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In the first chapter we present, *Innovation in knowledge transmission in the Mexican metal-mechanic industry: Practices and lessons from three strategic sectors*, by Bareño-Ramos, Enoc & Delgado-Torres, Claudia Lizethe, with ascription in the Tecnológico Nacional de México/Tecnológico de Saltillo and Tecnológico Nacional de México /Tecnológico de Nuevo León, as a second article we present, *Comparative analysis in mature fields through water exclusion in copano 41 and 45 wells of the Macuspana-Muspac asset*, by Guzmán-Isidro, Carlos Jesus, with secondment in the Universidad Olmeca, as the following article we present, *Evaluation of environmental impact manifestations of electric power transmission projects*, by Aguilar-Marin, Jorge Luis, Cisneros-Villalobos, Luis, Vera-Dimas, José Gerardo and Gutiérrez-Álvarez, Yair Alejandro, with affiliation at the Universidad Autónoma del Estado de Morelos, as next article we present, *Sustainable alternatives for water consumption in denim jeans washing: A systematic literature review*, by Araoz-Baltazar, Iván, Granados-Sánchez, Angelica, Martínez-Zárate, Israel and Del Angel-Medina, Oscar, with affiliation at the TecNM-Instituto Tecnológico de Tehuacán, as next article we present, *Advanced nanosystems for Breast Cancer therapy and diagnosis: A classification-based review*, by Martínez-Pérez, Beatriz, Mata-Rocha, Minerva and Fernández-Retana, Jorge, with affiliation at the Universidad Politécnica del Valle de México and Instituto Mexicano del Seguro Social, as next article we present, *MRI-Based prototype for early detection of muscular knee injuries with U-Net* , by Sánchez-González, Juan Alberto, Hernández-Reyes, José Manuel, and Escorza-Sánchez, Yolanda Marysol, with affiliation at the Universidad Politécnica de Tulancingo and Universidad Tecnológica del Valle del Mezquital, as next article we present, *Smart Phil Dispenser - SPD*, by Cortés-García, Alicia, Valencia-García, Alejandro Cesar, Rodríguez-Miranda, Gregorio and Feregrino-Martínez, Luz María, with affiliation at the Universidad Tecnológica de San Juan del Río




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Innovation in knowledge transmission in the Mexican metal-mechanic industry: Practices and lessons from three strategic sectors

Innovación en la transmisión del conocimiento en la industria metal-mecánica mexicana: prácticas y lecciones de tres sectores estratégicos

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




Abstract










This article analyzes innovation in the transmission of technical knowledge in the Mexican metal-mechanic industry. The objective is to understand the factors that facilitate effective knowledge transfer across different sectors, highlighting its strategic relevance for competitiveness and sustainability. The methodology was qualitative and documentary, based on the analysis of scientific literature and the review of ten case studies that illustrate successful practices in dual training, the use of digital platforms, and university-industry collaboration. The results show that the combination of technical competencies, enabling technologies, institutional networks, and organizational culture strengthens knowledge transfer, especially in sectors such as aerospace and automotive. In contrast, SMEs face structural limitations, although they manage to innovate through alliances and support programs. The main contribution lies in offering a referential framework that guides inclusive policies and practices for the management of technical knowledge.

Resumen

Este artículo analiza la innovación en la transmisión del conocimiento técnico en la industria metalmeccánica mexicana. El objetivo es comprender los factores que facilitan la transferencia efectiva del conocimiento en distintos sectores, destacando su relevancia estratégica para la competitividad y sostenibilidad. La metodología fue cualitativa y documental, sustentada en el análisis de literatura científica y en la revisión de diez casos de estudio que ilustran prácticas exitosas en la formación dual, el uso de plataformas digitales y la colaboración universidad-industria. Los resultados muestran que la combinación de competencias técnicas, tecnologías habilitadoras, redes institucionales y cultura organizacional fortalece la transferencia de conocimiento, especialmente en sectores como el aeroespacial y el automotriz. En contraste, las pymes enfrentan limitaciones estructurales, aunque logran innovar mediante alianzas y programas de apoyo. La principal contribución radica en ofrecer un marco referencial que orienta políticas y prácticas inclusivas para la gestión del conocimiento técnico.

Innovation in Knowledge Transmission in the Mexican Metalworking Industry		
Goals	Methodology	Contributions
 Analyze the factors that facilitate the transfer of technical knowledge across different sectors of the metal-mechanic industry.	 Applied and documentary research with a systematic literature review and industrial case studies.	 Technical competencies, enabling technologies, and a learning culture as central pillars for knowledge transfer.
 Identify successful practices that strengthen business competitiveness and sustainability.	 Integration of Learning Management Systems [LMS] and predictive analytics within a digital ecosystem.	 Evidence that advanced sectors [aerospace, automotive] have greater capacity for knowledge transfer than other sectors.
 Propose a framework to design inclusive and regionalized public policies in this sector of the industry.	 Analysis of 10 case studies in sectors such as aerospace, automotive, and multisectoral SMEs.	 Theoretical-practical framework to preserve technical knowledge and optimize processes.

Knowledge management, organizational innovation, metal-mechanic industry, technical transfer.

Innovación en la Transmisión del Conocimiento en la Industria Metalmeccánica Mexicana		
Objetivos	Metodología	Contribuciones
 Analizar los factores que facilitan la transferencia de conocimiento técnico en distintos sectores de la industria metalmeccánica.	 Investigación aplicada y documental con revisión sistemática de literatura y casos industriales.	 Competencias técnicas, tecnologías habilitadoras y cultura de aprendizaje como ejes centrales para la transferencia de conocimiento.
 Identificar prácticas exitosas que fortalezcan la competitividad y sostenibilidad empresarial.	 Integración de LMS, y análisis predictivo en un ecosistema digital.	 Evidencia de que los sectores avanzados [aeroespacial, automotriz] tienen mayor capacidad de transferencia que otros sectores.
 Proponer un marco de referencia que permita diseñar políticas públicas inclusivas y regionalizadas en este sector de la industria.	 Análisis de 10 casos de estudio en sectores como el aeroespacial, automotriz y pymes multisectoriales.	 Marco teórico-práctico para preservar el saber técnico y optimizar procesos.

Gestión del conocimiento; transferencia tecnológica; industria metalmeccánica.

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Peer review under the responsibility of the Scientific Committee MARVID[®] - in the contribution to the scientific, technological and innovation Peer Review Process through the training of Human Resources for continuity in the Critical Analysis of International Research.



Introduction

The transmission of technical knowledge is currently one of the most significant challenges for operational sustainability and continuous innovation in the industrial sector. This challenge becomes critical in the context of the relocation of production lines—particularly in strategic sectors such as automotive, aerospace, and household appliances in Mexico—where the transfer of machining, welding, or assembly processes to new sites entails risks associated with the loss of tacit knowledge, the learning curve, product quality, and operational safety.

Despite the economic weight of the manufacturing sector, which accounted for 18.5% of national added value and concentrated 47.9% of foreign direct investment during the period 2016–2020 [MFAT, 2021], there remains a lack of formal strategies to capture, document, and transfer technical knowledge. This research argues that many Mexican companies in the metalworking industry still lack systematic methodologies to ensure the continuity of critical capabilities during transfer or expansion processes.

Several recent studies highlight the benefits of institutionalizing knowledge management to build competitive advantages and reduce the loss of capabilities. For example, Huamaní et al. [2024] they document improvements in operational performance, internal learning, and innovation in Latin American industrial companies.

The study aims to analyze current and emerging practices of technical knowledge transmission in companies from three key sectors. Based on an exploratory and comparative approach, representative cases are documented to identify best practices, common barriers, and applicable lessons.

The added value of this research lies in four lines of analysis:

1. Modern learning techniques [García-García et al., 2024].
2. Use of technological platforms for documentation and teaching [González-Varona et al., 2021].
3. Integration of organizational training systems [CONOCER model].

4. Application of performance metrics linked to knowledge flow.

Each axis is examined on the basis of public data, institutional documents, and recent academic literature, generating a useful contribution for researchers, decision-makers, and industrial knowledge professionals.

2. Theoretical framework: foundations for innovation in the transfer of technical knowledge

A deep understanding of how technical knowledge is generated, transmitted, and adapted within the metalworking industry requires the articulated analysis of various conceptual frameworks.

This section provides the theoretical foundation for the key variables of the research, organizing them into five axes that range from the principles of knowledge management to their practical application in Mexican industries. Each subsection presents theories, models, and evidence that have been validated in highly complex industrial contexts and that are essential to understanding how companies can innovate in their mechanisms for transferring technical knowledge

2.1 Foundations of Technical Knowledge Management

Technical Knowledge Management [TKM] is distinguished by its focus on the systematic management of technical knowledge—both tacit and explicit—embedded in people, processes, and industrial technology, with the aim of ensuring operational continuity, adaptation, and the capacity for incremental innovation.

Unlike generic approaches to knowledge management, TKM emphasizes the capture and transfer of specific manufacturing and technical-operational processes.

Classical and Contemporary Models

The SECI model of Nonaka y Takeuchi [1998] provides the conceptual basis for how knowledge is transformed and circulates within technical organizations, while the contributions of Stiglitz y Greenwald [2014] underline the economic value of productive knowledge as a driver of systemic efficiency.

Recent studies such as that of Riascos-Eraza et al. [2021] in Latin American industrial companies confirm the persistence of challenges in the institutionalization of TKM, particularly due to weaknesses in organizational leadership and the limited use of knowledge technologies.

From an organizational perspective, Nonaka and Takeuchi’s SECI model proposes that knowledge is converted from tacit to explicit through four phases: Socialization, Externalization, Combination, and Internalization. This approach enables companies to capture practical experience and transform it into documented processes that are reusable and adaptable to new contexts [Nonaka & Takeuchi, 1998].

Current Empirical Evidence

Huamaní et al. [2024] document that, in Latin American industrial companies, the formal implementation of TKM—through tacit knowledge capture, competency-based training, and digital platforms—reduces operational errors and increases organizational innovation. These findings are consistent with studies from the OECD [2021] that link organizational capital, ICT skills, and training with significant improvements in industrial productivity.

Box 1

Table 1

Key Principles for Technical Knowledge Management in the Manufacturing Industry

Principle	Description
Capture of tacit knowledge	Techniques such as interviews, direct observation, and multimedia recording
Systematization and documentation	Standardization of processes, manuals, and the use of collaborative platforms
Continuous learning	Periodic technical updating and procedure review
Inter-area sharing	Mentoring, communities of practice, and cross-functional workshops

Source: Bareño and Delgado [2025], based on Nonaka & Takeuchi, Riascos Eraza et al., Huamaní et al., and OECD

Connection with the research axes

These principles support the four analytical axes of the study:

1. Modern learning techniques [AR, microlearning, TWI].

2. Technological platforms [LMS, digital twins, analytics].
3. Institutional training systems [CONOCER, internal mentoring].
4. Performance metrics linked to knowledge [learning curves, quality, efficiency].

2.2 Classical Theoretical Models in Technical Knowledge Management

Technical Knowledge Management [TKM] has been conceptually structured since the 1990s through theoretical models that explain how knowledge is generated, transformed, transferred, and applied within organizations. These frameworks remain relevant in contemporary literature, especially in industrial contexts. The SECI model, developed by Nonaka y Takeuchi [1998], describes the conversion cycle between tacit and explicit knowledge through the phases of socialization, externalization, combination, and internalization. It is widely used to implement communities of practice and technical standardization in industrial plants.

The knowledge spiral theory, proposed by Boisot [1995], analyzes how knowledge codification and its structured transfer can become competitive advantages, particularly in advanced technical industrialization. The 5Cs [Create, Capture, Share, Use, and Learn], systematized by Nonaka y Takeuchi [21], organize the complete cycle of structured technical knowledge management in contexts of high staff turnover or process relocation.

Box 2

Table 2

Classical Models of Technical Knowledge Management

Model	Brief Description	Source
SECI	Conversion cycle between tacit and explicit knowledge.	Nonaka & Takeuchi, 1998
DIKW	Data-to-wisdom hierarchy academically reviewed	Rowley, 2007
Knowledge Spiral	Knowledge codification flow as a competitive advantage	Boisot, 1995
5C Model	Stages: Create, Capture, Share, Use, and Learn.	Nonaka & Takeuchi, 2011

Source: Bareño and Delgado [2025], based on key academic studies

2.3 Innovation and Organizational Learning

The link between innovation and organizational learning has gained relevance in the metalworking industry, especially in contexts where the transfer of technical knowledge becomes a challenge due to operational complexity and technological obsolescence. Within this framework, companies are adopting hybrid models that integrate digital platforms, artificial intelligence [AI], and cyber-physical technologies to facilitate processes of continuous learning, technical standardization, and operational improvement.

In various industrial organizations within the automotive sector, an intensive digital technical learning strategy has been documented, which includes the use of 3D simulators, digital twins, data analytics, and augmented reality for training in processes such as casting and machining.

These tools enable the capture, organization, and transfer of expert knowledge, even across plants with different cultural and technological contexts. Multilingual collaborative platforms and digital technical repositories have proven to improve training times and reduce production defects. Lopes, W. A. C., Rusteiko, A. C., & Mendes, C. R. [2025].

On the other hand, recent research highlights how LMS platforms combined with digital twins are transforming learning in traditional industrial environments. The retrofitting methodology makes it possible to digitize legacy CNC machines with sensors, human-machine interfaces, and data protocols, creating adaptive learning ecosystems with models of interaction, understanding, and virtual simulation [González-Alcántara et al., 2024].

This translates into shorter adaptation times for technical staff and enhanced capabilities for operational decision-making. Additionally, recent academic literature emphasizes that digital transformation is not limited to the incorporation of technologies, but rather entails a redesign of the organizational learning model. According to Huamaní et al. [2024], Knowledge management as a driver of innovation requires strategies aligned with digital competencies, multidisciplinary collaboration, and the personalization of learning according to productive roles.

Technological capabilities must be accompanied by structured training programs and a culture that fosters the flow of knowledge through social and cognitive technologies such as conversational AI and predictive analytics.

Finally, data- and simulation-based adaptive models are facilitating the integration between human teams and automated systems, promoting new forms of organizational learning that are more dynamic and scalable. The continuous and incremental learning approach, leveraged by emerging technologies, represents a decisive factor in sustaining competitiveness in the 21st-century metalworking industry.

To facilitate the understanding of the structural differences between technical knowledge management approaches, the following comparative table is presented. Table 3 summarizes the main contrasts between classical models [such as SECI, DIKW, and 5C] and contemporary models based on digital platforms, artificial intelligence [AI], and emerging technologies. Key criteria such as general focus, technological foundation used, transfer speed, adaptability, dependence on human knowledge, and application examples are analyzed. This comparison clearly illustrates how organizational learning methods in the metalworking industry have evolved.

Box 3

Table 3

Comparison of Classical vs. Contemporary Models

Criterion	Classical	Contemporary
Approach	Socialization, codification, tacit-explicit conversion	Digital learning, automation, AI, simulation
Technological basis	Human networks, physical documents, or simple digital records	LMS platforms, LLM, digital twins, data analytics
Transfer speed	Slow or dependent on trainers	High, asynchronous and in multiple languages or formats
Adaptability	Limited to prior experience	High, with scalable and personalized content
Human dependence	High [tutors, technical experts]	Medium [interaction with digital systems]
Application examples	Technical mentoring, manuals, communities of practice	Digital twins, conversational AI, CNC retrofitting

Source: Bareño y Delgado [2025]

In addition to structural differences, it is important to evaluate the strengths and limitations of each type of technical knowledge management model. Table 4 presents a comparative synthesis between classical, contemporary, and hybrid models, highlighting their main advantages and disadvantages.

This information allows those responsible for technical, operational, or training areas to identify the most suitable approach according to the level of digitalization, the resources available, and the strategic objectives of each organization.

Box 4

Table 4

Advantages and Disadvantages by Model Type

Model type	Advantages	Disadvantages
Classical	Simplicity, low initial cost, immediate accessibility	Slow, expert-dependent, difficult to scale
Contemporary	Escalabilidad, velocidad, personalización, multilingüe	Requires digital infrastructure, technical training
Hybrid	Balance entre experiencia humana y capacidades tecnológicas	Complexity in integration, moderate investment

This table complements the comparative analysis by highlighting that, although contemporary models offer clear advantages in terms of efficiency and scalability, they also entail technical and organizational challenges. In this context, hybrid models emerge as a viable solution for many companies in the Mexican metalworking sector that are still in the process of digitalization.

Based on the theoretical review presented in Sections 2.2 and 2.3, as well as on the analysis of documented cases in the Mexican metalworking industry, the following table is presented as a reference guide.

Table 5 presents a classification of industrial scenarios in which the application of a specific type of model [classical, contemporary, or hybrid] is suggested, considering factors such as the required speed of transfer, the criticality of technical knowledge, technological availability, and the level of operational standardization.

This approach is not prescriptive but rather indicative, and seeks to facilitate strategic decision-making on organizational learning and technical knowledge management in real contexts.

Box 5

Table 5

Suggested Application of Models According to the Industrial Context

Application context	Suggested application
Training of new plant personnel	Hybrid model
Transfer of production lines [relocation]	Contemporary model
Training in critical or hazardous processes	Contemporary model
Corporate standardization across multiple plants	Contemporary model
Knowledge recovery upon expert turnover	Classical or hybrid model [depending on the time and urgency available]

2.4 Digital platforms and emerging technologies

Digitalization has transformed technical knowledge management models in the metalworking sector through the use of digital twins, advanced LMS systems, artificial intelligence [AI], simulators, and augmented reality. These technologies facilitate continuous, automated, and adaptive technical learning.

For example:

- The iDIGIT4L project [2024] describes a non-intrusive learning ecosystem that combines digital twins and expert knowledge to modernize tasks on existing CNC machines. Its three-level approach—interaction, understanding, and learning—has been tested in traditional Mexican factories, enabling the updating of technical training without halting production [García & Cañibano, 2024]
- The DETECTA program [2023] developed AI- and digital twin-based methodologies for predictive maintenance in industrial SMEs, successfully detecting technical anomalies and cyberattacks without interrupting production. This approach helps preserve operational knowledge while modernizing local technological infrastructure [García, Echeverría & Ovejero, 2023].

- The CONECT4 program [2021] combines augmented reality, virtual reality, expert knowledge, and digital twins to create industrial training environments in the automotive sector. Its application in Mexican companies has demonstrated improvements in technical training efficiency and collaborative knowledge management [González et al., 2021].

These cases illustrate how digital platforms transcend the mere digitalization of processes: they enable scalable, adaptable, and contextualized technical learning models, particularly useful in contexts with high staff turnover or diversified industrial infrastructure. This new paradigm departs from classical models of manual transfer, as technical training no longer depends exclusively on the human expert. Instead, digital tools make it possible to:

2.5 Application in the Mexican context

In Mexico, the professionalization of technical knowledge has gained strategic relevance in key industrial sectors. However, structural challenges persist, such as low investment in research and development [R&D], limited formalization of on-site learning processes, and weak articulation between academia, industry, and government. In the face of this scenario, various organizations have begun to implement innovative approaches to technical knowledge management with documented results:

- A prominent example is Whirlpool, which has adopted global manufacturing systems as part of its operational strategy. This implementation has required the development of technical capabilities at different levels of the organization, as well as the creation of effective knowledge management [KM] mechanisms within its plants. In particular, the adoption of the World Class Manufacturing model [WCM] has made it possible to standardize operational practices and transfer knowledge in a structured manner across different plants of the group, both nationally and internationally. This practice has strengthened inter-plant standardization and accelerated internal training processes and operational adaptation.

- CENIDET, as the technological research center of the National Technological Institute of Mexico, reports in its *Informe de Rendición de Cuentas 2023* the consolidation of projects aimed at strengthening its academic and laboratory infrastructure, as well as the promotion of advanced training programs for the development of technical competencies in strategic areas. These actions have made it possible to link applied research with high-level training, creating a favorable environment for academic knowledge to be translated into practical solutions for Mexican industry.
- A recent study on large corporations in Mexico shows that those that have adopted strategic knowledge management—including digital platforms, communities of practice, and formal technical training systems—exhibit greater adaptability in the face of technological and organizational changes [Arrieta & Mendoza, 2023].

Taken together, these cases illustrate that, despite the structural limitations Mexico faces in terms of R&D investment and institutional articulation, there are tangible efforts aimed at strengthening technical knowledge management.

The experience of corporations such as Whirlpool, the academic work of CENIDET, and the documented evidence in recent studies show that the combination of advanced manufacturing models, specialized training programs, and digital tools makes it possible to translate innovation into sustainable productive practices.

This outlook confirms that knowledge management is not only a strategic resource but also an essential element to drive competitiveness and adaptive capacity in industrial sectors within the Mexican context.

3. Methodology

The present research is conducted under a qualitative, documentary approach with an exploratory and analytical design.

This methodological strategy is relevant for understanding the complexity of technical knowledge transfer in the Mexican metalworking industry, as it allows for the interpretation of organizational cases and institutional practices from both a theoretical and applied perspective, without necessarily relying on the collection of quantitative field data.

As noted by Quecedo [2002] y Martínez [2022], qualitative and documentary research is based on the systematic analysis of secondary sources and on the interpretive construction of the phenomenon, while the exploratory design aims to generate initial approaches when the study topics have not been sufficiently addressed in the literature.

The method used is based on the review and analysis of peer-reviewed scientific literature, technical reports, and institutional documents published over the past twenty years, complemented by classical authors who have set conceptual milestones in knowledge management, technological innovation, and technical-industrial education.

The sources were selected through systematic searches in specialized databases such as Scopus, ScienceDirect, Redalyc, and Dialnet, as well as in repositories of the National Technological Institute of Mexico and international organizations such as the OECD and UNESCO, ensuring the robustness, timeliness, and relevance of the materials consulted.

Inclusion criteria were established to guide the documentary selection process:

- a. Studies addressing contemporary models of knowledge transfer and management in industrial environments.
- b. Research on the application of emerging technologies [AI, digital twins, AR/VR, LMS] in the transmission of technical skills.
- c. Texts exploring the role of universities, research centers, and industrial clusters in dual training and skills certification.
- d. Documents analyzing public policies or sectoral programs related to innovation and industrial competitiveness.

The unit of analysis consisted of ten documented cases of companies and representative sectors [aerospace, automotive, household appliances, and multisectoral SMEs], selected for their relevance in the transmission of technical knowledge in Mexico. Based on this foundation, a structured analysis system was developed around four axes: institutional infrastructure, technical competencies, enabling technologies, and organizational culture.

The information collected was systematized through analysis sheets and comparative matrices, prioritizing the identification of patterns, similarities, and divergences across sectors. No statistical instruments were employed, since the central objective was to generate a conceptual and applied proposal for the Mexican metalworking industry.

In line with this approach, the theoretical hypothesis is proposed that: *the successful transfer of technical knowledge in the industry depends on the articulation between certified competencies, digital technologies, institutional networks, and an organizational culture of continuous learning.*

4. Results

This section describes the findings derived from the documentary, comparative, and structural analysis conducted on current practices of technical knowledge transfer in the Mexican metalworking industry. Based on the review of verifiable public sources, ten representative cases were identified that demonstrate innovative strategies in knowledge management, technical training, and the appropriation of organizational capabilities in key sectors such as automotive, aerospace, railway, advanced manufacturing, and household appliances.

These results directly address the research questions posed:

- What models and practices are Mexican organizations using to transfer technical knowledge?
- What technologies, structures, or policies are facilitating such transfer?
- What tangible organizational impacts do these practices generate in terms of performance, efficiency, or retention of expert knowledge?

The systematization of these cases not only makes it possible to characterize common patterns and emerging trends, but also provides practical evidence for the proposed lines of research: modern learning techniques, applied technological platforms, organizational systems for technical training, and performance metrics associated with knowledge.

4.1 Comparative Analysis of Documented Cases

The documentary analysis identified ten representative experiences of technical knowledge transfer in the industry, organized by strategic sector: multisectoral, aerospace, automotive, and household appliances. Each case was selected for its methodological clarity, verifiable public evidence, and concrete contributions to the research questions.

Taken together, these experiences reflect how organizations have implemented practices of technical innovation, structured training, digitalization of learning, or collaboration with educational institutions to preserve and scale critical capabilities. The following tables present a structured synthesis by sector.

