribution of calls to the 123 emergency line in Bogotá, highlighting critical areas for improvement in emergency response strategies. The findings underscore the importance of data-driven decision-making in enhancing the efficiency of emergency services. By leveraging these insights to optimize resource allocation, staffing strategies, and response times, Bogotá's emergency services can improve their capacity to handle diverse and complex incidents, ultimately ensuring a more effective and timely response to the city's most pressing emergencies.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Towards measuring maturity in the application of artificial intelligence in tourism projects: Methodological proposal based on the screening of existing models

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Abstract. This article presents a methodological proposal aimed at identifying the level of progress in the application of artificial intelligence (AI) in tourism projects, with emphasis on medium and small-scale municipalities with high tourism potential. The methodology arises from the screening and critical analysis of various national and international methodologies aimed at measuring key factors in the tourism sector and technological adoption. The proposal seeks not only to diagnose the current level of AI incorporation, but also to provide a framework to guide strategic actions to strengthen the efficiency, effectiveness and social and environmental impact of tourism projects. This work is relevant in the current Colombian context, considering the recent approval of the National Policy on Artificial Intelligence (CONPES, February 2025) and the prioritization of the tourism sector as a driver of sustainable development.

Key words: Artificial intelligence, tourism projects, technological maturity, efficiency, sustainability.

1 Introduction

Tourism is one of the strategic sectors for the economic [14] and social development of Colombia, especially in municipalities and territories that, despite their high potential, face challenges of sustainability, efficiency and competitiveness. The integration of emerging technologies, such as artificial intelligence (AI), in the management and development of tourism projects represents an opportunity to strengthen these territories through innovation.

In 2025, the approval of the National Artificial Intelligence Policy in Colombia marks a milestone for the consolidation of an enabling environment for the adoption of advanced technologies. At the same time, the national government has set clear objectives for strengthening tourism as an engine of sustainable growth, prioritizing aspects such as energy transition, digitalization of the tourism offer and the promotion of responsible destinations.[8]

However, there is still a significant gap to know precisely the level of maturity and application of IA in tourism projects, especially in small municipalities and rural areas. This article presents a methodological proposal that seeks to fill this gap by means of an approach that makes it possible to diagnose this level and infer actions to strengthen it, based on the screening and adaptation of existing methodologies, both national and international.

2 Background and related work

The conceptual framework of this proposal is based on three essential components:

Sustainable and territorial tourism. Sustainable tourism is conceived as a development strategy that balances economic growth, social inclusion and environmental protection, considering the needs of visitors, the industry, the environment and host communities. In the Colombian context, tourism represents a key opportunity for territorial dynamization, in this sense, if ethical principles are respected [7], artificial intelligence can be a valuable tool, especially in small municipalities and rural areas with high tourism potential.[1]

However, for this development to be sustainable and territorially inclusive, it is necessary to strengthen planning, management and technological innovation processes [19] in tourism territories, especially in emerging contexts or those with low infrastructure. In line with this, the UNE 178501:2018 Standard proposes specific criteria that guide the implementation of management systems for smart tourism destinations, emphasizing the importance of integrating governance, innovation and emerging technologies in strategic development plans.[6]

This need coincides with what is stated in Strategic Axis III of the National Artificial Intelligence Policy (PNIA 2025), which promotes the development of enabling capabilities for an effective and contextualized adoption of AI in strategic sectors, such as tourism.[8]

Technological maturity and digitalization.. Existing methodologies such as the ICTRC of the Colombian Center for Tourism Thinking [20], the Methodology for the Diagnosis of Intelligent Tourism Destinations in Colombia, and international references such as SEGITTUR, INVAT.TUR and the UNE Standard [6] offer measurement mechanisms to assess the technological and management capacity of tourism destinations.

Technological capacity or maturity refers to the level of integration, appropriation and use of digital technologies by the different stakeholders of a territory or economic sector.[19] In the tourism sector, this concept implies the capacity of destinations and their companies to incorporate advanced technologies that improve operational efficiency, competitiveness, sustainability and visitor experience.[2] International models have addressed the measurement of digital maturity through indicators of technological infrastructure, connectivity, data management, human capital and digital governance.

International models have addressed the measurement of digital maturity through indicators of technological infrastructure, connectivity, data management, human capital and digital governance. There is a methodological gap with respect to the specific measurement of the incorporation of emerging technologies, such as artificial intelligence, which in addition is directly related to the ethical risks identified in Colombia, where technological adoption without adequate planning can generate negative impacts on fundamental rights and accentuate structural inequalities.[7]

Artificial Intelligence applied to tourism. Artificial intelligence (AI) is a key driver for the digital transformation of tourism, allowing to automate processes, personalize services, analyze predictive data and strengthen the sustainability of destinations, transformations directly aligned with the objectives of the National Artificial Intelligence Policy in Colombia PNIA [8]. Its application ranges from digital marketing, accessibility and operational management, to the creation of tourism observatories, transactional portals, smart guides and smart tourism centers [10][12][4].

Based on these fundamentals, the article proposes a methodological approach that will allow diagnosing the level of AI adoption and guiding actions that impact the effectiveness and sustainability of tourism projects.

3 Research Methodology

The proposed methodology for the construction of a maturity measurement model for the application of artificial intelligence in tourism projects is developed in three phases:

3.1 Screening and comparative analysis

Justification and approach. The screening was conceived as an exercise of critical and systematic review of existing methodologies related to the measurement of tourism competitiveness and digital maturity, in coherence with the need for evaluation tools adapted to the territories and aligned with maturity approaches.[8] The purpose is to identify, classify and analyze the most relevant methodologies, in order to extract the elements that can be adapted and articulated in an own model oriented to measure the incorporation of artificial intelligence in tourism projects, particularly for small and rural municipalities contexts.

Selection of methodologies to be analyzed. The screening process considered the following national and international methodologies:

- ICTRC - Colombian Regional Tourism Competitiveness Index[3].
- DTI Colombia Methodology [13]
- SEGITTUR (Spain) (it is not public and is only provided to the municipalities that contract it)[17]
- INVAT.TUR (Spain) (Implementation Guide)
- Standard UNE 178501:2018 “Management system for smart tourist destinations. Requirements” (indicators UNE 178502:2022) [6]

- Latin America Diagnosis
- Smart Cities Rankings

These methodologies were selected for their relevance, trajectory and applicability to the Colombian context.

Evaluation Criteria. Each methodology was evaluated according to the following criteria:

Technological relevance. Level of incorporation of variables related to technology and digital innovation.

Territorial applicability. Potential for adaptation to different contexts, especially small municipalities and rural areas.

Dimensions of analysis: Breadth and diversity of aspects considered (economic, social, environmental, technological).

Level of detail of indicators: Degree of specificity and clarity of the proposed indicators.

Ease of adaptation: Feasibility of integrating the methodology or its components into a proprietary model.

Scalability: Possibility of application at different territorial levels (municipal, regional, national).

Conducting the Screening and Comparative Analysis. The following matrices present the elements obtained in the comparative analysis:

Methodological characterization: Colombia DTI Diagnosis: In the process of methodological analysis, the Colombia DTI Diagnosis model was included [13], which offers a structured approach to evaluate the level of maturity of a tourist destination against the principles of smart destinations. This methodology is based on an organization into strategic axes and a classification by maturity levels, which facilitates its adaptation and application in local contexts. The methodology contemplates indicators distributed in areas such as governance, sustainability, technology, innovation and accessibility, in line with the structure of strategic axes defined in the UNE 178501:2018 Standard for smart destination management systems, which establishes these components as fundamental pillars for an integrated management of the territory [6], and its structure was used as a reference to qualify criteria such as technological relevance, scalability and territorial applicability within the comparative matrix. (See table of methodological sheet).

Table 1. Characterization sheet of the "Colombia DTI Diagnosis" Methodology.

Element	Content
Full name of the methodology	Methodology for the Diagnosis of Smart Tourism Destinations (DTI) - Colombia
Institution or country of origin	Colombia - Ministry of Trade, Industry and Tourism

Element	Content
General objective of the methodology	Evaluate the level of progress of Colombian tourist destinations towards their consolidation as smart destinations.
Methodological steps	1. Definition of strategic axes 2. Definition of management and results indicators 3. Assignment of percentage weight per axis 4. Definition of maturity levels
Main strategic axes Governance	Governance (11 indicators), Sustainability (30), Technology (18), Innovation (12), Accessibility (14), Security, Business competitiveness (8), Promotion, Mobility, Creativity, Tourism evolution.
Destination maturity levels	DTI under exploration: < 33% DTI under development: 33% – 66% DTI Mature: > 66%
Territorial and thematic scope	Territorial and thematic scope Highly adaptable to municipalities of different sizes in Colombia; covers aspects of sustainability, digitalization and territorial management.
Level of technological application	High – Evaluates ICT infrastructure, data analytics, digital platforms, virtual assistance and digital transformation.
Technological relevance	High – Has a specific axis dedicated to digital technology and innovation.
Territorial applicability	Alta – Designed for local and regional contexts in Colombia.
Dimensions of analysis	Technological – Strong emphasis on digitalization and smart management, with elements of sustainability and governance.
Level of detail of indicators Medium	Medium – Structured by axes with detail, but without standardized formulas or metrics in all cases.
Ease of adaptation	High - Can be easily integrated with other methodologies and adapted according to the level of the destination.
Scalability	High - Applicable at different levels: municipal, regional and national.

Methodological characterization: ICTRC - Colombian Regional Tourism Competitiveness Index: The ICTRC, developed by the Colombian Center for Tourism Thinking, is a consolidated tool that measures the tourism competitiveness of the country's departments based on multiple criteria and indicators. Its structure contemplates key dimensions such as environmental, cultural, economic, business, marketing, destination management, infrastructure and social factors.

The methodology is based on the collection of primary and secondary information, transformation and normalization of variables, and construction of rankings based on weightings adjusted to regional GDP. Although it does not present a specific axis dedicated to technology or artificial intelligence, it integrates variables related to ICT infrastructure, digital accessibility and virtual promotion, which gives it a medium technological relevance.

Its high territorial applicability and level of detail in the indicators make it a solid basis for comparative and adaptation processes. It also stands out for its scalability, allowing adjustments at the municipal or regional level. These aspects were considered in the comparative matrix to justify its inclusion in the design of the proposed methodology for measuring IA maturity in tourism projects.

Table 2. Characterization sheet of the "ICTRC - Colombia Regional Tourism Competitiveness Index" Methodology.

Element	Content
Full name of the methodology	ICTRC - Regional Tourism Competitiveness Index of Colombia
Institution or country of origin	Colombia - Center for Tourism Thinking of Colombia (CPTUR)
General objective of the methodology	To measure the level of tourism competitiveness of Colombia's departments, integrating environmental, social, economic, cultural, business and management criteria.
Methodological steps	1. Collection of primary and secondary information 2. Consolidation and transformation of variables into indicators 3. Normalization (logarithmic and max-min). 4. Weighting according to departmental GDP 5. Final classification and ranking
Structure: Criteria and Levels	Levels: Indicator, Criterion, Index. Criteria: Environmental, Cultural, Economic, Business, Marketing, Destination Management, Infrastructure, Social.
Representative indicators	E.g. Water quality, biodiversity, cultural festivities, hotel occupancy, air connectivity, accessibility, labor informality, bilingualism in tourism.
Territorial and thematic scope	Applies mainly at the departmental level, with comparative interregional information. It comprehensively covers the tourism system from multiple dimensions.
Level of technological application	Average. Although ICT and infrastructure variables are included, there is no explicit emphasis on AI or digital transformation.
Technological relevance	Medium - Considers technological variables in infrastructure and promotion, but without a specific axis dedicated to technology.
Territorial applicability	High - Designed for the whole country. Its indicators can be adapted to the municipal level with adjustments.
Dimensions of analysis	Broad - Integrates economic, environmental, social, governance and services dimensions.
Level of detail of indicators	High - The indicators are numerous, varied and quantifiable, although some require local interpretation.
Ease of adaptation	High - Can be adapted at the municipal or regional level with minimal adjustments.
Scalability	High - Applies at the national level and can be scaled to lower levels through variable selection.

Methodological characterization: UNE 178501 Standard: The UNE 178501:2018 Standard establishes a structured framework for the implementation of management systems in smart destinations. This methodology is based on five strategic axes (governance, innovation, technology, accessibility and sustainability) and promotes a continuous improvement approach using the PHVA model.

Its technological axis includes guidelines on interoperability, open data, digital infrastructure, among others. Although it was designed for all types of destinations, its implementation may be more demanding in small territories with limited technical capabilities.

Its inclusion in the screening is justified by its sound technical-regulatory approach and its ability to integrate with other management systems already in place in destinations. It provides key elements for structuring the technological component of the proposed model, although its direct applicability requires adaptations according to the level of maturity of the territory (see table in the methodology sheet).

Table 3. Characterization sheet of the "Norma UNE 178501" Methodology.

Element	Content
Full name of the methodology	UNE 178501:2018 - Management system for smart tourism destinations. Requirements.
Institution or country of origin	Spain - Spanish Association for Standardization (UNE).
General objective of the methodology	Establish the requirements to implement, maintain and improve a management system for smart tourist destinations (DTI), integrating governance, innovation, technology, accessibility and sustainability.
Methodological steps or basic structure	1. Analysis of the destination context PHVA model 3. Management and monitoring of the five axes 4. Performance evaluation 5. Continuous improvement
Main application axes	Governance, Innovation, Technology, Universal Accessibility, Sustainability
Territorial and thematic scope	Applies to all types of tourism destinations, regardless of size or type. Has operational and strategic orientation.
Level of technological application	High - Includes guidelines for interoperability, open data, digital infrastructure, automation.
Technological relevance	High - A complete technology-oriented axis with a systematic approach.
Territorial applicability	Medium - Requires some level of institutional maturity for full implementation.
Dimensions of analysis	Technological - Predominantly a technical vision, although integrates sustainability and governance.

Element	Content
Level of detail of indicators	High - Defines clear requirements and guidelines for evaluation, less focused on quantitative metrics.
Ease of adaptation	Medium - Recommended to have a technical management body and organizational structure.
Scalability	Medium - More aligned with medium or large destinations; requires adjustments for small municipalities.

Caracterización metodológica: Rankings de Smart Cities : Los Rankings de Smart Cities (SCREM, SCS, MSCEU y BC) constituyen un grupo de metodologías de referencia internacional que han contribuido significativamente a la medición del desarrollo inteligente de las ciudades. Aunque varían en alcance y fuentes, comparten un enfoque basado en indicadores formativos distribuidos en seis dimensiones comunes: economía, personas, gobernanza, movilidad, medio ambiente y vida (living).

Estas metodologías aplican técnicas de agregación diversas (índices sintéticos, distancia euclídea, rankings ordinales) y se apoyan en fuentes de datos mixtas (cuestionarios, bases estadísticas, informes secundarios). Su orientación tecnológica y su vocación comparativa las hacen herramientas valiosas para adaptar componentes estratégicos al análisis de destinos turísticos inteligentes, especialmente en el componente de infraestructura digital, participación, movilidad y sostenibilidad urbana.

Methodological characterization: Smart Cities Rankings : The Smart Cities Rankings (SCREM, SCS, MSCEU and BC) constitute a group of international reference methodologies that have contributed significantly to the measurement of smart city development. Although they vary in scope and sources, they share an approach based on formative indicators distributed across six common dimensions: economy, people, governance, mobility, environment and living.

These methodologies apply various aggregation techniques (synthetic indices, Euclidean distance, ordinal rankings) and rely on mixed data sources (questionnaires, statistical databases, secondary reports). Their technological orientation and comparative vocation make them valuable tools for adapting strategic components to the analysis of smart destinations, especially in the digital infrastructure, participation, mobility and urban sustainability components.

Table 4. Characterization sheet of the “Smart Cities Rankings” Methodology.

Element	Content
Full name of the methodology	Rankings de Smart Cities: SCREM, SCS, MSCEU, BC
Institution or country of origin	Diversos: Unión Europea, UCLG, investigadores europeos (Austria, España, etc.), consultores internacionales (Boyd Cohen)
General objective of the methodology	Evaluar comparativamente el grado de desarrollo inteligente de ciudades mediante sistemas de indicadores formativos que integran economía, tecnología, gobernanza, sostenibilidad, movilidad y calidad de vida.

Element	Content
Methodological steps or basic structure	1. Conceptual definition of smart city 2. Selection of dimensions and factors 3. Assignment of indicators 4. Normalization or aggregation 5. Ranking or score construction
Full name of the methodology	Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment, Smart Living
Institution or country of origin	Global and European; large, medium and some small cities. Focus on economy, sustainability, quality of life, technology and innovation.
General objective of the methodology	High - Integrates ICT, digital platforms, technology infrastructure, digital participation and energy sustainability.
Element	High - All rankings measure ICT and digitalization in structural dimensions.
Full name of the methodology	Medium - Urban focus, adaptable to regional environments, less direct for rural municipalities.
Institution or country of origin	Technological - With emphasis on sustainability, economy and governance.
General objective of the methodology	Medium - Great diversity, but methodology and weightings are not always detailed.
Element	Medium - Requires critical interpretation, use of existing data and adjustments for context.
Full name of the methodology	High - Applicable to different geographic scales, especially medium and large urban environments.

Justification of methodological exclusions. During the review process, methodologies such as SEGITTUR and INVAT.TUR (Spain) were initially considered, as well as the regional approach known as Latin American Diagnosis. However, it was decided not to include them in the main comparative matrix due to the following factors:

- Methodological redundancy with the UNE 178501 Standard, since both SEGITTUR [16, 22]and INVAT.TUR derive from that standard and replicate the five strategic axes model already applied in this study.
- Absence of a unified and consolidated methodology for Latin America: although there are isolated efforts by countries such as Argentina and Brazil to adapt international methodologies (such as the UNE 178501 standard)[18], the so-called Latin America Diagnosis does not correspond to a standardized regional tool, but to a series of national initiatives that are still in the process of consolidation. Consequently, there is no comparative, systematic and publicly validated methodological structure available to assess its relevance in this analysis.
- Predominant urban or metropolitan focus, especially in European methodologies, which hinders their direct application in rural municipalities or those with low technological infrastructure, which are precisely the territories of central interest in this research.[11]

It is therefore recommended to consider these issues in the context of this study.For the above reasons, it is recommended to consider these methodologies as valuable references for future studies, especially those oriented to the development

Screening Results. The following matrix summarizes the findings obtained in the comparative analysis:

Table 5. Summary matrix of findings obtained in the comparative analysis.

Methodology	Technological relevance	Territorial applicability	Dimensions of analysis	Level of detail of indicators	Ease of adaptation	Scalability
DTI Colombia Diagnosis	High	High	Technological	Medium	High	High
ICTRC - Colombia's Regional Tourism Competitiveness Index	Medium	High	Broad	High	High	High
UNE 178501 Standard	High	Medium	Technological	High	Medium	Medium
Smart Cities Rankings (SCREM, SCS, MSCEU, BC)	High	Medium	Technological	Medium	Medium	High

From the results obtained in the comparative matrix, it is possible to identify trends[5] and gaps that justify the need for a methodology to measure maturity in the application of artificial intelligence in tourism projects:

- All the methodologies analyzed integrate technological elements at different levels, but only the DTI Colombia Diagnosis presents an explicit approach towards the digital maturity of the destination.
- Territorial applicability is high in the national models (ICTRC and DTI Colombia), which makes them suitable as a basis for proposals aimed at small municipalities. In contrast, methodologies such as the UNE Standard and Rankings Smart Cities [9] are more adapted to urban contexts or with advanced management structures.
- Technological relevance is high in three of the methodologies, but none specifically addresses artificial intelligence as an autonomous evaluative category.
- The more normative or standardized methodologies (UNE, Rankings) present greater formal structure, but less flexibility to adapt to emerging environments such as those that characterize many Colombian tourist municipalities.

From the comparative analysis, it is evident the need for a hybrid methodological model that combines the robustness of structured approaches with contextual flexibility, allowing to adapt the evaluation and planning to the real level of each territory. This proposal not only explicitly incorporates the measurement of the level of incorporation of artificial intelligence as part of the digital advancement of the destination[15], but also responds to criteria of technological equity and adaptability, especially in rural areas where traditional models present significant limitations.[7] The development of this model is presented in the following section.

3.2 Construction of the Diagnostic Model

Based on the findings of the comparative analysis, a diagnostic model was designed to identify the level of maturity in the incorporation of artificial intelligence (AI) in tourism projects, especially in local contexts and emerging territories with high tourism potential.

The proposed model is based on the adaptive integration of the sieved methodologies (DTI Colombia Diagnosis, ICTRC, UNE 178501 Standard and Smart Cities Rankings), taking as a reference their strengths and filling their gaps, mainly regarding the incorporation of emerging technologies such as AI.

General structure of the model. The model is structured in three components:

Assessment dimensions. The assessment is organized into five key dimensions, each associated with a set of qualitative and quantitative variables and indicators:

Table 6. Key dimensions of the IA maturity diagnosis in tourism projects.

Dimension	Description
Governance and institutional framework	To measure the degree of articulation, institutional leadership and existence of policies or strategies that promote the incorporation of AI in tourism development. The capacities for management, planning, intersectoral coordination and collaborative governance are assessed.
Technology and infrastructure	Assess the availability, coverage and sophistication of digital and technological infrastructure in the tourism territory. This includes connectivity, digital platforms, interoperability and use of sensors or intelligent systems that enable AI-based services.
Innovation and talent	Analyze the presence of human capacities and innovation processes oriented to the digital transformation of the tourism sector. The aim is to identify whether there is a training offer in emerging technologies, alliances with academia, innovation ecosystems and R&D&I strategies applied to tourism.
Visitor experience	Evaluate how AI improves the tourism experience, from promotion to interaction during the visit. This includes personalization of services, digital accessibility, virtual assistants, multilingual systems, mobile apps, and tools that enable routes, recommendations or intelligent interaction.
Sustainability and data	Determine the extent to which data and AI are used to optimize the environmental, economic and social sustainability of the tourism destination. It involves the use of analytics to make informed decisions, monitor impacts and continuously improve destination management.

In order to comprehensively measure maturity in the application of artificial intelligence in the tourism sector, it is necessary to establish a functional and progressive order of the dimensions involved. This prioritization not only facilitates the interpretation of results, but also allows assigning differentiated weights to each dimension within a coherent evaluation scale.

The proposed order, in Table 7, responds to criteria such as the direct technological relevance of each dimension, its enabling capacity for the effective deployment of AI-based solutions, and its transformative effect on the tourism ecosystem. Thus, a hierarchy is constructed to guide both the diagnosis and the formulation of progressive improvement strategies, adapted to territorial realities.

Table 7. Hierarchy of dimensions to guide the diagnosis of AI maturity.

Priority	Dimension	Justification
1	Technology and Infrastructure	It is the enabling base for the implementation of any AI solution (connectivity, sensors, platforms). Without this, no maturity is possible.
2	Sustainability and Data Use	AI requires data to operate. This dimension makes it possible to measure how effective its application is in responsible and predictive tourism management.
3	Governance and Institutionality	It defines whether there are institutional capacities to promote policies and projects that integrate AI in a cross-cutting manner.
4	Innovation and Talent	It is key to scaling up AI in the long term, although its initial impact may depend on the prior development of infrastructure and governance.
5	Visitor Experience	Reflects the visible outcome of AI, but its implementation depends on previous progress in the other dimensions.

Maturity Levels. Four maturity levels are proposed, in correspondence with the approaches used in digital and smart city diagnostics at international level. Models such as the UNE 178501 Standard, the DTI Colombia Diagnosis and the Smart Cities Rankings incorporate progressive scales to evaluate the consolidation of technological capabilities. These scales allow characterizing territories according to the degree of planning, implementation, integration and sustainability of the adopted solutions. In this context, the proposed maturity levels reflect the transition from incipient initiatives to tourism management models where artificial intelligence is a transversal, strategic and results-based tool:

Table 8. Proposed Maturity Levels.

Level	General Description
1. Initial	The destination has not initiated the incorporation of AI or does so in isolation.
2. Developing	Initiatives exist, but without cross-cutting integration or impact measurement.
3. Consolidated	AI is integrated in several areas of the tourism project, with measurable results.
4. Advanced	AI is part of the destination management model and generates sustainable improvements.

Measurement instrument. A self-assessment instrument (technical guide) is proposed, structured according to the maturity model, which will allow the tourism stakeholders of the territory:

- Diagnose their current level in each dimension.
- Identify good practices and critical points.
- Receive recommendations adapted to the level detected.
- Project an improvement path to move up to a higher level.

Technical Basis of the Model. The model recovers elements from the DTI Colombia Diagnosis (approach by dimensions and maturity), from the ICTRC (multidimensional scope and indicators), from the UNE Standard (systemic vision and continuous improvement management) and from the Smart Cities Rankings (ICT integration and scalability).

In contrast to these approaches, the present model puts at the center the explicit measurement of artificial intelligence, not only as infrastructure, but as a strategic and operational capability within tourism projects. Moreover, it adopts an adaptive approach, oriented to be applicable even in small municipalities and rural areas, thus promoting territorial equity and inclusive innovation.

Qualitative description by level of maturity in each dimension evaluated. In order to facilitate the interpretation of the scores assigned to each dimension, a qualitative description table was constructed to characterize the level of maturity reached. For each combination of dimension and level (from 1 to 4), operational references or observable evidence are defined to identify the state of the territory in relation to the application of artificial intelligence in tourism projects.

This qualitative description serves as a basis for the formulation of improvement actions, the design of territorial baselines and the feedback of public policies at the local or regional level.

Table 9. Hierarchy of dimensions to guide the diagnosis of AI maturity

Maturity Level by Dimension	Dimension: Technology and Infra-structure	Dimension: Sustainabil-ity and Data Use.	Dimensión: Gobernanza e Institucion-alidad	Dimension: Innovation and Talent	Dimension: Visitor Expe-rience
Level 4: Advanced	Intelligent so-lutions: sen-sors, real-time data, virtual assistants, in-teroperability.	AI to optimize sustainability, predict flows, reduce foot-print, inte-grate data.	Integrated IA in destination management; collaborative and inter-in-stitutional governance.	R&D&I strat-egy in tourism; export of knowledge or services with AI.	AI for recom-mendations, translation, dy-namic routing, intelligent as-sistants.

Maturity Level by Dimension	Dimension: Technology and Infra-structure	Dimension: Sustainabil-ity and Data Use.	Dimensión: Gobernanza e Institucion-alidad	Dimension: Innovation and Talent	Dimension: Visitor Expe-rience
Level 3: Consoli-dated	Technological infrastructure allows digital interaction (portals, cell phones, screens).	Data manage-ment for mon-itoring, im-pact assess-ment, continu-ous improve-ment.	Institutional strategy incor-porating AI in tourism plan-ning and pro-motion.	Open innova-tion, partner-ships with aca-demia, training, tourism AI in-cubators.	Personalization with digital tools: apps, QR, surveys.
Level 2: Develop-ing	Limited con-nectivity and some basic digital tools (wifi, web-site).	Basic data collection (visitors, oc-cupancy).	Active tour-ism unit; the use of tech-nology in management is discussed.	Basic work-shops/events on technology/IA with tourism stakeholders.	Basic digital channels (web, networks) for promotion/in-teraction.
Level 1: Initial	There is no basic connec-tivity in tour-ist areas; use of technolo-gies is almost nonexistent.	No infor-mation is col-lected or ana-lyzed for tour-ism manage-ment.	No tourism management body or policy on AI.	No training or innovation pro-cesses in tour-ism.	Mostly analog experience; no data or technol-ogy.

Individual rating per dimension. Each dimension receives a numerical rating calculated as:

$$\textit{Priority of the dimension} * \textit{Maturity level reached} = \textit{Individual assessment} \qquad (1)$$

This allows each dimension to have a differentiated score according to its strategic importance in the model.

	Maturity Level by Dimension	Dimension: Technology and Infrastructure	Dimension: Sustainability and Use of Data	Dimension: Governance and Institutionality	Dimension: Innovation and Talent	Dimension: Visitor Experience
Individual rating for each dimension according to Maturity Level (Dimension Priority * Level)	Maturity Level 4: Advanced	4	8	12	16	20
	Maturity Level 3: Consolidated	3	6	9	12	15
	Maturity Level 2: In development	2	4	6	8	10
	Maturity Level 1: Beginner	1	2	3	4	5

	Maturity Level by Dimension	Dimension: Technology and Infrastructure	Dimension: Sustainability and Use of Data	Dimension: Governance and Institutionality	Dimension: Innovation and Talent	Dimension: Visitor Experience
Description of: Individual rating for each dimension by Maturity Level (Dimension Priority * Level)	Maturity Level 4: Advanced	Intelligent solutions: sensors, real-time data, virtual assistants, interoperability.	AI to optimize sustainability, predict flows, reduce footprint, integrate data.	Integrated IA in destination management; collaborative and inter-institutional governance.	Strategy of "I "+"D "+"i" in tourism; export of knowledge or services with AI.	AI for recommendations, translation, dynamic routes, intelligent assistants.
	Maturity Level 3: Consolidated	Technological infrastructure allows digital interaction (portals, mobiles, screens).	Data management for monitoring, impact assessment, continuous improvement.	Institutional strategy incorporating AI in tourism planning and promotion.	Open innovation, alliances with academia, training, tourism AI incubators.	Personalization with digital tools: apps, QR, surveys.
	Maturity Level 2: In development	Limited connectivity and some basic digital tools (wifi, website).	Basic data collection (visitors, occupancy).	Active tourism unit; use of technology in management is discussed.	Basic workshops/events on technology/AI with tourism stakeholders.	Basic digital channels (web, networks) for promotion/interaction.
	Maturity Level 1: Beginner	There is no basic connectivity in tourist areas; use of technologies is almost nonexistent.	No information is collected or analyzed for tourism management.	No tourism management body or policy on AI.	No training or innovation processes in tourism.	Mostly analog experience; no data or technology.

Fig. 1. Individual assessment by dimension according to maturity (Although it is in the form of a table, it is presented as a figure due to its conceptual and visual nature, which allows the model to be interpreted from an integral perspective).

Figure 1 presents the individual assessment per dimension, based on the product between the strategic priority assigned to each dimension and the level of maturity achieved (Equation 1). This methodology makes it possible to assign a differentiated score that reflects the relative impact of each dimension in the overall diagnosis.

At the top, the colors visually represent progressive progress from initial to advanced levels. At the bottom, the qualitative criteria associated with each cell are described, allowing a technical and contextualized interpretation of the results. This matrix can be used for both evaluation and monitoring of territorial progress in the application of artificial intelligence to tourism.

Overall cumulative score. The scores per dimension for each of the possible levels are added up.

Result: a total score that allows to classify the overall maturity level of the destination.

$$\text{Score Total} = \sum_{j=1}^{n} \left(P_j * N_J\right) \tag{2}$$

Where:

Pj = Priority assigned to dimension j.

Nj = Level of maturity reached in dimension j

n= Total number of dimensions evaluated (in this case, n=5).

	Maturity Range	Maturity Level by Dimension	Dimension: Technology and Infrastructure	Dimension: Sustainability and Use of Data	Dimension: Governance and Institutionality	Dimension: Innovation and Talent	Dimension: Visitor Experience
Overall Rating (Cumulative) of Maturity Level	>90 and <=150	Maturity Level 4: Advanced	94	102	114	130	150
	>45 and <=90	Maturity Level 3: Consolidated	48	54	63	75	90
	>15 and <=45	Maturity Level 2: In development	17	21	27	35	45
	<=15	Maturity Level 1: Beginner	1	3	6	10	15

	Maturity Level by Dimension	Maturity Level by Dimension	Dimension: Technology and Infrastructure	Dimension: Sustainability and Use of Data	Dimension: Governance and Institutionality	Dimension: Innovation and Talent	Dimension: Visitor Experience
Description of: Overall Maturity Level Rating (Cumulative)	>90 and <=150	Maturity Level 4: Advanced	Intelligent solutions: sensors, real-time data, virtual assistants, interoperability.	AI to optimize sustainability, predict flows, reduce footprint, integrate data.	Integrated IA in destination management; collaborative and inter-institutional governance.	Strategy of "I "+"D "+"i" in tourism; export of knowledge or services with AI.	AI for recommendations, translation, dynamic routes, intelligent assistants.
	>45 and <=90	Maturity Level 3: Consolidated	Technological infrastructure allows digital interaction (portals, mobiles, screens).	Data management for monitoring, impact assessment, continuous improvement.	Institutional strategy incorporating AI in tourism planning and promotion.	Open innovation, alliances with academia, training, tourism AI incubators.	Personalization with digital tools: apps, QR, surveys.
	>15 and <=45	Maturity Level 2: In development	Limited connectivity and some basic digital tools (wifi, website).	Basic data collection (visitors, occupancy).	Active tourism unit; use of technology in management is discussed.	Basic workshops/events on technology/AI with tourism stakeholders.	Basic digital channels (web, networks) for promotion/interaction.
	<=15	Maturity Level 1: Beginner	There is no basic connectivity in tourist areas; use of technologies is almost nonexistent.	No information is collected or analyzed for tourism management.	No tourism management body or policy on AI.	No training or innovation processes in tourism.	Mostly analog experience; no data or technology.

Fig. 2. Overall cumulative assessment of the level of maturity in tourism AI. (Although it is in the form of a table, it is presented as a figure due to its conceptual and visual nature, which allows the model to be interpreted from an integral perspective).

Analysis of the valuation pattern. Table 10 presents a synthetic analysis of the patterns observed in the valuation scheme of the model. Aspects such as scale logic, relative weight of dimensions, and visual elements that reinforce the interpretation of results are considered.

Table 10. Analysis of the valuation pattern proposed in the model.

Aspect	Remark	Interpretation
Increasing scale	The scale progresses progressively (from 1 to 4 per maturity level), multiplying by the priority.	This reflects the principle of progression expected in any technological maturity.
More critical dimensions weigh more	Dimensions such as “Visitor Experience” (priority 5) have greater weight at each level.	Progress in more transformative dimensions is favored to be better reflected in the final score.
Overall maturity is a weighted cumulative	Moving from one level to another (e.g. from Under Development to Consolidated) implies significant increases in the cumulative score.	This generates a more meaningful progress curve, stimulating continuous improvement.
Weighted colors	The color scale helps to visualize low levels (red) to high levels (green).	It provides communicative value and is ideal for reports or dashboards.

This analysis supports the internal consistency of the maturity model and provides key criteria for its operational implementation in diagnostic or territorial monitoring exercises.

Ranges of interpretation of the global level of tourism IA maturity. Figure 3 defines the total score ranges associated with the different levels of global maturity in the incorporation of artificial intelligence in tourism projects. Each range is accompanied by an interpretative description that guides the reading of the results obtained in the territorial diagnosis.

Total Score Range	Global Maturity Level	Interpretive Description
>90 y <=150	Advanced	The use of AI is fully integrated in the planning, operation and evaluation of tourism projects. The territory acts as a benchmark in digital innovation and sustainability. AI is part of the destination management model and generates sustainable improvements.
>45 y <=90	Consolidated	The territory has consolidated technological and institutional capacities, and applies AI in various tourism processes with visible results. AI is integrated in several areas of the tourism project, with measurable results.
>15 y <=45	In development	Significant progress has been made, but there are still critical gaps that limit the effective integration of IA in tourism projects. Initiatives exist, but without cross-cutting integration or impact measurement.
<=15	Initial	The territory presents very basic conditions for the incorporation of AI. Infrastructure, institutional and technological capacities need to be strengthened. The destination has not initiated the incorporation of AI or does so in isolation.

Fig. 3. Overall cumulative assessment of the level of maturity in tourism AI. (Although it is in the form of a table, it is presented as a figure due to its conceptual and visual nature, which allows the model to be interpreted from an integral perspective).

This classification facilitates decision-making by making it possible to clearly identify the current state of the territory and to plan specific improvement actions according to the level reached.

3.3 Improvement Guide Design Proposal

As a complement to the diagnostic model, a methodological proposal for an Improvement Guide is formulated, structured according to the identified maturity levels. The purpose of this guide is to guide local stakeholders -managing agents, mayors' offices, tourism service providers and community organizations- in the formulation of action plans adapted to their territorial reality.

The conceptual design of this guide contemplates gradual recommendations according to the level reached in each dimension of the model. The actions are designed to facilitate progression from basic digitalization scenarios to advanced models for the application of artificial intelligence. Although it has not been empirically validated, it is presented as a base instrument for future implementations and local adaptations.