4.2 Sectoral Evidence: Documented Cases of Technical Knowledge Transfer

The ten documented experiences presented below show that the transfer of technical knowledge in the Mexican metalworking industry is manifested across a wide diversity of sectors, ranging from aerospace precision manufacturing to household appliance production.

Despite technological and organizational differences, it is possible to identify common elements: collaboration with universities or technological centers, the use of digital platforms [such as digital twins or augmented reality], and the progressive professionalization of suppliers or technicians through structured training models. In all cases, innovation acts as a catalyst for these processes.

Box 6

Table 6

Multisectoral Cases of Technical Knowledge Transfer

Company / Project	Project description	Citation
Siemens México	Integration of IT, connected platforms, and digital twins to train operators and technicians in complex industrial environments. Impact: improvement in operational efficiency and retention of technical knowledge.	García Garnica, A. [2023]. <i>Siemens en el contexto de la Industria 4.0: Algunas estrategias para mantener y ampliar sus capacidades tecnológicas y de aprendizaje organizacional.</i>
National Study Mexico – UNAM	Cross-sectional study on the adoption of knowledge management in Mexican industrial organizations. Impact: mapping of best practices and organizational barriers.	Delgado-Hernández, D. J., et al. [2009]. <i>A case study on knowledge management adoption in Mexico.</i> IEEE Xplore.
iDIGIT4L Project – Cidaut	Use of non-intrusive digital twin in traditional machinery with retrofitting techniques and human-machine learning. Impact: enhancement of operators' digital skills.	García, Á., & Cañibano, E. [2024]. <i>iDIGIT4L: Digital twin retrofitting for industrial learning in SMEs.</i> arXiv.

Box 7

Table 7

Aerospace Sector Cases: Technical Knowledge Transfer

Company / Project	Project description	Citation
Safran Querétaro / UNAQ	Technical training between Safran and the Aeronautical University of Querétaro [UNAQ]. Impact: development of human capital and industry-university collaboration.	Salinas-García, R. J. [2012]. <i>Desarrollo industrial y formación profesional en la industria aeronáutica en Querétaro</i>
Clúster Aeroespacial Querétaro	Aerospace innovation ecosystem in Querétaro: coordination among CIDESI, CIATEQ, CIAT, and CAT UNAM for technical training and collaborative R&D development. Impact: regional consolidation as an aeronautical hub.	Muñoz-Sánchez, C., Soto-Flores, M. del R., Rocha-Lona, L., Garduño-Román, S., & Garza-Reyes, J. A. [2019]. <i>Aerospace Industry in Queretaro, Mexico: A perspective of Regional Innovation System.</i>

Box 8**Table 8**

Industry Cases: Technical Knowledge Transfer

Company / Project	Project description	Citation
CONNECT4 Project [Mexico]	Immersive learning platform based on Augmented Reality, Virtual Reality, and non-intrusive digital twins for predictive maintenance in automotive plants. Improves efficiency and reduces operational errors.	González, S., García, Á., & Núñez, A. [2021]. <i>CONNECT4: Desarrollo de componentes para entornos de aprendizaje hombre-máquina en automoción.</i> arXiv.
Automatic inspection with Deep Learning [automotive]	Application of deep learning models for visual inspection of defects in automotive assembly lines. Precise recognition with an impact on quality and waste reduction.	Mazetto, M., Teixeira, M., Rodrigues, É. O., & Casanova, D. [2020]. <i>Deep Learning Models for Visual Inspection on Automotive Assembling Line.</i> arXiv.
Systematic review on AI in automotive quality control	Analytical study on AI and neural network implementations in quality control and predictive maintenance in the automotive industry. Identifies impacts and trends applicable to Mexican companies.	Morales Matamoros, O., Takeo Nava, J. G., Moreno Escobar, J. J., & Ceballos Chávez, B. A. [2025]. <i>Artificial Intelligence for Quality Defects in the Automotive Industry: A Systemic Review.</i>
PACE Program – Tecnológico de Monterrey & Automotive Industry	University–industry collaboration through real projects in automotive design and manufacturing. Interdisciplinary and international teams participate, using both virtual and face-to-face environments. Impact: development of applied technical competencies, transfer of practical knowledge, and strengthening of global networks.	Esqueda-Merino, D. M., García-García, A. D., García-Morán, E., Morano-Okuno, H. R., & Sandoval-Benítez, G. [2019]. <i>Industry-University Collaboration: An Educational Program with Automotive Industry.</i>

Box 9**Table 9**

Household Appliances Sector Cases: Technical Knowledge Transfer

Company / Project	Project description	Citation
Household appliances in Mexico	Technology transfer to local suppliers through integration into global value chains. Includes process standardization, technical learning, and continuous improvement.	Velarde-Moreno, J., Blanco, C. E., & Jiménez, A. [2020] <i>Mexican local suppliers in home appliance value chains.</i>

The multisectoral evidence presented above will serve as the basis for the following sections of the analysis, in which cross-cutting elements, key capabilities, and replicable lessons are identified that characterize successful projects of technical knowledge transfer in Mexico.

4.3 Technical Capabilities and Prioritized Competencies

The cases analyzed reflect not only the transfer of technical knowledge in operational terms but also the active development of specific professional capabilities. These competencies are strategically prioritized according to the sector and demonstrate how technical knowledge is institutionalized within organizations.

At least seven of the cases document a clear focus on the understanding of technical regulations and certifications, such as AS9100 or ISO standards, particularly in regulated industries such as aerospace and household appliances. Examples of this include competency validation programs in GE-MABE and the dual technical training schemes of Safran–UNAQ.

In at least six cases, priority was given to the technical operation of advanced machinery such as CNC, robotic lines, or automated systems. This is clearly observed in the project iDIGIT4L, which documents the use of digital twins for training purposes in industrial machinery, and in the training processes applied in plants of Whirlpool.

Basic programming and the management of digital interfaces appear in five projects, particularly where technologies such as IoT, AR/VR, or monitoring software were introduced. Cases such as CONNECT4 y Siemens México stand out for integrating these competencies into their continuous technical training.

Finally, collaborative work and continuous learning appear transversally in five cases, documenting the incorporation of mentoring programs, technical performance evaluation, and structured feedback. This can be seen in the Estudio UNAM sobre gestión del conocimiento and in the co-learning processes documented in CONNECT4.

This set of prioritized capabilities allows us to conclude that the transfer of technical knowledge in the metalworking industry goes beyond operational training to become a process of strategic construction of key competencies.

4.4 Analysis of Results

The analysis of the ten documented cases on technical knowledge transfer in the Mexican metalworking industry allows for the empirical validation of several premises proposed in the theoretical framework.

The evidence shows that the effective transfer of technical knowledge depends on an articulation between institutional infrastructure, technology, specific competencies, and organizational culture.

- 80% of the documented cases [8 out of 10] were driven by technological centers, universities, or regional clusters, which confirms the hypothesis that these collaborative ecosystems enhance transfer. This finding is consistent with studies such as the Diaz Rodriguez y Morales Sanchez, V. [2021], which analyze the Regional Innovation Systems in Mexico and their impact on the transfer of technical knowledge.
- 70% of the cases involved emerging technologies such as digital twins, augmented reality, LMS platforms, or applied artificial intelligence, which is consistent with recent studies on Industry 4.0 and knowledge management [Alonso et al., 2024].
- 90% of the cases prioritized specific technical competencies such as the operation of advanced machinery, interpretation of CAD drawings, use of digital interfaces, and mastery of certifiable standards, thereby validating models of technical professionalization and knowledge management [Gajdzik, 2022]
- 50% of the cases explicitly highlighted collaborative work and continuous learning, reinforcing the need to strengthen organizational culture as a strategic component of technical knowledge transfer.

These observations make it possible to directly address the central hypothesis of the study: *“The effective transfer of technical knowledge in the Mexican metalworking industry depends on the articulation between technology, competencies, institutional structures, and organizational culture.”*

Likewise, sectoral and territorial asymmetries were identified. While industries such as aerospace [Querétaro] and household appliances [Nuevo León and Guanajuato] show mature ecosystems with specialized infrastructure, many SMEs lack access to digital platforms, structured training, or institutional linkages.

In summary, the empirical findings not only confirm the models analyzed in the theoretical framework but also make it possible to identify critical replicable factors for the design of policies and organizational strategies that strengthen technical knowledge management in the current Mexican context.

5. Discussion

The transfer of technical knowledge in industrial environments constitutes a multifactorial process that depends on the interaction between individual capabilities, institutional frameworks, and technological appropriation. The results obtained from the ten cases analyzed allow for a contrast between the conceptual frameworks reviewed in Chapter 2 and the empirical evidence presented in Chapter 3, outlining common patterns, sectoral differences, and critical conditions.

The findings show that collaborative ecosystems are configured as the main enablers of knowledge transfer, since in eight of the ten cases analyzed the participation of universities, innovation centers, and clusters was decisive.

This coincides with the literature that underscores the role of relational infrastructure as a catalyst for organizational learning. Likewise, it is observed that emerging technologies function as central vehicles for knowledge codification: digital twins, augmented reality, artificial intelligence, and LMS platforms proved to be strategic resources for organizing, replicating, and standardizing processes in highly regulated sectors such as automotive and aerospace.

At the same time, it is confirmed that the priority given to certifiable competencies constitutes a fundamental axis, as the systematization of technical skills through certifications, international standards, and dual training programs transforms tacit knowledge into tangible and transferable organizational capital.

These results reinforce Nonaka and Takeuchi's theory of organizational knowledge creation regarding the need for codification and institutionalization to transform tacit knowledge into explicit knowledge. They also confirm the relevance of Etzkowitz and Leydesdorff's Triple Helix model, by demonstrating the centrality of collaboration among universities, industry, and government.

However, the analysis also reveals limitations in the Mexican context, where cultural and territorial gaps introduce obstacles not foreseen in these conceptual frameworks, making it necessary to propose adaptations that recognize national specificities.

From a sectoral perspective, the study identifies differentiated lessons. In the aerospace industry, transfer is mainly sustained by certification and institutional articulation through specialized clusters. In the automotive sector, digitalization and process standardization appear as the dominant strategies to ensure the replicability of knowledge within global production chains. In the household appliances sector, the integration of suppliers into collective learning dynamics stands out, extending professionalization throughout the entire value chain.

Finally, multisectoral SMEs, despite their resource limitations, demonstrate the possibility of sustaining transfer processes through frugal innovation, leveraging external networks, and employing structured mentoring strategies.

Transversally, the analysis highlights four critical conditions for the successful transfer of technical knowledge: the existence of institutional infrastructure and collaborative networks, the development of structured technical capabilities, the adoption of enabling environments based on emerging technologies, and the consolidation of an organizational culture oriented toward continuous learning.

The interaction of these factors confirms that effective transfer does not depend on a single element but rather on a systemic balance that combines structure, technology, and culture.

In this regard, an integrated conceptual model is proposed for the Mexican metalworking industry, supported by a collaborative institutional core—where universities, clusters, and government act as articulators—, by enabling technological axes that include digital twins, augmented reality, LMS systems, and artificial intelligence, by the professionalization of technical competencies through certification, and by the construction of an organizational culture that values collaborative and continuous learning.

This model articulates theory and practice, offering a framework adapted to the national reality, recognizing both the achievements made and the structural limitations still present, and serving as a guide for future initiatives of innovation in the transfer of technical knowledge.

6. Conclusions

The results obtained in this study confirm that the effective transfer of technical knowledge in the Mexican metalworking industry is not an isolated process but a complex phenomenon that requires the simultaneous articulation of multiple dimensions: technology, organizational culture, institutional networks, and structural support from public policy.

The empirical evidence documented in the ten cases studied validates the central hypothesis proposed in the conceptual framework: the professionalization of technical knowledge is a key factor in ensuring operational continuity, applied innovation, and the territorial scalability of productive capacities. This conclusion aligns with theoretical models such as the SECI cycle and the theory of organizational knowledge creation of Coltman, T., Devinney, T. M., Midgley, D. F., & Venaik, S. [2008], The most recent approaches to digital platforms as enablers of learning confirm that the development of digital capabilities constitutes a critical factor for organizational transformation [Kans & Campos, 2023].

Moreover, the findings show that the more advanced sectors [such as aerospace and automotive] possess institutional conditions that favor the structured transfer of knowledge: dual training, consolidated clusters, international certifications, digital platforms, networks of technical mentors, and active linkages with universities.

In contrast, multisectoral SMEs face deeper structural limitations, although some cases show that it is possible to innovate despite scarcity through external networks, frugal reconversion, and structured mentoring.

These observations make it possible to question approaches that privilege only investment in technology without accompanying it with training and knowledge management processes. Digital technologies [such as digital twins, AR/VR, or LMS systems] do not replace human knowledge, but they do amplify and systematize it—provided that an organizational structure exists to leverage them. In this regard, the conclusions of this study reinforce the stance that innovation in technical knowledge is both social and technological.

In terms of public policy, the study confirms that sustainable and territorially differentiated programs are required, as demonstrated by successful experiences linked to CONOCER-certified training programs and the role of public research centers such as CIDESI, as documented in recent industrial studies and projects such as CONECT4. However, it is also evident that many successful strategies depend on individual leadership or temporary funding, which limits their replicability.

In summary, the contrast between the documented cases and theoretical frameworks allows us to assert that the transfer of technical knowledge is viable, replicable, and scalable, provided that four key elements are articulated: codified technical content, appropriate technologies, active institutional networks, and an organizational culture of learning.

Based on these findings, concrete proposals can be derived to redesign public policies, structure industrial intervention models, or strengthen the internal capacities of Mexican companies seeking to compete in high-technical-demand sectors.

6.1 Recommendations

Based on the analysis of the ten documented cases and the critical conditions identified, recommendations are proposed at four strategic levels aimed at strengthening the processes of technical knowledge transfer in the Mexican metal-mechanical industry.

a. Organizational Level [Companies]

- Standardize technical knowledge through LMS platforms and operational documentation systems [manuals, instructions, technical videos].

For example, Metalsa It implemented a corporate knowledge management system based on LMS and QAD to standardize competencies across its plants.

- Establish internal mentoring programs to capture expert knowledge and facilitate technical generational succession.

In Whirlpool Celaya, SME suppliers were accompanied by expert personnel to replicate critical manufacturing processes.

- Promote a culture of continuous learning through recognition of best practices, improvement circles, and horizontal feedback.

b. Interinstitutional Level [Clusters, Chambers, Universities]

- Promote lasting partnerships between clusters, technological universities, and public R&D centers to ensure dual training and professional internships aligned with real technical needs.

The Clúster Aeroespacial de Querétaro succeeded in consolidating certified training with the participation of CIDESI, UNAQ, and Safran.

- Establish regional networks of certified instructors who can address the technical needs of SMEs in areas with lower infrastructure.
- Create shared learning assessment mechanisms, supported by industrial chambers and certification systems [e.g., CONOCER].

c. Technological Level

- Prioritize immersive and accessible technologies such as augmented reality, AR/VR, or digital simulators to train operational personnel.

In the CONECT4 project virtual learning environments were used to train technicians in complex industrial processes.

- Integrate open digital documentation platforms [interactive instructions, virtual tours, digital twins] to share knowledge across networks.
- Document digital learning and build internal repositories that allow training to be scaled without relying on external providers.

d. Public Policy Level

- Strengthen national programs such as CONOCER with a focus on priority industrial sectors [automotive, aerospace, metal-mechanical]

Competency certification under CONOCER has been key to validating technical skills in programs such as those offered by UTEQ.

- Reactivate the PROSOFT program or develop an updated equivalent for digitalization and technical transfer in industrial SMEs.
- Articulate a national industrial technical training strategy, coordinated among the Ministry of Economy, SEP, CONACYT, and the states, with a territorial focus.
- Fund permanent training structures beyond temporary competitive grants, ensuring the continuity of successful projects.

6.2 Future Research Directions

This study confirms that the transfer of technical knowledge in the Mexican metal-mechanical industry is not only a desirable process but also feasible and strategic. The ten cases analyzed show that when there is a solid organizational structure, a learning culture, and enabling technologies, knowledge can flow among diverse actors and generate measurable operational impact.

In general terms, the proposed hypothesis is validated: the articulation of technical competencies, technological platforms, institutional networks, and organizational culture is critical for the successful transfer of technical knowledge.

Additionally, critical factors that favor knowledge transfer were identified, such as the use of digital platforms [digital twins, AR/VR, LMS], dual training with certification [as in the case of Safran and UNAQ], and collaboration with universities or centers such as CIDESI. These elements are present in the most advanced sectors, such as aerospace and automotive. In contrast, multi-sector SMEs face structural barriers, but they have demonstrated that innovation is possible through external networks, technical mentoring, and leveraging programs such as CONECT4. This adaptive capacity reinforces the importance of designing inclusive and regionally tailored public policies.

- Conduct longitudinal studies to measure the impact of these practices on knowledge retention and operational performance.
- Investigate the effects of generative artificial intelligence and other emerging technologies on the transmission of technical skills.
- Expand the analysis to under-studied industrial sectors such as mining or metal-mechanical agroindustry.
- Evaluate the role of microenterprises and artisanal workshops in the informal transmission of technical knowledge.
- Develop standardized indicators of technical knowledge transfer that can be integrated into quality or innovation systems

This work contributes to the practical and theoretical understanding of knowledge management in real industrial contexts and opens the door to new research agendas that recognize the social, technological, and institutional dimensions of technical knowledge.

6.3 Final Considerations

The sectoral analysis of technical knowledge transfer in the Mexican metal-mechanical industry confirms that innovation does not rely solely on technological advances, but on the capacity of organizations to manage knowledge as a strategic asset.

The documented cases reveal that the articulation of technology, technical competencies, organizational culture, and institutional networks is the determining factor for success in knowledge transfer processes. Furthermore, it is confirmed that interinstitutional collaboration and structured learning are necessary conditions to generate sustainable innovation ecosystems, especially in sectors such as aerospace and automotive.

However, persistent challenges are also identified, such as territorial asymmetries, low formalization in SMEs, and the lack of continuity in public policies.

The evidence presented allows us to assert that a national technical transfer strategy must be multisectoral, territorially differentiated, and technologically scalable. Additionally, it must recognize the value of tacit knowledge, professionalize operational capabilities, and foster organizational environments open to learning.

Finally, this study provides an empirical and methodological foundation for the design of knowledge-centered industrial policies, proposing clear pathways for Mexico to strengthen its competitiveness through the structured management of technical learning in industry

Declaration

Conflict of Interest

The authors declare no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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Authors' Contributions

Bareño-Ramos, Enoc: Lead author. Study design, case analysis, structural writing of the article, synthesis of findings.

Delgado-Torres, Claudia Lizethe: Document curation, methodological design, support in results interpretation, source verification, final formatting of tables.

Availability of Data and Materials

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Abbreviations

CIDESI	Center for Engineering and Industrial Development
CONOCER	National Council for Standardization and Certification of Labor Competencie
LMS	Learning Management System [LMS]
RV	Virtual Reality [VR]
UNAQ	Aeronautical University of Querétaro

References

Background

Alonso, G., Pérez, M., & Torres, L. [2024]. [Industry 4.0 and Knowledge Management in Manufacturing Sectors](#). *Journal of Industrial Innovation*, 15[2], 45–63.

Article

Arrieta, J., & Mendoza, R. [2023]. *Strategic Knowledge Management in Mexican Corporations: Digital Platforms and Communities of Practice*. *Journal of Organizational Studies*, 19[3], 77–94.

CAINTRA Nuevo León. [2024]. *Industrial Indicators of Mexico*. Chamber of the Manufacturing Industry of Nuevo León.

Delgado-Hernández, D. J., Wong, K. Y., & Rigaud-Tellez, N. [2009]. *A case study on knowledge management adoption in Mexico*. 2009 *IEEE International Conference on Industrial Engineering and Engineering Management*, 1566–1570.

Díaz Rodríguez, A., & Morales Sánchez, V. [2021]. *Regional Innovation Systems in Mexico: An Empirical Approach*. *Journal of Regional Innovation*, 5[2], 33–49.

INEGI. [2023]. *Censos Económicos de la Industria Manufacturera*. Instituto Nacional de Estadística y Geografía.

Basics

Boisot, M. [1995]. *Information space: A framework for learning in organizations, institutions and culture*. Routledge.

Nonaka, I., & Takeuchi, H. [1998]. *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. Oxford University Press.

Nonaka, I., & Takeuchi, H. [2011]. *The big idea: The wise leader*. *Harvard Business Review*, 89[5], 58–67.

Rowley, J. [2007]. *The wisdom hierarchy: Representations of the DIKW hierarchy*. *Journal of Information Science*, 33[2], 163–180.

Rassini. [2022]. *Advanced Training in Digital Manufacturing*. *Innovation and Development Report*.

Support

Bareño, E., & Delgado, R. [2025]. *Multisectoral Cases of Technical Knowledge Transfer*. *Academic document, no URL*.

Briseño, J., & Castellanos, A. [2021]. *Digitalization and Technical Knowledge Transfer at CENIDET*. *Journal of Educational Technology*, 18[1], 98–110.

García, Á., & Cañibano, E. [2024]. *iDIGIT4L: Digital twin retrofitting for industrial learning in SMEs*. *arXiv preprint*.

González-Varona, J. M., López-Paredes, A., Poza, D., & Acebes, F. [2021]. *Building and development of an organizational competence for digital transformation in SMEs*. *Journal of Industrial Engineering and Management*, 14[1], 15–24.

Muñoz-Sánchez, C., Soto-Flores, M. del R., Rocha-Lona, L., Garduño-Román, S., & Garza-Reyes, J. A. [2019]. *Aerospace industry in Queretaro, Mexico: A perspective of regional innovation system*. *Proceedings of the International Conference on Industrial Engineering and Operations Management*.

Differences

Gajdzik, B. [2022]. *Technical knowledge management and professionalization in manufacturing industries*. *International Journal of Production Research*, 60[14], 4211–4226.

García, Echeverría & Ovejero. [2023]. *DETECTA program: AI and digital twin predictive maintenance in SMEs*.

Kans, M., & Campos, F. [2023]. *Digital platforms as enablers of organizational learning: A review in industrial contexts*. *Journal of Manufacturing Systems*, 68, 33–49.

QAD. [2021]. *Metalsa: From fragmented systems to centralized digital transformation*. QAD Case Study.

Quimmco. [2022]. *Technical Training and Dual Certification Program*. *Sustainability Report* <https://quimmco.com/media/sustentabilidad2022.pdf>

Romo, R., & Ramírez, M. [2020]. *Organizational Learning in the Metal-Mechanical Supply Chain in Sonora*. *Journal of Urban, Rural, and Regional Economy*, 9[15], 45–65.

Discussions

Barrios-Tinoco, L. M., Montañez, A. P., Huamaní, R., & Flores-Limo, F. A. [2024]. [Knowledge Management as a Key Factor in Business Innovation](#). *Venezuelan Journal of Management* 29[106], 760–775.

Salinas-García, R. J. [2012]. [Industrial Development and Professional Training in the Aeronautical Industry in Querétaro](#). *Journal of Education and Development*, 23[Oct–Dic], 55–72.

Velarde-Moreno, J., Blanco, C. E., & Jiménez, A. [2020]. [Mexican local suppliers in home appliance value chains](#). *Inquietud Empresarial*, 20[1], 22–39.

Whirlpool México. [2023]. [Technical Training and Transfer in Line Processes](#). *Whirlpool Annual Report*.

Zárate, M. [2023, octubre 16]. [Artificial Intelligence and Computer Vision for Quality Control at Nemak](#). *El Financiero*.

Comparative analysis in mature fields through water exclusion in copano 41 and 45 wells of the Macuspana-Muspac asset

Análisis comparativo en campos maduros a través de la exclusión del agua, en los pozos copano 41 y 45 del activo Macuspana - Muspac

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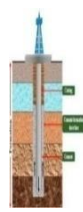


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Abstract

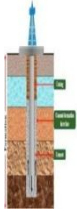


This non-experimental study assesses the effectiveness of Conformance Sealant Technologies, specifically the MOC-ONE and SOS systems, in wells Copano 41 and 45 of the Macuspana-Muspac Asset in southeastern Mexico. The methodology involved injecting a micro-fine oil-based cement slurry combined with NO₂ gas to seal water-producing zones. Results showed a substantial reduction in water cut, decreasing from 80% to 48%, which led to increased oil production and enhanced operational efficiency. The MOC-ONE system demonstrated high chemical resistance and adaptability to pumping conditions, while the SOS system allowed continuous production without relying on motor-compressors. Successful implementation of these technologies in the challenging environment of this mature field underscores their potential to optimize hydrocarbon recovery and control water production in similar reservoirs. These findings highlight not only technical effectiveness but also the potential economic benefits, providing a viable strategy for improving profitability in mature oil fields with complex operational conditions.