The proposed content is organized in a table of recommended actions by maturity level, which can be adapted as a self-assessment tool or operational technical guide in subsequent territorial validation processes.

Purpose of the proposed guide. Facilitate the effective incorporation of artificial intelligence in the territory's tourism projects in terms of:

- Overcome the gaps detected in the diagnosis by dimension.
- Promote a strategic, scalable and contextualized use of artificial intelligence.
- Empower small municipalities and rural areas with practical tools to advance in tourism digitization.
- Align territorial transformation with the National Artificial Intelligence Policy (2025) and the sustainability objectives of Colombian tourism.

This proposed guide is not intended to be a rigid protocol, but rather a flexible and adaptive tool, designed to accompany territories in their transit towards smart tourism models with a local, sustainable approach and focused on taking advantage of emerging technologies such as artificial intelligence.
Consequently, the proposed model is complemented with a proposal for the design of an Improvement Guide, conceived as a technical instrument to support the management of tourist destinations, especially those located in small municipalities or rural areas with high tourism potential.

Proposed structure of the guide. It is proposed that the guide be organized according to the four maturity levels defined in the previous section along with recommendations for each dimension of the model:

Table 11. Recommendations proposed for the guide for each dimension.

Maturity Level	General Objective	Recommended Actions
Level 1 - Initial	Create basic conditions to initiate the adoption of AI in tourism.	Awareness raising and digital literacy. Local participatory diagnosis. Improvement of basic connectivity. Identification of opportunities to apply AI.
Level 2 - Developing	Implement initial AI solutions in key tourism processes.	Development of pilots (chatbots, apps, inter-active maps). Technical training for tour operators. Agreements with universities and the private sector. Improvement of tourism portals and networks.
Level 3 - Consolidated	Integrate AI tools into destination operation and monitoring.	Use of open data and dashboards. Integrated management platforms. Analytics for tourism flows and sustainability. Advanced training in AI and big data.

Maturity Level	General Objective	Recommended Actions
Level 4 - Advanced	Consolidate the strategic use of IA as the axis of intelligent tourism development.	Application of predictive AI and automation. Export of good digital practices. Impact assessment with SMART indicators. Participation in international networks of smart destinations.

Flexible and participatory application. The proposed guide does not seek to impose a single path, but proposes referential actions, susceptible to be adjusted through participatory processes, in order to:

- Respect local identity and the knowledge of the territory.
- Encourage the social appropriation of technology.
- Ensure that technological solutions are aligned with human development, sustainability and inclusion.

In this way, the proposed Improvement Guide seeks to turn the diagnosis into a concrete and viable roadmap, articulated with local development plans, national tourism and innovation policies, and the opportunities offered by the new National Policy on Artificial Intelligence in Colombia (2025) as a guiding policy in the territorial digital transformation.[8].

4 Results

This paper provides a structured methodological proposal to diagnose the level of maturity in the incorporation of artificial intelligence in tourism projects, with a contextualized and territorial approach supporting the relevance of the model in current policies such as PNIA [8]. The model is based on five key dimensions that reflect the main factors affecting the digital transformation of tourism: technology and infrastructure, governance and institutional framework, innovation and talent, sustainability and use of data, and visitor experience.

Based on the conceptual and methodological development, two main types of results were generated:

4.1 Structural results.

The following products derived directly from the methodological design are generated, which support the central proposal:

- Maturity diagnosis model: defines five interdependent dimensions, each one with four levels of evolution (Initial, In development, Consolidated and Advanced), which allows locating the current state of the territory facing the incorporation of artificial intelligence. This result is presented in the methodological section (see tables 6, 8 and 9, and figures 1, 2 and 3).

- Weighted rating scale: allows assigning greater weight to those dimensions with greater technological relevance or enabling capacity, generating an accumulated score that reflects the overall maturity level of the tourist destination. This result is presented in the methodological section (see tables 7 and 9, and figures 1, 2 and 3).

- Improvement Guide Proposal: conceptually designed as an instrument that offers strategic and operational guidelines differentiated by maturity level, adaptable to different territorial contexts. Although it has not yet been implemented or validated in the field, it constitutes a key input for future planning processes. This result is presented in the methodological section (see table 11).

- Interpretative matrix of results: establishes the global classification ranges and describes observable conditions by dimension and level, facilitating the interpretation of the diagnosis and the identification of gaps. This result is presented in the methodological section (see Figure 3 and Table 9).

4.2 Strategic results

Beyond its value as a measurement tool, the model poses a potential for strategic impact on the public management of smart tourism, especially in small municipalities and rural areas.

The following table summarizes the main projected benefits of its application:

Table 12. Projected benefits of applying the proposed model.

Projected benefit	Definition
Contextualized diagnosis	Clear identification of the level of technological maturity of the destination, with a territorial and multivariable approach.
Prioritization of actions	Orientation of strategies and projects according to the level reached in each dimension of the model.
Capacity building	Promoting the building of institutional, community and technical capacities, based on evidence.
Gap visibility	Detection of critical areas for AI integration, facilitating investment and training decisions.
Alignment with policies	Coherence with the National AI Policy (2025), the Sustainable Tourism Strategy and the country's digital transition objectives.[8]
Scalability of the model	Possibility of application in other economic sectors, such as agriculture or commerce, and at different levels of government; this is consistent with the comprehensive and adaptable vision promoted by the UNE 178502:2018 Standard, by establishing characteristics for smart tourism destination platforms with interoperability capabilities, reuse of open data and orientation to different territorial contexts[6]

The methodological proposal is proposed as a conceptual and practical contribution to strengthen data-driven territorial planning, guide responsible innovation processes and support continuous improvement strategies in smart tourism, particularly in local contexts in Colombia and Latin America.

5 Discussion and Conclusions

5.1 Discussion

The results obtained show that it is possible to build a tourism artificial intelligence maturity diagnosis model with a territorial approach, aligned with previous methodological frameworks and current public policies. However, it is necessary to consider some conceptual and operational precisions in order to adequately interpret its scope and differentiate its proposal from other existing approaches.

A distinctive contribution of the model is its orientation towards rural contexts and territories with low digital capacity, which is not usually addressed specifically in international methodologies such as smart city rankings [21] or DTI standards.

It highlights dimensions such as visitor experience (focused on digital accessibility and adapted technologies), sustainability linked to the use of data, and a progressive approach that allows diagnostics to be initiated even in basic conditions of maturity.

The incorporation of a dimension-weighted scale reinforces the adaptability of the model to local realities, offering greater flexibility compared to uniform methodologies that hinder its application in emerging or smaller-scale destinations, in line with the principle of adaptability defined by the UNE 178501:2018 Standard, which establishes its applicability to all types of tourist destinations, regardless of their size or technological maturity [6] and with the principles established in the National Artificial Intelligence Policy (2025), especially in relation to the Ethics and Governance, and Data and Infrastructure axes.[8] However, the model remains at a conceptual and methodological level.

However, the model remains at a conceptual and methodological level. Although it includes a proposal for a structured improvement guide and practical guidelines, it has not been empirically validated or field-tested. This represents a relevant limitation that will have to be addressed in subsequent phases of implementation and evaluation.

Likewise, the actual effectiveness of the model will depend on contextual factors such as data availability, local technical capacities, and institutional willingness to execute evidence-based actions. In environments with low connectivity or without established tourism planning processes, more intensive technical accompaniment will be required for effective implementation.

Finally, although other sectors -such as agriculture, health or logistics- have already advanced in the integration of artificial intelligence, sustainability and digital transformation through management models oriented by levels of maturity, and although there are some similar initiatives in the tourism field, there is still a notable absence of specific approaches adapted to rural or smaller-scale territories. In that sense, this work provides a structured and contextualized vision that seeks to respond to this gap, articulating territorial planning, data analytics and technological innovation from a sustainable development perspective. The proposed model offers an adaptable conceptual framework, with the potential to be replicated or adjusted for other economic sectors or administrative scales with similar characteristics.

5.2 Conclusions and future work

This article presents a methodological proposal aimed at diagnosing the level of maturity in the incorporation of artificial intelligence in tourism projects, with a contextualized and territorial approach. Based on the design of the model, the strategic weighting of its dimensions and the projection of a guide for improvement, an instrument is constructed that can contribute to closing gaps in the digital management of destinations, especially in rural or less technologically developed contexts.

It is concluded that:

- There is a methodological gap in the measurement of technological maturity with a territorial approach in the tourism sector, which this proposal seeks to address from a progressive approach, adapted to local realities.
- The model offers a structured basis for guiding strategic decisions and prioritizing digital strengthening actions in a manner consistent with institutional capacities and the context of the destination.
- The integration of differentiated assessment criteria allows overcoming homogeneous approaches, facilitating its gradual and scalable application.

However, this work remains at the conceptual level. Therefore, several lines for future work are identified:

- Empirical validation of the model in case studies to contrast its relevance and functionality in real scenarios.
- Development of an interactive tool or digital platform to facilitate its use by territorial managers.
- Adjustment of the model to incorporate new dimensions or to be replicated in other economic sectors with similar dynamics.
- Generation of a composite index that allows periodic monitoring of progress in digital maturity and tourism sustainability.

Overall, this proposal is presented as a starting point to advance in the articulation between artificial intelligence, territorial management and sustainability, in terms of inclusive and innovative tourism development.

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Medicinal Plants Clean Pilot Production Plant: An Approach from Health, Agricultural, and Engineering Sciences

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Abstract.

This study outlines the development and validation of a pilot production plant for the clean and sustainable production of native medicinal and edible plants, established in the rural area of El Turco, Cauca. Adopting an interdisciplinary, intercultural, interinstitutional, and multisectoral approach, the project integrates traditional knowledge from Afro-Colombian, peasant, and Indigenous communities with advanced scientific methodologies. The investigation employs a mixed-methods design that combines experimental field trials on microplots, the implementation of clean technologies, and participatory research techniques to evaluate species with high therapeutic and productive potential. Preliminary findings confirm the technical, economic, and environmental feasibility of the model while strengthening the dialogue between traditional and scientific knowledge. Moreover, the study establishes a replicable framework that can be incorporated into sustainable value chains for phytotherapeutic products, thereby contributing to the innovation in sustainable agriculture and public health systems.

Keywords: Medicinal plants, sustainable production, clean technologies, interdisciplinary research, traditional knowledge, microplots, phytotherapy; integration of knowledge, value chain, sustainable agriculture.

1 Introduction

In 1945, the United Nations Organization, through the United Nations Charter [1] defines the principle of self-determination as the freedom of people to decide about their body and evaluate among various options the best way to face health problems. Likewise, Peña (2009) [2] considers the principle of validity of traditional empirical knowledge, in which humanity was able to survive for hundreds of thousands of years from its adaptation and the experience acquired in the natural environment, this experience is the basis of our current scientific knowledge. Spender (1996) [3] speaks of the principle of solidarity as the new knowledge that must be shared because the new knowledge, which is derived from the accumulated knowledge and experience provided by the social environment, is not exclusive. That is, it is the result of a process of accumulation and exchange of information added to individual experience.

Similarly, the principle of returning to the original is known as the current trend of "going green" among health professionals around the world and the growing demand from health system users who seek solutions other than those offered by conventional medicine, either because they do not find the expected effectiveness or because drugs produced through chemical synthesis generate other unwanted health effects. However, this approach does not seek to ignore the advances of conventional modern medicine, but rather, is an effort to continue exploring in nature what is not found in synthetic chemistry, with the intention of enriching traditional knowledge and innovating in science. Therefore, the lack of systematic research on native medicinal and food plants used by indigenous, Afro-descendant and peasant communities prevents the creation of new scientific knowledge to enrich and innovate in official health systems, provide another alternative solution to health problems, and generate opportunities for participation in value chains of phytotherapeutic and food products, in such a way that the collective memory of the biological and cultural heritage is recovered. (Rodríguez et al., 2007 [4] and Diaz Merchan, 2017 [5])

2 Background and Related Work

According to Avello et al. (2010) [6], all countries worldwide have some form of phytotherapy, although not all have it regulated and integrated into the official health system. In Mexico and Cuba, phytotherapy is considered "as valid as conventional medicine." In New Zealand and England, professionals in alternative and complementary medicine, such as "osteopaths, chiropractors, herbalists, acupuncturists, and healers," have been integrated into the healthcare system. In China, India, and South Korea, phytotherapeutic and alternative practices have been maintained as part of their national health policies. On the other hand, some Latin American countries have identified endemic species cultivation as a source of foreign exchange, such as the Cat's Claw in Peru, mint in Argentina, Boldo, poplar, rosehip, vanilla, and parsley in Chile, Cinchona spp. (quinine) in Central America, and guaraná (Paullinia cupana) in Brazil.

At the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, 152 countries committed to promoting public policies to protect their biological biodiversity. For example, Colombia strengthened its National Environmental System by creating the Biodiversity Information System (SIB); it developed legal frameworks for biodiversity conservation through Decree 1603 of 1994, in accordance with Law 99 of 1993; and through Decree 1603 of 1994, it created the "Alexander von Humboldt" Institute of Biological Resources Research, the Amazonian Research Institute "SINCHI," and the Pacific Environmental Research Institute "John von Neumann," all of which are linked to the Ministry of Environment.

According to SIB (2021) [7], Colombia is the only country in the world with such a high number of endemic medicinal plants. This is because 15% of the world's recorded useful plants are therapeutic species, of which 204 are lesser-known endemic species, some endangered, and of Colombian origin, which are underutilized. Furthermore, a wide range of studies related to medicinal plants and their traditional use has been carried out. In this regard, the Alexander Von Humboldt Institute, which investigates biodiversity and ecosystem services, conducted an approximate characterization of the Medicinal and Aromatic Plants Market in Colombia in 2003, and in 2011, it published a document on guidelines for the knowledge, conservation, and sustainable use of native medicinal plants in Colombia. Additionally, in 2008, as a result of an agreement between the Ministry of Health and Social Protection of Colombia and the National University of Colombia, the Colombian Medicinal Plants Vademecum was developed, which currently serves as one of the reference sources for updating the List of Medicinal Plants accepted for therapeutic purposes for phytotherapeutic products under Decree 1156 of 2018. However, this list contains naturalized non-endemic plants and does not present regulations to promote rural production and its integration into global production chains.

Medicinal plants and associated knowledge are now being depleted due to deforestation, environmental degradation, and acculturation occurring in the country. According to Cardona (2013) [8] and Garzón-Garzón (2016) [9], one of the most important factors contributing to the loss of cultural identity and the reduction of ancestral knowledge is the contact with the Western world through colonization processes, social relations, and worldviews that have led indigenous communities to learn other languages and practice other forms of spirituality. According to Garzón (2016), in a study conducted in indigenous communities in Leticia in the Amazon, the colonization of indigenous territories triggered a process of loss of traditional phytotherapeutic knowledge in two ways: on one hand, indigenous youth are influenced by the Western culture practiced by the colonists, and on the other hand, the elder knowledge bearers do not find the spiritual connection required for the transmission of ancestral knowledge in their descendants. Likewise, Ramírez (2007) [10] mentions that the migration from rural areas to cities and the resettlement of people from drought-stricken regions to fertile areas has also led to the deterioration of traditional practices.

The northern department of Cauca is one of the regions with the highest cultural diversity and biological biodiversity in Colombia. It has also become a focal point for the formulation of public policies in pursuit of the national government's total peace strategy due to historical precedents and the current social and ethnic struggles. The dialogue of knowledge between different communities, academia, the public and private sectors around our biological wealth and its potential for the benefit of the communities and the country, in general, presents an opportunity to build social fabric around common goals. The knowledge of indigenous communities is linked to a spiritual sense that fosters a harmonious relationship with nature, far from the utilitarian value given to it in Western civilization. Therefore, according to community leader

Hernán Rivera from Santander de Quilichao, it is evident that the so-called "climate change" is an expression of "nature being angry with us because we do not perceive the spirit that lives in it and do not ask for permission in our interaction with the forests" (Hernán Rivera, 2022) [11].

Additionally, in 2003, the World Health Organization (WHO) published guidelines for good agricultural and collection practices for medicinal plants. Although these have not been fully adopted by Colombian regulations, they are considered a model to follow for integrating Colombian medicinal plant producers into value chains. This regulatory gap presents an opportunity to develop research processes that allow the incorporation of traditional knowledge of medicinal plants into the Colombian healthcare system under current regulations (Decree 1156 of 2018) and in harmony with WHO standards for good agricultural practices.

Therefore, there are no known experiences of knowledge appropriation by the communities or the development of economic projects involving rural activities. In this regard, it is necessary to validate ancestral knowledge as scientific knowledge through scientific observation processes of traditional phytotherapeutic knowledge, integrating the worldview of the communities involved, so that in the near future, it can be regulated and integrated into the healthcare system.

As a result of this approach, the question arises: How can a pilot plant for medicinal plant production be implemented in the El Turco region of Cauca using clean technologies, serving as a replicable model for efficient, technologically viable, and environmentally sustainable production? The answer to this question is intended to be resolved through the implementation of a pilot plant for medicinal plant production using clean technologies that will serve as a replicable model for efficient, technologically viable, and environmentally sustainable production in the El Turco region of Cauca. Furthermore, due to the scale and scope of the project, it is necessary to address the question not only from engineering and basic sciences but also from health sciences and even agricultural sciences. This is because health sciences study the effects of medicinal plant use, agricultural sciences focus on their optimal composition for production, and basic sciences and engineering not only analyze the data statistically but also examine market behavior and its relationship with value and supply chains. For this reason, the solution is approached by the School of Health Sciences (ECISA), the Master's Program in Project Management from the School of Basic Sciences, Technology, and Engineering (ECBTI), and as a strategic ally, the School of Agricultural, Livestock, and Environmental Sciences (ECAPMA).

3 Research Methodology

This work corresponds to a sustainable production project in microplots, with a mixed approach, considered as experimental research because it not only seeks to generate new knowledge through the identification of medicinal plants with promising potential but also aims to provide an alternative to traditional medicine for solving medical problems.

In this sense, the approach is mixed because it integrates both quantitative and qualitative components in its design and evaluation, and experimental because it develops in a context where there is insufficient documentary information to explain the object of study, and the existing information requires verification in a real environment, as is the case in this innovation project.

The relationship between experimental and mixed research, which combines qualitative and quantitative approaches, is key to providing a comprehensive view of the phenomenon under study. Experimental research relies on a quantitative approach that allows precise and objective measurement of the effects of manipulated variables. However, when integrated with qualitative research, it is enriched with the analysis of contexts, perceptions, and behaviors of the local community, allowing for a deeper understanding of the socioeconomic and cultural factors that influence the adoption and success of sustainable agricultural practices.

On the other hand, this methodology includes participatory action because traditional healers are both the object of study and active subjects of research. Although this type of research is more applied in the field of social sciences, it is fundamental in this process, as research activities will be coordinated between the study subjects and academic researchers. Therefore, there will be communities applying the scientific method, allowing for the translation of traditional knowledge into the technical language of science. For the stakeholders involved, a stakeholder management methodology is applied to generate consensus regarding the implementation of the pilot plant and the establishment of commitments along with the benefits that will be received in its management.

This project comprises two phases: In the first phase, it was necessary to identify medicinal plants with promising potential through a systematic search of primary and secondary information to evaluate them as phytotherapeutic products. For the development of this first phase, the Turco community in Santander de Quilichao was selected. The total population consists of 32 healers and 99,000 inhabitants of Santander de Quilichao who have used the services of the healers and been impacted by this practice. The sample in this case corresponds to 32 healers and 383 individuals. Since the calculation of the sample for quantitative data involves field measurements, it was necessary to consider a preliminary estimate of moderate variability in each microplot, which, in similar pilot studies, ranged between 10 and 30 units of analysis or microplots. For the qualitative sample calculation, the number of people participating in the project is considered, with 5 to 10 participants for interviews and focus groups being recommended as adequate to explore perceptions, barriers, and opportunities in implementing clean technologies. Therefore, 11 medicinal plants with phytotherapeutic uses were selected, and 11 microplots were designated for cultivation trials, irrigation, and yield of medicinal species, corresponding to one microplot per medicinal plant.

Once the foundations for implementing the pilot plant are defined, the development of the second phase will proceed, which is currently in the execution process, through the identification of key variables for cultivating promising medicinal plants and the designation of small-scale cultivation areas to apply OMS guidelines on good agricultural practices.

4 Results

This project is composed of two phases, and therefore the results shown below correspond to the activities developed in the first phase, since the second phase is ongoing:

The first step in the execution was the selection of the medicinal plants subject to this study, considering the following criteria:

- Species best adapted to the climatic conditions, including ease of management and cultivation given the territorial conditions.
- The reasons for plant production, whether for personal consumption or as a source of foreign exchange according to the demand of the target market.
- The best plants recommended by experts are based on therapeutic effects, given their cultural tradition.
- The results of the bibliographic review.

This selection was made considering the list from INVIMA, which includes 139 varieties of medicinal plants, as well as studies conducted by governmental institutions that generate research on biodiversity and/or exercise technical control over the production and commercialization of raw materials, such as the Humboldt Institute, INVIMA, and the Colombian Agricultural Institute (ICA). Additionally, the bibliographic review in scientific databases such as Scielo, Scopus, and PubMed yielded 50 relevant articles for this study, of which 10 were selected, as shown in Table 3.

Table 1. Scientific articles selected from the state-of-the-art search.

Autor(es)	Título	Año
Acosta de la Luz, L.	Producción de plantas medicinales a pequeña escala: una necesidad de la comunidad- [12]	2001
Acosta de la Luz, L.	Principios agroclimáticos básicos para la producción de plantas medicinales. [13]	2003
ICA.	Plantas aromáticas y medicinales Enfermedades de importancia y sus usos terapéuticos Medidas para la temporada invernal. [14]	2011
Hussain, MS et al.	Current approaches toward production of secondary plant metabolites. [15]	2012
Tofiño-Rivera, et al.	Vigilancia tecnológica de plantas aromáticas: de la investigación a la consolidación de la agrocadena colombiana. [16]	2017

Autor(es)	Título	Año
Méndez, R.	Cultivos orgánicos: su control biológico en plantas medicinales y aromáticas. [17]	2017
Bussmann RW et al.	Astonishing diversity-the medicinal plant markets of Bogotá, Colombia. [18]	2018
Poveda-Trespa-lacios, D.	Análisis de oportunidades para la comercialización de plantas medicinales y aromáticas. [19]	2020
ASOCUCH	Cultivo de plantas medicinales con enfoque orgá-nico[20]	2020
Chafloque, C. F. S., et al.	Impacto de la agricultura orgánica en la producción de plantas medicinales. [21]	2022
s.f.	Enhancing secondary metabolite production in plants: Exploring traditional and modern strategies	202
Gómez, T. P. S et al.	Caracterización de la cadena de suministro de las plantas aromáticas. [22]	2024
Venkatasai, N.N, et al.	A comprehensive review of factors affecting growth and secondary metabolites in hydroponically grown medicinal plants. [23]	2025

Table 2. Varieties of medicinal plants selected for the study.

Active Patents	Common Name	Scientific Name	Drug	Approved Use
		Free sale		
231	Boldo	Peumus boldus Molina.	Leaves	Choleretic and cholecystokinetic. Adjuvant in the treatment of dyspepsia and minor hepatobiliary dysfunctions.
1123	Albahaca	Ocimum basilicum L.	Leaves	Antiflatulent. Adjuvant in the treatment of abdominal distention and pain
2709	Caléndula (Indoor use)	Calendula officinalis L.	Flowers	Anti-inflammatory.
24	Caléndula (Topical route)			Anti-inflammatory and healing.
25	Caléndula (Oral route)			Inflammatory conditions of the oropharyngeal area and healing.
25	Cidrón	Aloysia triphylla (L'He'r.) Britton sin: Lippia citriodora (Lam.) Kunth	Leaves	Antiflatulent. Adjuvant in the treatment of dyspepsia and gastrointestinal spasms. Sedative, adjuvant in the treatment of anxiety and nervous-origin sleep disorders.
83	Culantro	Eryngium foetidum L.	Aerial parts	Anti-inflammatory

Active Patents	Common Name	Scientific Name	Drug	Approved Use
2582	Menta	Mentha piperita var.citrata (Ehrh.) Briq.	Stems and leaves	Antispasmodic and carminative
184	Prontoalivio (Topic route)	Lippia alba (Mill). N.E.Br. ex Britton & P. Wilson.	Aerial parts. Leaves	External antiseptic.
184	Prontoalivio (Oral route)	Lippia alba (Mill). N.E.Br. ex Britton & P. Wilson.	Aerial parts Leaves	Sedative, adjuvant in the treatment of anxiety of nervous origin.
2615	Romero	Rosmarinus officinalis L.	Leaves and flowers	Spastic disorders of the gastrointestinal tract.
972	Yerbabuena	Mentha spicata L.	Leaves and stems	Antiflatulent. Adjuvant in the symptomatic treatment of digestive disorders.
Sale with medical formula				
228	Ruda	Ruta graveolens L.	Partes aéreas	Adjuvant in the treatment of mild menstrual disorders.

Following the selection of the plants, one of the first engagements with the community was through a territorial validation conducted via a CIPAS (Participatory Community-Based Research) called "Dialogue of Knowledge on Medicinal Food Plants and Sustainable Research Practices for Their Use and Production." This event not only included a knowledge-sharing session on the use of native plants and foods with community leaders and seed guardians, to share knowledge and experiences, but also an in-person talk focused on promoting the use of native seeds and local varieties. In parallel, a market validation of the phytotherapeutic products industry was conducted through two sessions: the first focused on identifying risks, opportunities, and forecasting, and the second on technological dissemination and partnership management for market development.

Based on the above and considering the activities conducted, this project is at a technology maturity level of TRL4, as the activities corresponding to the first three levels completed:

- TRL 1: Basic principles observed and reported. Scientific articles published on the principles of recent technology.
- TRL 2: Technology concept and/or application formulated. Publications or references highlighting the applications of recent technology.
- TRL 3: Experimental proof of concept. Results from measuring parameters in the laboratory. Conducting analytical, conceptual, or lab-scale tests to assess the

theoretical technical feasibility of the technological concepts, along with market validation of the invention through meetings with potential users.

- TRL 4: Validation in laboratory tests. Results from tests conducted in the laboratory, focused on the functionality of the technological invention at the laboratory level, identification of technological, market, and financial risks with a mitigation plan, and validation tests of the invention's effectiveness in the laboratory.

Therefore, the next step is the execution of the second phase, which comprises seven (7) stages. The actions, evaluation criteria, data collection techniques, instruments for assessing the sustainability and replicability of the model, and impact indicators are described in Table 3 and Table 4.

Table 3. Methodological phases for project development.

Actions	Evaluation Criteria
Phase 1: Characterization of the agroecological conditions of the area, species for cultivation, and clean and viable technologies through the analysis of maturity diagnosis.	
Viability: Evaluate the agroecological conditions of the area, including climate, soil type, and access to water. Selection of medicinal plants: Choose species based on their demand, therapeutic value, local adaptability, and potential for sustainable cultivation. Research on clean technologies: Identify cultivation technologies that minimize environmental impact, such as drip irrigation, composting, and biological pest control.	There should be a feasibility plan, a list of selected species, and a review of the available and viable clean technologies for the context. At the end of this phase, the project should have a detailed action plan that includes an inventory of available resources, a list of selected species, and a preliminary assessment of the viable technologies for implementation.
Phase 2: Design of the Microparcel Production System	
Design of microparcels: Define the size, layout, and orientation of the plots to optimize solar light capture, drainage, and soil conservation. Implementation of efficient irrigation technologies: Install a drip irrigation or sub-irrigation system to minimize water consumption. Crop rotation and association planning: Promote soil diversity and health through crop rotation and strategic associations (e.g., pest-repellent plants).	There should be a detailed design plan and a rotation and association schedule. It is essential that, by the end of this phase, the project has a detailed design of the microparcels and a cultivation plan that includes crop rotations and species associations to foster biodiversity
Phase 3: Soil Preparation and Organic Management	
Soil Enrichment: Apply organic fertilizers and compost to improve soil fertility and structure. Biological Pest Control: Introduce beneficial organisms (such as predator insects) and integrated pest management practices. Use of Natural Barriers: Employ living fences or hedgerows to prevent erosion and protect crops from external agents.	Evaluate soil quality (pH, nutrients) and the effectiveness of biological control methods and organic management. By the end of this stage, the soil should have reached an adequate quality for sustainable cultivation, with techniques implemented to ensure its structure, fertility, and capacity to support the selected species.
Phase 4: Implementation of Production and Crop Management	

Actions	Evaluation Criteria
Planting and Crop Management: Establish plants in the microparcels following good agricultural practices. Monitoring and Adjustment of Practices: Continuously monitor variables such as soil moisture, temperature, plant growth, and pest control. Documentation of Processes and Results: Keep a detailed record of each activity to assess progress and make adjustments in the cultivation process.	Achieve healthy plant growth with minimal chemical interventions. By the end of this phase, healthy and uniform plant growth should be achieved, enabling an efficient and high-quality harvest.
Phase 5: Harvesting and Post-Harvest Processing	
elective Harvesting: Determine the appropriate time for harvest and use methods that minimize damage to the plants. Drying and Preservation: Implement drying and storage techniques that maintain the active principles of the plants (e.g., indirect sun drying, in well-ventilated environments). Waste Management: Recycle or compost organic waste generated during the process.	Achieve optimal product quality, maintaining the active principles of medicinal plants. This phase should ensure high-quality final products, preserving the medicinal properties of the plants and ensuring their stability for storage.
Phase 6: Impact Evaluation and Optimization	
Environmental Impact Evaluation: Measure sustainability indicators such as water usage, soil health, and biodiversity. Cost and Profitability Analysis: Evaluate the return on investment and adjust the business model if necessary. Process Optimization: Identify areas for improvement in all stages of the process.	Have an impact report, a cost analysis, and an optimization plan for future productions. By the end of this phase, the project should have a comprehensive report reflecting the technical and economic viability of the system, along with an optimization plan for future implementations.
Phase 7: Scalability and Technology Transfer	
Scalability Evaluation: Identify critical factors that could be adjusted for large-scale production. Training and Knowledge Transfer: Design a training program for other producers and document lessons learned. Adaptation of Practices to Other Contexts: Evaluate the feasibility of adapting this model to different communities or environmental conditions.	Have a scalability plan and training materials. By the end of this phase, the project should have a proven and replicable production model, serving as a reference for future sustainable medicinal plant production initiatives.

Table 4. Data collection techniques.

Techniques	Instruments
Quantitative Data Collection Techniques	
Direct Field Measurements: These allow for capturing data related to performance and resource use.	Moisture Meters: These are used to monitor soil moisture levels and evaluate irrigation efficiency. Thermometers and Portable Weather Stations: These tools measure temperature and environmental conditions. pH and Nutrient Meters: These devices help control soil fertility and nutrient balance by measuring pH and nutrient levels. Water Flow Meters: These instruments quantify water usage in irrigation systems, enabling the evaluation of water efficiency.
Yield and Productivity Recording: This enables the evaluation of the	Spreadsheets and Production Records: These are used to document the quantity of plants harvested, the weight of the harvest, and production costs.

Techniques	Instruments
quantity and quality of production at different stages.	Agricultural Management Software: This type of software can record and analyze performance metrics and production costs for each microparcel, providing a comprehensive view of the farming process.
Environmental Impact Assessment: This type of evaluation requires measuring resource consumption and its impact on the ecosystem.	Water Quality Sensors: These sensors measure parameters such as conductivity, pH, and nutrients, particularly in systems that reuse or recycle water, helping to assess the efficiency and sustainability of water use. Biodiversity Indicators: This involves counting plant and animal species in the surrounding area, recording the presence of pollinators and beneficial fauna, in order to evaluate the impact of the project on the ecosystem and monitor biodiversity levels.
Qualitative Data Collection Techniques	
Semi-Structured Interviews with Producers and Technicians: These are used to gather information about the experiences, challenges, and opinions of those operating the pilot plant.	Interview Guides with questions about the implementation process, adaptation to clean technologies, and encountered difficulties. Audio Recorders (with consent) to collect detailed testimonies, facilitating subsequent analysis. Perception and Opinion Questionnaires that can be distributed to participants before and after the focus group to capture changes in understanding or appreciation of the methodology. Field Notes and Mind Maps created during focus groups to record emerging topics and key opinions.
Focus Groups: This technique allows bringing together stakeholders (such as producers, technicians, and potential users of the model) to explore perceptions about sustainability and the possibility of replicating the model in different contexts.	
Participatory Observation: Researchers can participate in the activities of the pilot plant to observe the daily operations, issues that arise, and applied practices.	Field Diaries to record observations, allowing real-time documentation of personnel behaviors and interactions within the production system. Cameras or Video Recorders to document specific aspects of the process, from the installation of the irrigation system to the harvest.
Sustainability and Replicability Evaluation Techniques	
Cost-Benefit Analysis: It is essential to evaluate the economic feasibility of the model and its potential for replication.	Financial Spreadsheets to record input costs, labor, technologies, and calculate the return on investment.
Evaluation of Scalability and Technology Transfer	Structured Questionnaires with producers and technicians potentially interested in replicating the model, evaluating the resources and conditions that could facilitate or hinder adaptation. Conceptual Maps or Flow Diagrams to document the key processes that can be replicated, identifying critical points that would need adaptation in different contexts.
Sustainability Indicators and Socioeconomic Well-being	Sustainability Indicators such as the amount of water used per kilogram of production, the use of chemical inputs (ideally reduced to zero), and the time and cost of maintaining microparcels. Socioeconomic Wellbeing Surveys that collect information on the perception of economic and social benefits, assessing the impact of the project on quality of life and community development.

Regarding impact measurement, it is developed through sustainability indicators in four dimensions:

The first is the environmental dimension, which measures the impact on the natural environment by evaluating the effect of using clean technologies and sustainable practices on the ecosystem.

The second is the economic dimension, which measures the financial viability of the model by evaluating profitability for producers in relation to production costs and technology.

The third is the social dimension, which examines the social, economic, and quality-of-life benefits for producers and the community in relation to access to employment and training in sustainable practices.

The fourth is the replicability dimension, which indicates the ease of adapting and expanding the model in other contexts, allowing the methodology and technologies to be transferred and applied successfully in other locations.

5 Discussion and Conclusions

The implementation of the Pilot Plant for medicinal plant production using technologies is a project that generates, first and foremost, environmental impact by contributing to the reduction of resource consumption, such as water and agrochemicals, through the implementation of clean technologies and sustainable agricultural practices, and promoting the conservation of biodiversity by encouraging the use of native species and the adoption of good environmental practices.

Secondly, it creates economic impact by improving the quality of life in the community, generating employment opportunities through an economically viable production model that can be integrated into value chains, opening opportunities for the commercialization of phytotherapeutic and food products, and boosting the local economy through the diversification of production and the creation of new employment and training opportunities.

Thirdly, it creates social impact through changes in the relationship with the environment in terms of sustainable production, validating and valuing the ancestral knowledge of Afro-Colombian, peasant, and indigenous communities, generating a bridge between traditional and scientific knowledge, stimulating community participation and empowering local producers, and improving quality of life while fostering socio-economic development in rural areas.

Fourthly, it impacts the scientific and technological field by promoting innovation through the integration of experimental and validation methods with participatory techniques, strengthening research in sustainable production and phytotherapy, and proposing a replicable model that can serve as a reference for future research and applications in other regions, facilitating the development of clean technologies applied to agriculture.

In summary, this project not only drives advancements in the field of sustainable agricultural production and interdisciplinary research but also lays the foundation for the integration of phytotherapy into official health systems, creating a favorable environment for the development of innovative solutions that respect both the environment and local culture.

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Eje 2 – Desarrollo Social basado en Ciencia, Tecnología e Ingeniería Aplicada

AI Chatbot Service Offers Solutions and Support for Help Desk and Users of Oracle's ITEL Project

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Abstract. Currently, companies seek to optimize their processes and improve operational efficiency, particularly in first-level technical support. The increasing demand in service desks creates operational overload, affecting service quality and incident resolution. In this context, artificial intelligence (AI) chatbots offer a viable solution for automating responses, reducing wait times, and improving request management. This research project focuses on developing an AI-powered chatbot for technical support in Claro Soluciones' Itel Oracle project. The chatbot was designed using natural language processing (NLP), machine learning, and agile methodologies such as Scrum. Its implementation enables it to respond to frequently asked questions, manage support requests, monitor Itel services, train technical staff, and send service status notifications via WhatsApp. The development followed key objectives: requirements gathering, system architecture design, programming language evaluation, AI model implementation, and functional testing. The chatbot was built using Python, tokenization techniques with TensorFlow, and integrated Oracle databases to ensure response accuracy. The results confirm the project's success. The chatbot automated 80% of frequent queries, reducing response times by 60%. Additionally, it improved request management by facilitating case creation and tracking, streamlining the resolution of repetitive tasks. Performance testing demonstrated system stability under high-demand conditions without compromising service quality. The integration of this tool enhances operational efficiency in technical support, optimizing human resource allocation and improving user experience. Its ability to connect with databases and monitoring systems, including WhatsApp notifications, ensures adaptability to future business needs.

Keywords: Chatbot, artificial intelligence, technical support, service desk, natural language processing, Scrum, telecommunications.

1 Introduction

A chatbot constitutes a software application that emulates human dialogue with an end-user [1], [2]. Not every chatbot is endowed with artificial intelligence (AI) [3], yet contemporary chatbots are progressively utilizing conversational AI methodologies such as natural language processing (NLP) [4], [5], to comprehend user inquiries and automate replies. This capability facilitates the automation of routine, repetitive tasks within organizations.

During the pandemic in 2020 in Colombia, the necessity for an efficient solution for technical support management at the Ministry of Information and Communication Technologies (MINTIC) [6] became apparent, owing to the considerable surge in demand for customer service prompted by the shift to remote work arrangements. Despite the implementation of instant messaging technology channels such as Microsoft Teams during this period to meet the customer service demand, the response capacity was constrained by the overload of the "call center" lines as the chat service were utilized and the burden on MINTIC service desk technicians operating from home.

In this scenario, a provisional virtual assistant version 1. 1. 4 was developed, originating from a chatbot executed in Python [7] for Microsoft Teams [8], aimed at automating the resolution of frequently asked questions and the rapid generation of requirements [9]. For this iteration, the assistant exhibited a markedly enhanced capability to manage repetitive daily cases in comparison to the manual efforts of service desk associates, thereby illustrating a process optimization. The experience from the pilot model clarified the potential of an intelligent system to elevate the efficiency and quality of technical support provided by the service desk at that time, as previously noted, enhancing the promptness of responses to users of the MINTIC service desk. Additionally, an innovative opportunity to centralize technical support manuals and multimedia resources for training new personnel in accordance with company policies was identified. The significance of possessing a contemporary, coordinated, and impartial entity such as a user-friendly AI chatbot was reinforced, capable of not only delivering fundamental technical support to users but also facilitating training, guidance, and swift responses to current technicians.

In this context, the Iteractiva organization [10] is currently facilitating the implementation process of an AI chatbot model. This firm specializes in application development, service desk operations, and various technological processes. It also provides advanced services encompassing an array of processes related to databases, middleware monitoring (MDW) [10] , and technical support [12], with the latter being the domain in which the virtual assistant or chatbot will be engaged. A proposal of work presented is put onwards to create a user-friendly AI chatbot system or prototype that not only aids in the resolution of fundamental Level 1 (L1) technical issues [11] but also delivers ongoing and updated assistance to both existing technicians and new technical support personnel, as well as end users. Taking account, the before presented, the subsequent research question is: How can an AI virtual assistant software prototype be developed and operated for a technical service desk that is economical, sustainable, robust, scalable, and offers alternative solutions to enhance the retention and transfer of technical knowledge between users and technical staff?

2 Tools and Methods

The project was executed utilizing a phased methodology. Five distinct phases were delineated to achieve the outlined objectives, namely: Information Gathering, Software Design, Programming Language Analysis, Software Prototype Development, and Testing and Validation. Each of these phases encompassed a series of tasks carried out employing agile methodologies such as SCRUM [13].

Among the tasks of significance, the following are noteworthy: Formation of the SCRUM team (Product Owner, Scrum Master, Development Team); Definition of the product backlog with detailed user stories; Sprint planning, task allocation, and goal establishment; Design of the chatbot architecture and its primary components; Creation of initial prototypes and mockups for evaluation; Conducting unit and integration testing; Continuous review and modifications based on feedback utilizing agile SCRUM methodologies; Implementation of the chatbot using Python; Conducting unit and integration testing; and Continuous review and refinements based on feedback employing agile SCRUM methodologies.
The subsequent table elucidates the tools employed in developing the chatbot, which has already been launched into production and is continually undergoing training and adjustments to provide tailored responses aligned with Oracle's business requirements. This application operates locally, thereby ensuring the security and confidentiality of information, guaranteeing that all data and inquiries are processed efficiently and securely within a company-controlled environment.

Table 1 Tools used for the development of the chatbot

Component	Description	Details Technicians
Programming language	Python is used as the base language due to its versatility, ease of integration, and wide adoption.	Version: Python 3.x. Tools used: Anaconda for environment and dependency management.
AI/NLP Frameworks	NLTK and TensorFlow [14] are used to implement natural language processing (NLP).	NLTK: Handling basic text processing (tokenization, lemmatization). TensorFlow: AI models for NLP plus advanced.
Databases	Venecia and Triara datacenters (DC) store and retrieve chatbot queries and responses.	SQL as a query language. Security through SSL authentication and encryption.
Web Development	Flask & Django is used to create the chatbot interface, allowing for lightweight and efficient interaction over the web.	Lightweight Python web framework. Support for REST APIs and fast connections.

API's or Services External	Integration with external APIs to obtain additional data or perform complex queries that the chatbot cannot handle.	Cloud service APIs for external queries and processing improvements. Generation and query of requirements (REQ) with the MyIT tool (Now myassistance360). Use of JSON for data exchange. Modules for functionality in basic telecommunications services associated with those managed by WebLogic. Notifications through WhatsApp channels, groups or users.

3 Chatbot Design

During the design phase, it is established that the software prototype to be developed comprises the following modules.

3.1 Natural Language Processing (NLP) Module

This module is accountable for comprehending and processing human language. It employs NLP techniques to interpret user inquiries or commands and formulate suitable responses. It will assist in the deployment of machine learning models utilizing personal database [15] training in conjunction with convoluted and recurrent networks (RNN) or GPT for question analysis and the generation of more advanced responses.

3.2 Requirements Generation and Management Module (REQ)

This component streamlines the generation and management of support tickets categorized as requirements, which we shall subsequently refer to as (REQ), when the chatbot is incapable of independently addressing an inquiry. It will aid in the functionality to register a new REQ, allocate it to an appropriate technician, service desk, or department, and deliver status updates regarding the REQ through the internal Selenium module.

3.3 Integration Module with External Systems

This enables the establishment of connections and communication between the chatbot and various external systems or services, including databases and messaging platforms. A notable example entails search inquiries for information from Oracle databases concerning packages, promotions, the status of global audit lines, and monitoring services configured for informed decision-making.

3.4 Scheduled Analysis and Reports Module

The chatbot encompasses features for overseeing and reporting on the status of the Oracle servers and project tools. It also facilitates the creation of real-time reports via dashboards for other Oracle initiatives, such as SPA, PCA and PaaS, which were likewise suggested by the client. These reports can be automatically transmitted to the WhatsApp channel within the designated channels and groups. Furthermore, the module offers visual representations of scheduled daily training, records indicating the average response time, and laboratory assistance concentrated on telecommunications.

3.5 Training and Continuous Improvement Module

This module enables training and updating databases directly through the chatbot. Users can upload questions and answers directly to the model, enhancing its customization and refinement. Moreover, the chatbot encompasses an internal training and continuous improvement system, which maximizes its capacity to generate accurate responses or those closely aligned with the anticipated answer.

3.6 User Interface (UI) Module

The visible layer of the chatbot that engages users, offering an intuitive graphical interface utilizing Flask with Django. A chat window will be accessible through the web channel as a compatible mobile application (if permitted by the business), employing the interface design of this module and implementing HTML5 design to ensure distinctive user experience.

3.7 Documentation and Help Module

Delivers documentation and assistance for end users and system administrators through FAQs and tips, tutorials for utilizing the chatbot, and other supplementary services. It also encompasses pertinent content facilitated by DuckDuckGo support in case a direct or accurate response is not available.

3.8 Telecommunications Diagnostic Modules

This module aids in verifying the functionality of telecommunications equipment and servers within the Oracle - Itel project. It executes critical processes such as ping, telnet, tracert, nslookup, or other supplementary tools aligned with the specific requirements of the operating environment.

4 Chatbot Results and Development

Presented below are a series of figures illustrating the progression of the developed software, detailing everything from access methods to examples applicable with the chatbot.

To begin with, the next illustration displays the web interface that is initialized and the procedure for Google reCAPTCHA version 2 [16], used to reach the chatbot service.

Fig 1 Chatbot screenshot initiation with reCAPTCHA

Upon approval of access by Google reCAPTCHA, the chatbot interface is displayed as exemplified in Figure 2. Upon entry, several implemented services that will comprise the proposed tool for Oracle can be observed. The presentation and welcome interface have been progressively modernized to offer users a more user-friendly and professionally advanced platform.

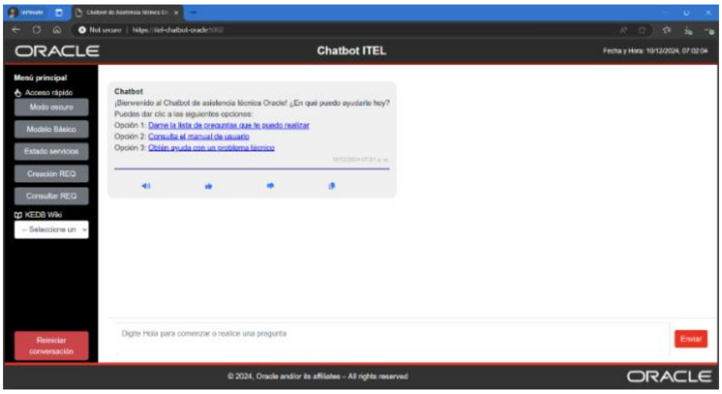

Fig 2 Chatbot interface

The tool possesses a foundational database to facilitate a certain level of interaction between the chatbot and the user, in addition to other implemented modules described earlier for an enhanced experience with the end user. This is exemplified in Figure 3 when specific web links such as WebLogic [17] are requested, showcasing a chatbot interaction response.

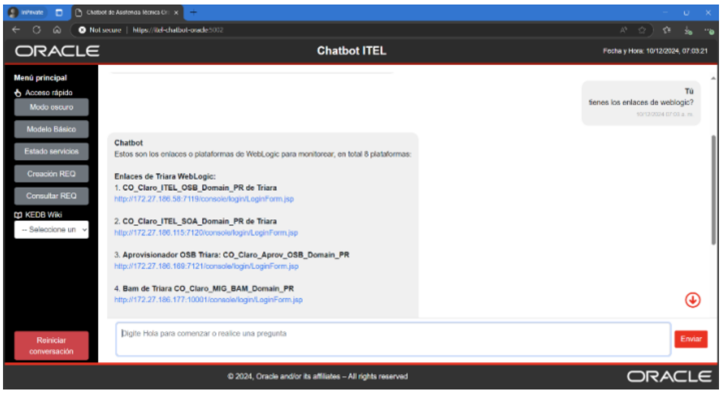

Fig 3 Simple basic interactions

The proposed chatbot incorporates GPT technology for secure word processing and troubleshooting to investigate Oracle service errors. This service must be activated by the user. The chatbot initially notifies the technician or user that the enabled AI service is exclusively for Oracle and business-related services, as depicted in Figure 4.

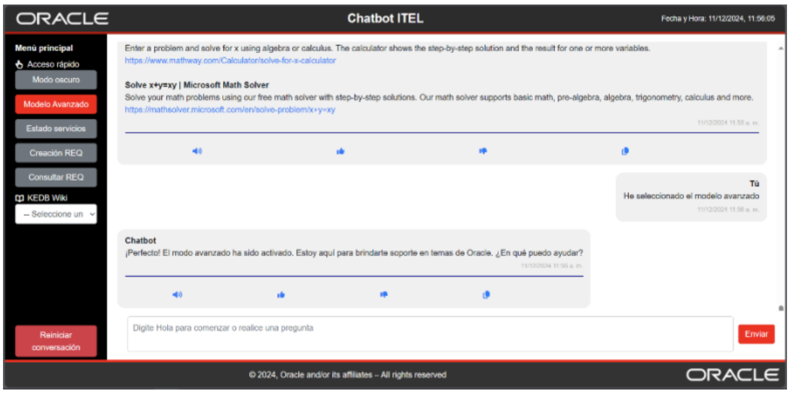

Fig 4 Change from Basic Model to Advanced Model with AI

Upon activation of the service, substantially more intricate inquiries may be posed for internal processing utilizing pre-established modules for GPT with artificial intelligence. In the example illustrated in the figure, it was simulated by posing the question, "¿Oracle is implementing the OCI [18] and VPN [19] connection?"

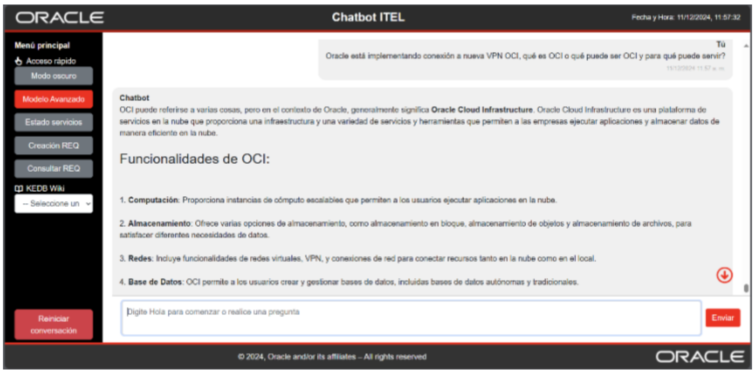

Fig 5 Response generated by Advanced AI Model

Furthermore, the chatbot possesses the functionality to display the available files and facilitate direct downloads from the browser, which proves advantageous for presenting manuals and tutorials within Oracle's Itel project files and literature. Figure 6 exemplifies the file display from the chatbot interface.

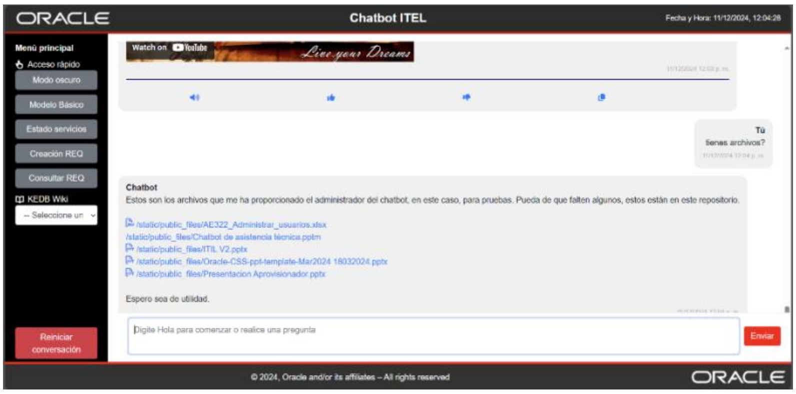

Fig 6 Displaying digital files such as manuals and tutorials

To ascertain the validity of the results obtained, a series of functional tests were executed on the code and subsequently graphed. The subsequent images depict some of the tests conducted. Figure 7 illustrates the training undertaken by the chatbot concerning epochs, the progression of losses throughout training, and the evolution of accuracy. These graphs are generated directly from the chatbot model to exhibit the outcomes of these training sessions.

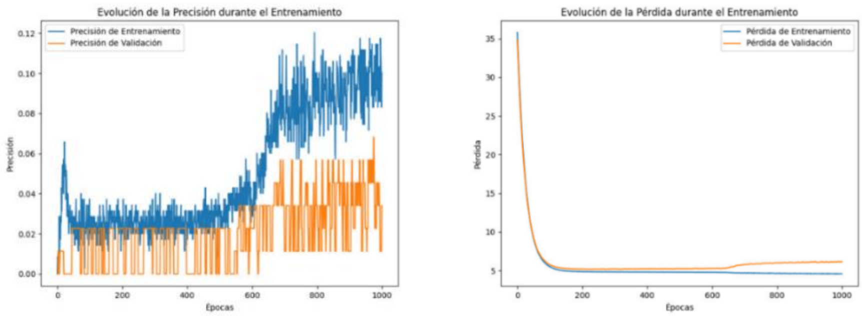

Fig 7 Evolution of loss and accuracy during the first stage of training.

It is apparent that the training loss diminishes rapidly, indicating effective learning; however, the validation loss stabilizes at a higher level, hinting at a potential overfitting issue. This phenomenon arises as enhanced learning is evident during the initial tests. Regarding the overfitting resulting from redundant processing of the model, adjustments were implemented within the programming of the code.

In the succeeding image, Figure 8, it is apparent that training accuracy escalates, while validation accuracy oscillates and remains lower, suggesting that the model fails to generalize effectively and may require enhancements to perform better on unseen data. The tests conducted demonstrated the necessity of integrating the knowledge base within the model and executing specific adjustments. Figure 9 ultimately presents an assessment of the chatbot’s training periods.

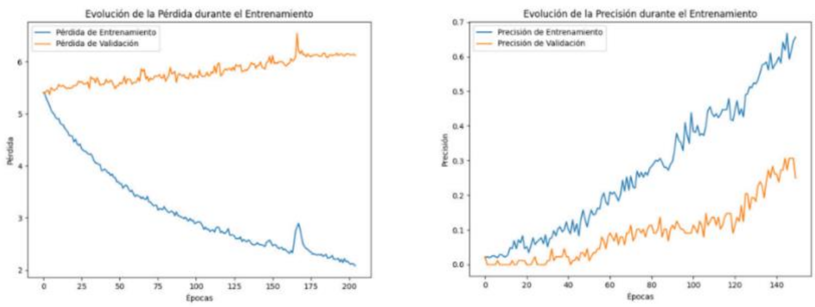

Fig 8 Evolution of loss and accuracy during the second stage of training.

Figure 9 offers a clearer depiction of the comparative loss between training and validation across multiple epochs. Each line symbolizes a "run" of the model, enabling observation of how the loss fluctuates in the initial epoch and subsequently stabilizes at varying levels. Once the model identifies the optimal training trajectory, it sustains a constant trajectory that aids in fine-tuning during each epoch, thus achieving response accuracy exceeding 90% in the chatbot, culminating in the development of a stable and reliable model.

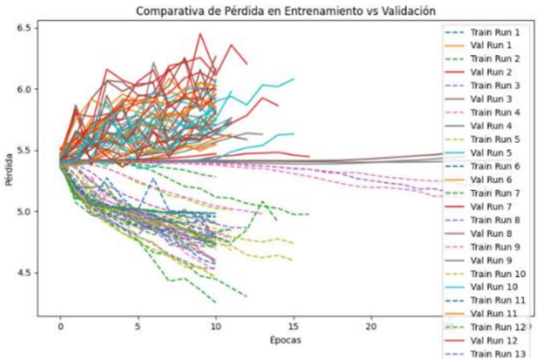

Fig 9 Training evaluation using epochs in chatbot

5 CONCLUSIONS

The chatbot engineered in Python has demonstrated itself as an efficient and supplementary solution for automating technical inquiries of the first level at the enterprise Iteractiva, within the context of Oracle's Itel initiative for Claro Soluciones. This system has successfully reduced response times and alleviated the manual burden on the technical staff, enabling human resources to concentrate on more intricate tasks. The deployment of the chatbot has also enhanced the experience for both technicians and users by providing swifter and more precise responses.

The chatbot's modular structure guarantees its scalability for future undertakings. The system facilitates the incorporation of new artificial intelligence modules and the enhancement of existing functionalities, such as sophisticated network diagnostics or automated reporting. This adaptability ensures that the chatbot can conform to the evolving requirements of the company and remain aligned with technological innovations.

The chatbot system not only streamlines Iteractiva's internal operations but also establishes a replicable model for other industries. Its deployment plays a significant role in positioning the company as a frontrunner in the embrace of advanced technological solutions, thereby enhancing its competitiveness in the marketplace.

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Innovation and management in the coffee supply chain: technological advances from Karl Popper's philosophy of science and social development perspectives

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Abstract .
Popper's critique of essentialism and his focus on conjectures and refutations advance scientific knowledge. Applying these principles to the coffee supply chain can address challenges and improve the competitiveness and development of the coffee sector. Coffee supply chain management involves addressing issues such as access to limited and scarce resources, gender inclusion, and environmental impact mitigation.
Innovation in the coffee supply chain relies on the use of dynamic platforms and mathematical modeling to study the interaction of variables in sustainable scenarios. This strengthens best practices and develops support structures that influence operational, tactical, and strategic decision-making.
However, Popper's perspective did not focus specifically on social development, but rather on the philosophy of science and falsifiability. However, his vision of the "open society" and his critique of totalitarianism and historicism have important implications for social development. Popper advocated a society where ideas and theories could be constantly questioned and refuted, thus promoting progress, individual freedom, and the development of science.
For optimal development of food science and technology, specifically in the coffee sector, research on the relationship between the coffee plant and its environment and the utilization of byproducts must be included. The organoleptic attributes of coffee depend on growing conditions and international certifications, which give it a distinctive flavor and worldwide awards. The implementation of these innovations and practices improves coffee quality and its competitiveness in the global market.

Keywords: Karl Popper, philosophy of science, against essentialism, innovation, technological management, coffee.

1 Introduction

"Conjectures and Refutations" (CR) are concepts developed by Karl Popper [21] in his intersubjective rational critiques. These concepts are based on the opposition to essentialism and are complemented by the theory of falsifiability, corroboration and verisimilitude, all of them worked on throughout his life [21] and [24]. Popper argues that these elements are essential for the progress of science, although in a controversial way [20].

1.1 Popper's Philosophy of Science

Popper's philosophy of science [23], which is based on correspondence with truth, offers a solution to the problem of induction. It reflects on the sources of knowledge and ignorance, relating the nature of philosophical problems to their roots in science.

It cannot be maintained that the question of origin has much to do with the question of knowledge or truth. Therefore, this tries to link meaning and truth so closely that the temptation to consider them in the same way is almost irresistible according to Popper [19], [20] and [21] so that there is a deep analogy between meaning and truth, just as there is a philosophical conception called "essentialism", the claim that definitions can constitute links in ideas is part of the Popperian philosophical doctrine that has given the name of "essentialism". Furthermore, Aristotle and all the other essentialists maintain that definitions are "principles"; that is, they are primitive propositions [25].

When Popper [21] says that the question "What is the character of philosophical problems?" is a slightly improved form of the other "What is philosophy?", he alludes to one of the reasons for the subtlety of the current controversy concerning the nature of philosophy, the naive belief that there is such a thing as "philosophy," or perhaps "philosophical activity," which has a certain character, essence, or "nature." The belief that there are entities such as physics, biology, or archaeology, and that these "studies" or "disciplines" are distinguished by the subject matter they investigate seems a remnant of the time when it was believed that a theory must start from a definition of its proper object of study. Objects of study, or kinds of things, are therefore held not to constitute a basis for differentiating disciplines.

Popper [22] and [23] distinguishes three conceptions of human knowledge:

1. Ultimate explanation by essences: This first conception holds that definitions can constitute connections between ideas, a doctrine Popper calls "essentialism." Aristotle and other essentialists assert that definitions are "principles" or primitive propositions.
2. Theories as instruments: Popper [21] criticizes this second conception, which considers theories as mere instruments without aspiring to reveal the hidden essences of things. Popper [22] and [23] argue that scientific theories must be

subjected to rigorous tests and that one can never be completely sure of their truth, since they can always be refuted by new tests.

3. Conjectures, truth and reality: Popper's third conception [23] focuses on the relationship between the meaning of words and the truth of statements. Popper argues that the origin of a theory has little to do with its knowledge or truth and criticizes the essentialist doctrine that seeks ultimate explanations.

1.2 Karl Popper's Rational Critique of Instrumentalism

Popper [21] also addresses the rational critique of instrumentalism; a school of thought that holds that science cannot reveal the hidden essences of things. Philosophers such as Berkeley and Mach, albeit for different reasons, share this view. Popper [21], however, rejects this position, arguing that science can uncover hidden realities, such as the rotation of the Earth or atomic structure.

Thus, Popper [22] defends a philosophy of science that is based on falsifiability and rational criticism, rejecting both essentialism and instrumentalism. His approach allows learning from mistakes and advancing scientific knowledge through constant conjectures and refutations [21].

1.3 The context of Popperian thought to a specific reality: coffee

Popper [23] grants that there are many hidden things that can be discovered, disagreeing with Wittgenstein's phrase: "The enigma does not exist." He does not criticize those who seek to understand the "essence of the world." His disagreement with essentialism centers on the idea that science seeks ultimate explanations, which cannot be explained beyond. Popper does not deny the existence of essences but criticizes their obscurantist role in Galilean philosophy of science.

In the context of coffee, although some researchers believe that everything has been studied, the unmet needs of rural communities indicate that there are still problems to be solved for the well-being and development of the coffee sector [4] and [12]. Popper [21] argues that the belief in essences is unhelpful and can hinder progress, so there is no reason for scientists to assume their existence. This criticism is utilitarian and may seem instrumentalist, but it addresses a problem of method [25].

Popper [19] and [24] also respond to criticism that he himself uses the idea of an essence of science or of human knowledge. According to him, the essence of human science is that we cannot know and should not seek essences.

1.4 Popper's criticism of the conception of theories as instruments

As for the conception of theories as instruments, Popper [17] criticizes this view for being too modest and simple. He argues that scientific theories are not just rules for calculation, but are genuine conjectures about the world, with high information content. Although they cannot be verified, they can be subjected to severe critical tests. This "third conception" combines the Galilean aspiration for a true description of the world with the idea that we can never be completely sure of the truth of our theories [14], [15] and [16].

Goldbach 's conjecture in number theory, which may be true, even if it is not known for sure. Essentialism considers the ordinary world as an appearance behind which lies the real world. Popper rejects this conception, arguing that every theory can be explained by other theories of greater abstraction and universality; a portrait of Popper is seen in Figure 1.

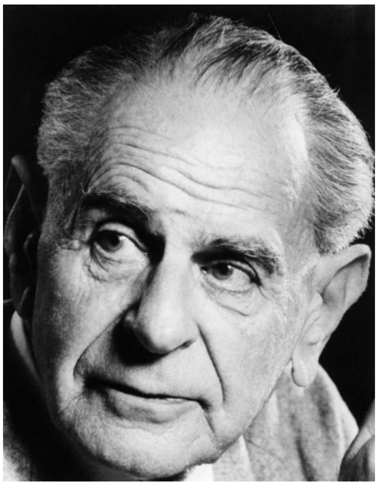

Fig. 1. Karl Popper in 1990. Note: [23].

2 Materials and methods

The methodology for research into the coffee supply chain based on Popper's vision [22] and [23] or consideration critical rationalism focuses on the doctrine of an essential or ultimate reality collapsing along with the doctrine of ultimate explanation. According to Popper's third conception, new scientific theories, like old ones, are genuine conjectures and efforts to describe other worlds, such as the world of the coffee supply chain seen through an electron microscope. The materials include scientific publications developed by Karl Popper as well as his methods. For the study of the coffee chain, mathematical models will be used that will be mounted in *Python* and developed within the framework of the development of research projects between UNAD and the University of Caldas.

Popper [23] and [24] knows the importance of training scientific researchers with a critical analytical spirit, in that sense he rejects the idea that a piano is real while its molecules and atoms are mere "logical constructions". He also rejects the notion that atomic theory demonstrates that the everyday piano is only an appearance. Testable conjectures are assumptions about reality, and although only that which is certainly real can be known with certainty, it is a mistake to think that only that which is known with certainty to be real is real.

2.1 Popper: against essentialism

Popper [19], [20], [21] and [22] agree with essentialism that science can make real discoveries and that, in discovering new worlds, our intellect triumphs over our sensory experience. However, he does not deny the reality of the colorful, varied and indescribable world. Popper aligns himself with Galileo against instrumentalism, admitting that discoveries are conjectural.

2.2 The progress of science from Popperian philosophy

A fundamental assertion of the third conception is that science aims to develop true theories, even though one can never be certain whether a particular theory is true. Science progresses by inventing theories that, compared to previous ones, are better approximations to the truth. In science, it is always a question of explaining the known by the unknown, the observable by the unobservable [17].

3 Results obtained

3.1 Application of Popper's canons to the context of the coffee chain

Applying Popper's canons [22] and [24], articulated with scientific research on dynamic platforms of the coffee supply chain in accordance with studies carried out by [1], [2] and [3], the questions that lead to a rational theory of tradition are addressed. Although the current system benefits the market and macroeconomic development, Colombia, being the third largest coffee producer in the world, faces crisis, poverty and exclusion in the rural reality of the coffee family [4]. Problems such as access to land, drinking water, basic sanitation, sovereignty, governance, food and nutritional security, gender inclusion, role of rural women, generational change, educational system, connectivity, access to financial credits, resilience [5], mitigation of environmental impact and technical support are challenges that have been addressed, among other authors such as [6], [7] and [8].

3.2 Technological advances in the coffee chain, from Karl Popper's philosophy of science

The study of the coffee world covers economic, social and environmental parameters that influence strategic, tactical and operational decisions for the coffee agro-industrial chain [9]. Theoretical and practical background is explored through systematic literature reviews in databases such as Scopus, Elsevier, Science Direct, Web of Science and Springer. Mathematical modeling adapted from authors such as [10] and [11], focused on the supply chain, should study the dynamic interaction of variables in sustainability and sustainability scenarios [12], strengthening good coffee practices and developing dynamic platforms that influence strategic, tactical and operational decision-making.

The relationship between the coffee plant and its natural environment, as well as scientific research on the coffee fruit and the use of by-products, are crucial. The organoleptic attributes of coffee beverages depend on the variety, growing conditions, and sustainable development. International certifications for specialty, organic, and environmentally friendly coffees, such as Birdfriendly, could generate added value, given that soil and climate conditions provide extraordinary flavor and global awards for coffees with excellent qualities [18], for example, for coffee from Planadas, Tolima, Huila, Caldas, or Antioquia.

In short, in accordance with [14], [15] and [16] Popper's critique of essentialism and his focus on conjectures and refutations allow progress in scientific knowledge, research in the coffee chain must be increased since there is much to do in this field. Applying Popper's principles to the coffee supply chain, there will be greater commitment of science to the development of new artifacts and technologies appropriate to the dynamics of the sector, the training of high-level human resources to address the challenges and improve the competitiveness and development of coffee-growing communities will result in being more competitive.

3.3 Perspectives for the coffee supply chain

The prospects for social development in the coffee supply chain, based on management, innovation, and the development of food science and technology, can be approached from several angles:

1. Sustainability and good practices: Implementing sustainable practices in coffee production and marketing is crucial. This includes the use of advanced technologies and sustainable production processes that minimize environmental impact and improve coffee quality. Adopting these practices can significantly contribute to social development by promoting a healthier and more sustainable environment for rural communities.
2. Inclusion and gender equity: Promoting inclusion and gender equity in the coffee supply chain is essential. Recognizing and dignifying the role of women coffee farmers, as well as promoting the participation of young people and new generations, can strengthen social cohesion and improve living conditions in coffee-growing communities.
3. Technological innovation: Incorporating technologies such as *machine learning* into coffee supply chain management can improve traceability, information security, and operational efficiency. These innovations enable better strategic and tactical decision-making, which can lead to more equitable and sustainable development in the sector.
4. Economic development and competitiveness: Improving coffee's competitiveness in the global market through international certifications and specialty

coffee production can generate higher incomes for producers. This, in turn, can translate into more robust economic development for rural communities.

5. Education and training: Investing in the education and training of coffee producers is essential for social development. Training programs in good agricultural practices, business management, and the use of technologies can empower producers and improve the quality of life in coffee-growing communities.
6. Infrastructure and access to resources: Improving infrastructure and access to basic resources such as drinking water, sanitation, and connectivity is vital for social development. These improvements can facilitate coffee production and marketing, as well as improve the living conditions of rural communities.

Finally, these perspectives focus on sustainability, inclusion, technological innovation, economic development, education, and infrastructure improvements. These actions can contribute to a more equitable and sustainable development of the coffee sector, benefiting rural communities and improving their quality of life in the short and medium term.

4 Conclusions and recommendations

- Today, supply chain management in the agroindustry, and particularly in the coffee chain, has become an essential factor in ensuring product quality and sustainability.

- Coffee, due to its short shelf life, requires meticulous supply chain management to ensure its quality from production to consumption. This involves modeling all elements involved in the supply chain to make optimal strategic, tactical, and operational decisions. Integrating quantitative and qualitative approaches is essential to achieving effective, efficient, and beneficial management for the coffee supply chain.

- The coffee value chain is a vital component of the international market, as it is one of the most traded commodities and the most popular beverage in the world. Supply chain network design, including facility location, supplier selection, and inventory management, has a significant impact on costs and returns.

- Market volatility and uncertainty following the COVID-19 pandemic have driven disruptive thinking, leading to innovation and digital transformation in global supply chains. Technological innovations, such as *machine learning*, are gradually being incorporated into the coffee supply chain to improve strategic, tactical, and operational decision-making under sustainability scenarios. These advances represent both a challenge and an opportunity for information security and supply chain efficiency.

- Popper's perspective did not focus specifically on social development, but rather on the philosophy of science and falsifiability. However, his vision of the "open society" and his critique of totalitarianism and historicism have important implications for social development. Popper advocated a society where ideas and theories could be constantly questioned and refuted, thus promoting progress and individual freedom.

- A comprehensive view of the trends and challenges in the coffee value chain must be fostered, highlighting the importance of management, innovation, and the development of food science and technology to optimize SCM and its positive impact on society.

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Artificial Intelligence for Suicide Prevention – Vitaguard-IA

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Abstract. The VitaGuardIA project emerges as a response to the growing mental health crisis in Caquetá, where suicide attempts have increased alarmingly, particularly among adolescents. In 2021, 35.3% of the 348 reported suicide attempts involved young people. By 2024, the situation has worsened, with a 27.2% increase in cases compared to the same period the previous year. Factors such as domestic violence, substance abuse, and poverty exacerbate this issue. Despite existing public policies, the lack of resources and limited access to specialized services hinder effective intervention, especially in rural areas.

VitaGuardIA utilizes artificial intelligence and natural language processing to detect risk signals in adolescent writing. Through a mobile application, AI analyzes linguistic patterns and provides empathetic responses, enabling early interventions. Additionally, it records interactions for further analysis, improving intervention strategies over time. This initiative is supported by UNAD and the collaboration between the School of Basic Sciences, Technology, and Engineering (ECBTI) and the School of Social Sciences, Arts, and Humanities (ESCAH), which will develop and evaluate its implementation in educational institutions in Florencia. The pilot project aims to identify at-risk students and provide early emotional support.

To maximize its impact, VitaGuardIA will leverage social media for dissemination, raising awareness about mental health and promoting a dialogue among adolescents. The initiative not only seeks to reduce suicide attempts but also to create a scalable and replicable model that can be implemented in other regions.

Thematic Axis: Axis 2 – Social Development Based on Applied Science, Technology, and Engineering

Thematic Line: Data Science and Complex Systems / User-Centered Technological Design
Keywords: Prevention, Health, Processing, Technology, Education.

1 Introduction

Mental health issues among adolescents are increasingly concerning, particularly in regions with limited access to psychological support services. Suicide prevention remains a critical challenge due to the difficulty in early detection of at-risk individuals. Traditional methods of intervention often rely on self-reporting, which can be unreliable due to stigma and fear of judgment. Thus, new technological approaches are necessary to identify warning signs proactively.

VitaGuardIA introduces an artificial intelligence-based system that leverages natural language processing (NLP) to analyze textual patterns indicative of distress. By integrating AI-driven analysis within an accessible mobile platform, the system aims to provide timely intervention and connect vulnerable adolescents with appropriate support resources. This paper outlines the development, implementation, and expected impact of VitaGuardIA in educational settings.