Objectives	Methodology	Contribution
<p>The scheme demonstrates the use of oil-based micro-fine cement slurries and conformance sealing technologies, including diesel-based systems, to control water invasion in wells.</p> <p>This approach integrates field experience and technical judgment to enable early detection of water ingress, optimize treatment design and execution, block unwanted water</p> 	<p>Descriptive and quantitative study Copano 41 and 45 wells</p> <p>Analysis of production and mechanical condition in wells</p> <p>Water issues in specific sections</p> <p>MOC-ONE and SOS technologies</p> <p>Confidentiality and PEMEX policies</p> 	<p>The MOC-ONE and SOS technologies applied in Copano 45 and 41 wells significantly reduced water production and increased oil recovery.</p> <p>MOC-ONE exhibited high chemical resistance and pumping adaptability, while SOS optimized production without the need for motor-compressors.</p> <p>Both approaches improved operational</p> 

Water exclusion, mature fields, enhanced oil recovery.

Resumen

Este análisis no experimental evalúa la eficacia de las Tecnologías de Conformance Sellante, específicamente los sistemas MOC-ONE y SOS, en los pozos Copano 41 y 45 del Activo Macuspana-Muspac, en el sureste de México. La metodología consistió en la inyección de una lechada de cemento microfino base aceite y gas NO₂ para sellar zonas productoras de agua. Los resultados demostraron una reducción significativa del corte de agua, desde un 80% hasta un 48%, lo que a su vez incrementó la producción de petróleo y mejoró la eficiencia operativa. El sistema MOC-ONE mostró alta resistencia química y adaptabilidad al bombeo, mientras que SOS permitió mantener la producción sin necesidad de moto-compresores. La exitosa aplicación de estas tecnologías en las condiciones extremas de este campo maduro subraya su potencial para optimizar la recuperación de hidrocarburos y gestionar la producción de agua en yacimientos similares, impactando positivamente en la rentabilidad de las operaciones.

Objetivos	Metodologías	Resultados
<p>El esquema ilustra la aplicación de lechadas de cemento microfino base aceite y tecnologías de conformance sellante [incluyendo sistemas base diésel] para el control de invasión de agua en pozos.</p> <p>La estrategia combina experiencia de campo y juicio técnico para: Identificación</p> 	<p>Estado descriptivo y cuantitativo Pozos Copano 41 y 45.</p> <p>Análisis de producción y estado mecánico</p> <p>Problemas de agua en secciones específicas.</p> <p>Tecnologías MOC-ONE y SOS</p> <p>Confidencialidad y políticas PEMEX.</p> 	<p>Las tecnologías MOC-ONE y SOS en los pozos Copano 45 y 41 redujeron significativamente la producción de agua y aumentaron la extracción de petróleo.</p> <p>MOC-ONE mostró alta resistencia química y adaptabilidad al bombeo, mientras que SOS optimizó la producción sin necesidad de motocompresores.</p> 

Exclusión de agua, campos maduros, recuperación mejorada de petróleo.

Area: Dissemination and universal access to science

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Introduction

In the early 1990s, certain alternatives in cementing technologies for producing wells began to be explored, using oil-based micro-fine cement slurries as the technique. Although the initial treatments were successful, results declined due to field-related variables. Currently, treatments have been modified, and certain components have been introduced to serve as diesel-based sealants, such as the MOC-ONE and SOS systems.

The ten main basic water problems affecting production in mature fields have been identified, including: casing leaks, production tubing or packer leaks; channeling behind the casing; dynamic water-oil contact; flooded zone without transverse flow; fractures or failures between injector and producer wells; fractures or failures in a water layer; coning or cusp formation; poor sand sweep; gravitational segregation; and flooded zone with transverse flow.

Background

Currently, for every barrel of oil extracted, barrels of water are generated, which implies an annual expenditure exceeding 40 billion dollars to manage unwanted water. This situation affects both hydrocarbon production and treatment. Globally, 75% of well production is water, with daily production exceeding 250 MMBPD. By 2035, oil production is expected to reach 97 million barrels and water production 300 million barrels, with significant savings possible by reducing water production. In some sectors of the North Sea, water production increases in the same proportion as oil production rates decrease in the reservoirs. [Bailey, 2000]

It is proposed that, when extracting oil from a reservoir, at some point water from an underlying aquifer or from injection wells combines and is produced together with the oil. This movement of water through the reservoir is known as the water cycle. [Bailey, 2000]

Numerous and varied criteria have been proposed to calculate the costs related to unwanted water production. These costs are estimated to range between 5 and over 50 cents per barrel of water, depending on these criteria and the specific operational conditions. [Reyna, 2023]

Objectives

To convey field experiences and the application of sound judgment on how to perform these operations through the use of ultra-fine oil-based cement slurries or conformance sealing technologies, including diesel-based systems.

Specific Objectives

1. Timely identification of the water invasion problem.
2. Designing an appropriate treatment and suitable application technique for the technology.
3. Blocking the water flow while avoiding damage to the production zone.
4. Delaying water coning in well production.

Methodology

This descriptive and quantitative study analyzes data from Copano 41 and 45 wells using repair reports and technology tests. It evaluates production and mechanical status, identifying water issues through comparative analysis.

Focus is placed on MOC-ONE and SOS technologies. The study is academic, respecting PEMEX policies and document confidentiality. It centers on the Macuspana-Muspac production asset in Pichucalco, Chiapas. Copano 41 is located at 52.908 m above sea level, with detailed mechanical and geographic characteristics provided.

Results

MOC-ONE TECHNOLOGY TEST IN COPANO 45

The study is descriptive and quantitative, focused on analyzing information related to the Copano 41 and 45 wells, using specific repair reports and technological tests. Data on production and the mechanical condition of both wells will be evaluated, identifying water-related problems in different sections through comparative analysis. Emphasis will be placed on the application of MOC-ONE and SOS technologies to improve water management.

The study is limited to academic purposes, respecting the policies of Petróleos Mexicanos [PEMEX] and ensuring the confidentiality of internal documents. It specifically addresses the Macuspana-Muspac production asset, which includes these wells, located in Pichucalco, Chiapas. Copanó 41 is situated at 52.908 m above sea level, and its mechanical and geographic characteristics will be detailed, with specific coordinates provided for a comprehensive analysis of the production context and its impact on the region.

Box 1

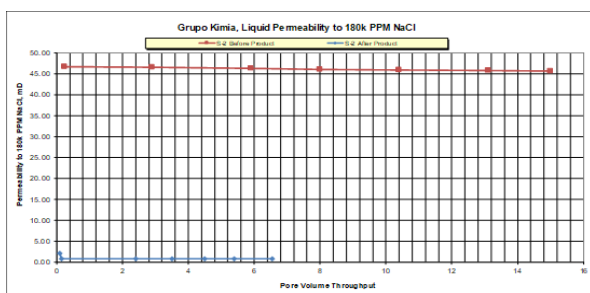


Figure 1

Laboratory test of permeability in Copanó 45 well, Kimia S.A. de C.V. Group, MACUSPANA-MUSPAC Production Asset, 2016.

Admission test of moc-one technology in copanó 45 well

An admission test was conducted with rates of 3–5 bpm, using a total volume of 112 bbls [17.8 m³], initial pressure of 573 psi, and final pressure of 0 psi.

The scheduled volume was adjusted because a pressure of 0 psi was observed, so it was not necessary to pump additional fluid into the well.

Box 2

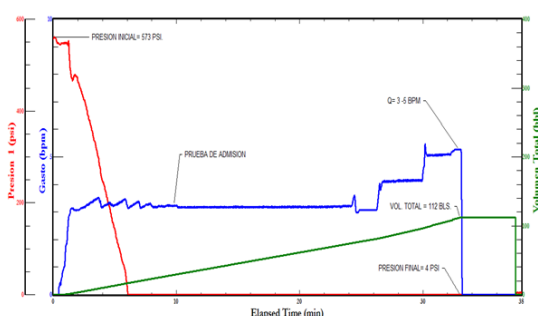


Figure 2

Fluid admission rate test in the well, Kimia S.A. de C.V. Group, MACUSPANA-MUSPAC Production Asset, 2016.

Moc-one technology treatment

As shown in the graph, only friction pressures were observed in the pumping lines; there was no backpressure during the system pumping, which indicates that there was no premature activation of the system. The displacement volume was adjusted from 25 m³ to 20 m³ [5 m³ of spacer plus 15 m³ of treated water] due to the well's admission conditions and to avoid over-displacement of the system.

The TR was maintained throughout the treatment, averaging 1400 psi, which indicates that no fluid entry occurred in the annular space.

Box 3

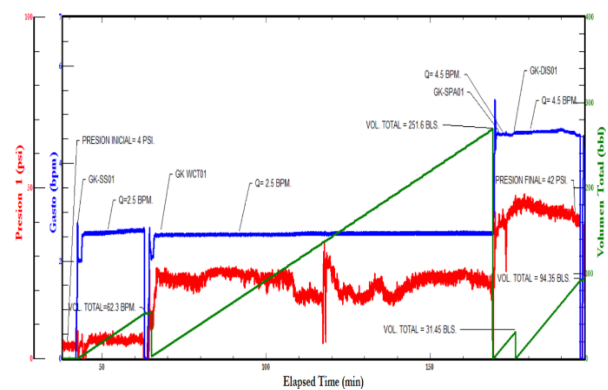


Figure 3

Fluid pumping test in Copanó 45 well, Kimia S.A. de C.V. Group, MACUSPANA-MUSPAC Production Asset, 2016.

Production behavior

During this phase of analysis, the volume of water extracted from the oil well initially showed high values, with percentages of 80% and 81% at the end of October and the beginning of November 2016.

However, from November 16, a notable reduction in water production was observed, reaching 53%. This decline continued more markedly on November 17, when water production dropped to 49%, allowing oil extraction to slightly exceed water production for the first time in the analyzed period.

Later, on November 30, a slight increase in water production was observed, reaching 57%, although it did not return to the high levels seen at the end of October and the beginning of November. In the first days of December, water production stabilized around 49% and 48%, reaffirming a downward trend compared to the initial records.

The oil well activity during the studied interval reflects a significant decrease in the amount of water extracted, resulting in an increase in oil production.

This phenomenon may suggest that the well has improved its efficiency or that more effective water management methods have been adopted. This is illustrated in the table and figures presented below.

Box 4

Table 1

Water production behavior in the well, Kimia S.A. de C.V. Group, MACUSPANA-MUSPAC Production Asset, 2016

Fecha	Qliq	Qo	Qw	%Agua
22-oct-16	437	89	348	80%
04-nov-16	326	63	263	81%
16-nov-16	279	132	147	53%
17-nov-16	355	180	175	49%
30-nov-16	236	102	134	57%
01-dic-16	234	119	115	49%
05-dic-16	232	121	111	48%

Box 5

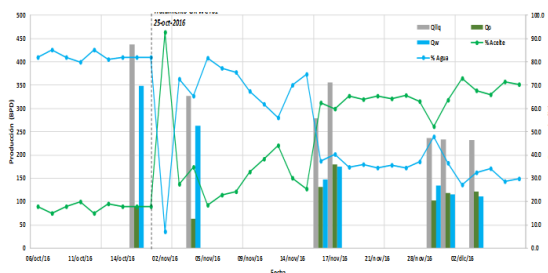


Figure 4

Performance in production with GK WCT01 treatment, Kimia S.A. de C.V. Group, MACUSPANA-MUSPAC Production Asset, 2016.

Box 6

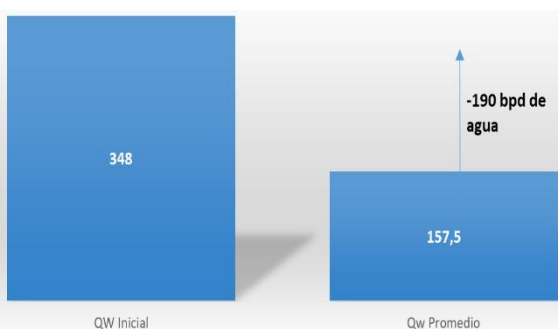


Figure 5

Water Production in Barrels per Day [BPD], Grupo Kimia S.A. de C.V., MACUSPANA-MUSPAC Production Asset, 2016.

System evaluation

Based on the observed characteristics of the oil well, the following points should be considered. The system exhibits a gradual response when it comes into contact with water, which promotes moderate and deep infiltration into formation fractures and relevant micro-annular areas.

This property is advantageous for selective water sealing, as it hardens exclusively in sections where water-bearing strata are present, increasing well effectiveness.

Additionally, the system's resistance to acidic conditions ensures the durability and stability of the treated formations, even under chemically aggressive environments. The ability to be pumped through flexible tubing [FT] adds adaptability to the system, allowing its application in various well configurations.

These characteristics demonstrate that the well has an enhanced capacity to manage water production, reducing its presence in hydrocarbon-producing zones and improving the selectivity of water sealing. Acid resistance and ease of pumping through FT reinforce these advantages, making this system a robust and effective solution for optimizing well production.

Box 7

Table 2

Reaction Activation Times of Brine Types, Grupo Kimia S.A. de C.V., MACUSPANA-MUSPAC Production Asset, 2016.

Tipo de Salmuera	Densidad	Ppm	Tiempo de Activación [min]
Agua de perforación	1.024	2,857	19:24
Agua de mar	1.041	19,047	22:36
Salmuera Cloruro de calcio al 37%	1.20	187,618	55:36
Salmuera Cloruro de calcio al 18%	1.15	107,618	29:48
Salmuera Cloruro de calcio al 5%	1.06	33,333	22:48
Salmuera Bromuro de calcio	1.26	134,761	26:00
Salmuera Bromuro de calcio	1.18	78,095	20:23

Box 8

Table 3

Penetration Capacity of Cement Types, Grupo Kimia S.A. de C.V., MACUSPANA-MUSPAC Production Asset, 2016.

Tipo de Cemento	Densidad [gr/cc]	Ancho de la Fisura [Pulg]	Porcentaje de la lechada penetrando a través de la fisura [%]
Micromatrix cement	1.45	0.006	91
Clase H	1.97	0.006	0
ΔP= 90 psi		Temperatura= 24 °C	

Box 9

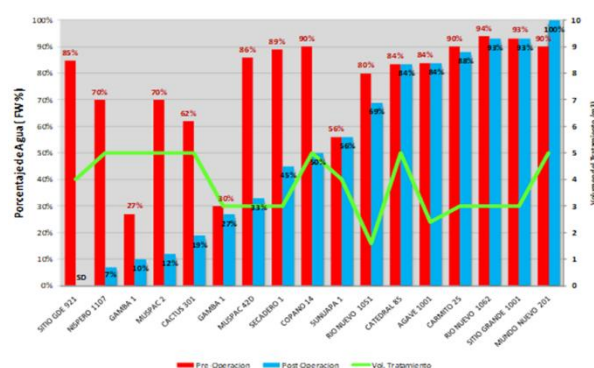


Figure 6

Background on the Application of Moc-ONE Technology in Different Wells of the Integrated Asset, Grupo Kimia S.A. de C.V., Macuspana-Muspac Production Asset, 2016.

Box 10

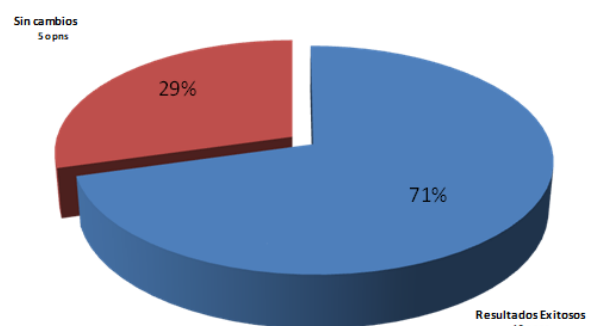


Figure 7

Success Rate of Moc-ONE Technology Operations in Different Wells of the Integrated Asset, Grupo Kimia S.A. de C.V., Macuspana-Muspac Production Asset, 2016.

SOS technology test in the copanó 41 well

The objective was set to restore a well to produce 150 bpd of oil and 1.0 MMcf/d of gas, in accordance with PEP's strategic goals.

Production analysis shows a strong start, with stability up to 90 days, followed by an increase in gas production and then a decline.

Strategic interventions have revitalized oil production; however, since 2004, gas production has decreased and water production has increased, indicating the need to adjust the strategies.

Box 11

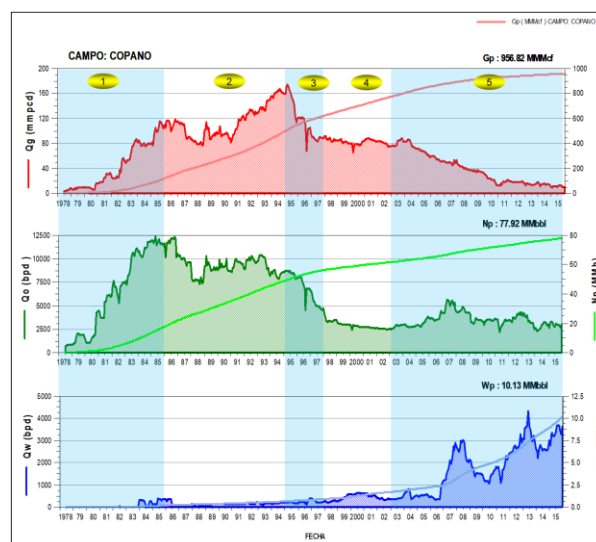


Figure 8

Historical Production Behavior of the Copanó Field, Copanó 41 Well Project, Macuspana-Muspac, 2016.

Box 12

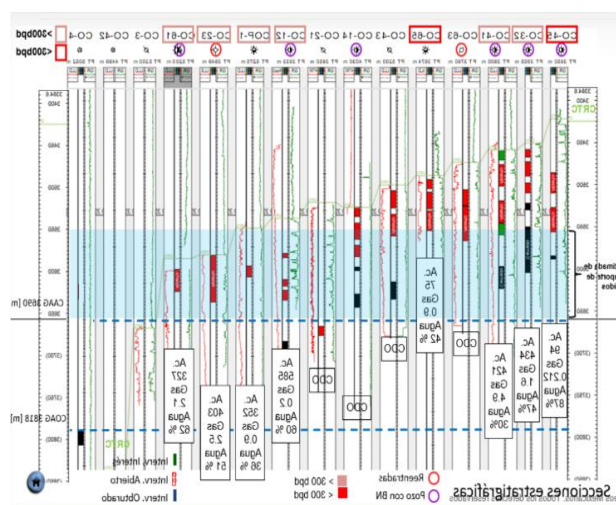


Figure 9

Stratigraphic Behavior of the Copanó Field, Copanó 41 Well Project, Macuspana-Muspac, 2016.

Discussions

Currently, the fields of the Muspac Asset exhibit static pressures of 50–100 kg/cm², where operational conditions have been adjusted for well treatment. A novel approach includes the use of volumes up to 6 m³ and prior bore cleaning with mechanical tools. It is recommended to test admission using centrifuged diesel and, when using nitroglycerin pumps, to prevent blockages with diesel or nitrogen.

To evaluate the need for additional treatments, radioactive tracers and over-displacement of the initial treatment are suggested. Logging of traced zones is crucial to define areas of effective placement.

In the analysis of wells from the Macuspana-Muspac asset using MOC-ONE technology, a 20% to 35% reduction in water production was observed, resulting in an increase in oil production. This change, in addition to improving efficiency, has a positive impact on costs and the operation's economics by reducing expenses related to water handling. Moreover, MOC-ONE technology not only provides an economic benefit but also promotes a more sustainable operation. Based on the results, it is suggested to continue implementing this technology in other wells with similar characteristics, accompanied by continuous monitoring to optimize results.

Previous experiences demonstrate that a data- and experience-based approach can improve the effectiveness of treatments applied in wells, contributing to better resource management in the petroleum industry.

Conclusion

The Oil-Based Ultra-Fine Cement Slurry system and SOS technology are effective strategies for water control in wells. These systems have reduced water cut to very low levels and allow production to remain open without the need for motor compressors, resulting in significant cost savings.

To optimize flow after treatment, it is recommended not to overproduce the interval.

Some recommendations include: identifying the source of water through cementing logs and PLT or PT analysis; using curve plots for diagnostic purposes; combining RPM to saturate zones of higher contribution before applying the Ultra-Fine Cement treatment; and, if additional treatment is required, inducing the well to attract water again.

In the Madura Macuspana-Muspac field, advanced technologies were implemented, highlighting the Copanó 41 well, which showed a significant increase in production after a minor repair. In 2016, SOS technology was applied, achieving a 20%–35% reduction in water production and a 10% increase in oil production, suggesting favorable economic viability for the future.

The Copanó 45 well, which underwent a major intervention using MOC-ONE technology, also showed a significant decrease in water production. The key is selecting the appropriate intervention to maximize benefits. Both SOS and MOC-ONE systems have proven effective, improving profitability and operational efficiency.

Referencias

Background

George O. Suman, JR. and Richard C. Ellis: “[World Oil Cementing Hand Book](#)”, 1977.

Basic

J.J. Jutten, P.A. Parcevaux and D.D. Guillot, Schlumberger: “[Relationship between Cement Composition, Mechanical Properties and Cement Bond Log Output](#)”. SPE 16652, Dallas, TX, September 27, 1987.

P.A Parcevaux and P.H. Sault, Schlumberger: “[Cement Shrinkage and Elasticity: A new Approach for a good Zonal Isolation](#)”. SPE 13176, Dallas, TX, 1984.

Support

Dan Mueller, BJ Services: “[An Evaluation of well cements for use in High Stress Environments](#)”. JPT, 1999.

Article

K.J. Goodwin, Mobil E&P Services Inc. and R.J. Crook, Halliburton Services: “Cement Sheath Stress Failure” SPE 20453, Diciembre 1992.

R. Abdul Rahman, Phil Rae, BJ Services: “A Simpler, More Effective Method for Cementing Surface Casings in Shallow Gas Zones: A Case History” SPE 54286, Jakarta, Indonesia, Abril 1999.

Gino Di Lulo, Phil Rae, BJ Services Company, SPE 62745: “Cements for Long-Term - Design Optimization by Computer Modelling and Prediction”, Sept 2000.



Discussions



Erik B. Nelson, David R. Bell, Schlumberger: [Well cementing](#). San Etienne, France. ISBN: 978-0-444-88751-1 ISSN: 0376-7361



Evaluation of environmental impact manifestations of electric power transmission projects



Evaluación de las manifestaciones de impacto ambiental de proyectos de transmisión de energía eléctrica

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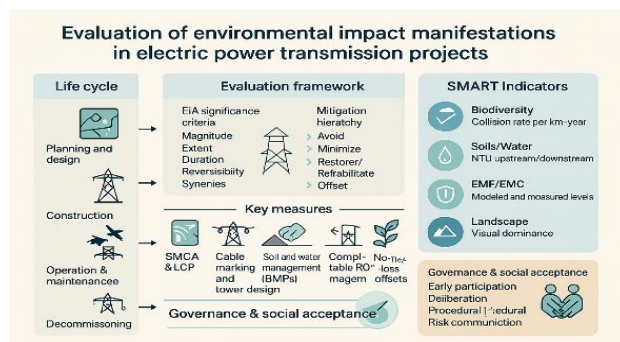


Abstract

The environmental impact of electrical transmission lines and substations is analyzed throughout their life cycle, from planning to decommissioning. Evaluation criteria and mitigation hierarchies are addressed, enabling cost-effective and socially legitimate decisions, integrating Environmental Impact Assessment [EIA] frameworks, valuation, and risk analysis. The approach includes the participation of project teams, local stakeholders, and life cycle considerations, with an emphasis on climate footprint and electrical losses. In addition, practical guidelines are proposed on aspects such as biodiversity, landscape, soil, water, and electromagnetic compatibility, promoting more robust EIAs for projects in contexts of accelerated energy transition.