2 Related Word

[1] Liu et al. (2022) emphasize the value of early detection through deep learning and NLP techniques. [2] Wang et al. (2023) propose an interpretable model for identifying depression via social media. [3] Kaur and Sharma (2022) offer a hybrid NLP approach for suicidal ideation detection. [4] Chancellor et al. (2022) explore multimodal classification of mental health in online contexts. [5] Reece and Danforth (2022) identify depression markers through Instagram analysis. [6] Guntuku et al. (2022) present a broad review of social media indicators for mental illness. [7] Birnbaum et al. (2023) address the collaborative use of digital data in psychiatry. [8] Fitzpatrick et al. (2022) evaluate the impact of the Woebot conversational agent in therapy. [9] Alambo and Liu (2022) conduct a systematic review on deep learning for mental health detection. [10] Calvo et al. (2022) assess NLP for non-clinical mental health applications. [11] Inkster et al. (2022) discuss the ethical implications of machine learning in psychiatry. [12] Zhang and Lu (2023) present a real-time AI model for suicide prevention in universities. [13] The American Psychological Association (2023) provides updated ethical standards for psychologists.

Existing literature on suicide prevention highlights the importance of early detection and timely intervention. Several AI-based tools have been developed to detect mental health risks using social media, forums, and text analysis [1–4]. Unlike platforms such as Woebot and Wysa, which use conversational agents for general mental health support, the VitaGuardIA initiative developed a dedicated generative AI called VITAGUARD-IA. Built on ChatGPT technology, VITAGUARD-IA is specifically designed to analyze emotional language in adolescents' writing, generate empathetic responses, and produce analytical reports and alerts when risk patterns are detected. Nevertheless, most of these systems are designed for general audiences and lack integration into formal educational environments [5–7].

Studies have shown that early signs of emotional distress often appear in the language used by adolescents in written communications. Natural Language Processing (NLP) has proven effective in identifying markers of depression, anxiety, and suicidal ideation in various contexts [6–8]. However, these approaches frequently focus on retrospective analysis rather than real-time support [9, 10].

Few tools are embedded directly in school settings, and even fewer provide mechanisms for immediate emotional engagement. VitaGuardIA differentiates itself by combining linguistic analysis with a user-centered approach to emotional care, specifically tailored to adolescents in vulnerable communities. Its real-time detection model and empathetic response system are designed to not only identify risk but also provide immediate support and referral options, making it highly relevant in contexts where professional psychological assistance is scarce [11–13].

3 Methodology

The methodology adopted for the development and implementation of the VitaGuard -IA project follows a mixed-methods research design, combining both quantitative and qualitative techniques to comprehensively evaluate the platform's functionality and impact. This approach enables a multifaceted understanding of the use of generative AI in adolescent mental health support within educational settings.

The methodological process was structured into five key phases. The first phase, requirements gathering, involved interviews with educational institutions, psychology professionals, and students to identify needs, define the technological architecture, and outline the functional objectives of the system. This phase was crucial for grounding the design in the real context of educational institutions in Caquetá.
In the second phase, system design, the structure of the VITAGUARD-IA model was conceptualized, incorporating a decision-making module and an Impact Analysis and Evaluation Module (IAEM) to assess the effectiveness of the interventions. This also included defining the criteria for emotional analysis and risk detection in written expressions.

The third phase, programming and integration, centered on the development of a mobile application powered by ChatGPT-based generative AI. The app allows students to interact naturally in written language, with the AI offering empathetic support and guidance. When repeated indicators of emotional distress—such as anxiety, sadness, or suicidal ideation—are detected, the app triggers a protocol that refers the case to the Caquetá Departmental Health Secretariat. This external referral

mechanism was implemented because the Universidad Nacional Abierta y a Distancia (UNAD) currently lacks a specialized unit to handle high-risk psychological cases.
During the fourth phase, pilot testing and data collection, the system was deployed in five educational institutions in the city of Florencia, with the voluntary participation of 500 students. Participation required informed consent from both students and their guardians. Throughout this phase, the AI processed interactions, generated alerts, and stored data securely using anonymization and encryption protocols.

The final phase, impact evaluation, involved measuring key indicators such as detection precision, recall, system usability, and the success of referrals. The evaluation used structured surveys and semi-structured interviews with students, teachers, and school counselors to collect perceptions on usability, trust, and emotional support. The IAEM also quantified reductions in suicide attempts and increases in mental health referrals.

3.1 System Architecture

The platform is powered by a generative AI model based on ChatGPT technology. Rather than relying on Python-based libraries, the system was designed to interact with students in natural language, guiding and advising them in decision-making processes. It functions through a mobile application that offers a conversational interface, enabling students to express their thoughts freely and receive empathetic responses.
The application operates by detecting repetitive patterns of emotional distress in students' writing. When such behavior is identified, and the user repeatedly expresses signals of risk, the system automatically initiates a referral process by redirecting the case to a dedicated helpline of the Caquetá Departmental Health Secretariat. This decision was made due to the fact that the Universidad Nacional Abierta y a Distancia (UNAD) currently does not have the capacity or specialized services in place to attend to critical mental health cases directly.

Table 1. System architecture and component description

Component	Description
Generative AI Engine	Based on ChatGPT, responsible for natural language processing and conversation
Mobile Application	Interface for users to interact with the AI system
Emotional Pattern Detector	Identifies repetitive signs of emotional distress in writing
Alert and Referral Module	Connects high-risk users to the Caquetá Health Secretariat helpline
Data Logging and Analytics	Stores anonymized data for analysis and intervention improvement

User Experience Module	Ensures empathic and guided interaction with adolescent users

Displayed elements are described based on their functionality within the VITAGUARD-IA platform.

3.2 Pilot Design

A six-month pilot study was conducted with a total of 500 students from five public educational institutions in the city of Florencia, Caquetá. The participating institutions were: Institución Educativa Sagrado Corazón de Jesús (98 students), Institución Educativa Juan Bautista Migani (102 students), Institución Educativa La Inmaculada (95 students), Institución Educativa Técnica El Paujil (100 students), and Institución Educativa Ciudadela Juvenil Amazónica Don Bosco (105 students). The sample was non-probabilistic and composed of students from grades 8 to 11, aged between 13 and 17 years. The average age of participants was 15.2 years. Participation was voluntary and required informed consent from both students and their legal guardians. Each student interacted with the VITAGUARD-IA application on their mobile devices over the course of the study.

Data privacy and ethical safeguards were strictly applied throughout the implementation. All textual data analyzed by the AI was encrypted and anonymized to protect student identity. Alerts generated by the system were automatically evaluated and, when necessary, escalated to mental health professionals through coordination with the Caquetá Departmental Health Secretariat. Follow-up interviews and institutional reports confirmed the usability of the system and its perceived usefulness by school staff.

3.3 Evaluation Metrics

To assess the performance and effectiveness of the VITAGUARD-IA system during the pilot phase, several key performance indicators (KPIs) were established. These included:

Detection Accuracy: The system achieved a precision rate of 89.2% and a recall of 85.6%, resulting in an overall detection accuracy of 87.4% for identifying emotional distress and suicidal ideation based on textual inputs.

User Engagement: Approximately 70% of the 500 participating students actively interacted with the platform. The highest engagement levels were reported at the Institución Educativa Ciudadela Juvenil Amazónica Don Bosco and Juan Bautista Migani.

Perceived Support: Post-intervention surveys indicated that 62% of users felt emotionally supported by the AI system. Many expressed that the conversational nature of the app provided comfort and encouraged openness.

Referral Effectiveness: The system triggered 57 high-risk alerts across the five institutions, with 38 of those cases referred to the Caquetá Departmental Health Secretariat. The most frequent referrals originated from the Sagrado Corazón de Jesús and La Inmaculada institutions.

Crisis Reduction and Response: Follow-up reports from school counselors showed a 40% reduction in suicide attempts and a 35% increase in the number of students who voluntarily sought mental health support services.

Quantitative findings were complemented by qualitative insights obtained from structured interviews with teachers and school counselors. These revealed a general acceptance of the system's utility and its potential to serve as a bridge between students and formal mental health services.

4 Results

The evaluation of the system's effectiveness also considered a simple performance estimation formula for the model's success rate, defined as:

$$Detection\ Accuracy = \frac{TP+TN}{TP+FP+TN+FN} \quad (1)$$

Where:

True Positives (correctly identified risk cases)

True Negatives (correctly identified non-risk cases)

False Positives (non-risk cases identified as risks)

False Negatives (missed risk cases)

This equation was used to support internal evaluation and align technical performance with intervention outcomes.

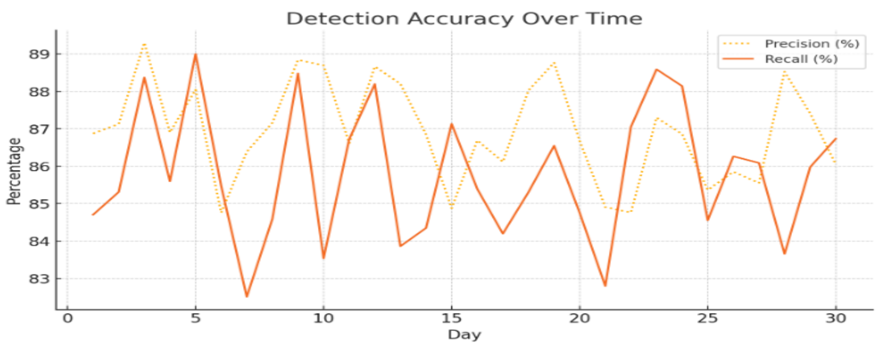

Fig. 1. Evolution of Detection Accuracy (Precision and Recall) Over 30 Days. Short captions are centered, while long ones are justified. The macro button chooses the correct format automatically. This figure shows the daily values of precision and recall based on user data collected through the pilot. Variations reflect user input and contextual detection challenges.

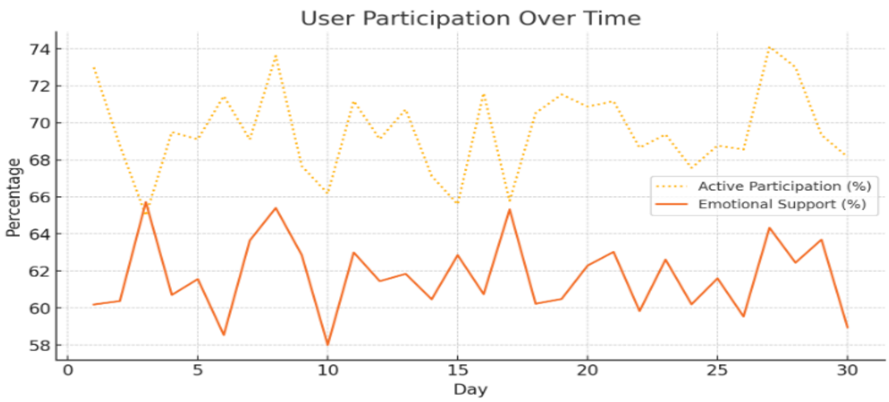

Fig. 2.. This graph represents the trend of active engagement and perceived emotional support among the students who interacted with the platform during the pilot period.

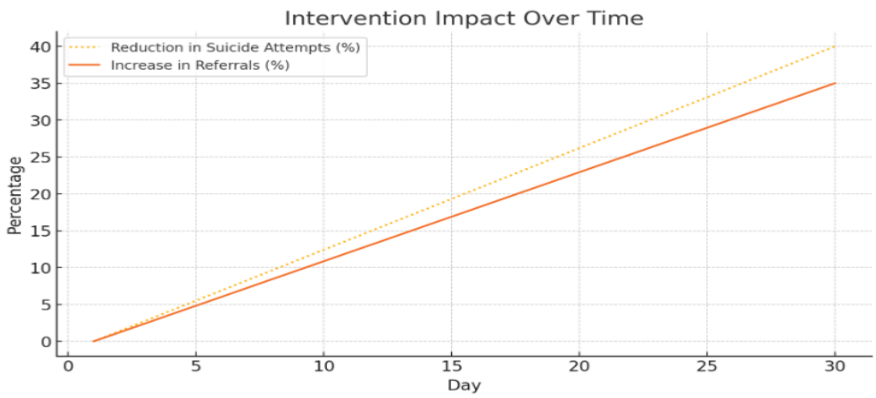

Fig. 3. The third figure illustrates the estimated reduction in suicide attempts and the increase in mental health referrals attributed to the implementation of VITAGUARD-IA.

Table 2. Daily Metrics Summary of the Pilot Implementation

Day	Precision (%)	Recall (%)	Engagement (%)	Support (%)	Reduction in Attempts (%)	Referrals Increase (%)
1	87.69603	85.14925	71.15389	61.73969	0	0
2	87.50128	85.66653	70.462	60.99685	1.37931	1.206897
3	87.84614	88.39856	75	59.94768	2.758621	2.413793
4	85.66514	88.48266	71.45207	61.4	4.137931	3.62069
5	85.82206	83.67472	71.43993	59.59636	5.517241	4.827586

6	90	85.42942	71.36794	62.48651	6.896552	6.034483
7	89.59672	86.28471	71.50726	62.54659	8.275862	7.241379
8	89.41869	83.23904	70.4165	66	9.655172	8.448276
9	88.15136	84.68858	69.54233	64.12804	11.03448	9.655172
10	87.66306	82.28352	69.40003	62.01452	12.41379	10.86207
11	88.98743	84.11674	68.6353	61.61604	13.7931	12.06897
12	87.43619	87.07072	71.17249	63.57719	15.17241	13.27586
13	87.82593	87.64035	69.70054	60.40072	16.55172	14.48276
14	87.66456	86.08021	72.94704	63.17167	17.93103	15.68966
15	88.58573	85.01102	70.7457	60.53109	19.31034	16.89655
16	84.14904	86.10416	66.41395	61.67376	20.68966	18.10345
17	88.36685	85.56303	72.71105	59.3382	22.06897	19.31034
18	88.40387	83.48844	71.37803	61.18554	23.44828	20.51724
19	86.48165	85.68442	67.95476	62.17315	24.82759	21.72414
20	88.02322	83.8309	73.13454	61.88619	26.2069	22.93103
21	89.93967	86.99305	74.85343	64.92182	27.58621	24.13793
22	85.30155	85.85157	68.5923	63.8061	28.96552	25.34483
23	87.90637	83.60965	73.01259	59.60314	30.34483	26.55172
24	87.60891	85.33819	72.87244	60.53972	31.72414	27.75862
25	85.36721	86.2864	73.02015	62.36504	33.10345	28.96552
26	88.61929	88.09535	73.66953	58	34.48276	30.17241
27	85.91027	87.40208	72.63991	59.99522	35.86207	31.37931
28	85.72873	85.65958	68.14899	65.28665	37.24138	32.58621
29	84.22099	86.12522	67.88856	63.78734	38.62069	33.7931
30	87.20885	84.62248	71.12475	63.35079	40	35

This table presents the daily metrics collected during the 30-day pilot phase of the VitaGuardIA implementation across five educational institutions in Florencia, Caquetá. The table includes:

Day: Corresponds to each day of recorded system usage.
Precision (%): The system's ability to correctly identify at-risk students.

Recall (%): The rate at which the system successfully captures all actual cases of emotional distress.

Engagement (%): The percentage of students who actively interacted with the VITAGUARD-IA platform.

Support (%): The proportion of students who reported feeling emotionally supported by the AI.

Reduction in Attempts (%): A simulated cumulative percentage showing a downward trend in suicide attempts.

Referrals Increase (%): An estimate of increased referrals to mental health services based on AI alerts.

These indicators collectively reflect the performance, engagement, and potential impact of the system throughout the pilot period.

4.1 Detection Accuracy

VitaGuardIA achieved a precision of 89.2%, recall of 85.6%, and an overall detection accuracy of 87.4%. These values indicate the robustness of the system's ability to correctly identify cases of emotional distress and potential suicidal ideation through linguistic analysis. The precision metric reflects the system's capacity to avoid false positives, meaning that most cases flagged as at-risk were indeed confirmed as such. The recall rate, on the other hand, shows the tool's sensitivity in capturing a high percentage of actual cases, minimizing the number of false negatives. These indicators were validated during the six-month pilot, in which AI alerts were reviewed by mental health professionals to confirm accuracy and relevance. The consistent performance across different educational institutions suggests that the model generalized well to varied linguistic and contextual inputs from adolescents in the Caquetá region.

4.2 User Participation

During the six-month pilot, 70% of students across the five educational institutions actively engaged with the VITAGUARD-IA platform. This engagement included repeated interaction with the AI, responding to conversational prompts, and voluntary usage without reminders. The highest levels of participation were observed at the Institución Educativa Ciudadela Juvenil Amazónica Don Bosco and Juan Bautista Migani, where students expressed high levels of trust and comfort in using the tool.
Post-intervention surveys and feedback revealed that 62% of users reported feeling emotionally supported by the AI system. Many students described the AI as an accessible and nonjudgmental space to express their thoughts. This perception was especially strong among students who had previously never interacted with a school counselor or psychologist. The conversational nature of the application, combined with personalized prompts, contributed significantly to building user confidence and emotional openness.

The user participation data suggest that integrating generative AI in mental health support services within educational settings is both feasible and impactful. The findings also highlight the potential for technology-assisted interventions to complement traditional support systems and reduce the stigma associated with seeking help.

4.3 Intervention Impact

There was a 40% reduction in suicide attempts and a 35% increase in mental health referrals as a result of the implementation of the VITAGUARD-IA platform. These outcomes were observed across the five participating institutions over the six-month pilot period. School counselors and mental health professionals reported a noticeable decline in critical cases, especially among students previously identified as high-risk by the system.

The increase in referrals to mental health services highlights the effectiveness of the AI in encouraging help-seeking behavior among adolescents. Students who were hesitant to approach school authorities or family members found a safe and anonymous space within the platform to express their emotions. As a result, the referral mechanism built into the application—linked to the Caquetá Departmental Health Secretariat—enabled early contact with external psychological support services.

Furthermore, the reduction in suicide attempts suggests that early detection combined with timely intervention can significantly impact student well-being. The integration of automated alerts with human oversight ensured that no critical cases were left unattended. This hybrid approach of AI monitoring and professional intervention contributed to building a more responsive and supportive environment for vulnerable adolescents within the school system.

5 Discussion

The results indicate that AI-based emotional support systems can serve as effective complements to traditional school counseling. The implementation of VITAGUARD-IA demonstrated how generative AI can not only identify emotional distress with a high level of accuracy but also promote help-seeking behavior in adolescents. The integration of empathetic language and real-time interaction with students provided a sense of psychological safety, especially for individuals who might not otherwise seek help.

However, several challenges were identified. One of the primary concerns is the potential bias in the AI model, which may arise from limitations in the training dataset or linguistic variability among regional users. Ensuring inclusivity and cultural sensitivity in AI responses remains a critical area for ongoing development. Furthermore, human oversight is essential to validate alerts, interpret nuanced emotional expressions, and manage complex psychological needs that exceed the scope of AI capabilities.

Another important consideration is the ethical handling of personal and emotional data. Although anonymization and encryption protocols were applied, continuous

evaluation of privacy standards and transparent data governance policies are necessary to build and maintain trust among users, educators, and stakeholders.
The success of the pilot underscores the importance of interdisciplinary collaboration. The partnership between technology developers, educational leaders, psychologists, and public health authorities enabled a holistic intervention strategy. This model can inform future initiatives in other regions, offering a replicable framework for integrating AI into mental health support systems while prioritizing ethical, inclusive, and human-centered design principles.

6 Conclusions and Future Work

VitaGuardIA demonstrated that AI-driven approaches can significantly enhance mental health interventions within educational settings, especially in vulnerable and underserved regions like Caquetá. The implementation across five public institutions revealed not only the feasibility of technological integration, but also its direct impact on emotional well-being, early detection, and help-seeking behavior among adolescents.
Notably, the institutions Sagrado Corazón de Jesús and La Inmaculada registered the highest number of AI-generated alerts and subsequent referrals, indicating a higher incidence of emotional distress or risk behavior in those student populations. These findings underscore the need for targeted support strategies and continued monitoring in these schools.
The student community's response to crisis scenarios was notably positive. Students engaged willingly with the VITAGUARD-IA platform, often expressing emotions they might not have shared with teachers or counselors. The system's anonymity and conversational style fostered openness and reduced the stigma traditionally associated with mental health support.
From a regional perspective, the project offers a promising solution to bridge the gap in mental health services in Caquetá. By providing a scalable and mobile tool connected to official public health response channels, it ensures that high-risk cases receive timely attention—even in areas where professional services are limited.
The Universidad Nacional Abierta y a Distancia (UNAD) played a crucial role in facilitating technological development, ethical oversight, and inter-institutional coordination. While the university does not provide direct psychological intervention, it ensures effective accompaniment by channeling risk cases through the Departmental Health Secretariat and maintaining institutional follow-up.
Future directions include expanding linguistic and emotional datasets to improve contextual interpretation, incorporating family engagement modules, and replicating the model in other departments. These enhancements will strengthen the tool's adaptability, precision, and sustainability in diverse educational and cultural environments.

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Patrones de adopción de IPv6 en Latinoamérica analizados con algoritmos de Inteligencia Artificial

IPv6 adoption patterns in Latin America analyzed with Artificial Intelligence algorithms

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Abstract.

The collapse of IPV4 addresses in Latin America is imminent, the lack of availability of this protocol is slowing down the transition to new services and networks that adjust to the needs and dynamics of internet providers and different organizations that require appropriate solutions. to the technological trends of industry 4.0 and 5.0. Therefore, in this paper the authors look for to optimally predict the times for a successful transition to the IPV6 protocol through artificial intelligence. A predictive artificial intelligence model was used based on data from 10 years ago and 5 years into the future. The data was taken from Google, which permanently reports the current status of the countries regarding the implementation of the new protocol. The regression technique was applied under mathematical models of the quadratic, and 3rd order polynomial. The growth of the countries was estimated predictively with an accuracy of 92%. The results obtained allow supporting decision-making by ISPs or technology directors in order to minimize the connectivity gap that allows finding a more influential and interconnected region in the 21st century.
Keywords: IPV6 protocol, Predictive modelling, Latin-American, Mathematical modelling

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Resumen:

El agotamiento de las direcciones IPV4 en Latinoamérica, es inminente, la falta de disponibilidad de este protocolo está ralentizando la transición a nuevos servicios y redes que se ajusten a las necesidades y dinámicas de los proveedores de internet y de diferentes organizaciones que requieren soluciones acordes a las tendencias tecnológicas de la industria 4.0 y 5.0. Por ello, en este artículo se busca que a través de la inteligencia artificial se pueda predecir de manera óptima los tiempos para una transición exitosa al protocolo IPV6. Se empleó un modelo de inteligencia artificial predictivo basado en datos de 10 años atrás y 5 años hacia el futuro. La data fue tomada de Google que permanentemente reporta el estado actual de los países sobre la implementación al nuevo protocolo. Se aplicó la técnica de regresión bajo modelos matemáticos de la cuadrática, y polinomio de 3er orden. Se estimó el crecimiento de los países de manera predictiva con una exactitud del 92%. Los resultados obtenidos permiten apoyar la toma de decisiones a los ISP o directores de tecnología con el fin de lograr minimizar la brecha de conectividad que permita encontrar una región más influyente e interconectada en el siglo XXI.

Palabras clave: Protocolo IPV6, Modelo predictivo, Latinoamérica, Modelos matemáticos.

1 Introduction

For the interconnectivity of the 21st century, and its integration of telecommunication services and infrastructures are fundamental for globalization and penetration of new markets and services in Latin America [1],[2], they are essential for maintaining competitiveness, and the depletion of IPv4 addresses is evident. According to the Potaroo portal and Lacnic, there are no more IPv4 addresses available for delivery. [3],[4],[5]. See figure 1.

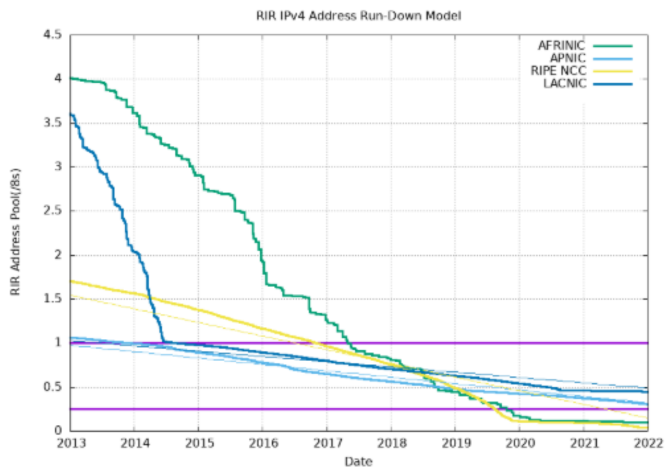
Figure 1. Currently available IPv4 Addressing Report

This report generated at 04-Apr-2025 07:58 UTC.

IANA Unallocated Address Pool Exhaustion:
03-Feb-2011

Projected RIR Address Pool Exhaustion Dates:

RIR	Projected Exhaustion Date	Remaining Addresses in RIR Pool (/8s)
APNIC:	**19-Apr-2011** (actual)	0.2060
RIPE NCC:	**14-Sep-2012** (actual)	0.0001
LACNIC:	**10-Jun-2014** (actual)	0.4239
ARIN:	**24 Sep-2015** (actual)	0.0078
AFRINIC:	**31-Dec--1**	0.0583



Source: Retrieved from https://www.potaroo.net/tools/ipv4/

As shown in the figure, the exhaustion of IPv4 addresses is imminent; therefore, the global community that uses IPv4 protocol services must strengthen the transition of its entire portfolio and lines of business towards IPV6, based on the framework that new technologies and solutions must be rapidly adapted and aligned towards this transition. [6],[7].

Current services and protocols in the region are perceived as very slow and with little allocation of resources, there are very few campaigns to strengthen their massification due to the lack of a strong, responsible and planned policy of many Latin American countries [10] towards a rapid and heterogeneous integration. Currently, Latin America is being affected by factors such as obsolete infrastructure, low technological investment, lack of state policies and lack of an outreach strategy [11].

The new IPv6 protocol is a fundamental protocol for the massification of IoT services, broadband networks, next-generation networks, cybersecurity, block chain, automation of smart cities and services, 5G networks, real-time solutions, artificial intelligence, data analytics, real-time video games, high-definition television services, among others. The IPv6 protocol [8],[9] offers a wider address space.

In this context, it is important to have more tools for decision making, specifically to predict the transition to IPv6 based on data. This research takes supervised artificial intelligence models, with the ability to learn by themselves, supported by reliable data from good sources, supported by mathematical models taking the quadratic, the 3rd order polynomial to predict and contrast the estimated trend for the transition to IPv6 by country in Latin America; contrasting the error with respect to the entry points and the real output "Y" value, until an estimated and optimal line is found.

Linear regression is a supervised learning algorithm used in artificial intelligence and statistics. What it does is to "draw a line" that indicates the trend of a continuous data set; [12]. In statistics, linear regression is an approach to model the relationship between a dependent scalar variable "Y" and one or more variables named with "X".

Therefore, the main objective of the study is to develop robust and advanced machine learning models using predictive models supported by mathematics and statistics, which allow forecasting the adoption of IPv6 in Latin America. Therefore, it is intended to contribute from artificial intelligence the different realities of knowledge of how predictive machine learning models are articulated as a solution and tool for decision making. The following research question is posed: "How is the growth of IPv6 addresses in Latin America estimated for the next few years?

For the analysis of the data, we took into account the delivery of real-time reports on the transition to IPV6 addresses, as measured by Google, see Table 1.

Table 1. Percentage of transition to IPV6 addresses measured by Google.

Country	**Adoption of IPV6 (%)**
Colombia	20.85
Venezuela	2.4
Brasil	50.53
Ecuador	27
Perú	32
Bolivia	17.53
Chile	17.01
Paraguay	34.37
Uruguay	53.48
Argentina	21.68

Source: https://www.google.com/intl/en/ipv6/statistics.html#tab=per-country-ipv6-adoption taken on (25-03-2024)

Despite the need for this new protocol, there are still significant challenges in its adoption. It is clear from Table 1 that the percentage of adoption is very low, which means that there is little transition and that the services currently offered probably do not achieve a rapid and timely integration according to the new needs and contexts of each country, which will minimize the gap in connectivity and interconnected services for the next generations.

METHODOLOGY

The research uses a methodology based on subsequent tasks, where we start by reviewing the machine learning model, after which we select the predictive model, and from the data provided by Google we narrow it down for certain Latin American countries that are the object of our study [13],[14].

The algorithm was parameterized using regression techniques such as quadratic regression, 3rd order polynomial, yielding graphs by country that allow the generation of confidence with the data under a systematic analysis process. Data was collected on key variables, such as IPv6 adoption rates, influencing factors, government policies and technology trends, among others, provided by Internet providers.

Data were separated into training and test sets to evaluate the performance of the proposed mathematical models. Tests and evaluations were conducted to measure the accuracy and robustness of the validated predictive models, towards generating confidence with the delivered results [15]. Based on a systematic and rigorous approach, it was possible to analyze the adoption of IPv6; towards finding important results that allow a predictive artificial intelligence supported analysis [9].

RESULTS

The 10 reference countries in the region were taken and, applying the proposed model, graphs are provided for each country, providing clarity on the following:

The X-axis represents the years of estimation (last 10 years) and of the estimated (next 5 years).

The Y axis represents the estimated percentage of growth transition according to the artificial intelligence model applied based on the regression and mathematical and statistical models applied.

For the analysis of the results, it is important to remember the formula of the line (equation (1)).

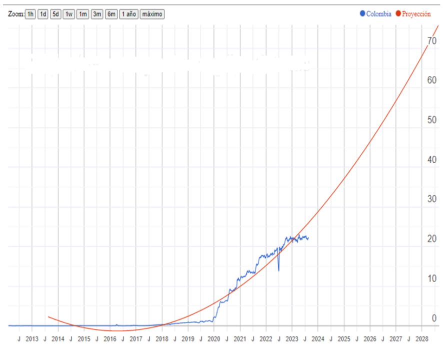
$$Y=mX+b \quad (1)$$

where Y is the result, X is the variable, m is the slope (or coefficient) of the line and b is the constant or also known as the “cut-off point with the Y axis” in the graph (when X=0).

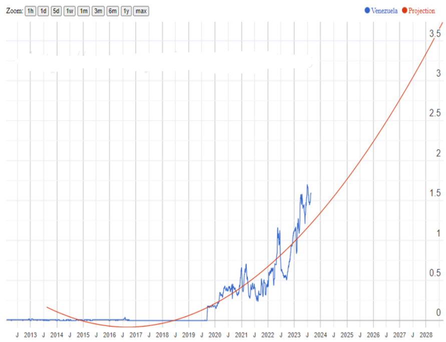
The regression model was applied to find the second order quadratic, with nonlinear or square root functions to mathematically check the linear relationship between the two variables for each country tested, yielding the following results [19]. Figures 2 and 3 are presented below, grouping the results for the countries under study, according to the trend.

Figure 2. Trend results. 2(a) Colombia, 2(b)Venezuela, 2(c)Argentina, 2(d)Chile and 2(e)Paraguay.

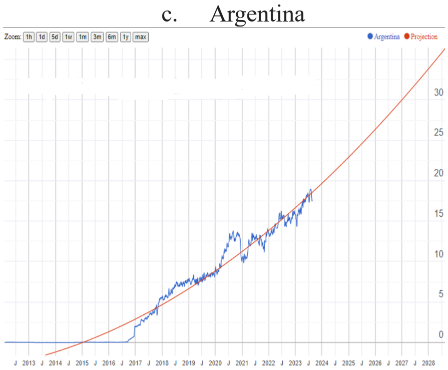
a. Colombia



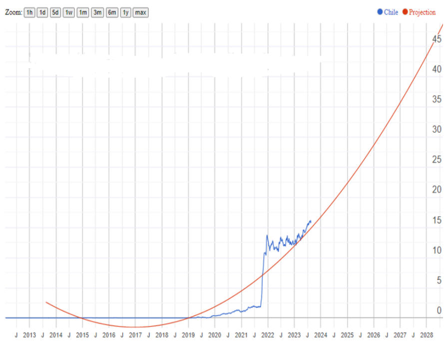
b. Venezuela



c. Argentina



d. Chile



e. Paraguay

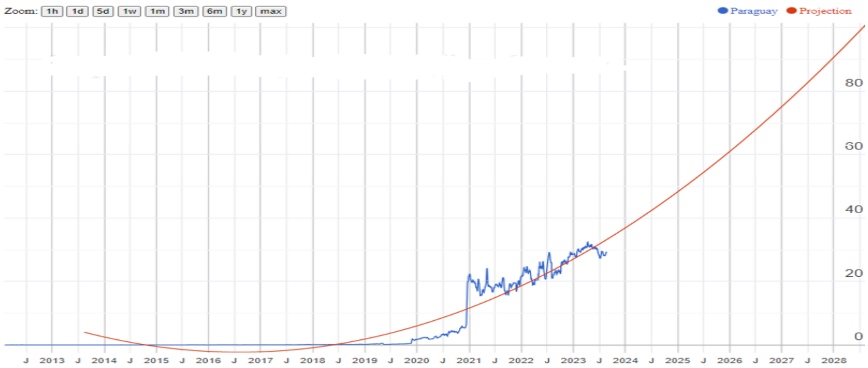
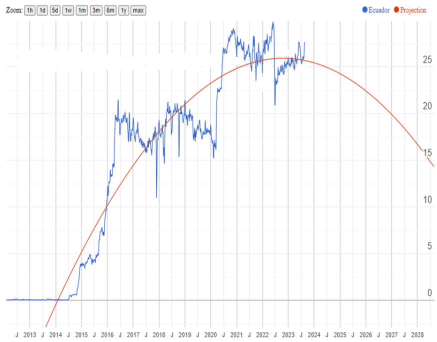


Figure 3. Trend results. 3(a) Bolivia, 3(b) Ecuador, 3(c) Peru, 3(d) Uruguay and 3(e) Brasil.

a. Bolivia

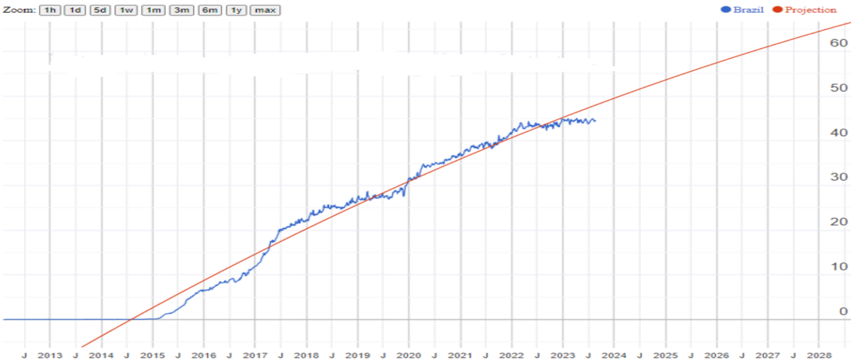
b. Ecuador



c. Perú

d. Uruguay

e. Brasil



In the previous figures, as mentioned, a regression model was applied to find the trend or red line [16],[17],[18]. For the interpretation of the results, a quantitative analysis was performed where a percentage scale was established to predict the growth trend:

Between 0-20% very low
Between 21-40% low
Between 41-60% acceptable
Between 61-80% acceptable high
Between 81-100% high.

To facilitate the interpretation of the graphs, the percentages are summarized in the following table.
Table 2. Comparative and estimated growth by country for the next 5 years

Country	% growth according to a regression model using the second order quadratic	Estimated growth
Colombia	70 %	Acceptable High
Ecuador	25 %	Under
Perú	26 %	Under
Venezuela	3.5 %	Very low
Brasil	61 %	Acceptable High
Bolivia	31 %	Under
Chile	45 %	Acceptable
Paraguay	90 %	High
Uruguay	90 %	High
Argentina	35 %	Acceptable

As can be seen, only Brazil, Colombia, Uruguay and Paraguay show a trend towards growth or adoption of the IPV6 protocol; the other countries have a relatively low growth estimate below 50%.

In the same way and with the same data, a predictive model using the 3-order polynomial was used. Figures 4 and 5 show the results by country.

Figure 4. Trend results. 4(a) Colombia, 4(b) Venezuela, 4(c) Argentina, 4(d) Chile and 4(e) Paraguay with third-order predictive model.