Resumen

Se analiza el impacto ambiental de las líneas y subestaciones de transmisión eléctrica a lo largo de su ciclo de vida, desde la planificación hasta el desmantelamiento. Se abordan criterios de evaluación y jerarquías de mitigación que permiten decisiones costo-efectivas y socialmente legítimas, integrando marcos de Evaluación de Impacto Ambiental [EIA], valoración y análisis de riesgo. El enfoque incluye la participación de equipos de proyecto, actores locales y consideraciones del ciclo de vida, con énfasis en la huella climática y pérdidas eléctricas. Además, se proponen lineamientos prácticos en aspectos como biodiversidad, paisaje, suelos, aguas y compatibilidad electromagnética, promoviendo EIAs más robustas para proyectos en contextos de transición energética acelerada.



Evaluación de impacto ambiental, líneas de transmisión, biodiversidad



Environmental impact assessment, transmission lines, biodiversity

Area: Promotion of frontier research and basic science in all fields of knowledge

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Introduction

Achieving deep decarbonisation of electricity systems requires not only rapid growth in low-carbon generation, but also a major expansion and modernisation of transmission networks that can transport energy from resource-rich areas to load centres, balance variability and improve system resilience. In practice, the deployment of overhead high-voltage lines and selective undergrounding presents a complex portfolio of biophysical, landscape and socio-environmental externalities distributed throughout the project life cycle, from planning and routing to construction, operation and decommissioning.

A robust environmental assessment must therefore anticipate cumulative, cross-cutting and often synergistic effects, rather than treating projects as isolated interventions. This perspective is increasingly present in recent research on linear infrastructure and its impact at the landscape scale [Teo et al., 2019; Morgan, 2012; Jones, 2016].

Conceptually, Environmental Impact Assessment [EIA] has established itself as a structured, evidence-based process that integrates assessment and scoping with baseline characterisation, impact prediction, analysis of alternatives, and the design of mitigation and monitoring plans. Best practices emphasise transparent significance criteria: magnitude, extent, duration, reversibility, probability, uncertainty, and possible synergies, and require that alternatives be justified with traceable criteria and explicit trade-offs.

The mitigation hierarchy [avoid, minimise, restore/rehabilitate, and compensate] should guide decisions throughout the project cycle and is increasingly framed within outcome-based and ‘net-zero loss’ biodiversity objectives [Glasson & Therivel, 2012; Morgan, 2012; Arlidge et al., 2018].

In this context, the literature on external costs offers complementary tools for internalising environmental damage when comparing technological options and routing alternatives under conditions of uncertainty. Classic and updated reviews highlight how valuation methods, both monetary and non-monetary, can reduce information asymmetries in decision-making, while cautioning that results are sensitive to assumptions, spatial boundaries, and dose-response functions.

For transmission planning, these approaches are useful when evaluating packages of measures such as selective burial in sensitive sections, alternative tower topologies, or intensified bird diversion programmes [Sundqvist & Söderholm, 2002]. Methodologically, transmission projects are paradigmatic linear infrastructures whose main ecological risks include habitat loss and fragmentation, connectivity disruption, edge effects, bird collisions and electrocutions, and disturbances during construction. A systematic review of biodiversity impacts associated with power lines shows consistent evidence of risks to birds and calls for a more robust approach to cumulative effects and improved monitoring designs [Biasotto & Kindel, 2018]. In parallel, a state-of-the-art synthesis indicates that the effectiveness of collision mitigation devices depends on the species, context, and study design, underscoring the need for before-and-after control [BACI] impact monitoring approaches and standardised carcass search protocols [Bernardino et al., 2018; Barrientos et al., 2012].

From a planning perspective, early-stage multi-criteria spatial analysis [MCSAs], together with least-cost route analysis, have proven valuable for corridor definition and micro-routing, jointly optimising engineering feasibility and environmental performance. Empirical applications integrate biodiversity layers, land use conflicts, visual exposure of key receptors, and proximity to sensitive social infrastructure, thus operationalising the ‘avoid’ step of the landscape-scale mitigation hierarchy [Bagli et al., 2011; Biasotto et al., 2022].

During the construction phase, well-documented impact pathways include soil erosion and sediment mobilisation from access roads and foundations, as well as dust and noise affecting nearby communities. Good management practices and event-based turbidity thresholds are recommended to address episodic heavy rainfall. Vegetation clearance in rights-of-way [ROWs] warrants compatible vegetation strategies and native revegetation to accelerate ecological recovery and maintain connectivity. Emerging evidence further suggests that properly managed ROWs can support pollinator diversity and other taxa, reframing residual ROWs as potential ecological assets when herbicide use is minimised and structural heterogeneity is conserved [Glasson & Therivel, 2012; Russo et al., 2021].

During operation and maintenance, three issues recur across jurisdictions. First, avian risk management must combine context-specific line marking, selective line burial in highly sensitive sections, and adaptive monitoring, recognising that average effectiveness masks substantial interspecific variation [Barrientos et al., 2012; Bernardino et al., 2018]. Second, public exposure to low-frequency [50/60 Hz] electric and magnetic fields is governed by geometry, phase, and distance; international guidelines establish basic restrictions and reference levels for general public exposure, and EIA documentation should transparently report modelling assumptions, distances to receivers, and risk communication strategies [ICNIRP, 2010].

Thirdly, audible noise and radio interference related to the coronavirus, under certain climatic conditions, require predictive assessment to avoid exceedances near sensitive receivers [Glasson & Therivel, 2012; ICNIRP, 2010].

From a life cycle perspective, while the largest climate contribution from the electricity sector occurs in generation, transmission and distribution [T&D] contribute additional loads through materials [steel, aluminium, concrete], insulating gases [in particular SF₆], construction, losses and end of life. Peer-reviewed life cycle assessments [LCAs] of grid components consistently show that electrical losses predominate in many impact categories, with SF₆ leaks being a relevant factor in cases where gas-insulated equipment is numerous.

Typical T&D contributions to the carbon footprint of supplied electricity are in the single-digit range of g CO₂-eq/kWh, with variations depending on the context.

These results are relevant for decision-making when comparing overhead and underground sections, conductor sizing and tower design, and for justifying selective burial when ecological or social sensitivities warrant it [Jorge et al., 2012; Turconi, 2014; Valheim, 2016].

Furthermore, prospective scenarios involving long-distance high-voltage direct current [HVDC] corridors to integrate remote renewable energy require explicit life cycle and systems analyses, so that additional material requirements and the impact of converter stations can be weighed against potential system-level benefits, e.g., reduction of constraints and flexibility. Recent studies on HVDC technologies and long-distance interconnectors support this systems approach and call for the integration of LCA with techno-economic planning models [Irnawan et al., 2024; Acaroğlu et al., 2022].

Crucially, social acceptance and governance dynamics are often decisive for transmission location and timing. Deliberative studies in affected communities show that perceptions of fairness, visual intrusion, communication of EMF risk, and the credibility of alternative analysis, e.g., undergrounding options, influence acceptance more than simple “NIMBY” approaches suggest. Transparent and iterative participation, integrated from the outset in the choice of routes and technologies, has been linked to greater legitimacy and fewer delays [Cotton & Devine-Wright, 2013; Lienert et al., 2015; Lienert et al., 2018].

Therefore, this article proposes and applies an assessment framework for the environmental impact statements of electricity transmission projects, explicitly based on the life cycle, which considers cumulative effects and is decision-oriented. The framework integrates [i] EIA significance criteria and mitigation hierarchy, [ii] the assessment of externalities to compare packages of measures under conditions of uncertainty, and [iii] SMART monitoring indicators by component [biodiversity, soil and water, electromagnetic fields, landscape, and life cycle performance]. In doing so, it seeks to bridge the persistent gaps between compliance-oriented assessments and preventive and adaptive management, aligned with the imperatives of decarbonisation and community well-being [Glasson & Therivel, 2012; Morgan, 2012; Jones, 2016; Arlidge et al., 2018].

Review methodology

A focused narrative review of indexed literature and reference texts was conducted. The following inclusion criteria were prioritised:

Article

- a) EIA manuals and reference books.
- b) Peer-reviewed articles on impacts on linear infrastructure and mitigation measures.
- c) Life cycle studies of electricity networks.
- d) Methodological contributions to risk assessment.

Impact statements were coded by life cycle phase, and assessment criteria, measures, and monitoring metrics were extracted. The selection includes [Glasson & Therivel, 2012], [Sundqvist & Söderholm, 2002], [Teo et al., 2019], [Barrientos et al., 2012], and [Turconi, 2014; Valheim, 2016].

Impact manifestations and life cycle phase

- Route planning and design

The definition of the corridor and micro-route determines habitat fragmentation, ecological connectivity, and bird collision risks. Therefore, multi-criteria analysis of alternatives with strata of biodiversity, land use, and the presence of sensitive receptors [schools, homes, health centres] is crucial from the outset of the scoping study. Landscape-scale assessment, including protected areas, wetlands and migratory routes, guides early solutions to avoid collisions [Glasson & Therivel, 2012; Teo et al., 2019].

Visual perception and landscape integration should be considered with simulations from key receptors to select types of supports, heights, finishes and alignments that reduce visual intrusion, especially in scenic and tourist environments [Glasson & Therivel, 2012].

Electromagnetic compatibility [EMC] and radio interference require design analysis [phase configuration, distances, shielding] to avoid disturbances to nearby equipment in urban and peri-urban corridors [Senapati & Ojha, 2017].

- Construction

Impacts on soils, erosion and sediments arise from access roads, earthworks and foundations. Evidence recommends best management practices [BMPs] [sediment barriers, temporary drainage, temporary stabilisation] and torrential rain management plans with turbidity thresholds and rapid response [Glasson & Therivel, 2012].

In terms of air quality and noise, dust control, fleet maintenance and scheduling noisy activities outside sensitive hours reduce impacts on nearby communities [Glasson & Therivel, 2012].

Strip clearing affects vegetation and habitat; right-of-way approaches based on compatible vegetation and revegetation with native species reduce residual effects and facilitate biological corridors [Teo et al., 2019].

Finally, when information is scarce, prioritising environmental risks based on the construction team's judgement, e.g., unstable soils, fires, watercourse crossings, allows for the targeting of prevention and contingency resources.

- Operation and maintenance

With regard to bird collisions and electrocutions, controlled studies with BACI design show that cable marking [deflectors] reduces mortality in a small but significant way: [Barrientos et al., 2012] estimated a 9.6% reduction after marking 72.5 km of transmission and distribution lines, with variability by species, reinforcing the need for contextualised design and post-implementation monitoring.

Exposure to 50/60 Hz electric and magnetic fields decreases with distance and is managed through design and regulatory compliance; the recommendation in the EIA is to document modelling, distances to recipients, and risk communication strategies, avoiding both alarmism and unfounded minimisation [Senapati & Ojha, 2017]. Corona discharge can cause noise and visual effects in certain weather conditions and should be modelled to avoid exceedances near sensitive receptors [Glasson & Therivel, 2012]. Management of buffer strips oriented towards compatible vegetation, minimal and selective use of herbicides, and monitoring of soils and water bodies reduce residual pressures [Teo et al., 2019].

- Dismantling and closure

The removal phase requires management plans for metal waste, foundations, and access roads, with geomorphological restoration and revegetation to restore connectivity and ecosystem functions. EIA guidelines recommend scheduling this phase from the project design stage [Glasson & Therivel, 2012].

Aguilar-Marin, Jorge Luis, Cisneros-Villalobos, Luis, Vera-Dimas, José Gerardo and Gutiérrez-Álvarez, Yair Alejandro. [2025]. Evaluation of environmental impact manifestations of electric power transmission projects. ECORFAN Journal Bolivia 12[22]1-8: e31222108 <https://doi.org/10.35429/EJB.2025.12.22.3.1.8>

Climate dimension and life cycle perspective

In terms of climate change, the electricity sector's largest contribution comes from generation. However, transmission and distribution add charges for materials, construction, operation [losses] and decommissioning. Studies on European and Nordic networks place transmission and distribution emissions in the order of a few grams of CO₂ per kWh supplied, with differences depending on the technological and geographical context.

For Denmark, [Turconi, 2014] reports that distribution infrastructure alone contributes ~2 g CO₂-eq/kWh, and [Valheim, 2016] estimates 2.5 g CO₂-eq/kWh for the entire network [development, operation and decommissioning], focusing on the role of materials [steel, aluminium, concrete], SF₆ and electrical losses.

These figures, although lower than those for fossil fuel generation, are relevant when comparing design alternatives, for example, selective burial, and when justifying investments according to comprehensive environmental performance criteria [Turconi, 2014; Valheim, 2016].

Complementarily, long-distance transmission scenarios using HVDC highlight the importance of evaluating international electricity bridges in terms of life cycle, considering the increase in materials and the potential systemic benefit of integrating remote renewables.

Results

The most effective measure is to avoid corridors through critical habitats and flight paths, applying a multi-criteria analysis with environmental and social variables from an early stage and considering technological alternatives [support height, geometric configuration, partial burial in sensitive sections] [Glasson & Therivel, 2012; Teo et al., 2019].

When avoidance is not feasible, cable marking reduces collisions, although its effects vary depending on the species and context. It is recommended to combine this with accurate micro-monitoring in wetlands, floodplains and wildlife crossings [Barrientos et al., 2012].

In CEM/CEM, minimisation is addressed through distances, shielding and optimised conductor configurations [Senapati & Ojha, 2017].

Revegetation with native plants, soil management, and post-construction drainage restoration reduce residual effects, with indicators of success and maintenance over several years [Teo et al., 2019].

In cases of unavoidable significant impacts on biodiversity, e.g., loss of habitat for sensitive species, net zero loss schemes and outcomes-based offsets require clear metrics and independent monitoring [Glasson & Therivel, 2012].

The assessment of externalities allows evidence-based comparisons of combinations of measures [markers vs. selective burial vs. redesign of supports] and supports decision-making under conditions of uncertainty. However, the literature recommends caution regarding assumptions and parameter sensitivity [Sundqvist & Söderholm, 2002].

Methods based on the judgement of the project team when robust series are not available facilitate environmental risk matrices [probability × consequence] that are useful for allocating resources to critical controls and contingencies.

- Monitoring metrics and indicators

To operationalise the EIA for transmission, SMART indicators are proposed for each component, with thresholds and actions:

1. Biodiversity/Avifauna: collision rate per km·year, search effort and correction for carrion removal and detection [to avoid bias], seasonal and species variation; success of measures, e.g., percentage change in post-marking [Barrientos et al., 2012].
2. Soil/Water: NTU at upstream/downstream points during construction and first rains, slope stability [safety factor], compliance with BMPs [percentage of verified effective measures] [Glasson & Therivel, 2012].

3. EMF/EMC: Modelled and measured levels at 50/60 Hz at boundaries and installations; reported and resolved interference events; compliance with national and international guidelines [Senapati & Ojha, 2017].
 4. Landscape: Assessment of contrast change and visual dominance through photographic audits by sensitive receivers; social perception [surveys] [Glasson & Therivel, 2012].
 5. Life cycle: Inventory of critical materials [steel, aluminium, concrete], SF₆ and technical losses; estimation of g CO₂-eq/kWh attributable to T&D and comparison with design alternatives [Turconi, 2014; Valheim, 2016].
- Social and governance considerations

In social terms, the EIA should integrate the mapping of key actors, communication and informed participation mechanisms, with special attention to local communities and indigenous peoples, as well as rights-based easement acquisition processes.

Comparative experience with infrastructure corridors underscores that the legitimacy of the process, transparency in the criteria for selecting alternatives, feedback on results, and collaborative design of measures reduce conflicts and implementation delays [Teo et al., 2019].

- Lessons from analogous sectors: geothermal energy as a methodological case

Although specific, geothermal developments offer extrapolatable lessons: anticipating seismic, emissions and groundwater risks through preliminary EIAs improves the quality of scoping analysis and adaptive monitoring. In this regard, technical reports from geothermal training programmes demonstrate the usefulness of interaction matrices and phased monitoring plans, which can be adapted to linear infrastructure in critical subsections.

- Technical-environmental comparisons: aerial vs. underground

The literature on the life cycle recommends avoiding generalisations: undergrounding reduces visual intrusion and the risk of bird collisions, but increases the complexity of materials, civil works and, in some cases, maintenance; overhead lines, on the other hand, require fewer materials per km, although they generate greater landscape exposure and collision risk.

In cold or humid climates, corona discharge and noise can be significant in high-voltage overhead lines. Multi-criteria assessment, based on life cycle inventories and technical losses of the system, is the recommended approach for deciding on selective undergrounding in sensitive sections [Turconi, 2014; Valheim, 2016; Barrientos et al., 2012].

Conclusions

The EIA for electricity transmission projects must go beyond formal compliance and operate with a preventive and adaptive approach: avoiding corridors over sensitive habitats, minimising cable marking and micro-routing with proven measures, and restoring and compensating according to net zero loss principles, with independent monitoring and periodic audits.

The assessment of externalities brings economic rationality to the selection of packages of measures under conditions of uncertainty, if assumptions are made explicit and sensitivity analyses are performed. This is particularly relevant in contexts of energy transition with multiple technological alternatives.

The life cycle perspective shows that, even when the climate loads of transmission and distribution per kWh are relatively low compared to generation, they are decisive for design decisions [materials, topologies, selective burial] and for avoiding overlapping impacts.

Informed participation and transparent governance, with mapping of key actors, risk communication and right-of-way agreements, promote social acceptance and the long-term viability of projects, an essential condition for networks that are compatible with biodiversity, the landscape and community well-being.

Aguilar-Marin, Jorge Luis, Cisneros-Villalobos, Luis, Vera-Dimas, José Gerardo and Gutiérrez-Álvarez, Yair Alejandro. [2025]. Evaluation of environmental impact manifestations of electric power transmission projects. ECORFAN Journal Bolivia 12[22]1-8: e31222108 <https://doi.org/10.35429/EJB.2025.12.22.3.1.8>

Article

Declarations**Conflict of interest**

The authors declare that they have no conflict of interest. They have no conflicting financial interests or known personal relationships that could have influenced the work presented in this article.

Contribution of the authors

Aguilar-Marin, Jorge Luis: Conceptualisation, methodology, writing [revision and editing].

Cisneros-Villalobos, Luis: Conceptualisation, methodology, research, supervision.

Vera-Dimas, José Gerardo: Conceptualisation, formal analysis, research.

Gutiérrez-Álvarez, Yair Alejandro: Conceptualisation, formal analysis, writing [review and editing].

Availability of data and materials

The original contributions presented in this study are included in the article. For further information, please contact the corresponding author.

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Abbreviations

BACI	Before-After Impact Monitoring
BMPs	Best Management Practices
CO ₂ -eq	Carbon Dioxide Equivalents
EIA	Environmental Impact Assessment
EMF	Electric and Magnetic Fields
EMC	Electromagnetic Compatibility
Hz	Hertz
HVDC	High Voltage Direct Current
ICNIRP	International Non-Ionizing Radiation Protection Commission
kWh	Kilowatt-hours
LCA	Life Cycle Analysis
NTNU	Norwegian University of Science and Technology
NTU	Nephelometric Turbidity Units
ROW	Right of Way
SF ₆	Sulphur Hexafluoride
SMCA	Multicriteria Spatial Analysis

SMART	Specific Measurable Achievable Achievable Relevant Relevant Time Limited
T&D	Transmission and Distribution

References**Background**

Arlidge, W. N. S., Bull, J. W., Addison, P. F. E., ... & Milner-Gulland, E. J. [2018]. [A global mitigation hierarchy for nature conservation](#). *BioScience*, 68[5], 336–347.

Bagli, S., Geneletti, D., & Orsi, F. [2011]. [Routeing of power lines through least-cost path analysis and multicriteria evaluation to minimise environmental impacts](#). *Environmental Impact Assessment Review*, 31[3], 234–239.

Barrientos, R., Ponce, C., Palacín, C., Martín, C. A., Martín, B., & Alonso, J. C. [2012]. [Wire marking results in a small but significant reduction in avian mortality at power lines: A BACI designed study](#). *PLoS ONE*, 7[3], e32569.

Biasotto, L. D., Bager, A., & Kindel, A. [2022]. [Routing power lines: Towards an environmental and engineering-friendly framework for avoiding impacts and conflicts in the planning phase](#). *Environmental Impact Assessment Review*, 95, 106765.

Biasotto, R., & Kindel, A. [2018]. [Systematic review of power lines impacts on biodiversity: Are we far from the facts?](#) *Environmental Impact Assessment Review*, 71, 7–14.

Cotton, M., & Devine-Wright, P. [2013]. [Putting pylons into place: A UK case study of public perspectives on the impacts of high voltage overhead transmission lines](#). *Journal of Environmental Planning and Management*, 56[8], 1225–1245.

International Commission on Non-Ionizing Radiation Protection [ICNIRP]. [2010]. [Guidelines for limiting exposure to time-varying electric and magnetic fields \[1 Hz–100 kHz\]](#). *Health Physics*, 99[6], 818–836.

Jorge, R. S., Hawkins, T. R., & Hertwich, E. G. [2012]. [Life cycle assessment of electricity transmission and distribution—Part 1: Power lines and cables](#). *The International Journal of Life Cycle Assessment*, 17[1], 9–15.

Article

Jones, F. C. [2016]. Cumulative effects assessment: Theoretical underpinnings and big problems. *Environmental Reviews*, 24[2], 187–204.

Lienert, P., Sütterlin, B., & Siegrist, M. [2015]. The influence of high-voltage power lines on people's well-being and perceived health risks. *Energy Policy*, 87, 125–134.

Lienert, P., Suetterlin, B., & Siegrist, M. [2018]. Public acceptance of the expansion and modification of high-voltage power lines in the context of the energy transition. *Energy Policy*, 112, 258–270.

Morgan, R. K. [2012]. Environmental impact assessment: The state of the art. *Impact Assessment and Project Appraisal*, 30[1], 5–14.

Russo, L., et al. [2021]. Power line right-of-way management and flower-visiting insect communities: Evidence for biodiversity-friendly practices. *PLOS ONE*, 16[1], e0244732.

Irnawan, R., Budiwati, I. M., & Setiadi, H. [2024]. Review of HVDC technologies for weak grid interconnectors. *Electrical Engineering [Springer]*.

Support

Bernardino, J., Bevanger, K., Barrientos, R., ... & Moreira, F. [2018]. Bird collisions with power lines: State of the art and priority areas for research. *Biological Conservation*, 222, 1–13.

Glasson, J., & Therivel, R. [2012]. *Introduction to Environmental Impact Assessment* [4.^a ed.]. Routledge.

Senapati, M., & Ojha, R. [2017]. Environmental impact of electrical power transmission networks. *International Journal of Computational Engineering Research*, 7[9], 105–109.

Turconi, R. [2014]. Life Cycle Assessment of electricity systems [Doctoral dissertation]. Technical University of Denmark.

Basics

Sundqvist, T., & Söderholm, P. [2002]. Valuing the environmental impacts of electricity generation: A critical survey [RR-03-005]. *International Institute for Applied Systems Analysis*.

Teo, H. C., Lechner, A. M., Walton, G. W., ... & Campos-Arceiz, A. [2019]. Environmental impacts of infrastructure development under the Belt and Road Initiative. *Environments*, 6[6], 72.



Valheim, T. M. [2016]. Environmental assessment of electricity transmission using life cycle assessment [Master's thesis]. Norwegian University of Science and Technology.



Acaroğlu, H., Yumurtacı, R., & Genç, M. S. [2022]. A life-cycle cost analysis of HVDC overhead transmission lines. *Journal of Cleaner Production*, 378, 134481.



Sustainable alternatives for water consumption in denim jeans washing: A systematic literature review



Alternativas sostenibles para el consumo de agua en el lavado de pantalones de mezclilla: Una revisión sistemática de literatura

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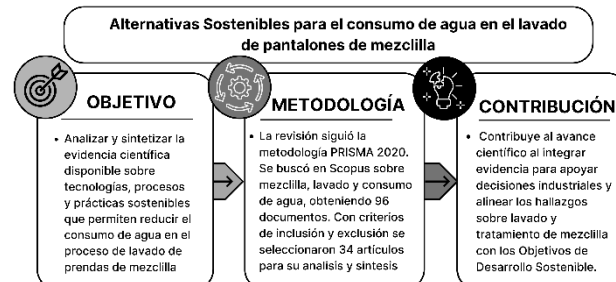
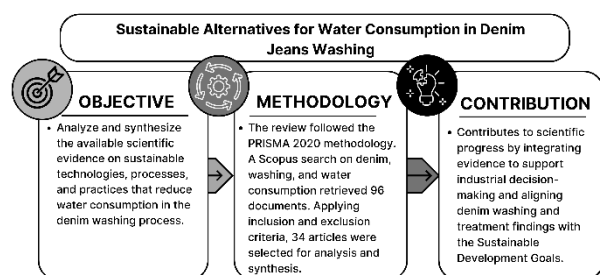


Abstract

The denim industry is characterized by high consumption of water, energy, and chemicals, generating effluents with dyes, heavy metals, and toxic compounds that are difficult to treat. The objective of this systematic review was to analyze and synthesize scientific evidence on sustainable technologies, processes, and practices to reduce water consumption and optimize wastewater treatment in denim laundries. The study followed the PRISMA 2020 methodology, based on 34 articles retrieved from Scopus. The results highlight technologies such as ozone, laser, nebulization, and enzymes, as well as the reuse of natural materials such as peach pits and rice husk. These alternatives have shown substantial reductions in water, energy, and pollutants, although most remain at experimental stages and face technical and scalability limitations. It is concluded that the integration of clean technologies with efficient treatment systems is essential to reduce the denim industry's water footprint.

Resumen

La industria de la mezclilla presenta altos consumos de agua, energía y químicos, generando efluentes con colorantes, metales pesados y compuestos tóxicos de difícil tratamiento. El objetivo de esta revisión sistemática fue analizar y sintetizar la evidencia científica sobre tecnologías, procesos y prácticas sostenibles que reduzcan el consumo de agua y optimicen el tratamiento de efluentes en lavanderías de mezclilla. El estudio se desarrolló bajo la metodología PRISMA 2020, a partir de 34 artículos seleccionados en Scopus. Los resultados destacan tecnologías como ozono, láser, nebulización y enzimas, así como el reuso de materiales naturales como huesos de durazno y cascarilla de arroz. Estas alternativas muestran reducciones sustanciales en agua, energía y contaminantes, aunque la mayoría se encuentra en fase experimental y enfrenta limitaciones técnicas y de escalabilidad. Se concluye que la integración de tecnologías limpias con sistemas de tratamiento eficientes es indispensable para disminuir la huella hídrica de la industria.



Denim, Water consumption, Sustainable processes

Mezclilla, Consumo de agua, Procesos sostenibles

Area: Advocacy and attention to national problems

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Introduction

The textile industry, particularly denim manufacturing, has been identified as one of the most resource-intensive sectors and one of the main contributors to water pollution worldwide. This sector consumes large volumes of water, chemicals, and energy, raising increasing concerns about its sustainability [Souza et al., 2016; Wahab & Hussain, 2020].

In particular, the garment finishing process, which includes industrial jeans washing, represents one of the most critical stages from an environmental perspective due to its high-water consumption, the chemical load of effluents, and the generation of solid waste and contaminant sludge [Atav et al., 2024; Nayak et al., 2022].

Traditional jeans washing requires between 30 and 70 liters of water, 150 g of chemicals, and 1 kWh of energy per garment [Ben Fraj & Jaouachi, 2021; Md. K. R. Khan & Jintun, 2021]. With an annual production of five billion pieces, global consumption is estimated at 350 million m³ of water, in addition to indigo loss and other non-biodegradable substances that create a difficult-to-mitigate environmental footprint [Arenas et al., 2017; da Costa et al., 2021].

Added to this is the pressure from fashion trends, which impose aesthetic demands that become commercial standards and promote highly polluting processes [Ivedi & Cay, 2023; Md. K. R. Khan & Jintun, 2021]. Trends demanding specific textures and shades increase the use of water and chemicals, generate complex residues that are difficult to manage, and hinder the adoption of sustainable practices, despite growing regulations and environmental awareness [Luo et al., 2022; Nadeem et al., 2024].

Denim washing generates effluents containing recalcitrant dyes, heavy metals, and toxic compounds that alter pH, reduce dissolved oxygen, and harm aquatic life; some, such as aromatic amines, are carcinogenic or bioaccumulative [González-López et al., 2024; Rodríguez et al., 2013].

Many treatments only transform these contaminants into industrial sludge [Souza et al., 2016].

Furthermore, workers are exposed to hazardous chemicals and surrounding communities face water scarcity and deficient wastewater treatment [Vos, 2019; Wahab & Hussain, 2020]. Additionally, techniques such as pumice stone washing accelerate machinery wear, generate large volumes of sludge, and increase solid waste [Catarino et al., 2025; Ivedi & Cay, 2023].

Increasing public criticism, environmental regulations, and shifting consumer preferences have fostered scientific and industrial interest in developing sustainable solutions. However, these solutions face technical, economic, and operational challenges that hinder large-scale implementation, particularly in industrial contexts such as Tehuacán, Puebla, where denim production is a key regional economic activity. Despite this interest, the available evidence remains fragmented and lacks a rigorous synthesis to guide decision-making in the sector.

The objective of this systematic review is to analyze and synthesize the available scientific evidence on sustainable technologies, processes, and practices aimed at reducing water consumption in denim garment washing and its subsequent treatment, to identify technically, economically, and environmentally viable alternatives for potential implementation in industrial laundries.

The central hypothesis is that the integrated adoption of sustainable technologies and practices can significantly reduce the water and environmental footprint while maintaining the technical and economic viability of industrial laundries, thereby aligning with the United Nations Sustainable Development Goals [SDGs], particularly SDG 6 [Clean Water and Sanitation], SDG 12 [Responsible Consumption and Production], and SDG 13 [Climate Action], which promote sustainable water management, the reduction of industrial environmental impact, and the adoption of responsible production and consumption practices [ONU, 2015]. Sustainability constitutes a strategic and non-negotiable requirement for the long-term viability and competitiveness of the textile industry [Bastidas Paredes et al., 2025]

The added value of this study lies in the fact that, unlike previous research focused on isolated cases or specific technologies, it provides a systematic and updated synthesis of scientific evidence on sustainable alternatives, offering a comparative and critical perspective that can guide decision-making in the denim industry.

This article is organized into four sections: the first describes the methodology used for systematic review; the second presents the main results; the third discusses the findings considering current challenges; and the fourth provides conclusions and recommendations for implementing sustainable processes in the denim industry.

Methodology

The development of this review followed the PRISMA 2020 methodology [Preferred Reporting Items for Systematic Reviews and Meta-Analyses], to ensure a rigorous, transparent, and reproducible process in the identification, selection, and analysis of the included studies [Page et al., 2021].

1.1. Search Strategy

An exhaustive search was carried out in the Scopus database, using a combination of key terms related to washing processes, denim, and water consumption. The search equation employed was as follows: *[technology OR washer OR machine OR "washing process" OR laundering OR laundry OR finishing] AND [denim OR jeans] AND ["water footprint" OR "water usage" OR "water consumption" OR "water reduction" OR "water treatment" OR wastewater OR sewage]*

This strategy initially retrieved a total of 96 documents, corresponding to different types of academic publications.

1.2. Inclusion Criteria

Documents were included if they met the following conditions: peer-reviewed articles on denim washing, finishing, treatment, or sustainability; studies on other fabrics with proposals applicable to denim; documents with accessible title and abstract; and research on wastewater treatment originating from denim laundries.

1.3. Exclusion Criteria

Documents were excluded if they met any of the following conditions: studies on denim fabric manufacturing or weaving without relation to garment finishing; research on wastewater treatment not originating from laundries; documents without an identified author or without an abstract; non-peer-reviewed publications; and outdated proposals or those lacking current contributions to sustainability in denim finishing.

1.4. Selection Process

From the initial total of 96 retrieved documents, the corresponding filters were applied according to the criteria above. As a result, 34 documents were selected for detailed analysis, including 28 scientific articles and 6 review articles. The filtering and selection process is shown in **Figure 1**.

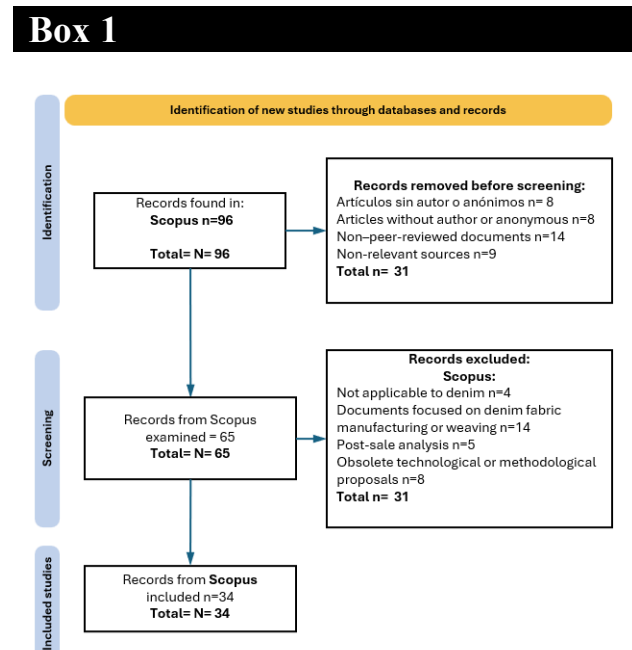


Figure 1

PRISMA 2020 Flow Diagram

Source: Own elaboration

Results

From the detailed analysis of the documents selected for this systematic review, it was possible to identify several research lines focused on sustainable alternatives for water consumption in the denim jeans washing process, which are described in the following subsections.

Box 2

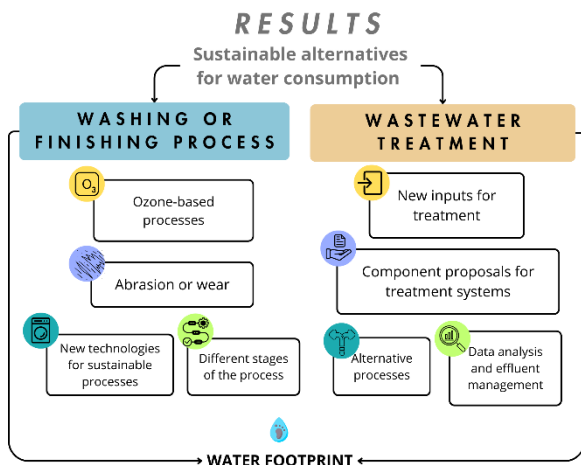


Figure 2
Conceptual map of the review results
Source: Own elaboration

Sustainable Optimization in Washing or Finishing Processes

One of the main objectives of denim garment finishing or washing is to provide a wide range of shades while ensuring consumer comfort. To achieve this, a large amount of chemicals, water, and energy is required, which makes conventional finishing processes—and the textile industry in general—one of the most polluting. [Arenas et al., 2017; Ben Fraj & Jaouachi, 2021; Chowdhury et al., 2020]. In this context and considering the sustainability approach that has been globally adopted by the industry in recent years, the denim sector has been compelled to research and implement modern washing and treatment techniques [Uysaler et al., 2025].

These efforts primarily aim to reduce water consumption, minimize environmental pollution, and decrease the generation of chemical waste and wastewater. Moreover, the intensive use of heavy chemicals in dyeing and finishing processes not only impacts the environment but also poses risks to workers' health.

All these factors reinforce the urgency for the textile industry to transition toward greener processes, clean technologies, and economically sustainable solutions [Arenas et al., 2017; Atav et al., 2024; Eroğlu, 2023].

1.4.1. Ozone-Based Processes

Ozone [O₃] is a gas naturally present in the atmosphere, generated through photochemical reactions induced by the sun's ultraviolet [UV] radiation. However, it can also be artificially produced through methods such as corona discharge, which forms the basis for the operation of ozone-generating machines in closed chambers [Atav et al., 2024; Ben Fraj & Jaouachi, 2021]. Ozone's oxidizing properties make it an efficient, consistent, and eco-friendly alternative to traditional denim bleaching methods. Among its most relevant advantages are its ability to avoid the formation of organochlorine residues, the drastic reduction in water consumption, and its natural reconversion into oxygen after the reaction. This prevents the formation of toxic by-products and reinforces their profile as an environmentally friendly technology [Nadeem et al., 2024]. **Table 1** presents the articles that investigated this technique and their respective proposals, as well as the benefits reported.

Box 3

Table 1

Proposals for ozone processes and benefits

Author	Author's proposal	Key Benefit
[Atav et al., 2024]	Ozone as a sustainable bleaching technology	Water, energy and chemical reduction; less polluting; greater fabric strength; lower cost per garment and lower carbon footprint.
[Ben Fraj & Jaouachi, 2021]	Ozone treatment as a substitute for abrasives	Reduction of water and chemicals; better whiteness without toxic products; control over shrinkage, resistance and bagging; less environmental impact and energy consumption; avoids hazardous waste.
[Hu et al., 2021]	Optimization of ozone washing using the orthogonal method	Control of the bleaching effect; simplification of the operational process; Greater reproducibility of results; Process efficiency
[Nadeem et al., 2024]	Gaseous ozone with fine water aerosolization.	Substitution of toxic bleaches; lower consumption of water, chemicals and sludge generation; improvement of mechanical and comfort properties; reduction in BOD and COD of effluents; control and reproducibility; mass transfer efficiency.
[Nayak et al., 2022]	Combining digital laser and ozone technologies with data from two Vietnamese companies.	Water, energy and chemical savings; water-free and effluent-free processes; precise and creative finishing effects; reduction of environmental pollution. lower operating costs; circular economy.
[Ben Hmida & Ladhari, 2016]	Evaluation of ozone concentration, and its effects on physical and chemical properties of the tissue.	Reduction of hot water and chemicals; zero hazardous waste; Higher ozone efficiency in physical and controlled wet environment; Less mechanical damage.

Despite its multiple advantages, the ozonation process in denim garments presents technical and operational limitations that must be carefully considered. One of the main concerns is the loss of mechanical strength in fabrics, particularly when treatment times or concentrations are exceeded, since ozone can break hydrogen bonds in cellulose and weaken the fiber structure [Atav et al., 2024; Ben Fraj & Jaouachi, 2021].

Another important limitation is the saturation of ozone gas within the treatment chamber, which can reduce its effectiveness in prolonged or poorly ventilated processes [Nadeem et al., 2024]. In addition, the process is highly sensitive to operating conditions, such as humidity [excessive water reduces effective contact between ozone and fabric], medium pH, and temperature, which affect the solubility and lifespan of the gas [Atav et al., 2024; Hu et al., 2021]. It has also been reported that some synthetic materials, such as PET, exhibit lower reactivity to ozone due to their compact structure, requiring specific parameters for each fiber type [Nadeem et al., 2024]. Finally, although not always explicitly mentioned, the initial investment in specialized machinery and the need for trained technical personnel may represent a barrier to the adoption of this technology, particularly in developing countries [Nayak et al., 2022].

1.4.2. Alternatives for Wear or Abrasion

One of the most valued finishes by both designers and customers is the *stone wash*, whose objective is to create a worn or aged effect in denim garments.

This effect is achieved through abrasion or mechanical friction, produced by the rubbing of pumice stones against the garment inside the washing drum [Arenas et al., 2017; Ivedi & Cay, 2023].

As an alternative, the use of cellulase enzymes has been proposed, which can achieve a similar or even superior finish without relying on mechanical abrasion [Kakkar & Wadhwa, 2022]. However, in real industrial environments, it is common to combine both methods to achieve the desired levels of wear and visual contrast.

This process has several disadvantages, including the difficulty of removing stones from garments at the end of washing, textile fiber damage, reduced fabric strength, the appearance of tears, obstruction of machine pipelines due to stone fragmentation, potential damage to machinery, and high-water consumption [Arenas et al., 2017; Ivedi & Cay, 2023; Kakkar & Wadhwa, 2022].

Table 2 presents the three articles that addressed studies with this approach, listing the authors' proposals, the identified benefits and limitations, as well as the stage of implementation in which they are currently positioned.

Box 4

Table 2

Proposals for ozone processes and benefits

[Ivedi & Cay, 2023]	
Proposal	Evaluation of the use of peach peach and synthetic stones.
Proceeds	Reuse of natural and synthetic materials more than 100 times Reduction of up to 50% of water Lower CO ₂ emission. 45% lower cost per unit Comparable results pumice stone
Limitations	Longer process time CO ₂ emission up to 13–14% Lower washout visual effect
Phase	Experimental tests in a real industrial environment
[Kakkar & Wadhwa, 2022]	
Proposal	Use of extremozyms to replace chemical processes.
Proceeds	Eco-friendly and biodegradable processes; lower use of water, energy and chemicals; applicable in extreme conditions; quality improvement; Less pollutants in effluents.
Limitations	Expensive and difficult production under laboratory conditions; requires genetic engineering; some have redeposition or spots.
Phase	In the development and experimentation stage.
[Arenas et al., 2017]	
Proposal	Abrasive rice husk ash [RHA] spheres
Proceeds	Reduction of damage to garments and machinery; simultaneous adsorption of dye and solid waste; Zero effluent discharge processes.
Limitations	It was not validated in real effluent; no mechanical strength is reported; no aesthetic or physical effects are evaluated.
Phase	Experimental laboratory test.

Source: Own elaboration

1.4.3. Alternatives in Different Stages of the Process

While ozone-based techniques and abrasion alternatives are the most widely studied within the scope of proposals applied to the washing process, the following individual studies aimed to develop, evaluate, and optimize sustainable processes for the washing, dyeing, or finishing of denim and cotton garments through alternative technologies such as laser treatment, automated systems, spraying methods, or enzymatic washing. These approaches seek to significantly reduce water, energy, and chemical consumption, as well as environmental impact, in comparison with conventional methods.

Table 3 presents five authors who proposed techniques, machines, chemicals, and methods oriented toward sustainably improving the efficiency of the washing process, along with the benefits and limitations identified.

Box 5

Table 3

Advantages and limitations of alternatives in different processes.

[Wahab & Hussain, 2020]	
Proposal	Adaptation of aerosol technology, using a mixture of pressurized air and minimal amount of water.
Proceeds	Water [75%] and energy [47%] savings; reduction of chemicals; color fastness and less rinsing.
Limitations	It requires redesign of machinery; only tested on socks; no aesthetic impact was evaluated.
[Chowdhury et al., 2020]	
Proposal	Substitution of sulfuric acid for acetic acid in the acid wash process, and use of sodium hyposulfite as a permanganate neutralizer instead of oxalic acid.
Proceeds	Use of safer substances; visual effects similar to the traditional method; simple and less corrosive processes.
Limitations	Slow bleaching; not validated on a large scale; requires testing on other denim blends.
[Hasan et al., 2024]	
Proposal	Misting where fine mist is used to apply finishing products.
Proceeds	Water [90.01%] and energy saving; high reproducibility and stability of the fabric; evaluation with EIM software.
Limitations	High chemical impact [EIM=85] due to the use of permanganate; safer alternatives were not evaluated; system depends on traditional chemicals.
[Nergi et al., 2023]	
Proposal	Process redesign by eliminating hypochlorite and permanganate, by organic bleach and laser
Proceeds	Lower water footprint [36%], lower gas use and permanganate elimination; Comparable visual quality.
Limitations	Higher electricity consumption [+46%]; it requires new products; terrestrial toxicity.
[Uysaler et al., 2025]	
Proposal	Optimization of the CO ₂ laser washing process and 10 minutes of enzymatic washing
Proceeds	Process without hazardous chemicals; less energy and time; good visual and mechanical properties.
Limitations	Increases yellowness and reduces drag; still requires a wet stage; applied only on two types of denim.

Source: Own elaboration

1.5. Sustainable Optimization in Wastewater Treatment.

Once the desired processes requested by customers are applied to denim garments, the water used—mixed with chemicals, dyes that do not bind to the fiber during the dyeing process, and residues such as lint—is discharged as wastewater. The high variability of these processes results in effluents with elevated concentrations of pollutants and a highly diverse composition, including synthetic organic substances such as detergents, dissolved salts, and numerous suspended solids. [Ergan et al., 2025; Majouli et al., 2012]. These effluents generally exhibit high values of pH, biochemical oxygen demand [BOD], chemical oxygen demand [COD], turbidity, and other toxic chemical compounds [Souza et al., 2016].

The treatment and recycling of effluents produced by the textile industry, utilizing advanced technologies, equipment, and materials, represent a task of significant importance. In recent years, the search for more efficient and sustainable wastewater treatments has become an increasing challenge, driven by rising environmental awareness and stricter environmental protection regulations. [Augusto Moreira et al., 2025; Catarino et al., 2025; Ergan et al., 2025]

1.5.1. Proposals for New Inputs

Among the alternatives to optimize wastewater treatment generated by processes applied to denim garments, several proposals have focused on the use of specific inputs or chemical products, which have been analyzed in various studies for their potential to improve the purification process.

Table 4 presents three studies in which the authors proposed new inputs aimed at adaptation in wastewater treatment. In addition, a fourth article by Méndez-Hernández et al. [2022] is included, which, although it does not evaluate the benefits of the analyzed input, focuses on its toxicity—a contribution that is also highly relevant for decision-making in industrial and environmental contexts.

Box 6**Table 4**

Proposals for inputs in effluent treatment systems

[da Costa et al., 2021]	
Proposal	Use of activated carbon from sugarcane bagasse to treat effluent.
Proceeds	High color removal [93%], low cost, effective with colorants.
Limitations	Does not meet COD standard, no affinity for other compounds and unadjusted pH.
Phase	Laboratory test with real effluent.
[Körlü et al., 2015]	
Proposal	Reuse of pumice stone as an adsorbent.
Proceeds	Reduction of COD/BOD, good performance with color, low cost and reuse of waste.
Limitations	The process is dependent on the initial dye concentration, does not eliminate all contaminants, and has not been evaluated for regeneration capability.
Phase	Test in industrial plant with real effluent.
[Augusto Moreira et al., 2025]	
Proposal	Synthesis of mesoporous silica with rice ash to remove methylene blue [MB] and contaminants.
Proceeds	High efficiency [~75%], good MB adsorption, high specific surface area and sustainable method.
Limitations	Efficiency only at pH 12, no regeneration study, not integrated with other technologies.
Phase	Laboratory test with real industrial effluent.
[Méndez-Hernández et al., 2022]	
Proposal	UASB anaerobic treatment of wastewater with high toxicity using Biolite BSN.
Proceeds	50% reduction in toxicity and 77% reduction in COD, identifies the toxic agent and possible methane recovery.
Limitations	Only simulated effluent was used, and toxicity remains high.
Phase	Laboratory test with simulated water.

Source: Own elaboration

1.5.2. Alternative Wastewater Treatment Processes

Given the limitations of conventional treatments, such as high sludge generation, excessive use of reagents, or reduced efficiency against certain pollutants, research on alternative processes has been promoted. These new methodologies—which include advanced biological treatments, chemical oxidations, hydrodynamic cavitation, and electrochemical technologies—seek not only to improve efficiency in pollutant removal but also to reduce energy consumption and facilitate the reuse of treated water [Solís et al., 2013; Zapata et al., 2021].

Table 5 lists five authors who proposed new techniques and methodologies for wastewater treatment. The exploration of these alternatives represents a significant step toward a more circular and responsible model in water resource management within the textile industry.

Box 7**Table 5**

Proposals for new techniques and methodologies

[Solís et al., 2013]	
Proposal	Sedimentation as a physical pretreatment to reduce solids, color and COD in denim effluents.
Proceeds	Up to 70% COD reduction, visible colour reduction, economical technique and allows water to be reused.
Limitations	Ineffective for dyeing, does not remove organic load or phytotoxicity, requires additional treatment.
Phase	Try it in real laundries in Tepetitla, Tlaxcala.
[González-López et al., 2024]	
Proposal	Use of native microorganisms for biological treatment without external activated sludge.
Proceeds	90% reduction in COD and color, easy start-up, local and sustainable alternative, low health risk.
Limitations	Slower color removal and no evaluation of fungus or long-term stability.
Phase	Laboratory test with real effluent.
[Butrón et al., 2007]	
Proposal	Indigo electrochemical incineration with FM01-LC cell and BDD electrodes.
Proceeds	100% removal and mineralization, energy efficient and no chlorine or additional reagents.
Limitations	Only in the laboratory, without analysis of by-products and mechanism not described.
Phase	Try synthetic solution.
[Yigit et al., 2009]	
Proposal	Bioreactor with membranes [MBR] for continuous treatment of textile water.
Proceeds	High removal of contaminants [>95%], process stability, possibility of reuse.
Limitations	It does not remove TDS, requires nanofiltration, temporary loss of efficiency, and is not validated on an industrial scale.
Phase	Pilot test in denim plant.
[Zapata et al., 2021]	
Proposal	Hydrodynamic cavitation to remove physicochemical and microbiological contaminants.
Proceeds	Reduction of pH, TSS, BOD5, COD, fats, oils and E. coli, low energy consumption, complies with regulations.
Limitations	No temperature control recommends combining with other technologies to improve results.
Phase	Try real laundry effluent.