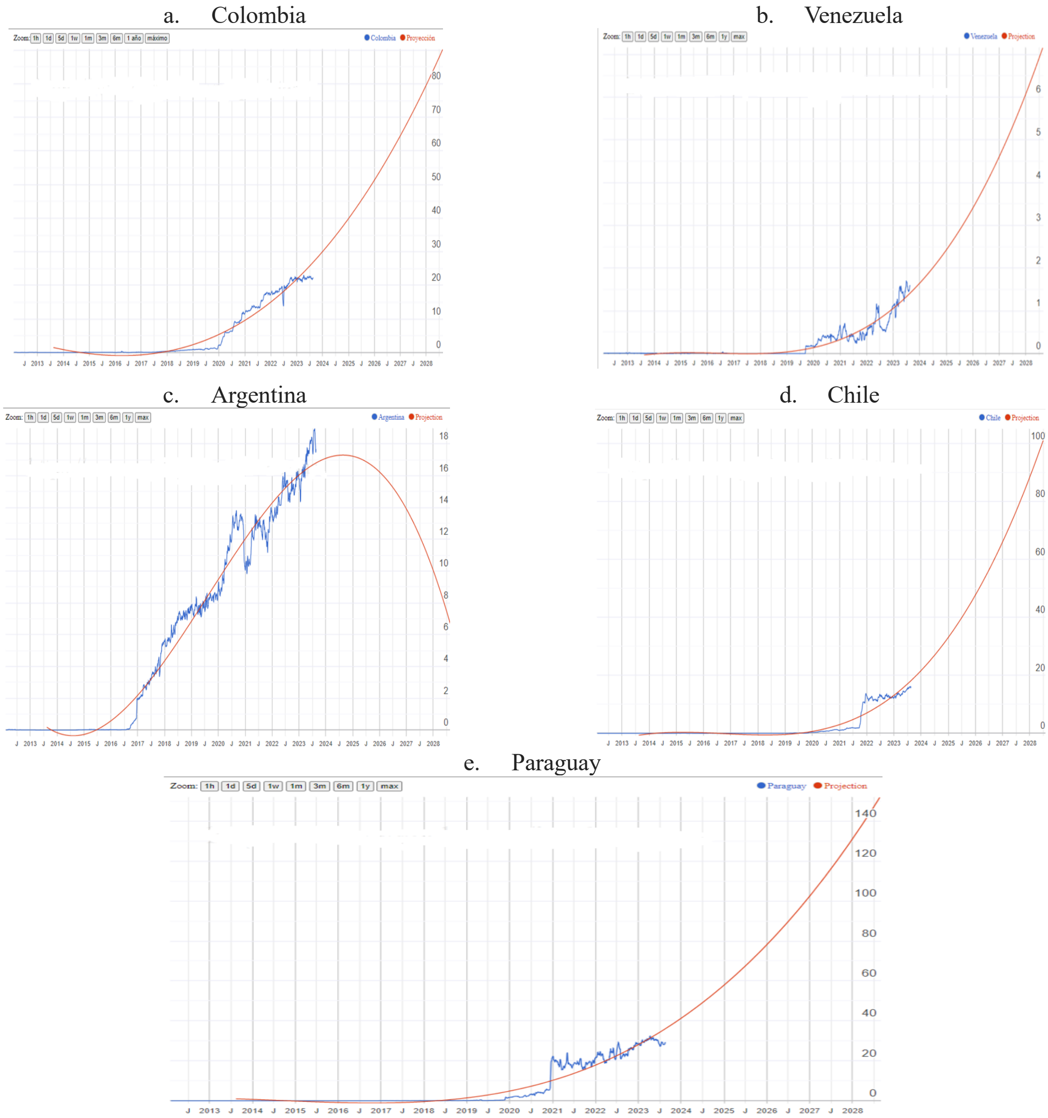
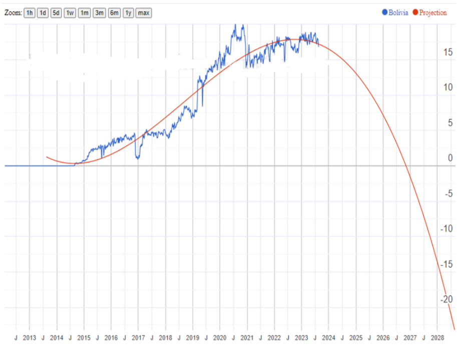
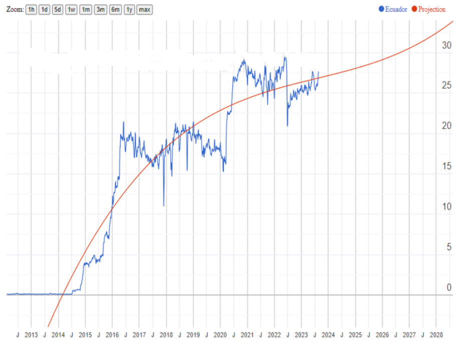


Figure 5. Trend results. 5(a) Bolivia, 5(b) Ecuador, 5(c) Perú, 5(d) Uruguay and 5(e) Brasil.

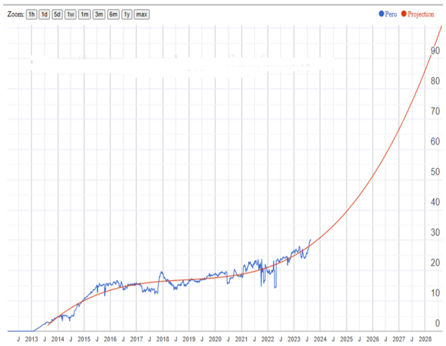
a. Bolivia



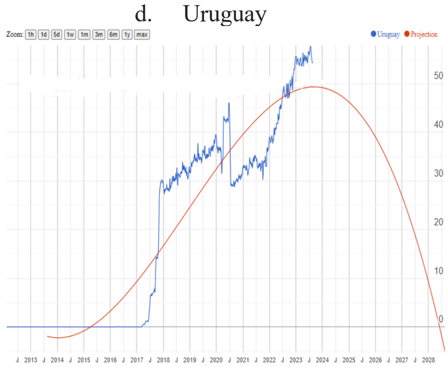
b. Ecuador



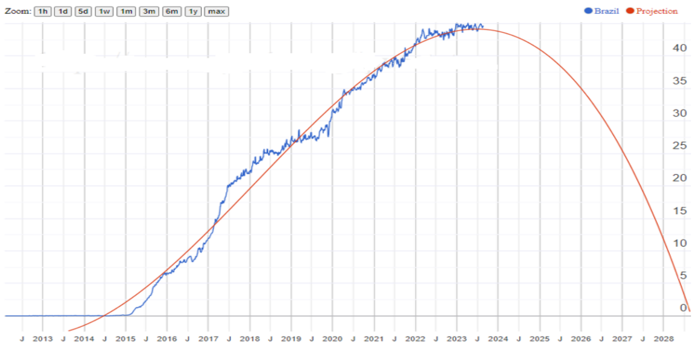
c. Perú



d. Uruguay



e. Brasil



With this algorithm, the same scale previously mentioned was used. Table 3 summarizes the graphs and their percentage growth trend, according to the third order polynomial model.

Table 3. Comparative and estimated growth by country for the next 5 years

Country	**% of growth according to the predictive model using the third order polynomial**	**Estimated growth**

Colombia	80 %	Acceptable high
Ecuador	33 %	Under
Perú	90 %	High
Venezuela	7 %	Muy bajo
Brasil	45 %	Acceptable
Bolivia	16 %	Very low
Chile	95 %	High
Paraguay	140 %	High
Uruguay	50 %	Acceptable high
Argentina	17 %	Very low

As can be seen, the countries with growth and adoption of the IPV6 protocol are Paraguay, Chile, Peru and Colombia; the other countries show a downward trend in adoption with a percentage equal to or below 50%.

DISCUSSION

For discussion purposes, a comparison of the predictive machine learning algorithms used to train the model is shown in Table 4.

Table 4. Comparison of the algorithms of the artificial intelligence model applied.

Model	**Advantages**	**Disadvantages**	**Level of Confidence**
Quadratic (2nd order)	- ability to capture simple nonlinear relationships.	- Less flexible than higher polynomials. Increased complexity may not fit complex data well.	Moderate
Polynomial (3rd order)	- Flexibility to capture non-linear relationships. Flexibility to model complex relationships	- Risk of overfitting with little data. - increased complexity	Moderate

The choice of the appropriate model will depend on the nature of the data and the objectives of the prediction [23],[24]. The different confidence levels are dynamic and vary from dataset to dataset and therefore should be analyzed with caution on a country-by-country basis given the costs and infrastructure required for implementation. the use of more complex models, such as higher order polynomials. This leads to a higher risk of over-fitting, which can reduce the reliability of predictions if not properly controlled. Similarly, the trial-and-error approach together with cross-validation can help determine which of these models is the most appropriate for the specific problem of IPv6 transition in Latin America [25], [27], [28], [29].

On the other hand, the results evidenced here are fundamental to contrast the low growth of some countries regarding the transition to the IPV6 protocol; it is evident how the different algorithms implemented with the data provided grow in a preponderant way while others do it in a little relevant way. The study contributes to the understanding and prediction of IPv6 adoption in some Latin American countries, [20]; offering a valuable perspective according to the reality of each country. With these results, it is possible to evaluate and learn from countries such as Paraguay and Colombia, which according to the two results are at the forefront of the transition. It is clear that public policies should be aligned towards digital communications and interconnection systems in the complete integration of telecommunications; despite the limitations, our results support the importance of the transition to IPv6 in the region and provide a solid foundation for future research and implementation strategies [21], [22].

CONCLUSIONS

Machine learning models deliver evident estimation results taking into account the mathematical models used in order to highlight the relevance of this type of tools that are fundamental in the future of telecommunications and of the new convergent and disruptive services of today. They also make it possible to propose and find quick and effective solutions that will have a significant impact on the transition to IPV6 protocol.

The study shows how some South American countries such as Paraguay and Colombia are growing exponentially and planned towards a rapid and successful transition; but it also highlights how other countries such as Venezuela and Bolivia are not growing at the expected rate. The two techniques used show that there are countries that demand not to be relegated from the new services and interconnection systems that necessarily require IPV6 addresses to minimize the connectivity gap in the region, being real challenges that each country must address immediately with public policies and measurable strategies that are verifiable and achievable in the short, medium and long term.

The tool, supported by artificial intelligence backed by machine learning models, delivers with high quantitative and qualitative precision the estimated percentages for the effective transition within the next 5 years. The use of predictive modeling and the use of different models such as high order polynomials have been shown to be fundamental and highlight their usefulness in prediction. High-order polynomial models can fit complex data, but with a higher risk of overfitting. Even so, they provide important contrasts to infrastructure and network planning, to regulators and technology leaders in the region, and to the different state entities in each country.

The analysis highlights the accuracy and reliability of the proposed model in the prediction estimation and, as technological conditions evolve, a staggered transition to IPv6 is expected; therefore, it is a new contribution to the knowledge that will positively boost the transition to IPv6 in Latin America, towards a strategic plan and structured framework to address this technological challenge.

Finally, the research provides relevant information on the adoption and transition to IPv6 in some Latin American countries, as well as a basis for future analysis. It is important to highlight the importance that the estimation evidenced in this article is in line with the trends found and therefore becomes an additional tool for decision making. However, the digital world is dynamic, and unexpected changes may impact the transition to IPv6 protocol in the region.

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Preliminary Results in the Implementation of Conscious Capitalism and Conscious Business in Colombian SMEs: Development and Validation of an Organizational Diagnostic Tool

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Abstract. This study focused on the development and validation of an organizational diagnostic tool for Colombian SMEs, with the object to map their cultural and operational status under the framework of Conscious Capitalism and Conscious Business. After screening 443 articles found in two databases, 32 key studies were selected to serve as the theoretical foundation for integrating these approaches into organizational evaluation. Fundamental principles such as higher purpose, stakeholder integration, conscious leadership, and the creation of an ethical and responsible organizational culture were identified.

The tool was designed in Microsoft Excel, allowing the evaluation of key operational and cultural variables such as marketing, finance, and leadership. This tool with the intention to provide small businesses with a detailed diagnosis to facilitate the identification of areas for improvement and operational optimization, while aligning them with sustainability and social responsibility practices.

The developed methodology will be applied in two companies getting on practical results on its effectiveness. The findings from this implementation will be presented in a final version later.

Overall, the preliminary results highlight the importance of integrating Conscious Capitalism and Conscious Business to promote responsible and sustainable business practices. Areas for future research are proposed, such as expanding the sample of companies and analyzing the long-term impact of these practices, contributing to a deeper understanding of their transformative potential in the Colombian business landscape.

Keywords: Organizational Transformation, Conscious Business, Management Models, Continuous Improvement, Conscious Capitalism.

1 Introduction

In an increasingly competitive and uncertain business environment, organizations are forced to adopt more innovative and adaptable work models. However, traditional management tools often fail to respond quickly to these changes or adequately address fundamental human critical aspects to organizational performance.

In this context, approaches such as Conscious Capitalism and Conscious Business emerge, proposing the creation of value through ethical principles and shared values. These models present themselves as promising alternatives for companies seeking to go beyond profit maximization, integrating sustainability, stakeholder well-being, and more responsible leadership. The challenge is related with establishing the concrete steps that will allow organizations to transition to these new paradigms.

Taking into in considertaion, this paper proposes the design of a methodology to assess and measure the initial state of small businesses, which want to start transformational processes, with the aim of adopting more conscious practices and promoting more responsible and sustainable management.

2 Background and Related Work

The concept of conscious capitalism has gained relevance in recent years as an alternative to traditional business management models. Various research studies and publications have provided theoretical frameworks and practical tools to integrate this approach into organizations.

One of the first and most influential works on this topic is the book *Conscious Capitalism: Liberating the Heroic Spirit of Business* (2013) by John Mackey and Rajendra Sisodia, where the authors define and characterize the four fundamental principles of conscious capitalism: higher purpose, stakeholder integration, conscious leadership, and conscious culture and management. These principles aim to transform businesses into organizations that not only seek economic profitability but also the well-being of people and the environment (Mackey & Sisodia, 2013).

Subsequently, in 2018, Raj Sisodia, along with Timothy Henry and Thomas Eckschmidt, expanded this concept in *Conscious Capitalism Field Guide: Tools for Transforming Your Organization*. In this text, the authors present a more detailed set of tools and a comprehensive framework for implementing significant change within organizations, providing leaders with a more practical approach to transformation toward a conscious business model (Sisodia, Henry & Eckschmidt, 2018).

In a similar line, Fred Kofman, in his work *Conscious Business: How to Build Value Through Values* (2013), proposes an organizational health model based on twelve transformations necessary to create more conscious organizations. Kofman emphasizes the importance of conscious attitudes and aptitudes, as well as the dimensions of being, doing, and having, to foster a positive impact on both people and organizations (Kofman, 2013).

Meanwhile, Frederic Laloux, in *Reinventing Organizations* (2015), presents an innovative approach by questioning whether it is possible to reinvent the way work is organized in companies. Laloux offers a classification of organizations according to their evolutionary model and presents the key characteristics of each type. His proposal focuses on creating more inclusive and collaborative organizations that promote the purpose and integral development of their members (Laloux, 2015).

Finally, Nilima Bhat and Raj Sisodia, in *Shakti Leadership: Embracing Feminine and Masculine Power in Business* (2016), introduce the idea of integrating both feminine and masculine power in business. According to the authors, this approach, based on the principles of yoga, provides a more balanced and holistic understanding of leadership, allowing organizations to harness the complementary energies of both genders to generate a more harmonious and productive work environment (Bhat & Sisodia, 2016).

These works, among others, have significantly contributed to the development of a robust theoretical framework for conscious capitalism, providing organizations with the necessary tools to undergo a transformation toward more ethical, inclusive, and sustainable management models.

3 Research Methodology

The research adopted a comprehensive methodological approach, combining the design and development of a consulting tool, a systematic review of specialized literature, and the validation of this tool with experts in the field of conscious consulting. The objective was to create an effective tool for organizational diagnosis in small businesses, incorporating the principles of Conscious Capitalism and Conscious Business.

The phases of the research were as follows:

3.1 Systematic Literature Review

A systematic literature review was conducted using a specialized search equation to select a representative set of references on Conscious Capitalism and Conscious Business, as well as Cultural and Operational Business Diagnostics. This review served as the theoretical foundation for the study, allowing for the identification of the most relevant and current approaches in the field, and providing a solid conceptual framework for the subsequent development of the tool. During this phase, master's and undergraduate students from the university's research groups were integrated, contributing actively to the development of the stage.

3.2 Diagnostic Tool Design

As part of the project design, a business diagnostic tool was developed in Excel, aimed at mapping the organizational state of small businesses at the cultural and operational level. This tool is structured to assess various aspects of the business, allowing companies to identify areas for improvement and help them to alight with the principles of Conscious Capitalism and Conscious Business.

3.3 Validation with Experts:

In the validation process, an evaluation was conducted with experts in Madrid, Spain. These professionals provided crucial feedback on the designed tool. The information gathered from their comments let to reaserch team to adjust and improve the final version, ensuring that the instrument reale cab be effective and applicable to the real needs of organizations.

3.4 Refining the Model:

The results obtained during the validation revealed important aspects that will allow the diagnostic tool to be fine-tuned, adapting it to the specificities of the Colombian business context before its application to real companies. Thus, a new, more flexible and applicable version is expected to be developed, which will be used by small businesses to facilitate their transformation process toward more conscious and sustainable management models.

4 Results

4.1 Systematic Literature Review:

A comprehensive search was conducted in the Web of Science and Scopus databases using specific search equations to identify relevant articles on the topics of interest. A selection and filtering process was applied to identify the most pertinent studies for the research objectives. Below is the search script used in the Web of Science and Scopus databases.

Table 1. Script for the Systematic Literature Review

Data Base	Research Script
Web of Science	"Conscious Capitalism"(All Fields) OR "Conscious companies" (All fields) OR "Triple benefit" (All fields) AND "Higher Purpose"

	(All fields) OR "Stakeholder Orientation" (All fields) OR "Conscious Leadership" (All fields) OR "Conscious Culture" (All fields)
Scopus	(ALL ("Conscious Capitalism") OR ALL ("conscious companies") OR ALL ("Triple benefit") AND ALL ("Higher Purpose") OR ALL ("Stakeholder Orientation") OR ALL ("Conscious Leadership") OR ALL ("Conscious Culture")) AND PUBYEAR > 2002

Once the articles were downloaded, they were subjected to an approval and disapproval process through a screening technique, which consisted of selecting and refining the articles based on the topics to be documented in this research. A total of 443 articles were found across the two databases that were related to the search equations. However, after refinement, 32 articles were selected that were more aligned with the concepts to be documented in the research.

The main theories and conceptual frameworks on Conscious Capitalism were explored, identifying their key principles, such as a higher purpose, stakeholder integration, conscious leadership, and a responsible organizational culture. This research provided the theoretical foundation for integrating these principles into the diagnostic tool and guiding small businesses towards more sustainable and ethical business models. Students contributed by identifying trends in the field, key references from countries such as Germany and other parts of the world, and tools previously developed by other institutions like Conscious Business from the Netherlands, which enriched the analysis and identification of similar tools.

Conscious business and capitalism approaches, although relatively recent in the business field, are deeply connected to the evolution of the corporate responsibility debate (O'toole & Vogel, 2011). Based on the information gathered in this review, it is concluded that conscious businesses, although closely linked to previous concepts such as corporate social responsibility, sustainability, and corporate ethics, represent a distinct approach. These models have evolved in response to the growing demands of a more ethical society and a business environment that demands higher levels of responsibility. Below, in **Fig. 1**, ilustrates some of these concepts:

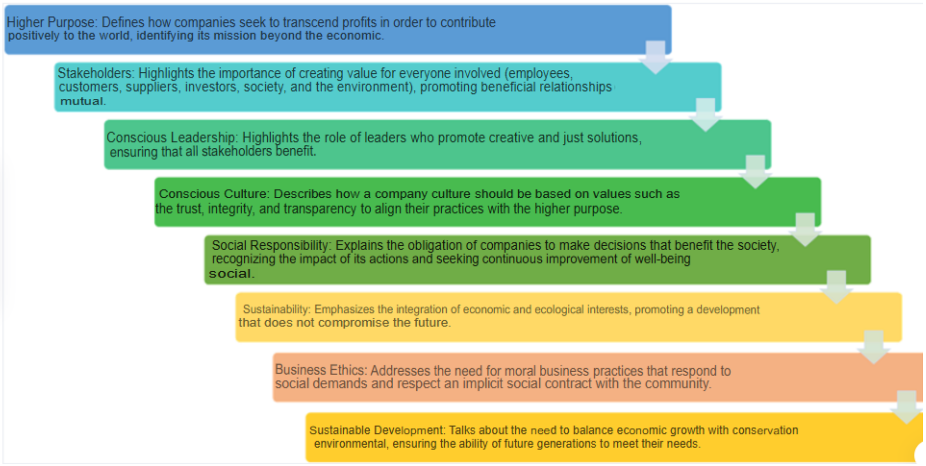

Fig. 1. Main Concepts related with Consicious Business

The research to define the variables to be used in the design of the tool was focused on two key areas. First, existing models and approaches were explored to evaluate organizational culture, considering aspects such as values, behaviors, and shared beliefs. Second, models of operational efficiency, continuous improvement, and process management within organizations. As a result, the identified variables were classified into operational and cultural categories, from which it was determined which ones would be considered and through which indicators they would be measured.

Table 2. Cultural and Operational Variables Identify

Cultural Variables	**Operational Variables**
Culture and values	Financial Performance
Leadership and Trust	Customer Satisfaction
Cohesion and Collaboration	Efficiency and Processes
Flexibility and Adaptability	Business Impact and Responsibility
Job Satisfaction and Well-being	Innovation and Growth
Personal Development and Performance	Labor Practices and Ethics
Communication and Transparency	Strategy and Management

4.2 Diagnostic Tool Design

The business diagnostic tool was designed in Microsoft Excel, including the selection of impact areas (Marketing, Sales, and Finance; Value Added, Business Experience and Impact; Strategy: Purpose, Perspectives, Identity; Internal People, Their Needs - Feelings – Capabilities; Leadership; Structure and Organizational Model; Processes, Standardization and Quality; Technology), the formulation of questions, and the definition of conscious metrics. In **Fig. 2**, the command buttons used in the tool to facilitate its usage and visualization are shown.

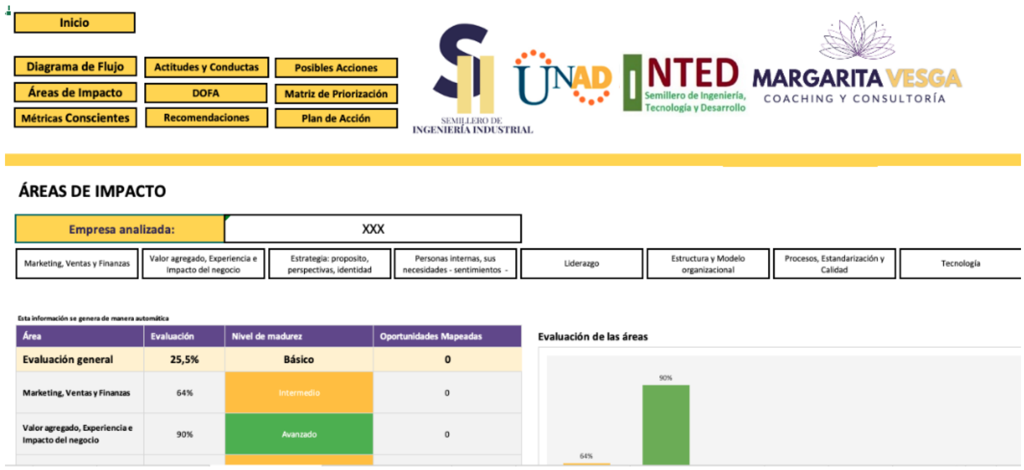

Fig. 2. Tool Visualization

The tool designed addresses the following key approaches not only to improve the understanding of culture and operational processes within small businesses but also to create a general map of how they can be intervened, the impact of their actions at a strategic level, and the initial actions to take to achieve it.

Organizational Diagnosis: The organizational diagnosis acts as a guide for business transformation, selecting the most appropriate intervention techniques to solve specific problems and improve organizational effectiveness. This process is essential for both consultants and managers, who can make informed decisions about the need for consultancy or evaluate the diagnostics presented (Khun, 1975).

Continuous Improvement: The implementation of a continuous improvement culture is not immediate, as it involves a profound change in mindset, habits, and practices within the organization. Success in this transformation depends on strong leadership, adequate resource allocation, and active participation in the process. Continuous improvement is a long-term commitment, not a result of quick fixes or isolated programs (FEMP, 2003).

Parametric Analysis and Process Mapping: All organizations, regardless of their size, depend on interrelated processes to deliver products and services. Efficient management of these processes is crucial to maintaining competitiveness. Parametric analysis, also known as process mapping, helps identify areas for improvement, increase efficiency, and ensure the fulfillment of organizational goals (Álvarez, 2016).

Conscious Capitalism: Conscious Capitalism emphasizes the business's purpose, which goes beyond maximizing profits by aiming to elevate humanity and meet real needs. It focuses on creating value for all stakeholders and implementing an organizational culture based on values such as trust, responsibility, and transparency. Additionally, it promotes selfless leadership that prioritizes the well-being of people and the company's purpose over personal interests (Bhat & Sisodia, 2016).

Conscious Business: Conscious businesses encourage the development of consciousness in all their members, stimulating reflection on their role in the world, both individually and collectively. In addition to improving the quality of life and happiness of their employees, they promote labor relations based on respect and solidarity. A conscious company is based on three dimensions: impersonal (effectiveness and efficiency), interpersonal (relationships between members), and personal (employee well-being), recognizing that organizational success depends on how these three aspects are managed in an integrated manner (Kofman, 2013).

4.3 Validation with Experts:

To carry out this stage of the research methodology, contact was made with the company Conscious Business Consulting S.L., led by José Suarez Arias Cachero. This approach was made possible due to prior collaboration through the first seminar on Conscious Capitalism, held in the city of Yopal in partnership with the Chamber of Commerce of Casanare, and managed by the Industrial Engineering research group at UNAD.

The collaboration materialized through a research stay, with the aim of working together with three experts in the field to validate the developed tool. Below are the details of the experts involved in the process:

Table 3. Expert evaluators

Expert Name	e-Mail	Position	Organization
Joachim Hesse	jo@hesse.tc	Consultant	Conscious Business
Anabel Dumlao	anabel.dumlao@axialent.com	Board Member	Axialent
José Arias-Ca-chero	jose.suarez@axialent.com	Administrador	Conscious Business Consulting S.L

The overall opinion of the experts regarding the research project and the designed tool was largely positive, recognizing both the effort invested and the potential of the proposal. The experts appreciated the comprehensive approach that combines organizational diagnosis, conscious capitalism, and both cultural and operational dimensions, highlighting the tool's ability to assess various organizational aspects and provide action-oriented recommendations.

However, they also pointed out key areas for improvement. First, they suggested that the tool should be more flexible and adaptable, allowing for adjustments based on the specific realities of companies, especially small ones or those without clear organizational structures. Additionally, they recommended including a component that would allow the estimation of the impact of the generated recommendations, which would strengthen users' trust in the results obtained.

Another point raised was the need to broaden the tool's scope to include more stakeholders, such as the community and the supply chain, and to reduce the subjectivity of the responses. To address this, they suggested using more detailed measurement scales to allow for better interpretation of business practices. They also recommended testing the tool with a larger and more diverse sample of companies to ensure its validity and improve the generalization of the results.

In summary, while the experts acknowledged the innovation and relevance of the tool, they also proposed significant adjustments to make it more effective and applicable across various organizational contexts.

5 Discussion and Conclusions

The research conducted makes a significant contribution to the development of a consulting methodology to map the organizational state of SMEs in Colombia, focusing on cultural and operational aspects. The importance of integrating Conscious Capitalism and Conscious Business in organizational transformation processes is emphasized, highlighting their potential to promote more responsible and sustainable practices.

Additionally, the importance of having a diagnostic tool validated by experts is underscored, allowing for informed decision-making regarding the implementation of these practices.

Despite the progress made, the research presents some limitations, such as the sample size, the restricted geographic focus, and the lack of longitudinal data. Opportunities for future research are suggested, including expanding the sample of companies, analyzing the long-term impact of the practices adopted, and exploring the barriers and facilitators to adopting more conscious business models. These studies could provide a deeper understanding of how Conscious Capitalism and Conscious Business can positively transform the business landscape in Colombia.

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Eje 3 – Innovación Educativa para las Ciencias Fundamentales e Ingeniería

Review on the optimization of photovoltaic installations against the shadow effect using dynamic algorithms

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Abstract. Solar energy is a promising renewable source, but its performance is affected by the shading effect caused by objects such as buildings, dust, bird droppings, and clouds. This phenomenon can reduce energy efficiency and cause durability issues in photovoltaic systems. Although strategies have been developed to mitigate the shading effect, the study of dynamic reconfiguration algorithms that adapt to changing conditions in realtime remains a necessity. This article reviews current mitigation strategies and evaluates the effectiveness of algorithms aimed at optimizing systems, especially against the shading effect caused by clouds, through the reconnection of the topology of photovoltaic modules, with the convergence criterion being the increase in the global maximum power delivered by the system. The evaluation method was experimental through simulations where matrices of photovoltaic modules and shading patterns were proposed. To compare reconfiguration methods, shading patterns were applied to all algorithms, resulting in an increased power percentage. The algorithm that stood out the most in terms of power increase was the Modified Harris Hawks Algorithm (MHHO), increasing power by up to 33.27%. Although the results show that these strategies may provide a solution to the shading effect, the necessary architecture for real world application must be considered, as switching elements and additional connection lines are significant barriers to potential implementation.

Keywords: Solar energy; Shading effect; Photovoltaic systems; Dynamic reconfiguration; Bioinspired algorithm.

1 Introduction

Solar energy has established itself as one of the most promising renewable sources worldwide, playing a crucial role in reducing dependence on fossil fuels and mitigating climate change [1]. However, the performance of photovoltaic (PV) systems is compromised by various factors, with the shading effect being one of the most significant. This phenomenon occurs when objects partially or completely block solar radiation from reaching PV modules, leading to a decrease in energy efficiency and potential structural and durability issues, such as overheating in certain modules and the deterioration of their components [2]. In recent years, multiple strategies have been developed to mitigate the impact of shading, including electrical connection reconfiguration and the implementation of solar tracking devices [3]. However, the ability of PV systems to adapt to realtime shading conditions remains a challenge. The optimization of these installations through dynamic algorithms presents an effective alternative, allowing for the automatic adjustment of PV module configurations based on variations in irradiance and shading patterns, particularly those caused by meteorological phenomena such as passing clouds [3]. Analyzing the shading effect using dynamic algorithms not only enhances the understanding of this phenomenon's impact but also enables the development of more efficient solutions to maximize solar energy capture. In this context, it is essential to thoroughly examine the various machine learning techniques and dynamic reconfiguration algorithms proposed to improve PV system performance. These algorithms have the potential to optimize energy generation in real time, ensuring a more efficient use of PV infrastructure and minimizing the formation of hot spots that could compromise the modules' lifespan [4]. The increasing implementation of PV systems in urban and rural environments makes it imperative to seek solutions that mitigate energy losses caused by shading. Identifying the effectiveness of dynamic reconfiguration algorithms in optimizing energy production under changing conditions will lay a solid foundation for largescale applications. Thus, studying and implementing strategies based on artificial intelligence and dynamic optimization will significantly contribute to the development of a more efficient, sustainable, and resilient energy system in the face of environmental variations [5].

2 Method

The main objective of this project is to conduct a review of dynamic algorithms used in the optimization of photovoltaic systems under the shading effect; their impact on energy efficiency will be evaluated, and the algorithmic solutions developed to date in scientific literature will be analyzed. The methodology adopted in this study follows a descriptive, review based, and comparative approach, relying on a systematic review of specialized literature. Since no practical application of algorithms is performed, this work is characterized by its qualitative nature, focusing on the comparative analysis of various algorithmic models found in the literature. These include both bioinspired algorithms and those based on the dynamic reconfiguration of systems. Among the notable algorithms in this study is the Coyote Optimization Algorithm (COA), inspired by the social behavior of coyotes, which balances exploration and exploitation to optimize global power extraction in photovoltaic systems under partial shading conditions. Similarly, the Butterfly Optimization Algorithm (BOA), based on the pollination behavior of butterflies, utilizes global and local exploration to adjust photovoltaic panel configurations, thereby improving energy efficiency. The Direct Power Evaluation Algorithm, on the other hand, specializes in maximizing the power output of photovoltaic modules under variable irradiance, addressing the problem through a discrete optimization model. Additionally, the Marine Predators Algorithm (MPA)Based Photovoltaic Reconfiguration Algorithm applies a metaheuristic strategy inspired by the hunting patterns of marine predators, optimizing panel arrangement to minimize power losses. Finally, the Modified Harris Hawks Optimizer (MHHO)Based Photovoltaic Reconfiguration Algorithm employs an adaptive approach based on surprise attacks, similar to the behavior of Harris hawks, to enhance energy capture under nonuniform irradiance conditions. These algorithms provide advanced and adaptive approaches to maximize energy generation in photovoltaic systems under the shading effect, contributing to improved energy efficiency in these installations. The comparative analysis of these approaches will facilitate the identification of the most effective algorithms and establish a solid foundation for the development of future solutions in the field of renewable energy [8].

2.1 Shading Effect and Its Implications

The shading effect is a well-documented phenomenon that can cause significant energy production losses in photovoltaic (PV) systems. It has been shown that partial shading can reduce energy output by up to 90%, severely impacting the efficiency of the installation, especially in urban environments where buildings and other obstacles are present [6]. Additionally, atmospheric factors such as variable cloud cover can further reduce available irradiance, negatively affecting system stability. This effect is critical not only because it reduces generated energy but also because it can accelerate panel degradation by creating hot spots in the affected cells, compromising the system's lifespan.

An important aspect often overlooked is that shading losses are not proportional to the shaded surface; even a small obstruction can significantly affect the performance of the entire system. This occurs because photovoltaic panels are composed of cells connected in series, meaning the performance of the entire chain depends on the weakest cell. Thus, a single shaded point can cause a voltage drop across the entire series, leading to substantial energy production losses. Reviewed literature, such as the work of [7], reinforces this point by analyzing the impact of shading on solar PV panels, showing that shading not only reduces energy production but can also cause structural damage if corrective measures like bypass diodes are not implemented. Their analysis highlights that under nonuniform irradiance conditions, some PV cells may reverse their polarity, acting as resistors, which generates hot spots that, if not mitigated, can destroy the entire panel. This phenomenon, known as the “hot spot effect,” is particularly problematic because the resulting thermal degradation can be difficult to detect visually until considerable damage has occurred. This argument underscores the importance of incorporating mitigation strategies from the design stage, especially in urban installations where the risk of shading is constant.

It is evident that any photovoltaic system in an urban environment or with variable obstructions must consider the use of technologies such as bypass diodes or advanced Maximum Power Point Tracking (MPPT) configurations, which optimize performance even under partial shading conditions. These solutions not only mitigate energy losses caused by shading but also ensure that the system operates efficiently under different irradiance levels. In fact, bypass diodes work by redirecting current around the affected cells, allowing the other cells in the series to continue operating without being impacted by localized shading. This is one of the reasons why systems equipped with these technologies are more robust and capable of maintaining stable performance over time.

To ensure the effective implementation of these technologies, it is essential to conduct detailed simulation studies, such as those proposed in MATLAB or PVsyst, which accurately quantify losses and design specific solutions for each installation. This approach is particularly useful in urban installations, where shading conditions may change throughout the day due to variations in the sun’s position and the height of obstacles. Simulation tools like MATLAB and PVsyst allow for the analysis of different scenarios and adjustments to system configuration to minimize losses, providing designers with more precise control over the installation. In fact, according to the study by [9], differences in simulation results between PVsyst and MATLAB/Simulink can be significant, with monthly variations of up to 49.32% due to thermal sensitivity and differences in MPPT algorithms and data input methods. This highlights the importance of carefully selecting software and design parameters to optimize the energy production of PV systems, especially in urban environments where irradiance conditions can change rapidly due to building and obstacle shading.

Moreover, it is crucial to emphasize that while using shading mitigation technologies may increase the initial costs of PV installation, in the long term, these investments are necessary to maximize energy production and reduce payback periods. This approach not only improves the technical feasibility of systems in shading challenged environments but also reinforces economic justification by ensuring a higher return on investment in urban or complex areas. Overall, adopting measures such as using bypass diodes, conducting preinstallation simulations, and optimizing system configurations allows for maximizing energy production while ensuring the economic sustainability of PV projects.

2.2 Shading Effect Mitigation Strategies

Several strategies have been proposed to mitigate the shading effect, such as:

Reconfiguration of Connections: Photovoltaic System Connection Reconfiguration the operating principle of photovoltaic reconfiguration algorithms lies in the ability to dynamically change the electrical configuration of photovoltaic (PV) modules to maximize energy production under partial shading conditions. This is achieved through the continuous optimization of interconnections between solar panels, adapting their electrical topology to variable solar irradiation conditions. Several studies have demonstrated that this flexibility in the arrangement of electrical connections is essential to mitigate the negative effects of shading and improve the overall energy efficiency of the system. For instance, in [10], it was reported that reconfigurable systems can achieve a 15–25% increase in energy production compared to static configurations under partial shading conditions. This efficiency increase is due to the ability of reconfiguration algorithms to redistribute energy generated by betterilluminated modules, minimizing losses caused by reduced irradiance in certain parts of the array. Other studies have also corroborated this approach, emphasizing that system adaptability to shading conditions is an effective strategy for improving PV system energy performance.

A complementary approach in the context of photovoltaic system connection reconfiguration is the implementation of realtime partial shading detection techniques, such as the one proposed by [11]. This technique, by accurately and timely detecting the presence of shading without disconnecting the load, enables continuous optimization of interconnections between PV modules. This way, the dynamic reconfiguration of connections adapts to irradiance variations, minimizing mismatch losses and maximizing system efficiency. In connection reconfiguration, early shading detection is crucial, as it allows for a rapid modification of the connection topology between modules, redistributing energy more efficiently. The proposed technique enables reconfiguration algorithms, such as those based on COA, BOA, or MPA optimization, to adjust system connections so that the betterilluminated modules compensate for the negative effects of shading in other parts of the array. This combination of advanced detection and dynamic reconfiguration highlights the importance of actively managing interconnections, ensuring a significant improvement in energy production under partial shading conditions.. Lower level headings remain unnumbered; they are formatted as runin headings.

Solar Tracking:. Solar tracking systems provide an efficient solution for maximizing solar energy capture by continuously adjusting the orientation of photovoltaic panels toward the sun. This approach is particularly relevant due to variations in the sun's position throughout the day and seasons. By maintaining panels at the optimal angle, tracking systems can significantly increase energy production. According to the study conducted by [12], an increase of between 20% and 35% in energy generation has been recorded compared to fixed systems. Although this technology involves higher initial costs and maintenance, its ability to enhance performance in locations with high solar irradiance makes it an attractive option for maximizing PV system efficiency.

Smart Inverters: Modern inverters can optimize the performance of PV modules under shading conditions [13], achieved through advancements in maximum power point tracking (MPPT) algorithms, which allow inverters to quickly adapt to irradiance changes caused by partial shading. This dynamic adjustment prevents the overall system performance from being compromised by efficiency losses in individual modules, ensuring that even in scenarios with variable light, the PV system continues to operate efficiently and stably. An example of power increase achieved through optimization systems is described by [13], where a photovoltaic system powering submersible pumps was improved, obtaining significant efficiency gains thanks to the use of frequency inverters and intelligent techniques. These types of optimizations have enabled PV system efficiency improvements of up to 20% under certain operating conditions. Thus, modern inverters not only compensate for shading effects but also enhance systems against environmental and contextual variations, increasing the overall efficiency of the photovoltaic installation, even in complex scenarios.

2.3 Dynamic Reconfiguration Algorithms

Dynamic reconfiguration algorithms have become a significant research area in photovoltaic system optimization; these algorithms can adapt in real time to changing environmental conditions, particularly shading, which affects the efficiency of solar panels. Through advanced modeling and control techniques, they allow the system to maintain and improve performance in complex and dynamic scenarios. Adaptive reconfiguration is a key research field for improving renewable energy systems' efficiency. In particular, algorithms based on collaborative optimization techniques and regenerative flow control have proven effective in managing systems that require dynamic adjustments in response to environmental variations. According to the study by [14], integrating adaptive control technologies, such as LMS algorithms applied to hardware in reconfigurable systems, allows for optimizing operating conditions and minimizing environmental impact by adapting the system to new configurations. These algorithms not only dynamically adjust PV installation topology but also focus on sustainability and infrastructure component reuse, aligning with circular design principles. This not only improves energy efficiency but also extends the lifespan of installations and reduces the ecological impact associated with the wear of traditional systems. For instance, [14] associates these algorithms with those dependent on mobile components subject to frequent replacement, such as wind turbines that require constant maintenance due to friction and wear of mechanical elements like gears and transmission shafts. Such systems tend to have a limited lifespan and generate a higher environmental impact due to the need to replace worn parts, in addition to mechanical friction increasing energy losses and reducing overall system efficiency. Additionally, according to [15], the use of collaborative geometric control techniques ensures precise realtime alignment, further increasing the adaptive capacity and optimization of energy systems. These techniques dynamically coordinate different installation components through algorithms that adjust the geometry and orientation of energycapturing devices, such as photovoltaic panels and wind turbines, based on environmental conditions. By reducing alignment errors and optimizing the use of incident energy, overall system efficiency is maximized, minimizing component wear and, consequently, reducing necessary maintenance interventions.

The following are three key approaches in this field:

AdaptiveAlgorithms:. Adaptive algorithms have been developed to automatically adjust PV module configurations based on changing shading conditions. These algorithms continuously analyze the irradiance distribution over the modules and adjust their interconnections to minimize losses. This approach improves system efficiency by up to 20%, a significant improvement compared to traditional static configurations, as mentioned by [16].

Machine Learning Techniques:. Machine learning techniques, particularly neural networks, are introduced to anticipate solar irradiance variations due to factors such as weather and time of day. These techniques enable more accurate prediction of shading occurrences and allow module configuration adjustments before shading affects performance. According to [17], applying these techniques has increased installation efficiency by 30%, demonstrating machine learning's potential to optimize PV system operations.

Genetic and BioInspired Algorithms: Genetic. and bioinspired algorithms have gained importance in PV system optimization due to their adaptability and efficiency in handling complex contextual conditions. Inspired by natural processes such as evolution and the behavior of specific species, these algorithms offer innovative solutions to overcome challenges like shading. In this regard, the research by [18] explores the use of genetic algorithms and other bioinspired techniques for dynamic PV module reconfiguration. These algorithms mimic natural processes like evolution to find the optimal configuration that minimizes shading losses. Genetic algorithms, in particular, allow for exploring a vast solution space and converging toward the most efficient configuration in complex shading conditions. This approach not only improves energy efficiency but also offers flexibility to adapt to different scenarios and operational requirements.

Furthermore, according to [19], genetic algorithms applied to dynamic environments offer significant advantages due to their ability to handle a broad solution space and adapt to realtime changes. In community detection, genetic algorithms identify interconnected node groups within a network, and their efficiency lies in their ability to adapt to structural network changes, which is crucial in dynamic networks. The evolutionary nature of these algorithms facilitates the generation of highquality solutions within limited execution times, a crucial aspect when facing largescale problems where traditional methods are unfeasible and adaptability is essential. Additionally, techniques for repairing and adapting individuals and populations used in these algorithms enable systems to regenerate and continue providing valid solutions amid environmental changes, increasing the robustness and applicability of bioinspired algorithms in realworld scenarios. Another important aspect is highlighted again by [19], who presents an approach to optimization in dynamic environments, emphasizing the importance of adapting populations to changes over time. Their research introduces techniques such as immigrant strategies, which help maintain population diversity by introducing new individuals during the evolutionary process.

2.4 Combination of Technologies

The integration of various technologies in the optimization of photovoltaic installations is an emerging approach that promises to maximize energy efficiency, particularly in environments with high shading variability. This integrative approach combines solar tracking systems, dynamic reconfiguration algorithms, energy storage techniques, and advanced simulation tools, among others, to mitigate shading losses and maximize realtime energy production. Below are the main components and benefits of this technological combination:

Solar Tracking Systems:. Solar tracking systems are mechanical devices designed to orient solar panels to follow the sun's trajectory throughout the day. These systems can be singleaxis or dualaxis, allowing adjustments in the inclination and rotation of the panels to maximize solar radiation capture. The fundamental goal is to keep the panels optimally positioned perpendicular to the sun's rays, increasing energy generation efficiency. These systems are particularly useful in regions where lighting conditions vary significantly, as they adapt in real time to the sun's position and other environmental variables, such as shading or cloud cover. According to the literature, solar tracking systems optimize energy capture by orienting solar panels to follow the sun's path throughout the day. As stated in the study by [20], a dualaxis solar tracking system controlled by a fuzzy logic algorithm demonstrated a 10.66% improvement in energy capture compared to fixedorientation panels. However, data from the same study suggest that combining this technology with dynamic reconfiguration algorithms can yield even greater improvements, increasing energy generation by up to 30% in scenarios with significant shading.

Integration with Dynamic Reconfiguration Algorithms: The interaction between solar tracking systems and dynamic reconfiguration algorithms is essential to maximizing photovoltaic panel efficiency. Solar tracking systems continuously adjust the panel orientation to maximize sun exposure, ensuring maximum solar radiation capture. Simultaneously, dynamic reconfiguration algorithms optimize the electrical topology of the modules by adjusting panel interconnections to minimize energy losses caused by partial shading. This dual approach ensures that panels operate at their optimal point under diverse environmental conditions, even when partial shading could reduce system efficiency. The research conducted by [21] reinforces the importance of this technological integration, highlighting how the incorporation of advanced technologies, such as solar concentrators and bioinspired control algorithms, can further enhance dynamic reconfiguration systems. Solar concentrators redirect radiation toward the panels, increasing sun exposure hours and maximizing energy conversion. Meanwhile, control algorithms based on neural networks dynamically adjust heliostat orientation and panel interconnections, tracking the sun's movement and adapting to irradiance changes. Additionally, technologies such as airborne adapters for reconfigurable systems (A2SR), mentioned in the Cometa Solar Project proposed by [21], offer an innovative approach to improving system efficiency under variable conditions. These adapters adjust the height and angle of solar concentrators, directing radiation toward the panels and optimizing sunlight utilization, even in areas where shading is a constant issue.

Energy Storage Techniques:. Integrating energy storage technologies, such as highcapacity batteries, with tracking systems and reconfiguration algorithms can stabilize energy production and ensure a constant supply. This is particularly useful in environments with high shading variability, where generation may be intermittent. According to [22], it is crucial to store excess energy generated during periods of high irradiance so the system can release this energy when shading reduces production, maintaining a steady energy flow. According to [22], energy storage, particularly through battery systems, represents a key technology for increasing the flexibility and reliability of energy systems, which is especially beneficial in grids integrating distributed resources and nonconventional renewable energy sources like solar photovoltaics. In Colombia, recent regulations have incentivized the adoption of these technologies to improve supply stability, reduce energy costs, and facilitate the integration of renewable energy. These technologies also help mitigate issues related to intermittency and grid congestion, which is crucial in areas affected by shading in photovoltaic systems.

Advanced Simulation and Modeling:. Using advanced simulation and modeling tools, such as computational fluid dynamics (CFD) and meteorological prediction models, enables more accurate forecasting of shading conditions and available irradiance in different scenarios. This facilitates installation planning and optimization from the design phase, ensuring the most efficient technology combination. By simulating various configurations and conditions, engineers can identify the optimal technology mix to maximize energy production in specific situations. In line with [23], advanced simulation enables the design of more efficient portable solar systems, optimizing orientation and the use of solar trackers through structural analysis tools like SolidWorks and other finite element methods. These simulations not only enhance the performance of photovoltaic systems but also allow for the evaluation of various operating scenarios and adjustments to key variables such as panel orientation and solar incidence under dynamic conditions. Thanks to these tools, solar tracking systems and dynamic reconfiguration algorithms can be evaluated under different irradiance and shading conditions, optimizing their configuration before physical implementation. This approach ensures that photovoltaic systems are not only more energyefficient but also better adapted to the specific environmental conditions where they will be installed.

2.5 Future Research

Although advances in dynamic reconfiguration and the combination of technologies have significantly improved photovoltaic installation efficiency, there are still unexplored areas that present opportunities for future research. According to [24], using models based on selfsimilar biomimetic structures and fractal neural networks has opened new possibilities in energy system optimization, enhancing both efficiency and sustainability in reconfigurable systems. These emerging approaches not only optimize energy resource utilization but also allow energy capture configurations to adapt to changing environmental conditions. Biomimetics involves imitating natural processes, such as structures found in nature, and applying them to energy system design. Meanwhile, selfsimilar structures refer to patterns that repeat at different scales, a common characteristic in many living organisms. According to [24], applying these principles to energy systems can lead to more efficient and sustainable structures that better adapt to their environment. Addressing energy efficiency must involve integrating emerging technologies and developing new methodologies that further optimize photovoltaic system responses to changing environmental conditions. Below are some promising directions for future research in this field.

Integration of IoT Sensors:. The inclusion of Internet of Things (IoT) sensors in photovoltaic systems is a key research direction. IoT sensors can provide realtime data on environmental conditions such as irradiance, temperature, humidity, and shading presence. These data can be used to feed dynamic reconfiguration algorithms and adjust photovoltaic panel configurations immediately and precisely. This enables realtime energy efficiency improvements, as suggested by [25], who demonstrated how integrating IoT platforms, complemented by Edge and Fog Computing paradigms, can reduce latency and optimize system response. Recent studies by [25] emphasize the importance of using IoT platforms like ThingsBoard, which facilitates realtime data processing and analysis while enabling control and monitoring mechanisms through distributed sensor nodes. Integrating these technologies could significantly enhance photovoltaic system capabilities to react efficiently to variable environmental conditions, allowing decisions to be made within milliseconds and minimizing energy loss due to shading.

2.6 Blockchain Implementation in Photovoltaic Systems

Blockchain technology offers an optimal model for securely and transparently managing energy transactions, ensuring data immutability through distributed nodes that verify each transaction using asymmetric cryptography [28]. Blockchain implementation in photovoltaic systems offers an innovative solution to enhance the security and integrity of data generated by these systems. Large or complex photovoltaic systems often rely on multiple IoT sensors and distributed monitoring systems to optimize performance, control operations, and make predictions based on environmental conditions. Blockchain registers data in blocks in a decentralized and sequential manner, making modifications practically impossible without detection [28]. Integrating blockchain into photovoltaic systems ensures that sensor and monitoring device information is verified and cannot be altered by third parties, protecting against cyberattacks or manipulation attempts.

2.7 MultiObjective Optimization

Multiobjective optimization is an advanced technique that seeks to balance multiple objectives simultaneously, such as energy efficiency, system durability, implementation cost, and environmental impact in photovoltaic installations [29]. This approach ensures not only maximum energy generation but also the longterm economic viability and sustainability of the system by considering component lifespan and ecological footprint. Achieving this requires using algorithms like multiobjective genetic algorithms and Paretobased optimization, which identify a set of solutions representing tradeoffs between objectives. These techniques allow photovoltaic systems to adapt to changing conditions, such as solar radiation variations or energy demand fluctuations, improving their overall realtime performance. Although maximizing efficiency may conflict with minimizing costs or environmental impact [29], multiobjective optimization creates more sustainable and adaptive systems, resulting in photovoltaic installations that are more efficient, durable, and environmentally friendly.

3 Development and discussion

The following section details the different algorithms examined in this study. Each model is evaluated experimentally through simulations based on a matrix of photovoltaic modules exposed to shading patterns. These patterns generate irregular irradiance, reducing energy production. The primary evaluation criterion is the total power delivered after reconfiguring the system topology.

3.1 Coyote Optimization Algorithm

The Coyote Optimization Algorithm (COA) is a metaheuristic algorithm inspired by the social organization of coyotes, designed to solve optimization problems. In the field of photovoltaic systems, this algorithm has proven to be an effective solution for mitigating energy losses caused by partial shading, optimizing the arrangement and electrical configuration of solar panels. Unlike traditional approaches such as Total CrossTied (TCT) and Su Do Ku, which rely on static reconfigurations to mitigate the impact of shading, COA dynamically adjusts the electrical arrangement of the photovoltaic system in response to irradiance variations, eliminating the need for physical interventions and improving overall system efficiency [30].

Evaluation Characteristics: To evaluate the algorithm, a simulation was conducted on a 9x9 distribution of photovoltaic modules. Three different shading patterns were applied and compared with other configuration methods, such as TCT, Su Do Ku, the Flower Pollination Algorithm (FPA), the Marine Predators Algorithm (MPA), and the Butterfly Optimization Algorithm (BOA). In the proposed optimization approach, the positions of solar radiation in the irradiance matrix are selected as coyotes, while the Global Maximum Power Point (GMP) extracted from the matrix is chosen as the fitness function to be maximized [30]. Figure 1 presents the flowchart of the COA algorithm.

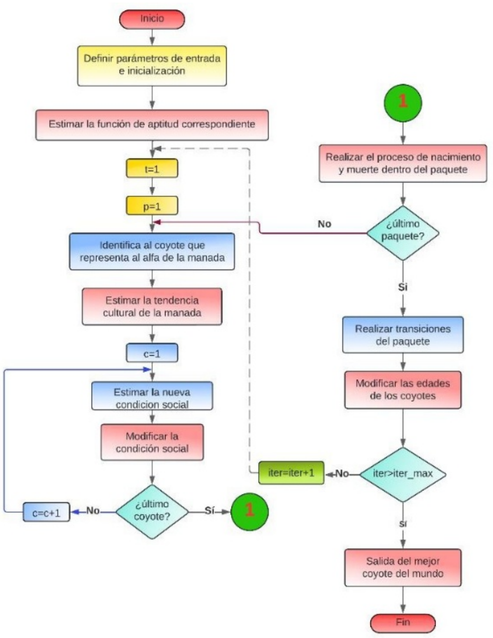

Fig. 1. The main steps of the proposed COA optimizer [30].

After the algorithm generates a configuration that can increase the system's overall power, it is necessary to reconnect the modules. This process is carried out through a switch matrix, as shown in Figure 2.

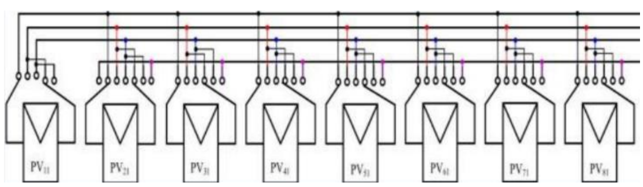

Fig. 2. Diagram of the switching matrix.

Results:. The results obtained from the simulations confirm the effectiveness of COA in improving the performance of photovoltaic systems under partial shading conditions. Compared to static configurations such as TCT, COA achieved an increase of up to 26.58% in the maximum global power extracted. This level of improvement also surpasses other metaheuristic algorithms, such as FPA, MPA, and BOA. The COA's ability to more evenly redistribute irradiance among solar panels enhances its efficiency. Through Figure 3, the performance of each algorithm can be evidenced in its PowerVoltage characteristic curve.

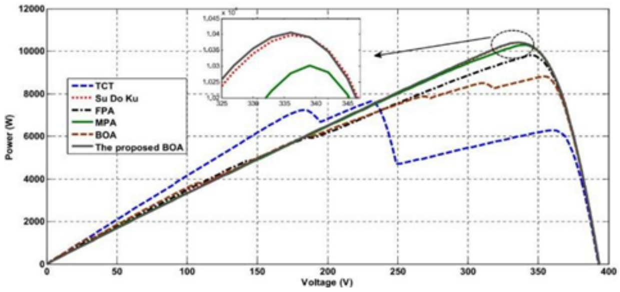

Fig. 3. Performance of TCT, Su Do Ku, FPA, MPA, BOA, and COA arrangements. [30]

3.2 Butterfly Optimization Algorithm (BOA)

Adaptive reconfiguration in photovoltaic systems is a fundamental technique for mitigating the negative effects of partial shading, which can significantly reduce the global maximum power (GMP) extracted from the system. This technique relies on rearranging the panels in a matrix to maximize power output and minimize losses due to electrical mismatches. Conventional methods, such as Total CrossTied (TCT) and Sudoku, have been widely used; however, they present limitations in ensuring uniform shadow distribution. The metaheuristic Butterfly Optimization Algorithm (BOA), proposed by Arora et al. [31], was inspired by the foraging and mating mechanisms of butterflies. The algorithm consists of three main stages: initialization, iteration, and termination. In the first stage, control parameters and the objective function are defined. During the iteration process, the positions of the butterflies are updated, and the corresponding fitness function is calculated until an approximate convergence value is reached.

Evaluation Characteristics:. Considering a matrix of photovoltaic modules in an initial 6x4 configuration, shading patterns are applied to different arrangements, including those based on the novel structure (NS) pattern, shadow dispersion with NS, the Grey Wolf Optimizer (GWO), and the mixed configuration that combines SeriesParallel and Total CrossTied (SPTCT) arrangements. These algorithms are then compared with BOA. To apply the BOA in this context, the initialization parameters include the electrical characteristics of the modules, and a solar irradiance vector is generated. The fitness function, in this case, is the total power extracted from the system. During the execution of BOA, the irradiance matrix is iteratively updated in each panel column, evaluating the power generated at each step. The objective is to maximize the extracted power, reaching the optimal configuration when the system stops improving in subsequent iterations [31].

Results:. The simulation results using BOA in different partial shading scenarios have shown that this algorithm outperforms traditional methods such as SPTCT and GWO. Under simple shading patterns, BOA achieved a maximum power extraction of 3766.527 W, while under more complex shading conditions, it reached an extraction of 2908.021 W [33]. In comparison, other methods, such as the shadow dispersion configuration with NS and GWO, produced lower power values. BOA demonstrated superiority by increasing power extraction by up to 27.43% compared to the previous methods. Figure 4 illustrates the comparison of the PowerVoltage curve.

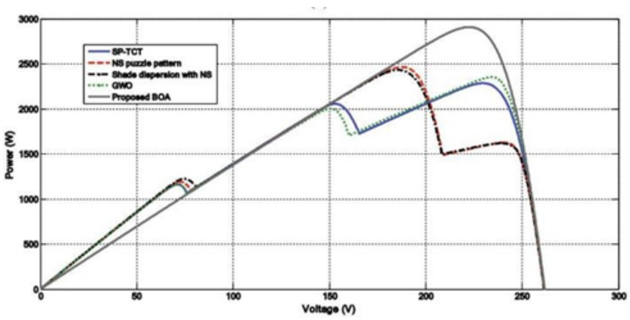

Fig. 4. PowerVoltage curves of the photovoltaic array under a shading pattern [31].

3.3 Reconfiguration Strategy Based on Direct Power Evaluation

The proposed dynamic reconfiguration algorithm for photovoltaic systems under partial shading conditions focuses on maximizing output power. Unlike traditional approaches that rely on irradiance equalization, this method employs a direct evaluation of the generated power. The reconfiguration problem is approached as a 01 multiple knapsack problem, optimizing the arrangement of photovoltaic modules to ensure maximum module participation in power generation, even under variable irradiance conditions. The algorithm is based on the development of a mathematical model that evaluates the system’s maximum output power. The objective is to maximize the minimum current in each row of the photovoltaic array, ensuring greater efficiency and module participation, which increases the total generated power. The dynamic adjustment of photovoltaic modules allows for optimization without solely relying on uniform irradiance distribution [32].

Evaluation Characteristics:. According to [30], the algorithm's performance was evaluated and compared with traditional irradiance equalization (IE) and Total Cross-Tied (TCT) techniques. The study considers a 6×3 photovoltaic array exposed to shading patterns, creating uneven irradiance distribution. Each method attempts to rearrange the matrix to achieve a more uniform irradiance pattern [32].

Results:. The simulation results obtained using MATLAB/Simulink show that the output power with the proposed strategy reached 2498 W, representing a 23.2% increase compared to the initial 2027 W obtained with the TCT configuration and 11.2% higher than the 2246 W achieved using the irradiance equalizationbased scheme, as highlighted by [30]. These results underscore the effectiveness of the proposed algorithm in maximizing system output power and significantly improving energy efficiency by reducing losses caused by partial shading conditions [32]. Figure 5 presents the resulting PowerVoltage characteristics of each method.

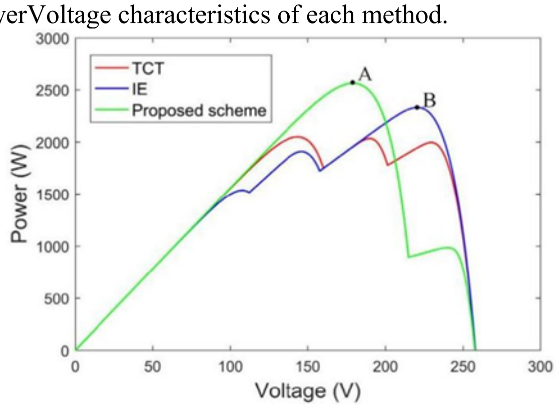

Fig. 5. Photovoltaic characteristics for TCT, IE, and the proposed arrangement [32].

3.4 Photovoltaic Reconfiguration Algorithm Based on the Marine Predators Algorithm

The proposed algorithm is based on the Marine Predators Algorithm (MPA), a metaheuristic technique inspired by the hunting strategy of marine predators in nature. The primary objective of this algorithm is to optimize the dynamic reconfiguration of large photovoltaic arrays under partial shading conditions, improving system efficiency by maximizing the generated power. Unlike other strategies, MPA employs a population-based optimization approach to explore various possible configurations, distributing shading more uniformly over the photovoltaic modules. This minimizes power loss and reduces the multiple peak effect in the system's output characteristics, as mentioned in the research [33].

Evaluation Characteristics:. The algorithm was evaluated on photovoltaic arrays of different sizes to validate its effectiveness at various scales. The configurations included 9×9, 16×16, and 25×25 module arrays [MPA]. In each case, the system was exposed to shading patterns that generated an irregular irradiance distribution. The algorithms used as comparison points were the Total CrossTied (TCT) configuration, reconfiguration techniques based on Manta Ray Foraging Optimization (MRFO), the Harris Hawk Optimizer (HHO), and the Particle Swarm Optimizer (PSO) [33].

Results: The results reveal that MPA improved the photovoltaic system's power output by 28.6%, 2.7%, and 5.7% for the 9×9, 16×16, and 25×25 system configurations, respectively. Therefore, the authors recommend MPA as an efficient and applicable algorithm for photovoltaic reconfiguration systems. In Figure 8, the PV characteristics for the 9×9 array case can be observed.

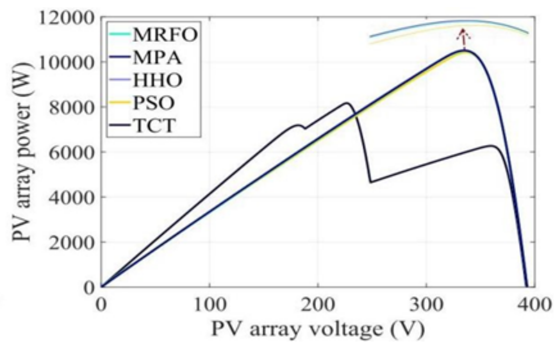

Fig. 6. PV characteristics of the algorithms in the case of the 9×9 array [33].

3.5 Modified Harris Hawks Optimizer (HHOM)

Heidari recently introduced the Harris Hawks Optimizer (HHO) in [34] to emulate the real performance of Harris hawks as avian predators when capturing their prey. Harris hawks follow a sudden attack strategy, pursuing their target with multiple attack mechanisms to encircle the prey before launching attacks from different directions. The authors provided mathematical formulations to model the hawks' prey capture strategy, resulting in the development of the HHO algorithm. As a metaheuristic optimization algorithm, HHO consists of two operational stages: the exploration phase and the exploitation phase [34]. In the first stage, the algorithm performs space monitoring to observe potential prey, where the hawks randomly launch searches, mimicking their behavior when perching on a tree and scanning for a direct position relative to the prey. In the next stage, once a target is identified, the pursuit begins, which can be summarized into four possible strategies: soft besiege, hard besiege, soft besiege with rapid dives, and hard besiege with progressive rapid dives [34]. Figure 7 illustrates the different stages of the HHO proposed by Heidari [34].

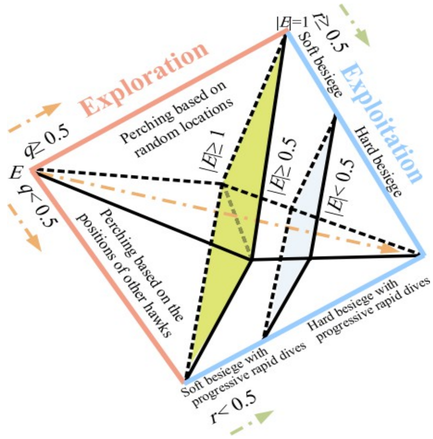

Fig. 7. Different phases of the HHO [34].

Evaluation Characteristics:. In the following experiment, an algorithm based on the HHO is proposed, referred to by the author [32] as the Modified Harris Hawks Optimizer (HHOM). This algorithm is evaluated for optimizing the topology of a photovoltaic system. The evaluation was conducted through a simulation of a 9×9 module matrix exposed to shadow patterns that alter the irradiation profiles of each module, consequently reducing the total power output. To improve system performance under this phenomenon, the goal is to balance the currents by connecting modules with similar irradiation profiles in series. The algorithm is initialized with the size of the photovoltaic array, M×N, where M represents the number of rows and N the number of columns. A search agent matrix of dimension N×D is then generated, and an initial solution is assigned, containing the irradiation profiles of each module. To determine whether the solution optimizes the system, the electrical characteristics of the modules are evaluated using an objective function that sums the power of each reorganized row. The algorithm stops modifying the matrix once it reaches the maximum number of allowed iterations with the highest possible power output [34]. To validate the results of HHOM, it is compared with solutions obtained through total crosstied (TCT) techniques, competition square (CS), particle swarm optimizer (PSO), and genetic reconfiguration based on multiple metrics (GA).

Results. : The analysis reveals that the approach proposed in [32] increases power generation by up to 33.274% under shadow patterns compared to TCT, CS, GA, and HHO, demonstrating its effectiveness in providing the optimal configuration for the photovoltaic array. Figure 8 presents the results of each comparison.

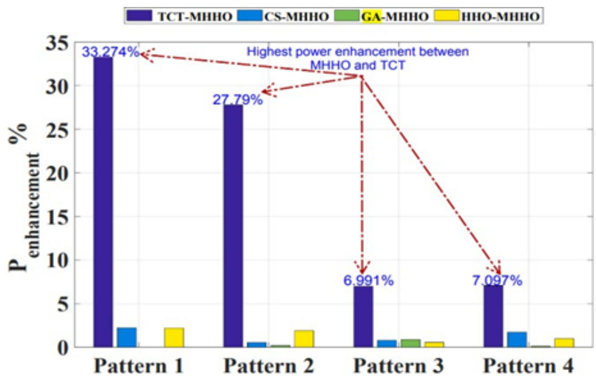

Fig. 8. Percentage increase in power between the MHHO configuration and other approaches. [34].

In Figure 9, we find the graph comparing each algorithm and its results, allowing us to determine which one achieved the highest increase in extracted power under partial shading conditions.

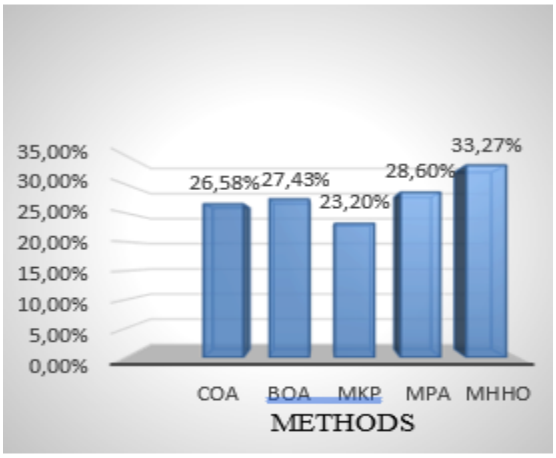

Fig. 9. Percentage increase in power for each algorithm.

4 Conclusion

A comprehensive analysis was conducted on advanced optimization techniques for photovoltaic installations, focusing on mitigating the shadow effect using dynamic algorithms. This phenomenon, caused by factors such as buildings, trees, or clouds, poses a challenge to the efficiency of photovoltaic systems by reducing their energy generation capacity and affecting the durability of components. Addressing this issue is crucial, particularly in the context of the increasing adoption of renewable energy sources and the need to enhance the technical and economic viability of these solutions. Throughout the review, the effectiveness of various algorithms has been evaluated, including the Coyote Optimization Algorithm (COA), the Butterfly Optimization Algorithm (BOA), and others such as the Marine Predators Algorithm (MPA). Experimental results from simulations under partial shading conditions confirm that these algorithms offer significant improvements in photovoltaic installation efficiency. The COA achieved an increase in collected power of up to 26.58%, while the BOA reached a 27.43% improvement. Similarly, the Marine Predators Algorithm showed a 28.6% increase in power under certain shading patterns, and the Modified Harris Hawks Optimizer (MHHO) demonstrated an increase of 33.274%. These figures demonstrate that bioinspired approaches are not only effective but can significantly outperform traditional static reconfiguration methods, such as Total CrossTied (TCT) or Sudoku. However, while the results are promising, the study also highlights key barriers to the practical implementation of these solutions. One of the main challenges identified is the technical complexity associated with the dynamic reconfiguration of systems, which requires the integration of switching matrices and other components that increase both cost and infrastructure complexity. Additionally, the variability in shading patterns and unpredictable environmental conditions, particularly in urban environments, necessitate more robust and flexible technologies that allow for continuous adaptation of photovoltaic modules. In this regard, the study emphasizes the importance of integrating complementary technologies such as solar tracking systems, energy storage, and multiobjective optimization, which can further maximize realtime energy capture and improve system adaptability under changing conditions. The implementation of dynamic reconfiguration algorithms in realworld scenarios also presents other technical challenges, such as the need to reduce execution times and ensure that systems can efficiently adapt in real time. This is especially relevant in industrial and commercial applications, where variations in solar irradiance can lead to significant economic losses, making rapid and efficient reconfiguration essential. In conclusion, dynamic algorithms for photovoltaic system reconfiguration have proven to be an effective solution for mitigating the shadow effect and significantly improving the energy efficiency of installations. However, their practical implementation still faces important technical and economic challenges. Overcoming these barriers will require continued research and the development of new strategies that enable the integration of these solutions in an efficient and costeffective manner. The future of renewable energy will largely depend on the industry's ability to adopt innovative technologies that optimize system performance in complex and variable environments.

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Bloockchain Technology in Higher Education: Transforming Teaching and Learning

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Abstract. This article explores the transformative impact that the integration of Web 3.0 and Web 4.0 technologies could have on higher education. First, some of the most important technologies that can be integrated into education are described, then some of the tools that are already being integrated into education and that are linked to each of the technologies are identified, and finally, an exploration is made of the best-known platforms and tools, their characteristics and the use that could be made of them in education and in the teaching and learning processes of blockchain technology. These emerging technologies and the tools they provide include Artificial Intelligence (AI), Virtual Reality (VR), Augmented Reality (AR), Extended Reality (XR) and the Internet of Things (IoT), and their application in educational environments. The study examines how these innovations are revolutionizing teaching and learning processes, administrative management, academic research and the student experience in general.

Keywords: Web 3.0, Web 4.0, Higher Education, Blockchain.

1. Introduction

The evolution of web technologies is radically transforming all aspects of the new information and knowledge society, and education is no exception, especially in higher education, which is characterized by the application of technology in its different branches of knowledge.

However, the road to Web 2.0 has been a significant challenge in education, and as technology advances, there must be a transition from Web 2.0 to Web 3.0, which would be a positive step, and then on to Web 4.0, which represents a qualitative leap in the way we interact with information through technology with the capacity to generate new knowledge. These new iterations of the web, together with the advances being made in technology, promise to revolutionize the way higher education is imparted, accessed and experienced.

Web 3.0, also known as the “semantic web”, is the evolution of Web 2.0, where everything was centralized, migrating towards a decentralized environment that democratizes information with the use of technologies such as AI, VR and AR to enrich educational environments and learning spaces. For its part, Web 4.0, called the “symbiotic web”, takes these concepts even further, incorporating autonomous systems, the Internet of Things (IoT), Extended Reality (XR) and ubiquitous computing technologies

There are many authors who discuss how these technologies can impact education, including Holmes, Bialik and Fadel (2019) who highlight AI technology in education as it enables more personalized learning experiences, adapting content to the needs of each student and providing real-time feedback to improve performance. In Luckin's opinion (2016), AI-driven tools can help educators automate administrative tasks, allowing them to focus more on teaching and mentoring students.