Source: Own elaboration

1.5.3. Proposals for Components in Textile Effluent Treatment Systems

The treatment of textile effluents represents a significant environmental challenge. To address these issues, several studies have focused on the design and optimization of components that integrate treatment systems, such as filtering materials, electrodes, modular reactors, and biological media. The proper selection and arrangement of these components directly influence the efficiency of the physical, chemical, or biological processes applied [Majouli et al., 2012].

For electrochemical treatments, for example, the choice of electrode type and hydrodynamic conditions are critical factors to ensure high pollutant removal without generating secondary waste [Rodríguez et al., 2013]. On the other hand, in biological systems, the type of support material in biofilters can determine adsorption capacity and the development of useful microorganisms for the degradation process [Moesriati & Wardani, 2019]

The technological component proposals summarized in **Table 6** aim to enhance overall treatment efficiency, facilitate scalability and adaptability, and advance toward more sustainable solutions for the textile industry.

Box 8

Table 6

Technological components for effluent treatment systems

[Majouli et al., 2012]	
Proposal	Ceramic microfiltration membrane with Moroccan perlite to treat textile effluents.
Proceeds	It removes turbidity, reduces COD [54–57%] and Kjeldahl Total Nitrogen [TKN] [56%], completely discolors and reduces the cost of the product.
Limitations	It does not remove soluble contaminants, no shelf life and lower efficiency than commercial membranes were evaluated.
Phase	Laboratory test with real laundry effluent.
[Moesriati & Wardani, 2019]	
Proposal	Anaerobic biofilters with three filter media for denim wastewater.
Proceeds	Reduction of Chemical Oxygen Demand [COD] [91.67%], Total Suspended Solids [TSS] [88.89%] and color [82.66%], passive and economical system and better performance with bioballs.
Limitations	Only first days of operation and no long-term evaluation or compliance with standards.
Phase	Pilot test [24 L; HRT of 8 h].
[Rodríguez et al., 2013]	
Proposal	DSA electrodes in FM01-LC reactor for degrading indigo carmine in chloride medium.
Proceeds	100% bleaching and mineralization, lower energy consumption than Boron-Doped Diamond [BDD], and potential for industrial scale-up.
Limitations	Zero absorbance and loss of efficiency at high densities were not achieved.
Phase	Test with model solution and real effluent.

1.6. Water Footprint

The Water Footprint [WF] is an indicator that quantifies the total volume of freshwater consumed or polluted throughout the life cycle of a product, and it is distinguished into three components: blue water [surface or groundwater not returned], green water [rainwater stored in the soil], and gray water [the amount of water required to dilute pollutants] [Hoekstra & Mekonnen, 2012].

This measure also enables the evaluation of real and comparable environmental impacts, serving as a useful tool for management and environmental labeling when properly contextualized [Forin et al., 2020]. In the specific case of textile products such as jeans, **Table 7** lists two documents that analyzed the full life cycle water footprint of a pair of cotton jeans.

Box 9

Table 7

Water footprint analysis documents

Criteria / Author	[Luo et al., 2022]	[Vos, 2019]
Type of water footprint	Scarce water, eutrophication Ecotoxicity	Blue and green water
Methodology	Modular, process-based assessment for the entire lifecycle [CF + WF]	Spatially explicit water footprint [hybrid approach between LCA and WFA]
Life cycle stages	Complete: from cultivation to end-of-life [use and disposal]	From cultivation to domestic use [does not include final disposal]
Results	13.74 m ³ H ₂ O eq [scarce water] 1.67×10 ⁻² kg PO ₄ ³⁻ eq [eutrophication] 112.41 m ³ H ₂ O eq [ecotoxicity]	2,701 L of blue water and 2,031 L of green water per garment
Contributions in water consumption	Textile finish, cotton cultivation and consumer domestic use	Cotton cultivation [64%] and consumer washing [32%]
Sustainability	Demonstrates the effectiveness of the modular method for identifying critical processes, assessing sensitivity, and usage scenarios	Locate geographic hot spots in the supply chain, useful for corporate decisions

Source: Own elaboration

Conclusions

The results of this systematic review reveal that, although there have been significant advances in the development of sustainable alternatives to reduce water consumption in the denim washing process, most of the identified proposals are still at the experimental or pilot stage. Of the 34 studies analyzed, only a small number reported implementation at an industrial scale under real operating conditions, which limits their practical applicability across diverse production contexts.

Furthermore, a concentration of research was observed in specific technologies such as ozone, laser, or nebulization, which have demonstrated substantial reductions in water, energy, and chemical consumption. However, these technologies present technical limitations, high adoption costs, and reliance on specialized equipment, which hinder their widespread application, particularly in small- and medium-sized manufacturing enterprises.

A noted limitation is the limited research available on comprehensive wastewater treatment systems suitable for industrial laundries. Most studies have focused on individual inputs or components, without considering the comprehensive optimization of treatment plants that integrate energy efficiency, minimal sludge generation, and the possibility of water reuse. This fragmentation restricts progress toward scalable and replicable solutions.

Another identification is the lack of differentiated studies on the specific water footprint for each type of washing and finishing. The absence of detailed metrics on the water impact of different colors or treatments prevents precise comparisons between technologies and limits the design of public policies that promote rational water use. Having this information would allow the establishment of differentiated regulations that more effectively control water consumption according to the type of process and its level of impact.

In this context, it is concluded that greater investment is still needed in research, technological development, and systemic evaluation of sustainable solutions that integrate both the washing process and subsequent effluent treatment.

These actions are essential to advance toward the fulfillment of the Sustainable Development Goals, particularly those related to clean water, responsible production, and climate action.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest.

Author contribution

Araoz-Baltazar, Iván: Project idea, literature review, supervision, final validation, and conclusions.

Del Angel-Medina, Oscar: Literature review, methodological development, and conclusions.

Granados-Sánchez, Angelica: Data analysis, review of graphs, and conclusions.

Martínez-Zárate, Israel: Literature review, abstract, results, contributions, revisions, and conclusions.

SECIHTI areas

This project aligns with the SECIHTI areas of "Advocacy and attention to national problems" and "Development of strategic leading-edge technologies and open innovation for social transformation," as it addresses the urgent environmental and social challenges linked to wastewater generated in the denim industry, a key economic activity in Tehuacán, Puebla, through the exploration of innovative, sustainable treatment alternatives that can be scaled and transferred to similar contexts

Availability of data and materials

The articles analyzed in this research are found in Scopus and Google Scholar databases.

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Abbreviations

BDD	Boron-Doped Diamond
CF	Carbon Footprint
BOD	Biochemical Oxygen Demand
BOD5	Biochemical Oxygen Demand at 5 days
COD	Chemical Oxygen Demand
DSA	Dimensionally Stable Anode
EIM	Environmental Impact Measurement
LCA	Life Cycle Assessment
MB	Methylene Blue
MBR	Membrane Bioreactor
O ₃	Ozone
SDG	Sustainable Development Goals
UN	United Nations
PET	Polyethylene terephthalate
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
UASB	Upflow Anaerobic Sludge Blanket
UV	Ultraviolet radiation
WF	Water Footprint
WFA	Water Footprint Assessment

References**Basics**

Forin, S., Mikosch, N., Berger, M., & Finkbeiner, M. [2020]. [Organizational water footprint: a methodological guidance](#). *International Journal of Life Cycle Assessment*, 25[2], 403–422.

Hoekstra, A. Y., & Mekonnen, M. M. [2012]. [The water footprint of humanity](#). *Proceedings of the National Academy of Sciences of the United States of America*, 109[9], 3232–3237.

ONU. [2015]. [Objetivos y metas de desarrollo sostenible - Desarrollo Sostenible](#)

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. [2021]. The PRISMA 2020 statement: [An updated guideline for reporting systematic reviews](#). *PLoS Medicine*, 18[3].

Antecedents

Luo, Y., Wu, X., & Ding, X. [2022]. [Carbon and water footprints assessment of cotton jeans using the method based on modularity: A full life cycle perspective](#). *Journal of Cleaner Production*, 332.

Souza, R. P., Freitas, T. K. F. S., Domingues, F. S., Pezoti, O., Ambrosio, E., Ferrari-Lima, A. M., & Garcia, J. C. [2016]. [Photocatalytic activity of TiO₂, ZnO and Nb₂O₅ applied to degradation of textile wastewater](#). *Journal of Photochemistry and Photobiology A: Chemistry*, 329, 9–17.

Vos, R. O. [2019]. [The spatially explicit water footprint of blue jeans: Spatial methods in action for sustainable consumer products and corporate management of water](#). *Case Studies in the Environment*, 3[1].

Wahab, A., & Hussain, T. [2020]. [Eco-Friendly garment processing using aerosol technology](#). *Water Resources and Industry*, 23.

Discussions

Bastidas Paredes, D., Quintero Martínez, V. A., & Elías Tous, J. J. [2025]. [Implementación de estrategias sostenibles en la industria textil-confección: una revisión de alcance](#) [Universidad CES].

Catarino, M. L., Sampaio, F., & Gonçalves, A. L. [2025]. [Sustainable Wet Processing Technologies for the Textile Industry: A Comprehensive Review](#). *Sustainability [Switzerland]*, 17[7].

Chowdhury, M. F., Khandaker, S., Sarker, F., Islam, A., Rahman, M. T., & Awual, M. R. [2020]. [Current treatment technologies and mechanisms for removal of indigo carmine dyes from wastewater: A review](#). *Journal of Molecular Liquids*, 318.

Article

Eroğlu, N. S. [2023]. [SUSTAINABILITY APPROACHES IN DENIM PRODUCTS AND PRODUCTION PROCESSES](#). *Tekstil ve Muhendis*, 30[132], 335–350.

Khan, Md. K. R., & Jintun, S. [2021]. [Sustainability Issues of Various Denim Washing Methods](#). *Textile and Leather Review*, 4[2], 96–110.

Supports

Arenas, C. N., Vasco, A., Betancur, M., & Martínez, J. D. [2017]. [Removal of indigo carmine \[IC\] from aqueous solution by adsorption through abrasive spherical materials made of rice husk ash \[RHA\]](#). *Process Safety and Environmental Protection*, 106, 224–238.

Atav, R., Gündüz, Ö., Yaz, S., Çakan, G., & Sevgili, B. [2024]. [Eco-Friendly Ozone Process for Denim Garments as an Alternative to Conventional Bleaching](#). *Fibers and Polymers*, 25[7], 2661–2667.

Ben Fraj, A., & Jaouachi, B. [2021]. [Effects of ozone treatment on denim garment properties](#). *Coloration Technology*, 137[6], 678–688.

Ben Hmida, S., & Ladhari, N. [2016]. [Study of Parameters Affecting Dry and Wet Ozone Bleaching of Denim Fabric](#). *Ozone: Science and Engineering*, 38[3], 175–180.

Butrón, E., Juárez, M. E., Solis, M., Teutli, M., González, I., & Nava, J. L. [2007]. [Electrochemical incineration of indigo textile dye in filter-press-type FM01-LC electrochemical cell using BDD electrodes](#). *Electrochimica Acta*, 52[24], 6888–6894.

da Costa, W. K. O. C., Gavazza, S., Duarte, M. M. B., Freitas, S. K. B., de Paula, N. T. G., & Paim, A. P. S. [2021]. [Preparation of Activated Carbon from Sugarcane Bagasse and Removal of Color and Organic Matter from Real Textile Wastewater](#). *Water, Air, and Soil Pollution*, 232[9].

Ergan, B. T., Yucel, O., Gengec, E., & Aydin, E. S. [2025]. [Integrating machine learning regression and classification for enhanced interpretability in optimizing the Fenton process for real wastewater treatment conditions](#). *Separation and Purification Technology*, 363.

González-López, F., Alonso-Molina, J. L., Mendoza-Roca, J. A., Cuartas-Urbe, B., Rendón-Castrillón, L., Ocampo-López, C., & Ramírez-Carmona, M. [2024]. [Native microorganisms for sustainable dye biodegradation in wastewaters from jeans finishing](#). *Environmental Science and Pollution Research*, 31[56], 64675–64687.

Hu, L., Zhou, X., Chen, J., Zhang, X., Chen, G., Chang, W., Ye, A., Yi, H., & Yi, C. [2021]. [Investigation of Color Fading and Fabric-Touch Test for Jeans through Ozonation](#). *Ozone: Science and Engineering*, 43[3], 276–283.

Ivedi, I., & Cay, A. [2023]. [Use of natural and synthetic materials in denim washing process as an alternative to pumice stone](#). *Tekstil ve Konfeksiyon*, 33[1], 68–76.

Kakkar, P., & Wadhwa, N. [2022]. [Extremozymes used in textile industry](#). *Journal of the Textile Institute*, 113[9], 2007–2015.

Körlü, A. E., Yapar, S., Perinçek, S., Yılmaz, H., & Bağırhan, C. [2015]. [Dye removal from textile waste water through the adsorption by pumice used in stone washing](#). *Autex Research Journal*, 15[3], 158–163.

Majouli, A., Tahiri, S., Alami Younssi, S., Loukili, H., & Albizane, A. [2012]. [Elaboration of new tubular ceramic membrane from local Moroccan Perlite for microfiltration process. Application to treatment of industrial wastewaters](#). *Ceramics International*, 38[5], 4295–4303.

Moesriati, A., & Wardani, L. K. [2019]. [Study of wastewater treatment of water used from jeans washing by using biological method](#). *Pollution Research*, 38, S115 – S119.

Nadeem, N., Zubair, U., Javid, A., Raza, H. S., Hussain, T., & Nawab, Y. [2024]. [Optimization of closed loop wet ozone process for controlled bleaching of Indigo coloured apparels through central composite design](#). *Process Safety and Environmental Protection*, 187, 749 – 761.

Nayak, R., George, M., Jajpura, L., Khandual, A., & Panwar, T. [2022]. [Laser and ozone applications for circularity journey in denim manufacturing - A developing country perspective](#). *Current Opinion in Green and Sustainable Chemistry*, 38.

Article

Rodríguez, F. A., Mateo, M. N., Aceves, J. M., Rivero, E. P., & González, I. [2013]. Electrochemical oxidation of bio-refractory dye in a simulated textile industry effluent using DSA electrodes in a filter-press type FM01-LC reactor. *Environmental Technology [United Kingdom]*, 34[5], 573–583.

Solís, M., Gil, J. L., Solís, A., Pérez, H. I., Manjarrez, N., & Perdomo, M. [2013]. The sedimentation process a simple method to diminish contaminants in textile effluents; [El proceso de sedimentación como una aplicación sencilla para reducir contaminantes en efluentes textiles]. *Revista Mexicana de Ingeniera Quimica*, 12[3], 585 – 594.

Uysaler, T., Altay, P., & Özcan, G. [2025]. More sustainable denim fading process of two different indigo dyed denim fabrics with laser treatment. *International Journal of Clothing Science and Technology*.

Zapata, S. I. N., Benites-Alfaro, E., Flores, C. G., Cabanillas, A. Z., Flores, J. V., Olivera, C. C., & Ruiz-Vergaray, M. [2021]. Hydrodynamic Cavitation as a Clean Technology in Textile Industrial Wastewater Treatment. *Chemical Engineering Transactions*, 86, 277–282.

Differences

Augusto Moreira, C., Eduardo Scanferla, C., Gonçalves Oliveira, A., Anthony Duarte, V., Augusto Arroyo, P., de Lara Andrade, J., Rodrigo Stival Bittencourt, P., Carla Garcia, J., & Martins Fernandes de Oliveira, D. [2025]. Bio-adsorbents based on mesoporous silica produced from rice husks with tunable architecture and surface area for remediation of industrial effluents. *Journal of Porous Materials*, 32, 27–46.

Hasan, S. M. M., Nahid-Ull-islam, M., Chowdhury, M. K. H., Akter, M., & Sakib, M. S. I. [2024]. Core 2.0 Nebulization Technique-A Sustainable Denim Finishing Approach. *Textile and Leather Review*, 7, 582–596.

Méndez-Hernández, J. E., Ramírez-Vives, F., Sobrino-Figueroa, A. S., Garza-López, P. M., & Loera, O. [2022]. Ecotoxicological Evaluation and Treatment of a Denim-Laundry Wastewater. *Water, Air, and Soil Pollution*, 233[1].

Nergi, B., Candan, C., Bo, D., Müjde, B., & Dursun, S. N. [2023]. Water Conscious Blue Jeans Washing Process: A Case Study of Turkey. *Tekstil ve Konfeksiyon*, 33[4], 322–329.

Yigit, N. O., Uzal, N., Koseoglu, H., Harman, I., Yukseler, H., Yetis, U., Civelekoglu, G., & Kitis, M. [2009]. Treatment of a denim producing textile industry wastewater using pilot-scale membrane bioreactor. *Desalination*, 240[1–3], 143–150.

Advanced nanosystems for Breast Cancer therapy and diagnosis: A classification-based review

Nanosistemas avanzados para el tratamiento y diagnóstico del Cáncer de Mama: clasificación basada en una revisión

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Abstract

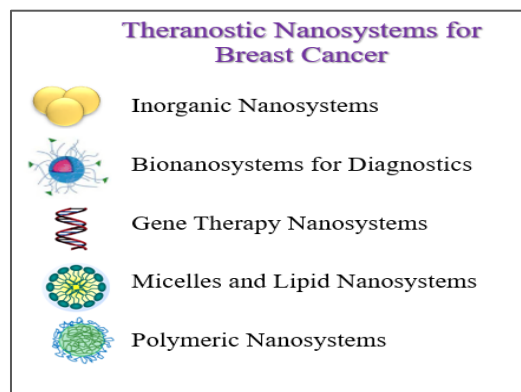
Breast cancer remains one of the leading causes of morbidity and mortality worldwide, particularly in aggressive subtypes such as triple-negative breast cancer [TNBC], for which conventional therapies exhibit limited selectivity, high systemic toxicity, and frequent drug resistance. In this context, nanotechnology has emerged as a pivotal strategy for the development of more effective, targeted, and precise diagnostic and therapeutic approaches. This review presents a comprehensive and up-to-date classification of advanced nanosystems applied to breast cancer diagnosis and treatment, encompassing organic, inorganic, hybrid, and biohybrid platforms. Polymeric and lipid nanoparticles, dendrimers, exosomes, carbon-based nanomaterials, MXenes, and multimodal theranostic systems are systematically analyzed. By correlating nanosystem composition, structural architecture, and therapeutic mechanisms, this classification provides a coherent conceptual framework to support the rational design of next-generation nanoplateforms aimed at precision medicine in breast cancer. Overall, this work highlights emerging trends toward multifunctional, stimulus-responsive, and integrated theranostic nanosystems with strong potential to overcome current clinical limitations, particularly in aggressive and treatment-resistant breast cancer subtypes.

Resumen

El cáncer de mama continúa siendo una de las principales causas de morbilidad y mortalidad a nivel mundial, particularmente en subtipos agresivos como el cáncer de mama triple negativo [CMTN], para los cuales las terapias convencionales presentan baja selectividad, elevada toxicidad sistémica y frecuente resistencia farmacológica. En este contexto, la nanotecnología ha emergido como una estrategia clave para el desarrollo de enfoques diagnósticos y terapéuticos más eficaces, dirigidos y precisos. La presente revisión ofrece una clasificación integral y actualizada de nanosistemas avanzados aplicados al diagnóstico y tratamiento del cáncer de mama, que abarca plataformas orgánicas, inorgánicas, híbridas y biohíbridadas. Se analizan de manera sistemática nanopartículas poliméricas y lipídicas, dendrímeros, exosomas, nanomateriales carbonosos, MXenes y plataformas teranósticas multimodales. Al correlacionar la composición de los nanosistemas, su arquitectura estructural y los mecanismos terapéuticos, esta clasificación proporciona un marco conceptual coherente para el diseño racional de nanoplateformas de nueva generación orientadas a la medicina de precisión en cáncer de mama. En conjunto, este trabajo destaca tendencias emergentes hacia nanosistemas multifuncionales, sensibles a estímulos e integrados, con alto potencial para superar las limitaciones clínicas actuales, especialmente en subtipos agresivos y resistentes al tratamiento.



Breast Cancer; Nanosystems of Drug Delivery; Theranosis



Cáncer de Mama; Nanosistemas para la liberación de fármacos; Teranosis

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Introduction

Breast cancer remains the most frequently diagnosed malignancy in women and one of the leading causes of cancer-related mortality worldwide, with approximately 2.3 million new cases diagnosed annually. According to the most recent GLOBOCAN data, breast cancer accounted for 11.7% of all newly diagnosed cancer cases globally, surpassing other malignancies in incidence [Sung et al., 2021].

Despite significant advances in targeted therapies and personalized medicine, the clinical management of breast cancer continues to face substantial challenges, particularly in aggressive subtypes such as triple-negative breast cancer [TNBC]. This subtype is defined by the absence of estrogen, progesterone, and HER2 receptors and is characterized by pronounced molecular heterogeneity, highly invasive behavior, elevated rates of early recurrence, and limited responsiveness to conventional therapies. Consequently, TNBC is associated with an unfavorable prognosis and restricted therapeutic options compared with other breast cancer subtypes [Bianchini et al., 2016; Garrido-Castro et al., 2019].

Early diagnosis is a critical determinant of breast cancer survival and mortality reduction; however, conventional diagnostic strategies remain associated with significant limitations. Mammography, the standard screening modality, exhibits variable sensitivity [68–90%], which decreases markedly in younger women and in patients with high breast density, where false-negative rates may exceed 20% [Nelson et al., 2016]. Similarly, ultrasound and magnetic resonance imaging [MRI], although valuable as complementary tools, are associated with high false-positive rates, elevated costs, and limited accessibility, restricting their widespread use in population-based screening programs [Mann et al., 2019]. These diagnostic limitations contribute to delays in the detection of early-stage lesions and microtumors, particularly in biologically aggressive subtypes such as TNBC, which lacks specific molecular imaging biomarkers and is characterized by rapid tumor growth and short screening intervals [Bianchini et al., 2016]. Moreover, conventional imaging modalities display limited capacity to discriminate between malignant and benign tissues at the molecular level, hindering the early identification of oncogenic processes and accurate assessment of tumor heterogeneity.

As a result, a substantial proportion of breast cancer cases continue to be diagnosed at locally advanced stages, especially in low- and middle-income countries, where access to advanced diagnostic technologies remains restricted [Sung et al., 2021]. These shortcomings underscore the urgent need for innovative diagnostic strategies that are highly sensitive and specific, capable of detecting early molecular alterations and, simultaneously, integrating therapeutic functionalities, as exemplified by theranostic nanotechnology-based platforms.

From a therapeutic perspective, breast cancer management depends on clinical stage, molecular subtype, and patient condition, and typically involves surgery, radiotherapy, chemotherapy, hormone therapy, and targeted therapies, either alone or in combination. Surgery remains the cornerstone of treatment in early-stage disease, achieving local control rates exceeding 85–90% when combined with adjuvant radiotherapy. However, its efficacy declines significantly in locally advanced or metastatic disease, where effective systemic control is required [Waks & Winer, 2019].

Radiotherapy, widely employed as adjuvant or palliative treatment, has been shown to reduce local recurrence and improve overall survival, but is associated with adverse effects such as skin toxicity, cardiopulmonary damage, and tissue fibrosis, particularly in high-dose or prolonged treatment regimens [EBCTCG, 2011].

Systemic chemotherapy constitutes a central therapeutic strategy for locally advanced and metastatic breast cancer, as well as for aggressive subtypes such as TNBC. Although chemotherapy can improve disease-free and overall survival, its clinical use is constrained by systemic toxicity, limited tumor selectivity, and the development of drug resistance, which frequently result in relapse and severe adverse effects, including cardiotoxicity, myelosuppression, and neurotoxicity [O'Shaughnessy, 2005; Longley & Johnston, 2005].