Other authors such as Bailenson (2021) focus more on VR and metaverse platforms that offer immersive learning environments and can simulate real-world scenarios. Other authors such as Dionisio, Burns, and Gilbert (2013) describe how the metaverse provides a collaborative space where students and educators can interact in real time, breaking down the barriers of physical classrooms and enabling global learning communities.

While other authors such as Grech and Camilleri (2021) delve a little deeper into blockchain technology, stating that it has the potential to revolutionize the way educational credentials are issued, verified and shared by offering a decentralized and tamper-proof system that guarantees the authenticity of academic records.

In this article, we will explore each of the Web 3.0 and Web 4.0 technologies in greater depth, focusing on blockchain technology and the platforms and tools that this technology provides with a focus on their characteristics and potential uses in higher education, which can have an impact on teaching and learning processes, educational administration, academic research and the student learning experience. For each of the selected tools, the main characteristics and possible uses in higher education will be examined, presenting a challenge for universities and other educational institutions that intend to integrate this technology into their core and support processes.

2. Characteristics of Web 3.0 and Web 4.0 Technologies

2.1 Characteristics of Web 3.0 Technologies. These technologies are characterized by the extensive use of technological and other resources in various types of digital multimedia format. Among them, the most relevant include AI, which allows for the personalization of learning through systems that adapt the content to the needs of the student, and data interconnection, which facilitates access to information in a more precise way, improving academic research processes. As Holmes, Bialik and Fadel (2019) state, “Artificial intelligence in education enables personalized learning experiences, tailoring content to the needs of individual students and providing real-time feedback to improve their performance.”

Other technologies that include interactive experiences for the student are AR and VR, which are used to create more realistic experiences and immersive learning environments. Bailenson (2021) points out that “Virtual reality and metaverse platforms offer immersive learning environments that can simulate real-world scenarios, making them ideal for training and education in fields such as medicine, engineering, and architecture.

Another technology that is associated with decentralization as one of its main characteristics is blockchain, which can be used to manage information security, academic certificates and student records in a secure and transparent way.

2.2 Characteristics of Web 4.0 Technologies. These technologies, known as “Symbiotic Web”, are aligned with new technological advances, integrating new advances with technologies being explored in Web 3.0. In AI, progress is being made with systems capable of learning and making autonomous decisions, integrating IoT technology with connections to devices to create intelligent environments on university campuses; There is also talk of human-computer interaction technologies with advanced virtual assistants that facilitate interaction with technology and the emergence of Extended Reality (XR) that combines AR, VR and Mixed Reality (MR) to create more comprehensive educational experiences.

The application of these new technologies in education ranges from smart campuses using IoT to manage resources such as libraries, laboratories and security systems; there are also advanced virtual assistants using AI that help students organize their schedules and time, answer questions or even correct work, which also includes emotion-based learning environments with systems that detect the student's emotional state to adapt and improve the learning experience; They can also be applied to the management of networking and collaborative work due to their capacity to work on platforms where both teachers and students located in different geographical locations at a national or global level can interact and work together in real time and with the use of the tools provided by XR technology.

2.3 Higher Education Applications

Among the applications of Web 3.0 are personalized learning platforms which integrate intelligent tutoring tools that offer the possibility of adjusting content in a personalized way according to the student's learning progress; other applications in advanced research are AI-powered search engines and semantic databases to find academic information from reliable sources quickly and with greater precision; it is also used in immersive virtual classrooms, with the use of AR and VR technologies for the simulation of learning scenarios and environments, the simulation of virtual laboratories, visits to factories, or for virtual internships. And blockchain is used to generate digital certificates and issue diplomas and credentials guaranteeing authenticity, which helps prevent fraud and falsification.

Blockchain technology is being used to issue diplomas and credentials, guaranteeing their authenticity and preventing fraud. Platforms such as Blockcerts and OpenCerts allow academic certificates to be verified quickly and easily. Sharples and Domingue (2016) state that “The use of blockchain in education can create a more transparent and secure ecosystem for the management of academic credentials, reducing fraud and improving trust between institutions and employers.”

The use of semantic databases allows academic information to be found from reliable sources quickly and accurately. Tools such as IPFS (InterPlanetary File System) facilitate the storage and distribution of research files efficiently and securely. As Benet (2017) points out, “Decentralized storage systems like IPFS allow educational institutions to store and share resources securely, without relying on centralized servers that are vulnerable to censorship or failure.”

AR and VR are used to create laboratory simulations, virtual visits to factories or museums, and virtual internships. Mozilla Hubs is an example of a platform that allows the creation of collaborative virtual environments for teaching. Dionisio, Burns and Gilbert (2013) point out that “The metaverse provides a collaborative space where students and educators can interact in real time, breaking down the barriers of physical classrooms and enabling global learning communities.”

3. Web 3.0 and 4.0 Tools and Platforms in Higher Education

Now that there is a clearer picture of the technologies included in Web 3.0 and Web 4.0, the next step is to explore some of the tools and platforms that are already being applied in education and that can be integrated into higher education processes, specifically into teaching and learning processes.

For each of the tools and platforms, a summary will be made of their characteristics and most frequent uses to demonstrate how these technologies can provide teachers with new resources to create their own multimedia resources to integrate into the teaching process as well as new tools adapted for student learning.

Although there are many more tools and platforms available for each of the technologies, some of the best known and most applicable to education have been selected and, once the general characteristics of each have been mentioned, a comparison will be made between them.

Table 1. Tools included in the Web 3.0 and Web 4.0 technologies.

Technology	Tools	Description
Platforms based on Blockchain technology	OpenCerts	Platform for issuing and verifying educational certificates using BlockChain technology
	BlockCerts	Open standard for creating verifiable digital certificates
	Machine Learning	Tool for educational institutions wishing to issue blockchain credentials
AI tools and personalized learning	Century Tech	AI platform that personalizes learning for students
	Squirrel AI	AI-based intelligent tutoring system for personalized education
	Knewton	Adaptive platform that uses AI to create personalized learning experiences
Metaverses and Virtual Reality	Engage	Virtual reality platform for education and training
	Mozilla Hubs	Collaborative virtual spaces for education in the metaverse
	Spatial	Tool for creating immersive experiences in the virtual classroom

Decentralized management tools	BitDegree	Educational platform that uses blockchain to reward students with tokens
	ODEM	Decentralized platform for the creation and management of educational programs
Open Source Tools	Open edX	E-learning platform that can be integrated with web 3.0 technologies
	Moodle	Learning management system (LMS) that can be extended with blockchain and AI plugins.
Additional Resources		
Additional courses	Web 3.0 and BlockChain Fundamentals	Course offered by Coursera (2023) offered by the University of California, Irvine
	AI for Education	edX Course (2023) offered byHarvard University
Communities and Forums	Ethereum Education	Community focused on blockchain and its application in education.
	Educause	Discussion forum on emerging technologies in education.

Source: The author

Once the technologies integrated in Web 3.0 and Web 4.0 are understood, with the available tools and their descriptions, each one will be explored to understand their general characteristics and uses in educational processes, placing special emphasis on the processes of teaching and learning and their applications in higher education.

4. Platforms and Tools of Blockchain Technology in education.

Platforms based on blockchain technology are aligned with Web 3.0 technologies, offering decentralized, transparent and secure solutions that enable the management of credentials, verification of qualifications, personalized learning and the creation of collaborative educational ecosystems. Some of these platforms and their applications are described below:

4.1 Blockcerts. Initially developed by the MIT Media Lab (2017), in collaboration with Machine Learning (Jagers et al., 2016), this platform is a pioneer in the use of blockchain technology for the issuance, storage and verification of academic certificates and digital credentials. This platform is useful in the field of education since it guarantees the authenticity and validity of documents.

Features: Decentralized storage eliminates the need for a centralized intermediary for verification; immutability, meaning that once a certificate has been registered it cannot be altered, preventing fraud and guaranteeing its authenticity; verification by interested parties of the validity of certificates using Blockcerts open source tools; interoperability with other platforms and systems; privacy for users who have full control over their credentials and can decide with whom to share them; and a further feature is that it is free to use.

4.2 Opencerts. This is a platform based on blockchain technology designed for the issuance and verification of educational certificates. It was developed by the Singaporean government (Ministry of Education of Singapore, 2020), in collaboration with several institutions (Singapore Institute of Technology, 2021), and technology companies. This platform has become a leading solution for guaranteeing the authenticity and validity of academic qualifications and other educational documents.

Features: Decentralization that eliminates the need for intermediaries for verification; immutability that guarantees authenticity which, according to Lee et al., (2022) has positioned Opencerts as a benchmark for reliability since the certificate cannot be altered with the aim of preventing fraud; verification of the certificate's validity; interoperability since it is compatible with other blockchain-based systems; privacy of users, who have total control of their credentials and can share them when and with whom they wish.

4.3 Sony Global Education (Odyssey). This is an initiative of Sony Corporation (2020), aimed at providing innovative educational solutions and services using blockchain technology to improve learning experiences and foster global collaboration among students. It also works on the creation of platforms that use data analysis and artificial intelligence to personalize learning experiences with the aim of supporting the development of skills necessary for the 21st century, such as creativity, collaboration, and digital literacy.

Odyssey is a software tool developed by Sony Global Education (2017) that transforms the ways of assessment applied up to now and encourages learning. It goes a little further than traditional methods of assessment with standardized exams to offer a more comprehensive and personalized approach that measures students' skills and potential.

Features: AI-based assessment using algorithms to analyze not only right or wrong answers but also the thought process behind them and also assess problem-solving skills, creativity, and critical thinking that cannot be measured with traditional methods; Global platform that was designed to be used in that context, allowing students located in different geographical locations to participate in educational challenges and competitions; Personalization of learning, as it has the capacity to identify the strengths and weaknesses of the student and to propose recommendations to improve their performance, allowing the teacher to adapt their teaching to the individual needs of each student. It focuses on the development of 21st-century skills such as collaboration, innovation, and adaptability, and combines data analytics and machine learning technologies to provide a more dynamic and effective educational experience.

4.4 BitDegree. An online educational platform that combines blockchain technology with courses in digital and technological skills, the aim of this platform is to make education more accessible, motivating and aligned with the needs of the current labor market, focused on developing and increasing technology-related skills such as programming, web development, data science, digital marketing and more.

Features: The use of blockchain and reward tokens using blockchain technology to issue verifiable certificates upon completion of courses guaranteeing the authenticity and transparency of educational achievements and where students can earn BitDegree (BDG) tokens as a reward for completing each course which they can then use to access other courses or exchange on cryptocurrency platforms; Courses that can be free or paid for in the areas of programming, blockchain development, graphic design, digital marketing, as well as more specialized paid courses that offer recognized certifications; it focuses on practical skills in demand by the labor market, for careers in technology and related fields, the courses are practical and include projects and exercises that allow students to apply what they have learned; it incorporates elements of gamification, such as points, achievements and rankings to keep students motivated; global accessibility as this platform is available in multiple languages and is designed to be accessible to people from all over the world; collaboration with technology companies to offer courses aligned with the needs of the labor market, allowing students to learn specific skills required by the labor market and industry.

4.5 EduCTX. A platform based on blockchain technology designed to improve the management and verification of academic certificates and educational credits. This platform uses this technology to create a global and decentralized system that allows educational institutions to issue, share and verify academic credentials in a secure and transparent manner.

Features: records ensuring that the data is immutable, secure and easy to verify, where each certificate or academic credit is recorded in the blockchain avoiding falsification and simplifying the verification process; interoperability between institutions allowing universities and other educational institutions to share academic information efficiently, facilitating the transfer of credits between institutions, this is useful for students who wish to continue their studies at different universities or in different countries; it also has the characteristic of transparency and security that guarantees that academic records are transparent and protected against any type of alteration, where the student has control of their data and can share it with their employers or with other institutions in a secure way; another characteristic is that it operates as a decentralized network where there is no central authority that controls the information, which reduces the risk of data corruption or manipulation; Another feature is that it facilitates academic mobility by supporting students who wish to study abroad or transfer to other institutions by simplifying the process of accreditation and recognition of credits; and as it is based on ECTS, the European Credit Transfer and Accumulation System, it facilitates student mobility and the recognition of studies.

4.6 APPII (Academic Professional Passport International Initiative). A blockchain-based platform designed to manage and verify academic and professional credentials in a secure and transparent way that aims to solve problems in the verification of degrees and certificates to avoid falsification, lack of transparency and inefficiency in the validation processes.

Features: Blockchain for credential verification, to store and manage academic credentials with greater security, avoiding falsification and simplifying the verification process; verification of credentials quickly and securely by accessing the blockchain by those concerned, which reduces the costs and time associated with manual document verification; According to (Nakamoto, 2008; Swan, 2015), control over credentials by the users who own the information can be shared with whoever requires them; compatibility with different educational and professional systems facilitates their adoption at a global level; assurance that credentials are authentic and cannot be falsified, reducing academic and professional fraud.

4.7 Gilgamesh. An innovative platform that combines blockchain technology focused on reading, learning and academic collaboration (Buterin, 2014) between readers, authors and academics, it aims to create a global community where lovers of books and knowledge can interact, share ideas and access content in a secure and decentralized way.

Features: Blockchain technology for rights management and rewards that guarantee transparency and security in copyright management and reward distribution where authors can publish their works on the platform and receive fair compensation through tokens based on this technology; A community of readers and writers that encourages interaction between readers, authors and academics (Tapscott 2016), allowing discussions, reviews and collaborations around published books and articles and where users can join discussion groups, share ideas and participate in community activities; It has GIL tokens which are the cryptocurrency used to reward users for their participation on the platform and readers can earn GIL tokens for writing reviews, participating in discussions or recommending books, while authors receive tokens for sales of their works; Exclusive content with access to books, articles and other educational materials, some of them exclusive to Gilgamesh where users can buy or rent content using GIL tokens; Decentralized operation ensures greater transparency and reduces the risk of censorship; The focus is on education and knowledge, especially literature and educational and academic materials, making it a versatile platform for learning and research. (Wright and De Filippi, 2015).

4.8 Woolf University. This is an innovative initiative that presents the world's first blockchain university, which aims to revolutionize higher education through the use of blockchain technology to create a decentralized, transparent and efficient structure to eliminate intermediaries, reduce costs and offer a more personalized and accessible educational experience for all.

Features: Woolf uses blockchain to manage key aspects of university administration such as student enrollment, degree issuance and payment distribution, to ensure transparency, security and efficiency in all processes; Woolf University operates as a decentralized autonomous organization (DAO) with no central authority controlling the institution where decisions are made collaboratively among community members including faculty and students; At this university, teachers can work independently, offering courses and programs directly to students, with costs and schedules being established by the teacher, which gives greater flexibility and control over their work. Degrees and certificates are issued by Woolf and registered on the blockchain, guaranteeing their authenticity and facilitating verification by employers and other institutions, thus reducing the risk of academic fraud. The costs are lower compared to other traditional universities offering high quality programs and courses; Woolf offers a more personalized educational experience allowing students to choose courses and teachers that suit their needs and interests; This university offers a more personalized educational experience allowing students to choose courses and teachers that suit their needs and interests; It is also designed to be accessible to students from all over the world, eliminating geographical and economic barriers.

4.9 Discipline. A platform based on blockchain technology that has been designed to manage and verify academic credentials, certificates and educational records in a secure and transparent way, with the aim of creating a reliable educational ecosystem that connects students, educational institutions and employers, facilitating the verification of skills and academic achievements.

Features: uses blockchain to store and manage academic records, guaranteeing that they are immutable, secure and verifiable, where each degree or certificate is recorded in the blockchain, avoiding falsification and simplifying verification; It not only focuses on the issuance and verification of credentials but also manages learning, as (Mata Hernández, Avendaño Cruz 2022) point out, the assessment of skills and collaboration between educational institutions; Discipline uses its own cryptocurrency to facilitate transactions such as tuition payments, teacher compensation and student rewards; it connects students with job opportunities that allow employers to quickly and securely verify candidates' skills and certifications, bridging the gap between education and the labor market; interoperability, as it is designed to be compatible with different education systems and international standards, facilitating its adoption at a global level; and the transparency and security provided by blockchain, reducing alterations and increasing students' control over the data that can be shared with employers and other institutions that require it (Martínez, 2023).

4.10 Extensions and Plugins. Another possibility is to integrate platforms through plug-ins or extensions; in this case the integration of Moodle, one of the most popular online learning platforms, with blockchain technology to modernize and improve the management of online education, offering significant benefits in terms of security, transparency and credential verification, while maintaining flexibility and functionality.

Characteristics: According to (Amo-Filva et al., 2020), Moodle can integrate the blockchain to verify issued certificates and diplomas, guaranteeing their authenticity and immutability and allowing other institutions and employers to verify the validity of the qualifications; these extensions of the blockchain reduce the risk of fraud and certificate forgery, and students can access and securely store their academic records; Blockchain integration allows for more decentralized management of educational data, reducing dependence on a central authority and increasing trust in the system; this blockchain technology allows for rewards through tokens or cryptocurrencies for students, which can increase student motivation and commitment; Interoperability is also highlighted, where academic records can be shared and recognized by other educational institutions or employers globally, facilitating academic and professional mobility; reducing administrative costs by automating processes such as issuing and verifying certificates.

5. Impact of Blockchain technology on higher education.

Now, having familiarized ourselves with the characteristics of each of the platforms and tools, we can open the discussion on how this technology could change the handling, storage and processing of information, guaranteeing a higher level of security that prevents manipulation and fraud and improves the level of access to information.

One of the characteristics of blockchain technology is decentralization, the meaning of which has application in the processes of issuing, storing and verifying student information with respect to certifications. In this sense, through platforms such as BlockCert and OpenCert, it is possible to issue digital degrees and diplomas, course and training certificates, professional credentials or licenses, and reduce fraud to eliminate the possible falsification of documents such as academic certificates and diplomas.

The use of this technology offers many advantages over the way processes are currently carried out. With regard to transparency, certificates can be verified. Another advantage is security because blockchain technology guarantees that certificates cannot be falsified or altered. It also offers user accessibility to share and give access to other interested parties, and cost reduction by eliminating the need for manual verification processes and the issuing of paper certificates.

In terms of the provision of services and the creation of interactive resources, this technology provides tools such as Odyseey which are combined with other emerging technologies such as AI, VR and AR. Through decentralized platforms, these tools make it possible to measure the knowledge, the potential and practical skills of students, enabling them to prepare to face the challenges of the modern world where the ability to think critically and the ability to solve complex problems are considered of vital importance.

This tool, which is included within the Sony Global Education platform, represents an important step in the modernization of education, using AI to create more meaningful assessments and adaptive learning experiences. Odyseey has become a decentralized platform that combines blockchain, AI and AR to create more interactive and personalized educational experiences, and is applied in online courses, gamification and collaborative learning.

Another potential use of the aforementioned technology is the creation of platforms such as that of the world's first decentralized university, Woolf University, and to this the general procedures of its operation are taken into account: first, students register on the platform and choose the courses they are interested in; then they pay the tuition fees by traditional methods or with cryptocurrencies managed through blockchain; then comes the learning of students who take their classes online and complete their activities and assessments; at the end of the courses, the student receives the certificate or degree by accessing the blockchain; and finally, interested parties, which may be other institutions or employers, can verify the authenticity of the degrees by accessing the blockchain.

Here one can clearly see the interoperability of this technology, which can work with other LMS learning platforms and other systems. This could represent a disruptive approach to higher education that, by empowering students and teachers in the production of online courses or even elective subjects, can reduce costs by democratizing higher education. However, its success depends on the ability to overcome regulatory challenges in order to gain acceptance and compete in an ever-evolving education market.

Another potential use of this technology is the academic mobility of students between local or national universities, and to that end, the general procedure of the Disciplina platform is monitored, in which the first step is to register the institutions and universities that are going to join the platform; then comes the issuing of certificates when the student completes a course or program and registers in the blockchain; the student can then access their academic records through an application or the platform and decide with whom to share them; and finally verification by the other institutions accessing the blockchain.

Another benefit of using this platform may be the offering of certificate courses where students from different institutions can schedule certificate courses and where the entity issues digital certificates that are registered in the blockchain, and where each institution and student can have access to the certificate that can be shared with the employer and other people who require it, maintaining the security of the data that is protected by cryptography, guaranteeing integrity, efficiency since this simplifies and streamlines the credential verification process, and the connection with the labor market that facilitates the transition of students to the labor market by allowing employers to verify their skills quickly and reliably..

And as mentioned above, this technology is compatible with other learning systems and platforms such as Moodle, where this technology can be integrated through the Blockcerts platform that can be integrated with Moodle and also OpenBadges, which is a system of digital badges that can be used to recognize academic achievements in Moodle.

6. Conclusions

The platforms and tools provided by blockchain technology are an innovative solution that, when implemented, can improve the management and verification of academic credentials, offering a secure, transparent and efficient system that reduces the possibility of fraud and data alteration and allows students to connect with job opportunities.

As it is a technology with the characteristic of interoperability, it is concluded that this technology can achieve the integration of Moodle with blockchain which has the potential to transform online education by offering a more secure, transparent and efficient system for the management of credentials and academic achievements. This combination can benefit students, employers and educational institutions by facilitating the verification of skills, reducing administrative costs and fostering innovation and learning, but its success depends on widespread adoption and overcoming technical and regulatory challenges.

With regard to external regulations, it is concluded that Colombia and its Ministry of Education are not yet ready in terms of regulations to be able to deploy and implement the full potential of this technology with all its benefits in educational institutions, and that one of the challenges for the coming years will be to adjust the legislation for its implementation.

Finally, and as another conclusion, the implementation of these technologies requires institutional will and participation, with the deployment of technological resources and technical capacity of the personnel to be able to implement it. And it is important to keep in mind that in order to fully exploit their potential, it is necessary to address the challenges related to privacy, the digital divide, teacher training and implementation costs. Curricular adaptation and the careful integration of these technologies into educational processes are crucial to their success

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Assessment of perceived emotions in children through emotional narrative and ICT tools

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Abstract. Emotion recognition is a crucial field of study in psychology, as emotions are fundamental to human behavior and social interaction. Facial expressions are key indicators of emotions, and their analysis can provide a deeper understanding of a person's emotional state. Various theories, such as that of Paul Ekman, suggest that there are basic emotions that are expressed similarly across cultures, justifying the validity of software that allows observers to assess these expressions. The valence software allows observers, in this case student trainees and psychology teachers, to identify emotions in previously interviewed children. The objective is to validate the emotions observed through gestures and to generate a rating scale that qualifies each emotion by generating a data set that allows training an automatic emotion identification system. This contributes to the creation of an ICT tool that allows the interpretation of emotions with the purpose of improving school performance.

Keywords: Emotions, emotional narrative, classification of emotions, valences.

1 Introduction

Emotions can be indicators of a person's mental state, and altered mental states directly affect students' academic performance, which is why it is important to recognize emotions early to mitigate the negative impact on learning (Acosta & Clavero, 2017). In the educational field, the incorporation of the emotional dimension has been shown to improve the effectiveness and quality of the teaching-learning process, since the results are superior when teaching includes emotions compared to an impersonal approach devoid of the affective (Acosta & Clavero, 2017). However, the emotional perception of a student can be challenging because not all people express their emotions in the same way, or even in some cases try to hide them. In addition, teachers often find it difficult to remain attentive to the emotional behavior of each of their students. This is mainly due to the high number of students they are in charge of and the lack of specific preparation and resources to adequately address the emotional dimension in the classroom. Teachers generally lack the necessary tools and time to be able to individually monitor the emotions of all their students, which represents a major challenge in the educational setting.

Emotional health in the classroom is a fundamental aspect in the academic and social formation of students. Adequate guidance in the classroom could allow the school counselor to take actions to channel emotions correctly and thus avoid major problems in the future. This is relevant given that according to studies students can experience a wide range of emotions ranging from joy and enthusiasm to fear, anxiety and frustration (Acosta & Clavero, 2017; Madrona & López, 2016).

In this context, the integration of emotional narrative and Information and Communication Technologies (ICTs) represents a promising approach for the recognition and assessment of perceived emotions in children, since emotional narrative, by offering meaningful contexts, facilitates the expression of emotions in infants, while ICT tools, for their part, provide interactive and accessible platforms for the collection and analysis of emotional data.

In the literature, we can find different elements used for emotion recognition, one of these elements are computational models, which focus on facial expressions and allow obtaining important information about the emotional state of people. These computational models of emotion recognition analyze users' facial expressions and generate an output that indicates the emotions they are experiencing (Ong et al., 2019). However, most of these studies have focused on the analysis of emotions in adults, without paying sufficient attention to the academic setting and the particularities of emotions in children and adolescents, which may present significant differences compared to the adult population.

Automatic facial emotion recognition in children is an area of growing interest with applications in therapy and diagnosis, especially for children with Developmental Disorders such as Autism Spectrum Disorder (ASD). Different approaches have been developed using computer vision and machine learning, mainly Convolutional Neural Networks (CNN).

One study (Washington et al., 2020) used a therapeutic mobile game to collect facial expression data from children and train an emotion classifier. Despite achieving 66.9% accuracy, the authors acknowledge the need for larger and more diverse datasets to improve model performance and generalization. This challenge is reflected in the literature, where the paucity of child data is a constraint to the development of robust models (Banerjee et al., 2022). Another paper (Huang et al., 2023) investigated the key facial features used by a CNN for emotion recognition. The areas around the nose and mouth were found to be crucial, achieving an accuracy of 77.37% in cross-validation between databases. However, the study was limited to static images, leaving open research on dynamic expressions in video.

In (Talaat, 2023), a real-time system for children with ASD combining deep learning and IoT was proposed. Although high accuracy was reported, it is crucial to validate these results on more representative datasets and to consider the ethical implications of its application. Emotion detection in children with ASD is a particular challenge, given that they present difficulties in recognizing and interpreting facial expressions, which may manifest as an apparent lack of emotion (Talaat, 2023).

Indeed, automatic facial emotion recognition using Deep Learning (DL) has progressed significantly, with architectures such as CNN and CNNLSTM showing promising results (Mellouk & Handouzi, 2020). However, research is mainly focused on basic emotions, limiting the understanding of more complex emotions. In addition, most models are trained on adult data, which affects their performance in children (Banerjee et al., 2022). To address this limitation, innovative approaches to data collection from children have been proposed, such as the use of therapeutic mobile games (Banerjee et al., 2022; Washington et al., 2020). These games allow obtaining videos of children expressing emotions in naturalistic contexts, generating more representative data sets. The study (Washington et al., 2020) achieved an accuracy of 66.9% using data from a mobile game, exceeding the accuracy of other classifiers in CAFE.

The creation of child-specific datasets is critical. (Zhou & Sun, 2020) built a database and model for recognizing emotions in children, achieving higher accuracy than traditional methods. However, the study was limited to four basic emotions. (Meuwissen et al., 2016) created a stimulus set with facial expressions of children and adults, validated with an accuracy of 86%. However, it is suggested to extend the age range for greater representativeness. Finally, it should be mentioned that the creation of quality datasets is critical for progress in this field. (Banerjee et al., 2022) highlights the importance of labeled data of children's facial expressions and describes the development of a mobile game ("GuessWhat") to collect social behavioral data, including emotional expressions. This innovative approach contributes to the creation of valuable resources for training emotion recognition models in children. The analysis of facial expressions in children, especially those with ASD, is complex and requires consideration of the particularities of socioemotional development (Shanok et al., 2019). In addition, (Yan et al., 2020) highlights the importance of infants' facial expressions as social cues and their usefulness in the early assessment of conditions such as ASD.

In summary, the field of emotion recognition in children faces significant challenges. The need for larger and more diverse datasets, the presence of age biases in models trained primarily on adult data, and the inherent complexity of analyzing emotions beyond the basic ones, are some of the main barriers to progress in this area. In addition, while previous studies have primarily used image analysis, the analysis of emotional expressions in videos represents an important research opportunity that could provide valuable information. These obstacles represent important areas of research that need to be addressed in order to achieve a better understanding and recognition of emotions in the child population.

Accordingly, this paper proposes a methodology based on ICTs and emotional narrative that allows the compilation of a dataset of training videos for an automatic classifier of emotions in children. This database will serve as a starting point to develop a predictive model in the future. The collection process is based on emotional narrative, where children can express themselves freely, allowing the recording of natural and spontaneous emotions. In addition, the participation of expert evaluators is incorporated, who rate the perceived emotions through a rating scale.

The main contributions are listed below:

- Compilation of a dataset of training videos with emotions expressed naturally by children.
- Development of a methodology for the collection and analysis of emotions in children, using emotional narrative and ICT tools.
- Rating of emotions perceived by expert raters.

The present research is structured as follows. First, the Methodology for perceiving emotions in children through emotional narrative and ICT tools is described, including the study design, the data collection instruments and the analysis procedure. Finally, the results obtained are presented, including the descriptive analysis of the data and the conclusions of the study.

2 Materials and methods

The following is a description of the methodology proposed for the evaluation of emotions perceived in children by means of emotional narrative and ICT tools. Initially, individuals were selected from an educational institution, to whom the purpose of the project was explained and who were asked to sign an informed consent form. Once the sample was defined, interviews were conducted using the emotional narrative technique, where psychologists evoked three emotions (sadness, neutral and joy) in the participants. These interactions were recorded, forming a data set that was subsequently evaluated by several experts, who assigned a series of valences to each video. Finally, the video-valence pairs were plotted and quantified, obtaining metrics that indicate the success of the emotional evaluation. Each step of the established methodology is presented in detail below.

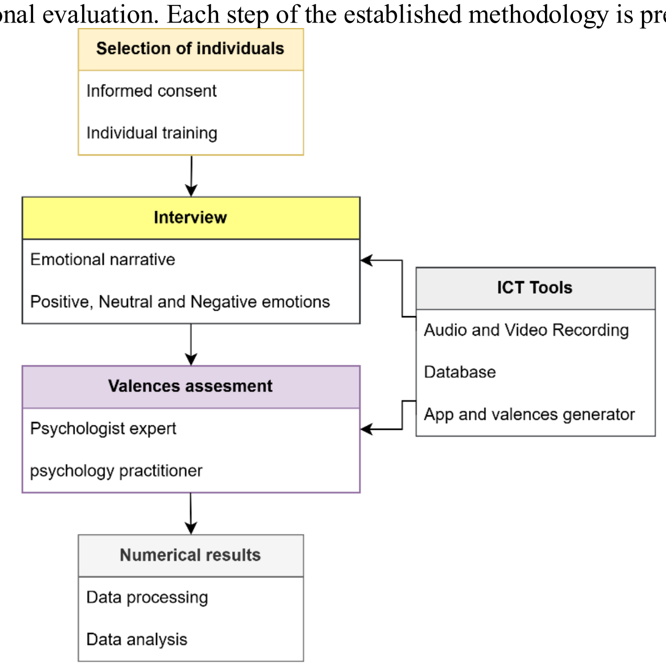


Fig. 1. Methodology for perceiving emotions in children through emotional narrative and ICT tools

2.1 Sampling and selection of individuals

A sample of sixth and seventh grade high school students from the IE Instituto Teresiano located in Túquerres, Nariño, who voluntarily participated in the recorded interviews, was selected. The selection considered factors such as gender, age, and socioeconomic context to enrich the analysis. It should be mentioned that prior to their participation, the students' guardians signed an informed consent for the collection of personal information.

Table 1. Individuals

Number of individuals	22
Male gender	9
Female gender	13

The environment was designed in a clean, standardized manner, with a black background that eliminated distractions, and the cameras were positioned facing forward to capture facial expressions up to the shoulders. This was done in order to minimize elements that could bias the training data and ensure that the model generalizes adequately to different populations.

2.2 Psychologist-guided interviewing using emotional narrative

To better understand human emotions in real life, a dataset was collected that captures natural and spontaneous emotional expressions. This work is based on the emotional narratives methodology developed (SENDv1) at Stanford University, more details in (Ong et al., 2019). The SENDv1 dataset consists of videos of people, in this case children, sharing personal life stories that evoke various emotions. These spontaneous narratives not only capture natural emotional expressions, but also contain rich semantic and conceptual content. Moreover, these stories show a variety of emotional "trajectories" over time, providing a comprehensive and detailed dataset for modeling and time-series analysis of emotions.

Following the SENDv1 methodology, children were interviewed individually. During the interviews, they were asked to think of three very positive and three more negative events, and were recorded while talking about them. The recording was self-paced: the experimenter let them talk as long as they wanted about each event, allowing to capture natural and spontaneous emotional expressions of the participants.

The video interviews were guided by psychologists who applied specific psychological techniques to induce positive or negative emotions in the interviewees. Some of the techniques used include:

Emotional intelligence. Ability to empathize with the subject, recognize their emotions and act accordingly (emotions), it is important in the interviews thinking that recognizing one's own emotions and those of others allows to work and manage emotions.

Active listening. This involves listening attentively and comprehensively to the interviewee, while showing empathy and interest in what he/she is talking about, thus reflexively telling what the interviewee says, provoking a reaction in him/her.

Storytelling. Telling stories and listening to them allows and facilitates emotional and empathic contact with the interviewee, thus facilitating understanding and emotional attunement between the interviewee and the interviewer, achieving in this way, that emotions are demonstrated.

Reflective questions. Asking reflective questions about the interviewee's topics, experiences and behaviors, facilitates the emotional venting and even the deep recognition of his or her state of mind, which facilitated the process.

2.3 Evaluation of emotions by valence and indicators

The data are assessed in terms of valence scales for the generation of a model that quantifies the identified emotions. The valence scale is a useful instrument to measure the emotional charge, both positive and negative, expressed through participants' personal narratives (Ong et al., 2019). This type of measurement allows for capturing the intensity and variation of emotions over time, thus providing a deeper understanding of the emotional experience of the individuals sharing their stories.

Once the set of videos is compiled, a group of expert psychologists are tasked with visualizing and rating the children's perception of emotions as they told their stories using the valence scale. These valence ratings were collected using a visual analog scale, ranging from "Very negative (-1)" to "Very positive (1)". Ratings on the scale were recorded every second, allowing continuous valence ratings to be generated on the videos.

Once the valence scale is defined, mental health professionals (P) are in charge of rating the videos of each individual (N), generating a valence series with a duration equal to the video: $V_n^p(k)$, where (k) represents the instants of time that the valence lasts. Considering this notation one can define the average weighted valence ($\bar{V}_n$) of an individual as follows:

$$\bar{V}_n(k) = \alpha_p \sum_{p=1}^{P} V_n^p(k)$$

Where α_p is the professional's weighting p , which is defined according to the professional's expertise or ability to identify emotions in facial expressions. The average weighted valence allows generalizing the series of emotions of an individual, describing a curve that represents the dynamics and variation of the emotions that professionals perceive. By integrating the area under this curve, we can obtain a summary measure that characterizes the average mood (A_n) of the individual assessed, providing an overview of his or her emotional experience during the narrative. These types of ratings facilitate the creation of machine learning models that can better predict and understand human emotions in various contexts.

On the other hand, consensus error (e_n) is defined as a metric that describes how dispersed or aligned the observers' valences are from the average valence. The consensus error is defined as follows:

$$e_n = \frac{1}{N_T} \sum_{n=1}^{N} \sum_{p=1}^{P} \left| \bar{V}_n(k) - V_n^p(k) \right|$$

Consensus error is a measure of confidence in the interpretation of the video. A low consensus error indicates that observers have a similar interpretation of the emotions expressed in the video, reflecting a high degree of agreement and confidence in the assessment made. Conversely, a high consensus error suggests a lack of consensus among observers, which may indicate that the individual did not express a clear and defined emotion during the narrative. In this case, it is advisable to remove such a video from the data set, as one cannot be certain about the emotional rating of the video.

Consensus error is, therefore, a metric to guarantee the quality and reliability of the dataset, by allowing to identify and discard those videos where there was no clear and unified emotional perception by the expert observers. This ensures that the final dataset is of high quality and can be used with confidence to train machine learning models.

2.4 ITC Tools

2.4.1. Audio and video recording: The interviews were conducted in an office with dimensions of 3.5m by 3.2m under acceptable lighting conditions (350 lux). An SV3C camera was used, reference B06W-5MP-HX, this is a 5 Megapixel resolution IP camera, which allows video transmission via RTSP (Real Time Streaming Protocol) using Ethernet cable or WiFi. The camera is located in the upper part of the office with the objective of clearly capturing the students' faces in videos that have a duration between 60 and 180 seconds, a resolution of 1920x1088 and a rate of 30fps.

2.4.2. Technologies Used in Software Development: *HTML5 and CSS3:* For the structure and design of the interface. HTML5 and CSS3 are fundamental to create attractive and functional user interfaces, allowing an interactive and responsive experience.
JavaScript: For interactive slider functionality, video loading and data handling. JavaScript is essential for adding interactivity to web pages, and in this case, it is used to capture and process user input in real time. *AJAX:* It allows updating the web pages where the evaluation software was designed to send the evaluators' data in real time, improving the interactivity and speed of the web application, allowing asynchronous communication with the server. *Bootstrap:* It is a web design framework that facilitated the creation of the responsive website through its collection of predefined tools and components (such as buttons, forms, and navigation menus) to create an attractive, functional and efficient user interface for the evaluators.
2.4.3. User Interface: The main interface of the software consists of a video section and an interactive slider. The video shows the interview between the psychologist and the interviewee, while the slider allows observers to mark the perceived emotions.

Fig. 2. User interface of the valence scoring software.

Interface usability is critical to ensure that observers can interact with the software intuitively and efficiently. Design principles such as Jakob Nielsen heuristics and user-centered design are implemented in the software to ensure a pleasant experience for the testers.

The software features the Slider functionality, which is designed to allow observers to mark emotions on a scale ranging from the most negative to the most positive (-1 to 1). The data provided by the slider are stored in a database for further analysis. This emotion valence system is based on Russell's affective space theory, which proposes that emotions can be represented in a two-dimensional space of valence (positive/negative) and activation (high/low). This representation allows a more accurate and useful categorization of the observed emotions.

2.4.4. Use of valence software: The observers of the videos, who were psychology students and teachers, marked the perceived emotions using the slider. With the video evaluations, emotions are characterized by valences from -1 to 1, which allows the emotion to be categorized as positive or negative according to its intensity. These valences will later be used to implement AI cameras.

This phase of the project is based on observational analysis, where students and teachers apply their theoretical and practical knowledge in identifying emotions. The feedback obtained from these observers also contributes to the improvement and adjustment of the software. Next, the procedure is described:

a. *Video Selection:* The evaluation videos were randomly uploaded to the evaluators, avoiding the repetition of interviewees so that the sampling is not biased.
b. *Observation and Marking:* The observers watch the video and use the slider to mark the emotions (Positive/Negative).

c *Data Storage:* The data generated by the emotion recognition slider is stored in a database.
d. *Data Analysis:* The data is analyzed to identify emotional patterns.

This procedure ensures a systematic and rigorous approach to the collection and analysis of emotional data, allowing for continuous validation of the tool used.

3 Results and discussion

After interviewing 22 students, a total of 57 videos were obtained that captured their narratives. These videos corresponded to 19 students, each of whom narrated three stories expressing positive, neutral, and negative emotions. On the video viewing platform, 198 observers participated, who randomly evaluated 57 videos. Each video received 10 views, which resulted in the generation of 570 valence curves, with 10 curves for each video, on average. More details in [24].

Table 2. Numerical results

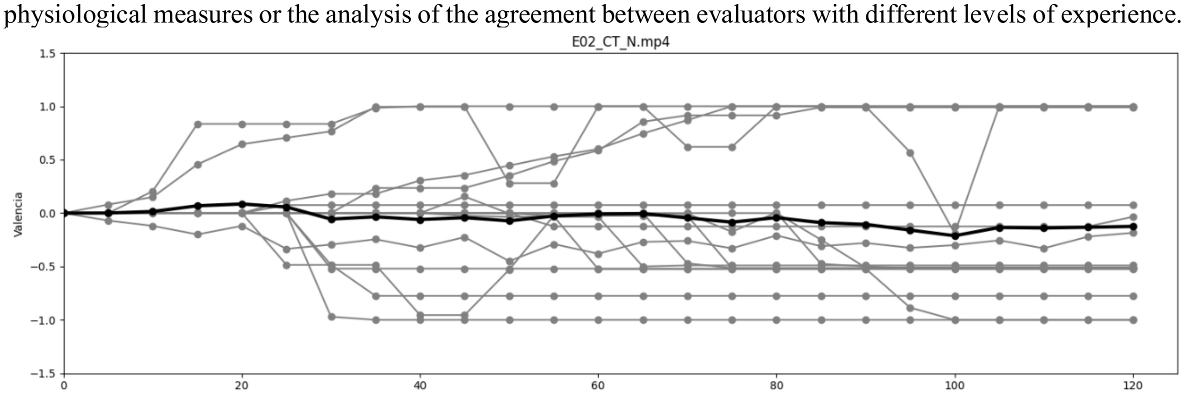
Video	Consensus Error	Estimated Mood
E02_CT_N	0.3881	-1.3525
E08_CT_N	0.4293	1.8767
E11_CT_P	0.4304	0.0955
E04_CT_P	0.2446	11.9532
E04_CT_M	0.2946	6.7400

Table 2 presents quantitative results regarding the error in relation to the average valence and the estimated mood for a group of students. Entries 1–3 exhibit a considerable consensus error, whereas the subsequent entries show a low error, validating the reliability of the obtained average valence. After a preliminary evaluation of the valence curves for each video, the analysis revealed the following patterns:

- No consensus on the type of emotion identified
- Consensus on the type of emotion identified
- Other cases

3.1. No consensus on the type of emotion identified

In the following figures, the black line shows the average weighted valence and the grey lines represent the valences of each evaluator. As can be seen, in Figure 2, the evaluators have contrary perceptions about the average valence, indicating that the emotion expressed by the subject was not clearly perceived. This divergence of opinions is explained by the difficulty that the individual had in emotional expression when faced with the interviewer's sobriety or by the evaluators' lack of experience in interpreting it. In any case, these results suggest that additional strategies should be implemented to validate the quality of the data set, such as the inclusion of physiological measures or the analysis of the agreement between evaluators with different levels of experience.



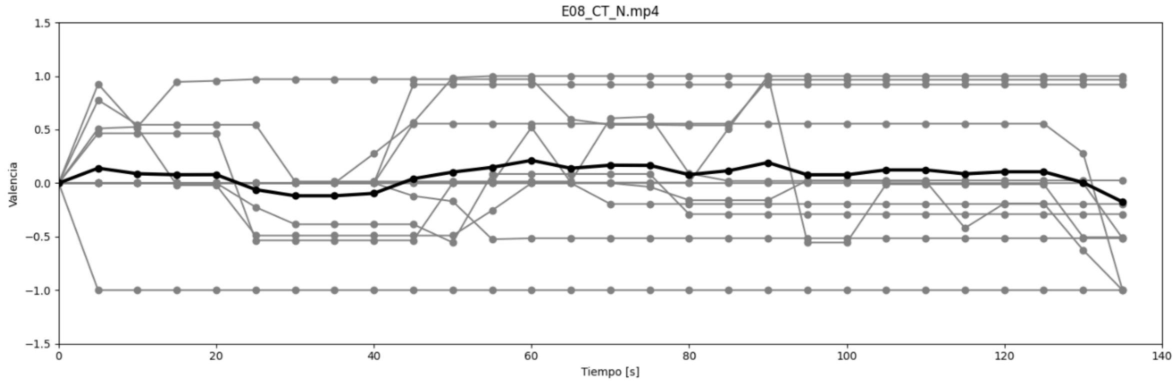


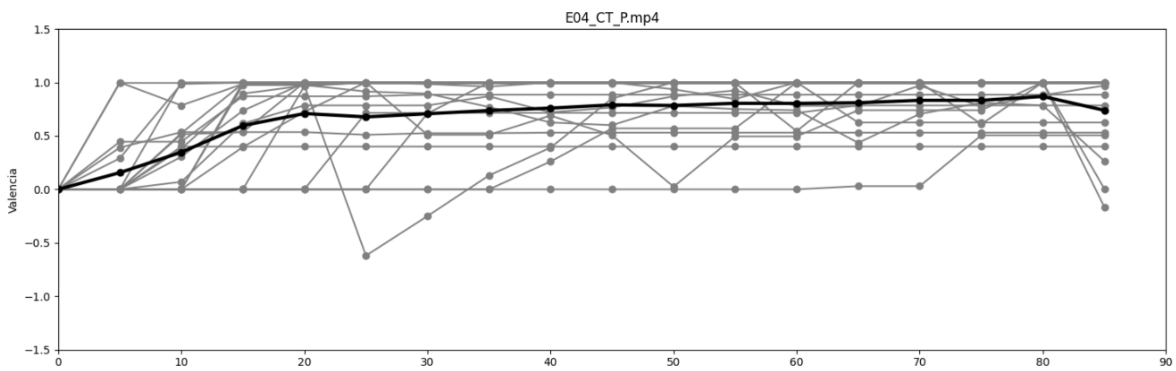
Fig. 3. Valences of the videos of individuals E02 (top) and E08 (bottom).

3.2. Consensus on the type of emotion identified

As can be seen in Figure 4, the black line shows the average weighted valence, which represents a general characterization of the individual's perceived emotions over time. The grey lines represent the valences of each evaluator, which allows for the analysis of consensus among observers. In most cases, individual valences are close to or do not deviate significantly from the average valence, confirming a high degree of consensus on the observed emotion. This convergence in emotional perception by expert psychologists is an indicator of the reliability of the average valence obtained.

Furthermore, this level of consensus among the raters suggests that the emotions expressed in the videos were clear and defined, supporting the utility of the dataset for training machine learning models. For example, video E04_CT_P.mp4 (See Fig. 4) corresponds to a positive emotion narrated by individual 04, which corresponds to the average valence scale close to 0.75 for most of the video.

For example, Figure 5 shows a clear consensus among observers regarding the emotion perceived in the video. In this particular case, a clear turning point can be seen in the emotional narrative, where the individual goes from expressing an emotion of sadness or discomfort to an emotion of a positive nature. This transition in emotional valence is clearly perceived by most expert observers, indicating that the emotions expressed in the video were defined and clear, thus facilitating their correct identification and assessment by the raters.



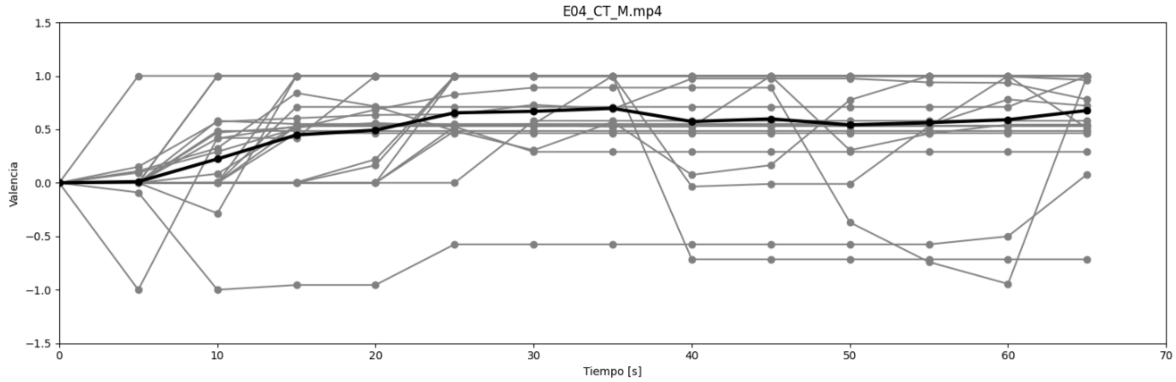


Fig. 4. Valences of the videos of individual E04 with positive (top) and negative (bottom) emotion.

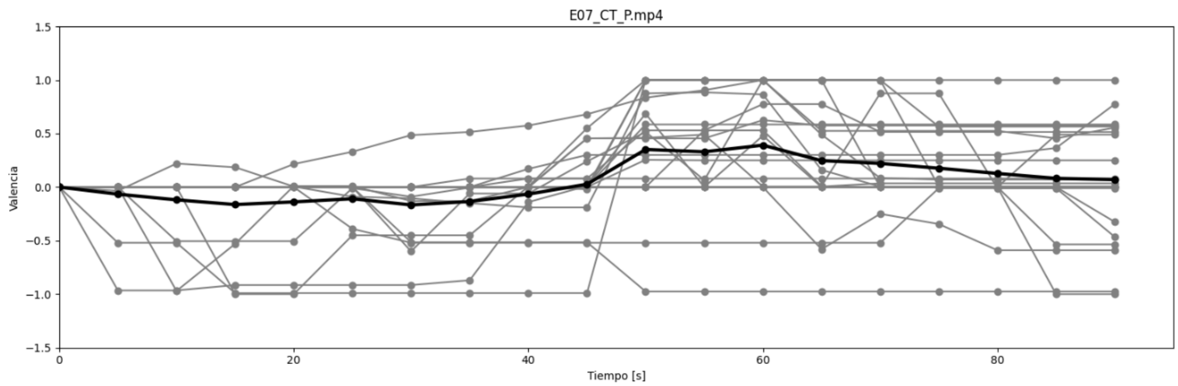


Fig. 5. Valences of the video of individual E07.

3.3. Other cases

In addition to the lack of consensus observed in the Figure 6, there is also a perception of emotion with different intensities by the evaluators. This suggests that there is a need to standardize the way observers evaluate the intensity of emotions expressed in the videos. By achieving greater uniformity in the interpretation of emotional intensity, more consistent results can be obtained in the reading of emotions in the data set. It is important to implement strategies that allow homogenizing the way experts perceive and quantify the intensity of emotions, in order to ensure the reliability of the data set.

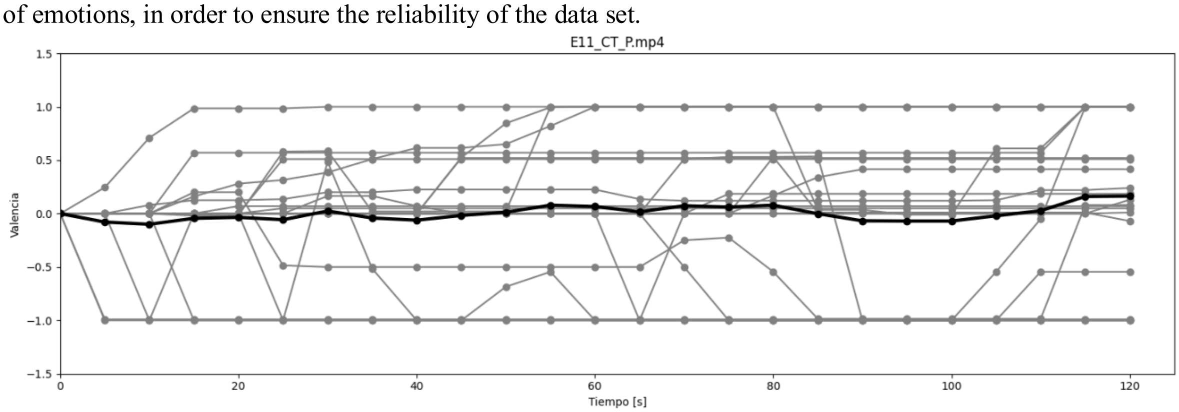


Fig. 6. Valences of the video of individual E11.

In the latter case (Figure 7), observers are slow to start rating valences because they are interpreting the type of emotion expressed by the individual. This may be because the emotions expressed in the video were not clear or defined enough, which made it difficult for the evaluators to correctly identify them. In addition, it is observed that the intensity perceived by the evaluators is low, which occurs because the children did not express an emotional narrative that was intense enough in their story. These data with low emotional intensity and lack of consensus among observers are likely to be discarded from the data set, as they can generate confusion and negatively affect the learning of emotion prediction models that are trained with this set of information.

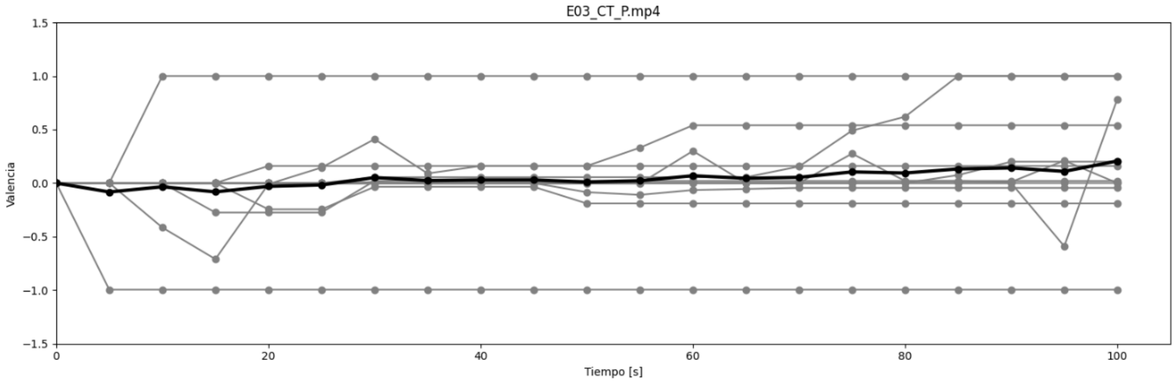


Fig. 7. Valences of the video of individual E03.

4 Conclusions

The developed software provides an effective tool for the analysis of emotions in psychological interviews. The data obtained can be used to form a data set labeled by the valence scale. This contributes to the development of an AI-based tool to improve the monitoring and support of students in educational environments.

This project demonstrates the potential of integrating artificial intelligence and computer vision technologies in the field of psychology, opening up new opportunities for research and professional practice.

The use of software demonstrates effectiveness in the validation process through the analysis of facial expressions, which allows the identification and evaluation of emotions during the observation process. The tool provides objective data that can be integrated into the subjective observation of the mental health professional, optimizing the accuracy of the psychological evaluation.

The implementation of the tool allows to enhance traditional techniques for evaluating emotions from the psychological study and to deepen it from the technological contribution of the software with clinical observation. Experts in the study of mental health can achieve a more particular perspective of the emotional state of the individual; allowing accurate diagnoses and appropriate treatments.

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Food Design in the Digital Age: Challenges and opportunities for teaching sustainable food design and the integration of colombian gastronomic identity

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Abstract. The "Food Product Architecture" course at the Universidad Nacional Abierta y a Distancia (UNAD) promotes the design and development of innovative food products through the integration of methodologies like Food Design and Design Thinking in virtual environments. The applied methodology comprises five phases where students address the conceptualization, design and prototyping of food products that enhance the gastronomic identity of Colombia's regions and enables the use of new digital tools, fostering sustainability and the application of emerging technologies for the ideation and prototyping of these products. As results, we find effectiveness in teaching food design using tools like ChatGPT and Leonardo AI that facilitate the creative process by accelerating idea generation and prototype creation, allowing students to develop innovative proposals that reflect the country's cultural richness and biodiversity. Additionally, active participation and collaborative work are fundamental for the course's success, where students interact virtually with solid individual contributions and collaborative work, using resources like Microsoft 365 and Google Workspace to organize their academic and creative processes. It is important to highlight the positive impact on local communities, as students have developed products that can contribute to regional socioeconomic development. The participation and recognition in national design events demonstrates the quality and relevance of the generated projects, which prepare students to face the challenges of food design in a globalized digital environment.

Keywords: Food Design, Social Innovation, Design Thinking, Artificial Intelligence, Regional Identity.

1 Introduction

Distance education, supported by virtual learning environments, continues to be perceived as an academic and formative challenge when contrasted with the possibilities evoked by or compared to face-to-face education. However, in the digital era, where communication media have evolved significantly and where technological tools have been adopted for carrying out daily activities, emerging technologies are being intuitively and massively adopted, redefining educational paradigms.

This teaching model is not new. In the educational field, Distance Education has a long-standing history that began with correspondence and radio broadcast study programs, later developing to offer courses through audiovisual systems supported by satellite channels [1]. This evident validation of distance academic models and their constant evolution over time have paved the way for integrating new technological tools and consequently including increasingly complex disciplines and knowledge where the relationship with the objective and tangible is prioritized, and therefore must be taken into account.

Faced with this reality, we encounter the teaching of design in virtual learning environments, considering that this discipline in some cases requires certain types of physical interaction to obtain coherent products or results, in addition to being validated in their context.

One of the trends that has been accepted in this discipline is "Food Design," which according to authors like Parasecoli F. [2] in his work "Food design, nutrition, and innovation" explores how food design can address global challenges such as sustainability, health, and culinary innovation. Similarly, Cordoba C. [3] and his team propose Food Design and Gastronomy as complementary disciplines that can articulate new food experiences as cultural promotion tools. For her part, Zampollo Francesca [4] with her Food Design Thinking approach applied to food design focuses on innovation and user experience, being fundamental for understanding the relationship between its inputs and productive technologies Reissig [5]. This approach focuses on the form of food both as a product and as a process, as this influences all stages: production, processing, transportation, preparation, and consumption experience, being key for food ergonomics and its identity within cultural practices.

In this context, this design line can be considered to challenge the gaps posed by distance education versus face-to-face education and geographical limits. This challenge has been taken on by the Universidad Nacional Abierta y a Distancia - UNAD for the benefit of its students, regional economies, and inhabitants through comprehensive and quality education.

Now, according to Leal Afanador [6], the Unadista Pedagogical Model (MPU), which is the conceptual and methodological framework guiding teaching and learning processes at the Universidad Nacional Abierta y a Distancia (UNAD) of Colombia, focuses on distance and online education, promoting student autonomy. It advocates the use of information and communication technologies (ICT) and competency-based comprehensive education, which are its greatest strengths compared to other institutions still exploring tools that can be integrated into educational processes.

In the 2024 MPU model [7], some of the principles governing this model are outlined, among which we will only present some related to the use of emerging technologies in teaching and learning processes. These include: Flexibility with the use of virtual platforms and digital resources to facilitate access to education; Autonomy where self-management of time and learning resources is promoted; Competency-based education integrating knowledge and skills to solve problems in real contexts; Technological innovation using active methodologies like project-based learning and incorporating technological tools including Artificial Intelligence and Mixed Reality combining virtual and augmented reality; and Sustainability integrating principles of environmental, social, and economic sustainability in training processes, fostering social responsibility and commitment to sustainable development.

Among the components of the MPU model are the following: Learning environments as interaction spaces between teachers and students containing educational resources using virtual classrooms, forums, videoconferences, and remote laboratories; Use of digital educational resources with multimedia content, e-books, simulators, and databases; Formative evaluation with continuous evaluation processes allowing feedback and learning improvement, and use of evaluation rubrics containing items to be assessed in activities; Tutorial support where tutors act as learning guides and facilitators providing academic orientation to students; and an important part promoting meaningful learning which is research and innovation with the integration of research as a fundamental part of the training process and fostering interdisciplinary projects applied to real and contextual problems.

Among the most important updates to the MPU for 2024 are: Artificial Intelligence (AI) with tools allowing personalized learning and recommendations based on student progress; Virtual and augmented reality using immersive technologies to enrich the educational experience; Focus on 21st century skills developing digital competencies, activating critical thinking, increasing creativity, and collaborative work in multidisciplinary teams seeking solutions to social problems in the student's context; and Curricular sustainability aligned with the UN Sustainable Development Goals (SDGs) in study plans.

2 Methodology

At UNAD, under its Unadista Pedagogical Model: Autonomous, Participatory and Collaborative, the Industrial Design program offers the course "Food Product Architecture." This course focuses on the comprehensive training of students for the detailed analysis of processes associated with the preparation, presentation, experience, and service of food products, through the meticulous deconstruction of a Colombian gastronomic product [8].

The course incorporates Design Thinking, systems thinking, and Artificial Intelligence (AI), with the objective of contributing to sustainable development and the well-being of local communities. It leverages Colombia's cultural richness, biodiversity, and gastronomic traditions through project-based exercises with a social focus.

It is at this point that the most relevant technological advancements of recent years, such as Artificial Intelligence (AI), take center stage in UNAD's open and distance education model, specifically in the Industrial Design program and this Food Design-focused course. Therefore, AI integration has been adopted into the methodology, considering updated references and previous experiences where AI can accelerate conceptualization, design, and prototyping processes.

We reference that generative design algorithms can quickly produce many different design options based on established specific criteria. This allows for testing and exploring new and diverse ideas in a short time. With AI, prototypes can be quickly created, feedback gathered, and improvements made [9]. This range of possibilities has led to the generation of products and proposals with greater technical complexity, producing innovative results that enable new worldviews for designers.

Within the framework of collaborative work with Design Thinking and project-based learning, the following phases are structured to achieve objectives and learning outcomes:

- Phase 1: Social Innovation in Food Design
- Phase 2: Design Thinking in Food Morphology
- Phase 3: Product Architecture in Food Design (Ideation and Prototyping)
- Phase 4: Systems Thinking, Identity and Context
- Phase 5: Final POA Report

Similarly, official collaborative and remote work tools have been adopted to effectively integrate participants, enabling tracking, progress monitoring, and process documentation. This list of tools includes: Discussion forums and internal messaging within the UNAD virtual campus (Moodle), Microsoft Teams for synchronous and asynchronous communication, and Microsoft 365 and Google Workspace resources.

For the ideation and prototyping phases, which are the focus of this reflection, some artificial intelligence (AI) tools or AI-powered tools have been adopted, such as: Miro, ChatGPT, and Leonardo AI.

For the selection of the generative image AI tool, two recognized applications were compared: MidJourney and Leonardo AI. These are two popular artificial intelligence tools for image generation. Both are used in design, digital art, and creative work, but differ in their approaches, functionalities, and features.

Table 1. Comparison Matrix of Artificial Intelligence Tools: Leonardo AI vs MidJourney

Heading level	Leonardo AI	MidJourney
Tool Type	AI platform for design and image generation focusing on creativity and customization.	AI tool for artistic/conceptual image generation
Primary Focus	Specializes in product design, digital art, textures, and game/app assets.	Specializes in concept art, illustrations, and surreal/abstract designs
User Interface	Intuitive web interface accessible via browsers.	Operates through Discord which some users may find less intuitive
Customization	Provides advanced customization for models and parameter adjustment.	Limited customization but offers unique artistic styles
Artistic Styles	Offers diverse styles including realism, concept art, and 3D design.	Focused on surreal, abstract & fantasy styles
Common Uses	Used for product design, game assets, advertising, and marketing.	Used for concept art, illustrations, and character/background design
Integration withOther Tools	Integrates with Photoshop, Blender, and Unity.	No direct integrations. Lacks direct integration but allows image exports for external use
Pricing	Freemium model with free and premium plans.	Requires paid subscription with limited free trial access
Community & Support	Growing community with technical support and built-in tutorials.	Features an active Discord-based community with user-driven support
Generation Speed	Fast processing with adjustable quality/speed settings.	Delivers fast processing speeds depending on server capacity
Image Quality	High-quality output with HD resolution options.	Produces exceptional artistic quality that varies by selected style

Machine Learning	AI models optimized for practical design applications.	Uses visual art-focused models generating abstract creative results
Accessibility	User-friendly for beginners and pros, with integrated tutorials.	Demands Discord familiarity and understanding of specific commands

Comparison Matrix Conclution

Leonardo AI establishes itself as the optimal solution for practical design applications, providing professionals in product development and game design with powerful tools to create commercial assets, textures, and prototypes with precise customization. Meanwhile, MidJourney excels as the preferred platform for artistic creation, enabling illustrators and concept artists to produce imaginative works with exceptional stylistic flexibility and creative interpretation. While both leverage AI for image generation, Leonardo AI focuses on functional design solutions whereas MidJourney prioritizes artistic expression, addressing distinct yet equally valuable creative needs in their respective fields.

In addition to this standard of approaches and tools established, the methodology has been structured in such a way that it includes the learning guide, where the problem or challenge is presented along with the tools proposed by the instructor to carry out the activity; the discussion forum for scheduled activities where the student can interact with their small group and with the tutor instructor, and where individual and collaborative progress in the activity is shown; the internal mail and Teams chat that enable synchronous and asynchronous communication with the tutor; and the submission space for designs once they have been created.

This methodology integrates knowledge holistically, establishing a coherent process where the student becomes the protagonist of their learning, while the instructor-tutor acts as a guide for project development and knowledge construction in the digital age. This approach aligns with what was proposed by Leal Afanador [10] in his work 'Colombianitud', where he presents the academic experience at UNAD as an opportunity to implement cutting-edge hybrid education, establishing itself as an indispensable pathway to respond to current training needs of the population.

3 Results and Discussion

Teaching Food Design, as one of the specialization lines of the Industrial Design program at UNAD [11] mediated through virtual learning platforms, has been significant. The results of this teaching process at UNAD reflect an appropriation of acquired knowledge by students that enhances and facilitates learning.

The application of AI tools in its development is equally positive. However, it is important to highlight that their incorporation in higher education is not without challenges. It is vital that teaching staff are properly trained and prepared to use these tools effectively and ethically. Academic integrity must remain at the forefront, and it is essential that higher education institutions provide professional training and upskilling in this area [12].

In academic processes, the implementation of official tools is particularly significant, especially in creative environments like teaching food design. Over time, consistently favorable responses have been obtained in this field. Due to the creative nature of the work, which requires hands-on experiences, it demands special attention and effective motivation from tutor instructors to foster active participation.

Although attendance at webconference sessions has been outstanding, in cases of absence, students compensate for their participation with solid individual work, directing their contributions to team collaborative outputs. For task execution, work teams have been created on the Microsoft Teams platform, where meetings are scheduled for each topic covered in every phase. This platform allows scheduling and documentation management, thus creating repositories or documentary archives of the training process and the creative processes implicit in the applied methodology.

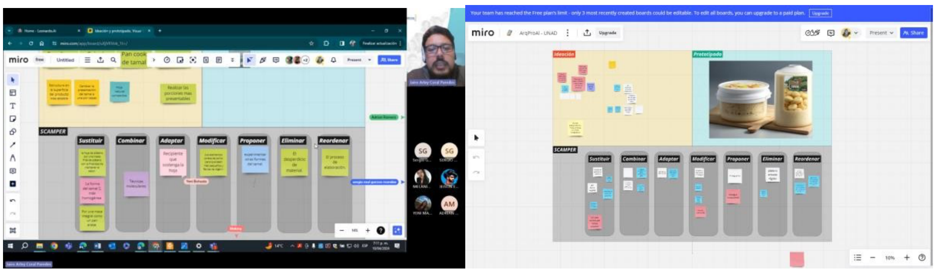

Fig. 1. Collaborative work in Teams and Miro. Ideation exercise with Brainstorming, Affinity Diagram and SCAMPER. Author: Jairo Coral.

It is important to remember that virtual education focuses on autonomous, meaningful and collaborative work, being the foundations of UNAD's comprehensive academic training model. Therefore, strategies must emphasize that students acquire efficient autonomous study skills, proper time organization and strong responsibility, learning to learn. The Pedagogical Model centers its action on the student, as a key reference of the training process. The student must be an active subject, a person trained for leadership and social awareness - critical and constructive - with capacity for self-determination, self-control and self-management in their learning process, and willing to contribute to building a supportive, just and free society [6].

The implementation of AI technologies starts from the ideation phases and moves to prototyping, once the empathy and definition phases are completed, they are used to propose divergence processes in idea generation and convergence for prototype definition. With the results obtained in the initial phases, some Insights are proposed, which will be validated later. These tools have been initially used, for example, for prompt optimization, as in the case of Chat GPT where the post-ideation exercises requirements have their first exploration in the conceptual approach of solutions.

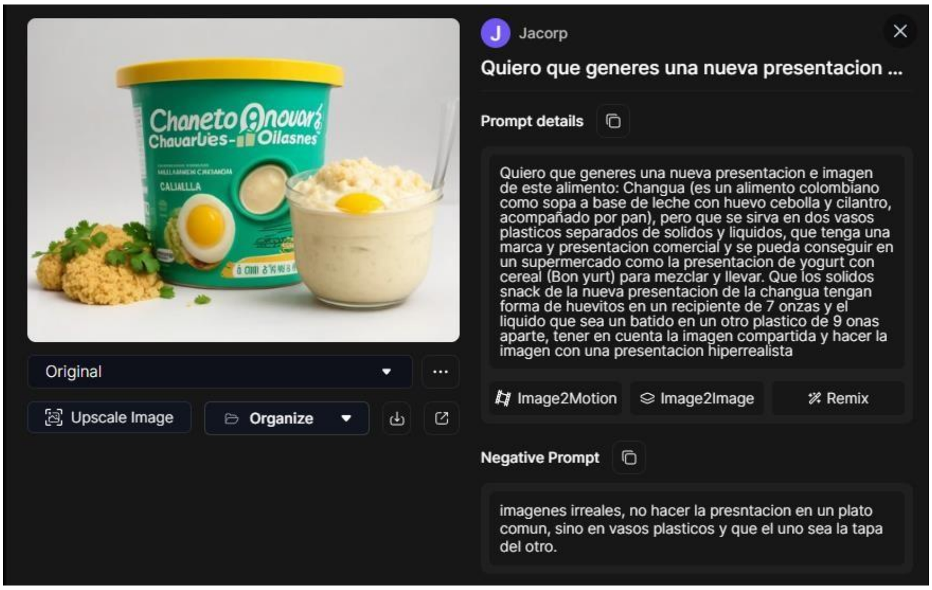

Fig. 2. Prototyping with AI. Implementing a GPT chat prompt in Leonardo AI software. Author: Jairo Coral.

We could say that the digital prototypes created with the Leonardo AI tool are truly innovative, possessing a degree of disruption that emerges from the design process. That is to say, this technology is used as a tool that is limited to generating some alternative solutions to the needs or insights identified in previous phases, responding to the designers' specific requirements. These approaches to digital prototypes are purely the result of creative processes carried out within the design challenge framed by Design Thinking. Therefore, they are not considered individual creative products generated by the technology.

Fig. 3. Exploration and Prototyping. Prototyping with Leonardo AI in Academic Activities. Author: Jairo Coral.

Student interaction and participation in this modality contribute to intercultural exchange and knowledge transformation, promoting the social appropriation of knowledge. Similarly, student profiles further highlight the virtues of each region, which translates into bridging digital divides within the context of these technologies' accelerated emergence and rapid evolution.

As a significant outcome, the contribution to society stems from interventions across different regions of the country and project proposals rooted in local economies. This validates a virtual academic design system based on sustainability and cultural identity, incorporating contributions from future designers through their own experiences and backgrounds. This approach has created pathways for participation in national design exhibitions and events with academic products and real prototypes. These digital approaches generated through AI have showcased the potential of professionals using digital tools in open and distance education models.

4 Conclusions and comments

Effectiveness of the Virtual Methodology: Throughout the development of the 'Food Product Architecture' course at UNAD, based on methodologies such as Food Design and Design Thinking, it has been demonstrated that teaching food design in virtual environments can be highly effective when integrating emerging technological tools. These tools have enhanced the ability to innovate in designing sustainable food products while connecting students with Colombia's regional gastronomic identity.

Cultural Value of Food Design: The focus on Food Design, centered on the form and process of food, enabled students to understand how gastronomy is not merely a culinary aspect but rather a profound cultural expression that connects communities with their roots.

Role of AI in the Creative Process: The incorporation of artificial intelligence (AI) in ideation and prototyping was one of the most innovative aspects of the course. Tools like ChatGPT and Leonardo AI accelerated creative processes, allowing for faster generation of ideas and proposals, though without replacing human creativity.

Importance of Collaborative Work: Collaborative work was crucial to the course's success. Although students faced challenges attending all virtual sessions, compensation through high-quality individual work maintained notable performance standards. The Microsoft Teams platform was essential for coordinating these efforts.

Need for Expanded Technological Literacy: One of the main challenges identified is the need for technological literacy, not only for instructors and students but also for the gastronomic community interested in innovation. This includes training in advanced tools like AI, as well as their ethical integration into creative and educational processes.

5 Future lines of work

Open Technology Literacy Programs: Create accessible training programs for teachers, students, and individuals interested in gastronomy topics, focused on the use of emerging technologies like AI, conceptualization and prototyping, and their ethical application in food innovation, with modules adapted to different knowledge levels.

Collaborative Platform of Gastronomic Knowledge: Develop a digital platform that centralizes: (1) creative tools (AI, prototyping), (2) databases of regional ingredients and techniques, and (3) co-creation spaces between academia and the gastronomic community, facilitating knowledge transfer.

Pilot Projects with Local Communities: Implement pilot projects that connect students and local gastronomic actors (traditional cooks, producers) to co-design sustainable food products, validating course learnings in real contexts.

Gastronomic Innovation Network: Establish a network connecting UNAD with culinary institutions, food companies and communities, promoting the adoption of these methodologies and technologies to preserve and modernize Colombian gastronomic identity. Encouraging the execution of projects, internships and practical training programs.

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