Notably, chemotherapy remains the primary therapeutic option for TNBC due to the absence of well-defined molecular targets, despite the high rates of early relapse and poor prognosis associated with this subtype [Bianchini et al., 2016].

While conventional therapies have substantially improved patient outcomes, critical limitations persist, highlighting the need for innovative strategies capable of integrating diagnosis, molecular targeting, and personalized therapy. Nanotechnology-based platforms offer the potential to overcome key limitations of traditional cancer therapies, including poor solubility of hydrophobic drugs, non-selective biodistribution, rapid systemic clearance, and dose-limiting toxicity. In addition, advanced nanosystems incorporate multifunctional features that enhance active targeting of tumor cells, optimize controlled drug release, and enable real-time diagnostic imaging, positioning nanoparticles as pivotal tools in the transition toward precision oncology. As highlighted by Mohajer et al. [2023], the field has rapidly evolved from monofunctional nanoparticles to sophisticated hybrid architectures capable of integrating chemotherapy, phototherapy, gene therapy, nanocatalytic therapy, and multimodal imaging within a single platform.

In parallel, nanocarrier-based formulations of bioactive compounds, including lipid nanoparticles and polymeric micelles, have demonstrated improved stability, bioavailability, and therapeutic potency of molecules such as curcumin, which inherently exhibits poor bioavailability. These formulations have shown significant synergistic effects in breast cancer cell lines, including MCF-7, MDA-MB-231, and SK-BR-3 [Zhu et al., 2024]. Furthermore, the development of stimulus-responsive platforms—activated by light, ultrasound, pH, or redox conditions—has enabled spatially and temporally controlled therapies, minimizing damage to healthy tissues while enhancing therapeutic precision.

Advances in gene therapy, particularly siRNA-based approaches, have positioned biopolymers and engineered exosomes as high-impact candidates for silencing key oncogenes, reversing drug resistance, and modulating tumor survival pathways, with robust effects demonstrated in solid tumors, including breast cancer [Subhan & Torchilin, 2023].

Concurrently, inorganic nanomaterials such as metal oxides, quantum dots, and two-dimensional nanomaterials [MXenes] have expanded therapeutic possibilities by integrating imaging modalities with photothermal therapy [PTT], photodynamic therapy [PDT], and nanocatalytic strategies based on reactive oxygen species generation.

More recently, advanced theranostic platforms capable of combining phototherapy, chemotherapy, nitric oxide release, ferroptosis induction, and immunogenic cell death [ICD] activation have emerged. Notably, ASNP-type nanosystems have demonstrated tumor microenvironment reprogramming and highly promising systemic antitumor effects in TNBC models [Zhao et al., 2025]. Similarly, biohybrid nanosystems—such as polydopamine nanoparticles loaded into mesenchymal stem cells—have exhibited enhanced tumor infiltration and superior therapeutic efficacy compared with conventional nanoparticulate platforms [Ferreira et al., 2021]. In addition, acoustically responsive systems, including perfluorohexane nanodroplets, enable ultrasound-guided tumor visualization and site-specific drug release following acoustic activation [Baghbani et al., 2017].

Collectively, these advances reflect a clear shift toward the development of highly integrated, intelligent nanosystems tailored to precision medicine. Nevertheless, there remains a critical need for a functional and comparative classification framework that systematically organizes nanosystems according to their composition, structural architecture, therapeutic mechanisms, and degree of diagnostic integration. Accordingly, the present work proposes a systematic reclassification of nanosystems applied to breast cancer treatment, grounded in recent evidence and a multidimensional analysis encompassing organic, inorganic, hybrid, biohybrid, and fully theranostic platforms. This classification aims to provide a conceptual framework for future nanotherapeutic development and a methodological reference for researchers seeking to design next-generation platforms capable of addressing the persistent clinical challenges associated with breast cancer.

Methodology

Study design

A comprehensive bibliographic review of nanosystems applied to the diagnosis and treatment of breast cancer was conducted, integrating experimental studies performed in vitro and in vivo, as well as specialized review articles.

Search strategy

The literature search was carried out using the following databases: PubMed, Scopus, Web of Science, ACS Publications, ScienceDirect, and MDPI. The search terms included combinations of the following keywords: breast cancer, nanoparticles, nanosystems, nanomedicine, theranostics, and photothermal therapy.

Inclusion criteria

Articles published between 2017 and 2025. Studies focused on breast cancer or closely related experimental models.

Reports describing nanoparticles characterized in terms of composition, architecture, or therapeutic mechanism.

Studies evaluating therapeutic efficacy, diagnostic performance, or theranostic functionality.

Exclusion criteria

Studies lacking experimental data or adequate nanosystem characterization.

Articles not related to breast cancer.

Review articles without relevant technical or methodological information.

Data extraction and analysis process

a] Information was extracted regarding nanosystem type, particle size, zeta potential, encapsulation efficiency [EE%], therapeutic mechanism, imaging modality, route of administration, cellular or animal models, and key outcomes.

b] Nanosystems were classified into four main categories: organic, inorganic, hybrid, and biohybrid platforms.

c] A comparative analysis was performed to identify emerging trends, functional complexity, and levels of integration between diagnostic and therapeutic capabilities.

Finally, the extracted data were consolidated into a global classification table aimed at supporting the rational design of nanotherapeutic platforms for breast cancer.

Results

Box 1

Table 1

Classification of nanosystems for the treatment and diagnosis of breast cancer

Main Class	Subclass / Example	Material / Structure	Diagnostic – Therapeutic Function	Key Mechanism[s]	Breast Cancer Applications	Reference[s]
Organic – Biodegradable Polymers	Polymeric NPs [PLGA]	Biodegradable polyesters and copolymers	Primarily targeted chemotherapy; can incorporate photo/sonosensitive agents	Controlled release, EPR effect, antibody or peptide conjugation	Paclitaxel and doxorubicin delivery	Liu et al., 2018
Organic – Dendrimers	PAMAM, PPI, QD- or metal-conjugated dendrimers	Highly branched, multifunctional architectures	Chemotherapy + PDT/PTT; fluorescent imaging in some designs	High density of terminal groups; co-delivery of drugs and photosensitizers	PAMAM-based systems with DOX or photosensitizers tested in MCF-7, MDA-MB-231, 4T1	Kim, 2007; Saw et al., 2022; Zhang et al., 2021; Zhou et al., 2023
Organic – Advanced Liposomes	RGD-Lip-CUR, HER2-immunoliposomes, Zn-loaded liposomes	Phospholipid bilayer encapsulating hydrophilic or lipophilic drugs	Targeted chemotherapy; combination of CUR with conventional drugs; imaging potential	Apoptosis induction, ROS generation, RGD/HER2 targeting, MDR overcoming	Treatment of MCF-7, SK-BR-3, HER2+ tumors	Harini et al., 2019; Jamshidifar et al., 2021; Mahmoudi et al., 2021
Organic – SLNs / NLCs / Nanoemulsions	CUR-SLNs, epirubicin+CUR SLNs, CUR or thymoquinone nanoemulsions	Solid or mixed lipid matrices; stabilized oil droplets	Chemotherapy with improved stability and sustained release	Mitochondrial apoptosis; synergistic drug effects; reduced systemic toxicity	MCF-7, MDA-MB-231, SK-BR-3	Zhu et al., 2024
Organic – Polymeric Nanogels & Micelles	TPP-PEG-PE-CUR micelles; chondroitin-CUR nanogels	Hydrophobic core / hydrophilic shell; mitochondrial or CD44 targeting	Advanced chemotherapy; combination therapy	Enhanced uptake, lysosomal escape, mitochondrial targeting	CD44+ BC models, MCF-7, TNBC	Soleymani et al., 2021; Yin-Hua et al., 2020
Organic – Biopolymers for siRNA	Chitosan, HA, alginate, collagen NPs; siRNA exosomes	Polysaccharide-based or biohybrid systems	Gene therapy [siRNA]; some co-deliver drugs	Silencing of STAT3, PIK3CA, survivin, EGFR; MDR reversal	MCF-7, MDA-MB-231, 4T1, orthotopic models	Inoue et al., 2012; Silva et al., 2022; Zhang et al., 2022
Organic – Exosomes / Exosome-Mimics	siSurvivin, siPIK3CA, siCD44 exosomes; EMs	Natural or mimetic vesicles with lipid membrane	Biohybrid vectors for siRNA and drugs; imaging ligands	Down-regulation of oncogenes; enhanced apoptosis	ER+, TNBC, HER2+ models	Yang et al., 2016
Bio-Based – Functionalized CNCs	CNCs/FA-CS-FITC	Rod-like cellulose nanocrystals coated with chitosan derivative	Targeted bioimaging; future theranostic platform	High affinity to folate receptor; 5x higher uptake	MDA-MB-231 [FR+]	Pinto et al., 2021
Inorganic – Metals & Oxides	SPIONs, AuNPs, Re-clusters, ferrites	Metallic or metal-oxide cores	MRI, CT, PAI + chemotherapy / PTT / PDT	Hyperthermia, ROS generation, stimulus-responsive release	Targeted BC imaging and therapy	Jamshidifar et al., 2021; Meng et al., 2009
Inorganic – Carbon-Based	GO, CNTs, CQDs/GQDs	2D graphene sheets, nanotubes, quantum dots	Theranostics: imaging + PTT/PDT + chemotherapy	NIR absorption, photothermal conversion, ROS	GO-DOX, CNT-CUR, CQDs in MCF-7	Ali et al., 2022; Badea et al., 2020; Ji et al., 2012
Inorganic – MXenes	Ti ₃ C ₂ T _x	Functionalized 2D nanosheets	High-efficiency PTT; drug delivery potential	High photothermal conversion; protein inhibition	BC PTT models; CD44/HER2 targeting potential	Liao et al., 2023
Inorganic – Mesoporous Silica	MSNs-DOX+CUR; MSNs-MTX+siRNA	Porous silica core, functionalized surface	Drug + gene co-delivery; imaging when doped	Synergistic therapy; MDR reduction	MCF-7, MDA-MB-231	Hanafi-Bojd et al., 2016; Hao et al., 2015

The analyzed studies reveal a broad and rapidly evolving landscape of nanosystems developed for breast cancer diagnosis and therapy. Based on compositional features, structural architecture, and functional integration, the reviewed nanosystems were classified into organic, inorganic, hybrid, and biohybrid platforms. Table 1 summarizes the main nanosystem classes, representative examples, diagnostic and therapeutic functions, key mechanisms, and reported applications in breast cancer models.

Organic nanosystems

Organic nanosystems constitute the most extensively explored category, particularly biodegradable polymer-based nanoparticles such as PLGA systems. These platforms are primarily employed for targeted chemotherapy delivery and can be further functionalized to incorporate photo- or sono-responsive agents. Their therapeutic performance is mainly attributed to controlled drug release, enhanced permeability and retention [EPR] effects, and the possibility of surface conjugation with antibodies or targeting peptides, enabling effective delivery of chemotherapeutic agents such as paclitaxel and doxorubicin [Liu et al., 2018]. Dendrimer-based nanosystems, including PAMAM and PPI dendrimers, represent a structurally sophisticated class characterized by highly branched architectures and a high density of functional terminal groups. These systems have been widely investigated as carriers for combined chemotherapy and photodynamic or photothermal therapy, as well as for fluorescence imaging when conjugated with quantum dots or metallic components. PAMAM-based platforms loaded with doxorubicin or photosensitizers have demonstrated enhanced cytotoxicity in breast cancer cell lines such as MCF-7, MDA-MB-231, and 4T1, highlighting their versatility for multifunctional applications [Kim, 2007; Saw et al., 2022; Zhang et al., 2021; Zhou et al., 2023].

Advanced lipid-based nanosystems, including RGD-modified liposomes, HER2-targeted immunoliposomes, and zinc-ion-loaded liposomes, exhibit improved tumor selectivity and therapeutic efficacy. These platforms enable targeted chemotherapy and combination strategies involving curcumin and conventional anticancer drugs, promoting apoptosis, reactive oxygen species [ROS] generation, and reversal of multidrug resistance through ligand-mediated targeting [Harini et al., 2019; Jamshidifar et al., 2021; Mahmoudi et al., 2021].

Solid lipid nanoparticles [SLNs], nanostructured lipid carriers [NLCs], and nanoemulsions have also been extensively investigated to enhance the stability, bioavailability, and sustained release of bioactive compounds such as curcumin and thymoquinone. These systems induce mitochondrial apoptosis and synergistic anticancer effects while reducing systemic toxicity, demonstrating significant antiproliferative activity in MCF-7, MDA-MB-231, and SK-BR-3 breast cancer models [Zhu et al., 2024].

Polymeric nanogels and micelles further expand the functional scope of organic nanosystems by enabling mitochondrial or CD44-mediated targeting. Formulations such as TPP-PEG-PE curcumin micelles and chondroitin-based nanogels exhibit enhanced cellular uptake, lysosomal escape, and increased apoptotic activity in TNBC and CD44-positive breast cancer models [Soleymani et al., 2021; Yin-Hua et al., 2020].

Gene delivery and bio-derived nanosystems

Biopolymer-based nanosystems designed for siRNA delivery, including chitosan, hyaluronic acid, alginate, collagen nanoparticles, and engineered exosomes, represent a highly specialized class within organic and biohybrid platforms.

These systems enable efficient silencing of oncogenes such as *STAT3*, *PIK3CA*, *survivin*, and *EGFR*, leading to inhibition of proliferation, metastasis, and reversal of multidrug resistance in *in vitro* and *in vivo* breast cancer models [Inoue et al., 2012; Silva et al., 2022; Zhang et al., 2022].

Natural and exosome-mimetic vesicles provide additional advantages, including intrinsic biocompatibility, reduced immunogenicity, and enhanced cellular targeting. Exosome-based delivery of siRNA targeting *BCL-2*, *PIK3CA*, or *CD44* has demonstrated significant apoptotic induction and improved therapeutic responses in ER-positive and TNBC models, as well as enhanced sensitivity to doxorubicin treatment [Yang et al., 2016].

Bio-based nanosystems derived from cellulose nanocrystals [CNCs], particularly when functionalized with chitosan derivatives, folic acid, and fluorescent markers, have emerged as promising diagnostic platforms. These rod-like nanostructures exhibit high affinity toward folate receptor–positive TNBC cells, such as MDA-MB-231, achieving up to five-fold higher cellular internalization while maintaining low cytotoxicity, thereby offering strong potential for future theranostic applications [Pinto et al., 2021].

Inorganic and hybrid nanosystems

Inorganic nanosystems, including metallic nanoparticles, metal oxides, and carbon-based nanomaterials, play a critical role in advanced diagnostic and therapeutic strategies. Superparamagnetic iron oxide nanoparticles [SPIONs], gold nanoparticles, rhenium clusters, and ferrite-based systems have been widely applied in magnetic resonance imaging [MRI], computed tomography [CT], and photoacoustic imaging, as well as in photothermal and photodynamic therapies. These platforms leverage hyperthermia, ROS generation, and stimulus-responsive drug release to achieve enhanced antitumor efficacy [Jamshidifar et al., 2021; Meng et al., 2009].

Carbon-based nanomaterials, including graphene oxide [GO], carbon nanotubes [CNTs], and quantum dots [QDs], function as highly efficient theranostic platforms due to their strong near-infrared absorption, photothermal conversion efficiency, and capacity for pH- or enzyme-responsive drug release. GO-based systems loaded with doxorubicin or hyaluronic acid–functionalized platforms targeting CD44 have demonstrated potent antiproliferative effects in breast cancer models, while CNT–curcumin conjugates exhibit enhanced photothermal and cytotoxic activity [Ali et al., 2022; Badea et al., 2020; Ji et al., 2012; Koh et al., 2019].

Two-dimensional MXenes, such as $Ti_3C_2T_x$ nanosheets, represent an emerging class of inorganic nanomaterials with exceptional photothermal efficiency and favorable drug-loading capacity. These materials have demonstrated strong potential for photothermal therapy and hybrid platform integration, particularly when functionalized with targeting ligands relevant to breast cancer biomarkers [Liao et al., 2023].

Mesoporous silica nanoparticles [MSNs] further bridge organic and inorganic strategies by enabling co-delivery of chemotherapeutic agents and siRNA. Functionalized MSNs loaded with combinations such as doxorubicin–curcumin or methotrexate–siRNA exhibit controlled release, enhanced apoptosis, and effective suppression of multidrug resistance in MCF-7 and MDA-MB-231 models [Hanafi-Bojd et al., 2016; Hao et al., 2015].

Discussion

The integrated analysis of the reviewed literature demonstrates that nanosystem development for breast cancer management has undergone a marked transition from monofunctional drug delivery platforms to highly hierarchical, multifunctional, and genuinely theranostic architectures, in which diagnosis, therapy, and tumor microenvironment modulation converge within a single nanoengineered system. This evolution reflects a broader paradigm shift in nanomedicine, where modern nanopatforms are no longer conceived solely as passive carriers but as active, stimuli-responsive systems capable of dynamic interaction with biological environments [Mohajer et al., 2023].

Among organic nanosystems, biodegradable polymers such as PLGA, PLA, HPMA, and PEA continue to form the structural backbone of numerous formulations due to their excellent biocompatibility, tunable physicochemical properties, and surface functionalization versatility. These characteristics enable efficient encapsulation of both hydrophilic and hydrophobic agents and facilitate molecular targeting strategies, which are particularly relevant for aggressive subtypes such as TNBC that lack well-defined therapeutic targets [Liu et al., 2018].

Moreover, the encapsulation of bioactive compounds such as curcumin into lipid-based systems—including RGD-modified liposomes, anti-HER2 immunoliposomes, solid lipid nanoparticles, and hyaluronic acid–functionalized micelles—results in pronounced improvements in cellular uptake, apoptotic induction, and circumvention of multidrug resistance mechanisms in breast cancer cell lines such as MCF-7, MDA-MB-231, and SK-BR-3 [Harini et al., 2019; Jamshidifar et al., 2021; Mahmoudi et al., 2021].

These findings position lipidic and micellar nanosystems as intermediate yet highly adaptable platforms within the functional classification, with increasing potential for theranostic integration.

A higher level of technological complexity is observed in nanosystems designed for gene therapy applications, particularly those employing siRNA delivery. Biopolymers such as chitosan, hyaluronic acid, alginate, and collagen, as well as natural and engineered exosomes, have demonstrated remarkable efficiency in silencing key oncogenic drivers, including *STAT3*, *PIK3CA*, *survivin*, *EGFR*, and *CD44*. These systems not only suppress tumor proliferation and metastatic potential but also restore chemosensitivity through the reversal of multidrug resistance pathways [Hanafi-Bojd et al., 2016; Hao et al., 2015]. Exosome-based platforms offer distinctive advantages over synthetic nanocarriers, including intrinsic biocompatibility, reduced immunogenicity, prolonged circulation time, and inherent cellular targeting capacity, making them particularly attractive for precision gene therapy in breast cancer [Yang et al., 2016].

Bio-based nanosystems derived from cellulose nanocrystals [CNCs] further expand the theranostic landscape by combining structural rigidity, surface modifiability, and biological affinity. When functionalized with chitosan derivatives, folic acid, and fluorescent probes, CNC-based platforms exhibit markedly enhanced internalization—up to five-fold higher—in folate receptor–positive TNBC cells such as MDA-MB-231, while maintaining low cytotoxicity and favorable colloidal stability [Pinto et al., 2021]. These attributes underscore their potential as next-generation bio-derived theranostic scaffolds.

Inorganic nanomaterials represent a complementary yet indispensable component of advanced breast cancer nanotherapy, particularly in applications requiring imaging integration and externally triggered therapies. Metallic nanoparticles [Au, Fe, Re], metal oxides [SPIONs, ferrites], and carbon-based nanomaterials [GO, CNTs, QDs] enable seamless coupling of diagnostic imaging modalities—including MRI, CT, fluorescence, and photoacoustic imaging—with photothermal therapy [PTT], photodynamic therapy [PDT], and nanocatalytic approaches based on reactive oxygen species generation [Jamshidifar et al., 2021; Meng et al., 2009].

Notably, graphene-based platforms and CNT conjugates demonstrate exceptional near-infrared absorption and photothermal conversion efficiencies, translating into potent antitumor activity and spatially controlled therapeutic effects in breast cancer models [Ali et al., 2022; Badea et al., 2020].

Emerging two-dimensional nanomaterials such as MXenes [e.g., $Ti_3C_2T_x$] further extend the functional horizon of inorganic nanosystems. Their large surface area, high photothermal efficiency, and capacity for drug loading and surface modification position them as promising second-generation platforms for PTT-based therapies and hybrid nanostructure development, particularly in the context of highly invasive breast tumors [Liao et al., 2023].

At the highest level of functional integration, fully hybrid and biohybrid theranostic platforms have demonstrated unprecedented therapeutic complexity and efficacy. Systems such as ASNP nanoparticles integrate photothermal therapy, nitric oxide release, ferroptosis induction, and immunogenic cell death activation within a single architecture, resulting in effective tumor microenvironment reprogramming and systemic antitumor immune responses in TNBC models [Zhao et al., 2025].

Similarly, polydopamine-based nanosystems loaded into mesenchymal stem cells act as biohybrid vectors with enhanced tumor homing and deep tissue penetration, achieving synergistic chemo-photothermal effects in three-dimensional tumor models [Ferreira et al., 2021].

Acoustic-responsive nanodroplets, such as perfluorohexane-based systems, further illustrate the potential of externally triggered nanotherapies by enabling real-time ultrasound imaging and site-specific drug release upon acoustic activation, achieving significantly increased intratumoral drug accumulation [Baghbani et al., 2017].

Collectively, these findings reveal a clear and consistent trend toward the development of intelligent, multifunctional nanosystems designed to address the biological complexity and heterogeneity of breast cancer, particularly in aggressive and treatment-resistant subtypes such as TNBC.

The proposed classification framework highlights the progressive integration of therapeutic modalities, diagnostic capabilities, and biological targeting strategies, providing a structured foundation for the rational design of next-generation nanoplatfoms. Ultimately, this integrative approach underscores the transformative potential of advanced nanosystems in overcoming longstanding clinical limitations and advancing precision oncology in breast cancer.

Conclusions

Conventional breast cancer therapies, while having significantly improved overall survival, continue to present critical limitations related to systemic toxicity, insufficient tumor specificity, and the development of therapeutic resistance, particularly in aggressive subtypes such as triple-negative breast cancer [TNBC]. In this context, advanced nanosystems represent a highly promising alternative to overcome these challenges through molecular targeting, controlled drug release, and multimodal therapeutic strategies.

The global classification proposed in this review provides a systematic organization of nanosystems applied to breast cancer into organic, inorganic, hybrid, and biohybrid platforms, integrating key parameters such as composition, structural architecture, therapeutic mechanisms, and diagnostic functionality. This framework reveals a clear evolutionary trajectory from monofunctional nanocarriers toward highly integrated, stimulus-responsive, and genuinely theranostic systems capable of combining chemotherapy, gene therapy, phototherapy, sonodynamic therapy, ferroptosis induction, and immunogenic tumor cell death within a single nanoplatfom.

Notably, biohybrid and multimodal nanosystems demonstrate exceptional potential to enhance tumor accumulation, modulate the tumor immune microenvironment, and improve therapeutic efficacy, particularly in preclinical TNBC models.

However, significant challenges remain for clinical translation, including long-term biosafety assessment, large-scale manufacturing, batch-to-batch reproducibility, and regulatory harmonization.

Overall, this review establishes a robust conceptual framework for the rational design of next-generation nanosystems aimed at precision medicine in breast cancer and provides a critical foundation for future research focused on clinical validation and translational development of advanced nanotherapeutic strategies.

Declarations

Conflict of interest

The authors declare no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Author Contributions

Beatriz Martínez-Pérez contributed to the conception of the study, definition of the methodology, and critical review of the literature. Minerva Mata Rocha and Jorge Fernández Retana contributed to the literature review and to the development and validation of the results table.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Use of Artificial Intelligence

The authors used ChatGPT solely as a supporting tool for language editing and final text revision. All scientific content, analysis, and intellectual decisions were made by the authors.

Abbreviations

A

- **ASNP** – Aza-BODIPY/S-Nitrosothiol Nanoparticles
- **AuNPs** – Gold Nanoparticles

Article

- B**
- **BC** – Breast Cancer
 - **BCL-2** – B-cell Lymphoma 2
- C**
- **CD44** – Cluster of Differentiation 44
 - **CD44+** – CD44-positive
 - **CNCs** – Cellulose Nanocrystals
 - **CNTs** – Carbon Nanotubes
 - **CQDs** – Carbon Quantum Dots
 - **CT** – Computed Tomography
 - **CUR** – Curcumin
- D**
- **DOX** – Doxorubicina
 - **DNAzyme** – DNA Enzyme
 - **DSPE-PEG** – Phospholipid polyethylene glycol side [surface modifier]
- E**
- **EE [%]** – Encapsulation Efficiency
 - **EGFR** – Epidermal Growth Factor Receptor
 - **ER / ER+** – Estrogen Receptor Positive
 - **EM / EMs** – Exosome Mimics
 - **EPR** – Enhanced Permeability and Retention Effect
- F**
- **FA** – Folic Acid
 - **FITC** – Fluorescein Isothiocyanate
 - **FR** – Folate Receptor
- G**
- **GO / rGO** – Graphene Oxide / Reduced Graphene Oxide
 - **GQDs** – Graphene Quantum Dots
- H**
- **HA** – Hyaluronic Acid
 - **HER2** – Human Epidermal Growth Factor Receptor 2
 - **HPMA** – N-(2-hydroxypropyl)methacrylamide
- I**
- **ICD** – Immunogenic Cell Death
- M**
- **MCF-7 / MDA-MB-231 / MDA-MB-468 / SK-BR-3 / 4T1** – Breast cancer cell lines
 - **MDR** – Multidrug Resistance
 - **MRI** – Magnetic Resonance Imaging
 - **MSC** – Mesenchymal Stem Cells
- N**
- **MSN / MSNs** – Mesoporous Silica Nanoparticles
 - **MTX** – Methotrexate
 - **MXenes** – Two-dimensional metal carbide/nitride materials
- O**
- **NIR** – Near-Infrared
 - **NLC** – Nanostructured Lipid Carrier
 - **NP / NPs** – Nanoparticle[s]
 - **NO** – Nitric Oxide
 - **NS** – Nanosponge
- P**
- **OCT** – Optical Coherence Tomography
 - **PAI** – Photoacoustic Imaging
 - **PAMAM** – Poly[amidoamine] Dendrimer
 - **PDT** – Photodynamic Therapy
 - **PEA** – Poly(ester amide)
 - **PEG** – Polyethylene Glycol
 - **PIK3CA** – Phosphatidylinositol-4,5-bisphosphate 3-kinase catalytic subunit alpha
 - **P-gp** – P-glycoprotein
 - **PFH** – Perfluorohexane
 - **PLGA** – Poly[lactic-co-glycolic acid]
 - **PTT** – Photothermal Therapy
- Q**
- **QDs** – Quantum Dots
- R**
- **RGD** – Arginine–Glycine–Aspartic Acid peptide
 - **ROS** – Reactive Oxygen Species
- S**
- **siRNA** – Small Interfering RNA
 - **SK-BR-3** – Human HER2-positive Breast Cancer Cell Line
 - **SLN** – Solid Lipid Nanoparticle
 - **SPIONs** – Superparamagnetic Iron Oxide Nanoparticles
 - **STAT3** – Signal Transducer and Activator of Transcription 3
- T**
- **TA** – Targeting Agent
 - **Ti₃C₂T_x** – Titanium Carbide MXene
 - **TNBC** – Triple-Negative Breast Cancer
 - **TPP** – Triphenylphosphonium
- Z**

Article

- Zn – Zinc

References

Antecedents

Baghbani, F., Chegeni, M., Moztaarzadeh, F., Aghazadeh Mohandesi, J., & Mokhtari-Dizaji, M. [2017]. Ultrasonic nanotherapy of breast cancer using novel alginate-shelled nanodroplets: *In vitro* and *in vivo* evaluation. *Materials Science and Engineering: C*, 76, 583–593.

Bianchini, G., Balko, J. M., Mayer, I. A., Sanders, M. E., & Gianni, L. [2016]. Triple-negative breast cancer: Challenges and opportunities of a heterogeneous disease.

Nature Reviews Clinical Oncology, 13[11], 674–690.

EBCTCG. Early Breast Cancer Trialists' Collaborative Group. [2011]. Effect of radiotherapy after breast-conserving surgery on recurrence and breast cancer mortality. *The Lancet*, 378[9804], 1707–1716.

Ferreira, L. P., Gaspar, V. M., Monteiro, M. V., Freitas, B., Silva, N. J. O., & Mano, J. F. [2021]. Screening of dual chemo-photothermal cellular nanotherapies in organotypic breast cancer 3D spheroids. *Journal of Controlled Release*, 334, 414–428

Garrido-Castro, A. C., Lin, N. U., & Polyak, K. [2019]. Insights into molecular classifications of triple-negative breast cancer. *Cancer Discovery*, 9[2], 176–198.

Longley, D. B., & Johnston, P. G. [2005]. Molecular mechanisms of drug resistance. *The Journal of Pathology*, 205[2], 275–292.

Mann, R. M., Cho, N., & Moy, L. [2019]. Breast MRI: State of the art. *Radiology*, 292[3], 520–536.

Mohajer, F., Mirhosseini-Eshkevari, B., Ahmadi, S., Ghasemzadeh, M. A., Mohammadi Ziarani, G., Badiiei, A., Farshidfar, N., Varma, R. S., Rabiee, N., & Irvani, S. [2023]. Advanced nanosystems for cancer therapeutics. *ACS Applied Nano Materials*, 6[10], 7117–7153.

Nelson, H. D., Fu, R., Cantor, A., Pappas, M., & Daeges, M. [2016].

Effectiveness of breast cancer screening: Systematic review and meta-analysis. *Annals of Internal Medicine*, 164[4], 244–255.

O'Shaughnessy, J. [2005]. Extending Survival with chemotherapy strategies for metastatic breast cancer. *The Oncologist*, 10[3], 20–29.

Subhan, M. A., & Torchilin, V. P. [2023]. Biopolymer-based nanosystems for siRNA delivery. *Pharmaceutics*, 15[1], 153.

Sung, H., Ferlay, J., Siegel, R. L., et al. [2021]. Global cancer statistics 2020. GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA: A Cancer Journal for Clinicians*, 71[3], 209–249.

Waks, A. G., & Winer, E. P. [2019]. Breast cancer treatment: A review. *JAMA*, 321[3], 288–300.

Zhao, M., Li, J., He, X., Yang, R., Zhang, Y., Wang, J., Song, J., Wu, Z., Zhai, T., & Qiu, S. [2025]. NIR image-guided multimodal nanotherapy synergizing photothermal, NO gas, and ferroptosis enhances immunogenic cell death in triple-negative breast cancer. *Materials & Design*, 260, 115071.

Basics

Hanafi-Bojd, M. Y., Ansari, L., & Malaekhe-Nikouei, B. [2016]. Codelivery of anticancer drugs and siRNA by mesoporous silica nanoparticles. *Therapeutic Delivery*, 7[10], 649–665.

Hao, N., Jayawardana, K. W., Chen, X., & Yan, M. [2015]. One-step synthesis of amine-functionalized hollow mesoporous silica nanoparticles. *ACS Applied Materials & Interfaces*, 7[2], 1040–1045.

Inoue, S., Patil, R., Portilla-Arias, J., Ding, H., Konda, B., Espinoza, A., Mongayt, D., Markman, J. L., Elramsisy, A., & Phillips, H. W. [2012]. Nanobiopolymer for targeting EGFR in triple negative breast cancer. *PLoS ONE*, 7[1], e31070.

Kim, K. Y. [2007]. Nanotechnology platforms and physiological challenges for cancer therapeutics. *Nanomedicine: Nanotechnology, Biology and Medicine*, 3[2], 103–110.

Article

Liu, J., Dong, J., Zhang, T., & Peng, Q. [2018]. Graphene-based nanomaterials and their potentials in advanced drug delivery and cancer therapy. *Journal of Controlled Release*, 286, 64–73.

Mohajer, F., Mirhosseini-Eshkevari, B., Ahmadi, S., Ghasemzadeh, M. A., Mohammadi Ziarani, G., Badiei, A., Farshidfar, N., Varma, R. S., Rabiee, N., & Irvani, S. [2023]. Advanced nanosystems for cancer therapeutics. *ACS Applied Nano Materials*, 6[9], 7123–7149.

Subhan, M. A., & Torchilin, V. P. [2023]. Biopolymer-based nanosystems for siRNA delivery. *Pharmaceutics*, 15[1], 153.

Supports

Ali, R., Aziz, M. H., Gao, S., Khan, M. I., Li, F., Batool, T., Shaheen, F., & Qiu, B. [2022]. Graphene oxide/zinc ferrite nanocomposite loaded with doxorubicin as a potential theranostic medium in cancer therapy and magnetic resonance imaging. *Ceramics International*, 48[7], 10741–10750.

Badea, N., Craciun, M. M., Dragomir, A. S., Balas, M., Dinischiotu, A., Nistor, C., Gavan, C., & Ionita, D. [2020]. Systems based on carbon nanotubes with potential in cancer therapy. *Materials Chemistry and Physics*, 241, 122435.

Harini, L., Srivastava, S., Gnanakumar, G. P., Karthikeyan, B., Ross, C., Krishnakumar, V., Kannan, V. R., Sundar, K., & Kathiresan, T. [2019]. Non-spherical mesoporous silica nanoparticles with curcumin induce apoptosis in MCF-7 cells. *Oncotarget*, 10[12], 1193–1208.

Inoue, S., Patil, R., Portilla-Arias, J., Ding, H., Konda, B., Espinoza, A., Mongayt, D., Markman, J. L., Elramsisy, A., Phillips, H. W., Black, K. L., Holler, E., & Ljubimova, J. Y. [2012]. Nanobiopolymer for targeting EGFR in triple negative breast cancer. *PLoS ONE*, 7[1], e31070.

Jamshidifar, E., Eshrati Yeganeh, F., Shayan, M., Tavakkoli Yarak, M., Bourbour, M., Moammeri, A., Akbarzadeh, I., Noorbazargan, H., & Hossein-Khannazer, N. [2021]. Super magnetic niosomal nanocarrier for breast cancer treatment. *International Journal of Molecular Sciences*, 22[15], 7948.

Ji, Z., Lin, G., Lu, Q., Meng, L., Shen, X., Dong, L., Fu, C., & Zhang, X. [2012]. Targeted therapy of SMMC-7721 liver cancer in vitro and in vivo with carbon nanotubes based drug delivery system. *Journal of Colloid and Interface Science*, 365[1], 143–149.

Koh, B., Park, S. B., Yoon, E., Yoo, H. M., Lee, D., Heo, J.-N., & Ahn, S. [2019]. $\alpha V\beta 3$ -targeted delivery of camptothecin using carbon nanotubes. *Journal of Pharmaceutical Sciences*, 108[11], 3704–3712.

Liao, T., Chen, Z., Kuang, Y., Ren, Z., Yu, W., Rao, W., Li, L., Liu, Y., Xu, Z., Jiang, B., & Li, C. [2023]. Small-size $Ti_3C_2T_x$ MXene nanosheets coated with metal-polyphenol nanodots for enhanced cancer photothermal therapy and anti-inflammation. *Acta Biomaterialia*, 159, 312–323.

Mahmoudi, R., Ashraf Mirahmadi-Babaheidri, S., Delaviz, H., Fouani, M. H., Alipour, M., Jafari Barmak, M., Christiansen, G., & Bardania, H. [2021]. RGD peptide-mediated liposomal curcumin delivery. *Journal of Biomaterials Applications*, 35[7], 743–753.

Meng, J., Fan, J., Galiana, G., et al. [2009]. LHRHfunctionalized superparamagnetic iron oxide nanoparticles for breast cancer targeting and contrast enhancement in MRI. *Materials Science and Engineering: C*, 29[4], 1467–1479.

Saw, W. S., Anasamy, T., Do, T. T. A., Lee, H. B., Chee, C. F., Isci, U., Misran, M., Dumoulin, F., Chong, W. Y., & Kiew, L. V. [2022]. Nanoscaled PAMAM dendrimer spacer improved the photothermal–photodynamic treatment efficiency of photosensitizer-decorated confetto-like gold nanoparticles for cancer therapy. *Macromolecular Bioscience*, 22[5], 2200130.

Silva, R., Ferreira, D., & Rodrigues, L. R. [2022]. Exosome-based delivery of RNAi leads to breast cancer inhibition. *Journal of Drug Delivery Science and Technology*, 78, 103931.

Soleymani, M., Velashjerdi, M., & Asgari, M. [2021]. Preparation of hyaluronic acid-decorated mixed nanomicelles for targeted delivery of hydrophobic drugs to CD44-overexpressing cancer cells. *International Journal of Pharmaceutics*, 592, 120052.

Article

Yang, Z., Xie, J., Zhu, J., et al. [2016]. Functional exosome-mimic for siRNA delivery to cancer: *in vitro* and *in vivo* evaluation. *Journal of Controlled Release*, 243, 160–171.

Yin-Hua, Y., Qi, G., Shan-Shan, Z., & Mi, T. [2020]. Preparation of curcumin TPP-PEG-PE nanomicelles with mitochondrial targeting and lysosomal escape functions and its effect on promoting breast cancer cell apoptosis. *Zhongguo Zhong Yao Za Zhi*, 45, 5495–5503.

Zhang, J., Li, M., Wang, M., Xu, H., Wang, Z., Li, Y., Ding, B., & Gao, J. [2021]. Effects of the surface charge of polyamidoamine dendrimers on cellular exocytosis and the exocytosis mechanism in multidrug-resistant breast cancer cells. *Journal of Nanobiotechnology*, 19, 135.

Zhang, Y., Liu, Q., Zhang, X., Huang, H., Tang, S., Chai, Y., Xu, Z., Li, M., Chen, X., Liu, J., & Yang, C. [2022]. Recent advances in exosomemediated nucleic acid delivery for cancer therapy. *Journal of Nanobiotechnology*, 20, 279.

Zhou, X., Xu, X., Hu, Q., Wu, Y., Yu, F., He, C., Qian, Y., Han, Y., Tang, J., & Hu, H. [2023]. Novel manganese and polyester dendrimer-based theranostic nanoparticles for MRI and breast cancer therapy. *Journal of Materials Chemistry B*, 11, 648–656.

Zhu, Z., Zhang, X., Li, C., & Wang, Y. [2024]. Curcumin nanoformulations for breast cancer: Curcumin for Treating Breast Cancer: A Review of Molecular Mechanisms, Combinations with Anticancer Drugs, and Nanosystems *Pharmaceutics*, 16[3], 412.

Differences

Liu, J., Dong, J., Zhang, T., & Peng, Q. [2018]. Graphene-based nanomaterials and their potentials in advanced drug delivery and cancer therapy. *Journal of Controlled Release*, 286, 64–73.

Pinto, R. J. B., Lameirinhas, N. S., Guedes, G., da Silva, G. H. R., Oskoei, P., Spirk, S., Oliveira, H., & Costa Lima, S. A. [2021]. Cellulose nanocrystals/chitosan-based fluorescent nanosystems: Synthesis, characterization and cellular uptake on breast cancer cells. *Nanomaterials*, 11[8], 2057.

Zhu, Z., Zhang, X., Li, C., & Wang, Y. [2024]. Curcumin nanoformulations for breast cancer: Curcumin for Treating Breast Cancer: A Review of Molecular Mechanisms, Combinations with Anticancer Drugs, and Nanosystems *Pharmaceutics*, 16[3], 412.

Discussions

Baghbani, F., Chegeni, M., Moztarzadeh, F., Aghazadeh Mohandesi, J., & Mokhtari-Dizaji, M. [2017]. Ultrasonic nanotherapy of breast cancer using novel alginate-shelled nanodroplets: *In vitro* and *in vivo* evaluation. *Materials Science and Engineering: C*, 77, 698–707.

Ferreira, L. P., Gaspar, V. M., Monteiro, M. V., Freitas, B., Silva, N. J. O., & Mano, J. F. [2021]. Screening of dual chemo-photothermal cellular nanotherapies in organotypic breast cancer 3D spheroids. *Journal of Controlled Release*, 331, 85–102.

Hanafi-Bojd, M. Y., Ansari, L., & Malaekhe-Nikouei, B. [2016]. Codelivery of anticancer drugs and siRNA by mesoporous silica nanoparticles. *Therapeutic Delivery*, 7[10], 649–665.

Hao, N., Jayawardana, K. W., Chen, X., & Yan, M. [2015]. One-step synthesis of amine-functionalized hollow mesoporous silica nanoparticles. *ACS Applied Materials & Interfaces*, 7[2], 1040–1045.

Harini, L., Srivastava, S., Gnanakumar, G. P., Karthikeyan, B., Ross, C., Krishnakumar, V., Kannan, V. R., Sundar, K., & Kathiresan, T. [2019]. Non-spherical mesoporous silica nanoparticles with curcumin induce apoptosis in MCF-7 cells. *Oncotarget*, 10[12], 1193–1208.

Jamshidifar, E., Eshrati Yeganeh, F., Shayan, M., Tavakkoli Yarak, M., Bourbour, M., Moammeri, A., Akbarzadeh, I., Noorbazargan, H., & Hossein-Khannazer, N. [2021]. Super magnetic niosomal nanocarrier for breast cancer treatment. *International Journal of Molecular Sciences*, 22[15], 7948.

Liao, T., Chen, Z., Kuang, Y., Ren, Z., Yu, W., Rao, W., Li, L., Liu, Y., Xu, Z., Jiang, B., & Li, C. [2023]. Small-size $Ti_3C_2T_x$ MXene nanosheets coated with metal-polyphenol nanodots for enhanced cancer photothermal therapy and anti-inflammation. *Acta Biomaterialia*, 159, 312–323.

Article

Liu, J., Dong, J., Zhang, T., & Peng, Q. [2018]. Graphene-based nanomaterials and their potentials in advanced drug delivery and cancer therapy. *Journal of Controlled Release*, 286, 64–73.

Mahmoudi, R., Mirahmadi-Babaheidri, S. A., Delaviz, H., Fouani, M. H., Alipour, M., Jafari Barmak, M., Christiansen, G., & Bardania, H. R. [2021]. RGD peptide-mediated liposomal curcumin targeted delivery to breast cancer cells. *Journal of Biomaterials Applications*, 35[6], 743–753.

Meng, J., Fan, J., Galiana, G., et al. [2009]. LHRHfunctionalized superparamagnetic iron oxide nanoparticles for breast cancer targeting and contrast enhancement in MRI. *Materials Science and Engineering: C*, 29[4], 1467–1479.

Mohajer, F., Mirhosseini-Eshkevari, B., Ahmadi, S., Ghasemzadeh, M. A., Mohammadi Ziarani, G., Badiiei, A., Farshidfar, N., Varma, R. S., Rabiee, N., & Irvani, S. [2023]. Advanced nanosystems for cancer therapeutics. *ACS Applied Nano Materials*, 6[9], 7123–7149.

Pinto, R. J. B., Lameirinhas, N. S., Guedes, G., da Silva, G. H. R., Oskoei, P., Spirk, S., Oliveira, H., & Costa Lima, S. A. [2021]. Cellulose nanocrystals/chitosan-based fluorescent nanosystems: Synthesis, characterization and cellular uptake on breast cancer cells. *Nanomaterials*, 11[8], 2057.

Yang, B., Ding, L., Yao, H., Chen, Y., & Shi, J. [2020]. A metal-organic framework (MOF) Fenton nanoagent-enabled nanocatalytic cancer therapy in synergy with autophagy inhibition. *Advanced Materials*, 32[12], e1907152.

Yang, Z, Xie, J., Zhu, J., et al. [2016]. Functional exosome-mimic for siRNA delivery to cancer: in vitro and in vivo evaluation. *Journal of Controlled Release*, 243, 160–171.

Zhao, M., Li, J., He, X., Yang, R., Zhang, Y., Wang, J., Song, J., Wu, Z., Zhai, T., & Qiu, S. [2025]. NIR image-guided multimodal nanotherapy synergizing photothermal, NO gas, and ferroptosis enhances immunogenic cell death in triple-negative breast cancer. *Materials & Design*, 260, 115071.

Zhu, Z., Zhang, X., Li, C., & Wang, Y. [2024]. Curcumin nanoformulations for breast cancer: Curcumin for Treating Breast Cancer: A Review of Molecular Mechanisms, Combinations with Anticancer Drugs, and Nanosystems *Pharmaceutics*, 16[3], 412.

MRI-Based prototype for early detection of muscular knee injuries with U-Net

Prototipo basado en resonancia magnética para la detección precoz de lesiones musculares de rodilla con U-Net

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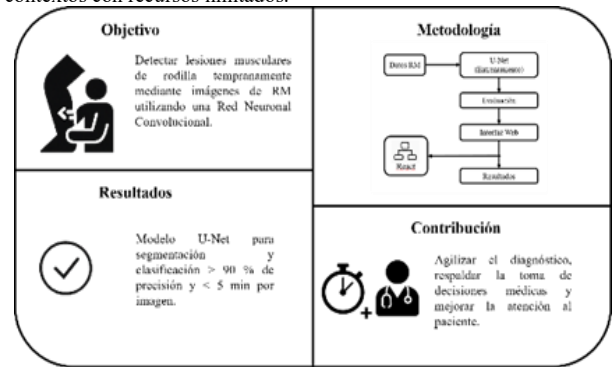
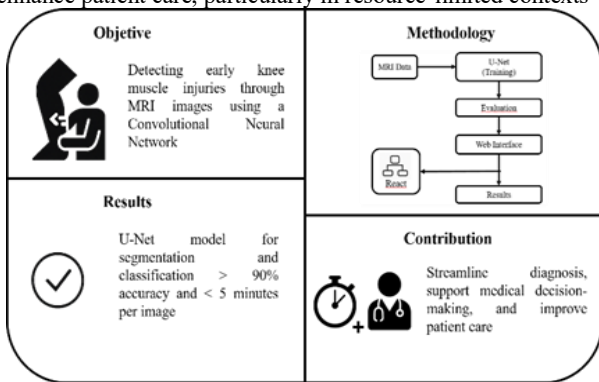


Abstract

This study presents the development and initial validation of an Artificial Intelligence [AI] based prototype for the early detection of knee muscle injuries using Magnetic Resonance Imaging [MRI]. The system leverages a U-Net architecture for lesion segmentation and classification, achieving performance above 90% in preliminary tests while reducing analysis time to less than five minutes per case. The development methodology included data preprocessing, model training and performance evaluation, as well as the implementation of a web interface [React for the frontend and Python for the backend]. The solution is designed for deployment in clinical settings, aiming to streamline diagnosis, support medical decision-making, and enhance patient care, particularly in resource-limited contexts

Resumen

Este estudio describe el desarrollo y validación inicial de un prototipo de apoyo al diagnóstico basado en Inteligencia Artificial[IA] para la detección temprana de lesiones musculares de la rodilla mediante imágenes de Resonancia Magnética [RM]. El sistema emplea una arquitectura U-Net para la segmentación y la clasificación de lesiones; en las pruebas realizadas alcanzó un desempeño superior al 90 %, lo que reduce el tiempo de análisis a menos de cinco minutos por estudio. La metodología de desarrollo comprendió el preprocesamiento de datos, el entrenamiento del modelo y la evaluación del desempeño, así como el desarrollo de una interfaz web [React para el frontend y Python para el backend]. La solución está concebida para su despliegue en entornos clínicos, con el objetivo de agilizar el diagnóstico, respaldar la toma de decisiones médicas y mejorar la atención al paciente, especialmente en contextos con recursos limitados.



Artificial Intelligence, Convolutional Neural Network, Magnetic Resonance Imaging

Inteligencia Artificial, Red Neuronal Convolutacional, Resonancia Magnética

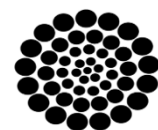
Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

According to recent estimates on the global burden of disease, more than 1.7 billion people suffer from musculoskeletal disorders. Although they affect individuals of all ages, their prevalence varies depending on the diagnosis and stage of life. High-income countries concentrate the largest number of cases [441 million], followed by the Western Pacific and Southeast Asia regions [427 and 369 million, respectively]. These disorders constitute the leading cause of Years Lived with Disability [YLD], accounting for approximately 17% of the global total, which is equivalent to about 149 million YLDs [World Health Organization, 2022].

In the Mexican context, musculoskeletal disorders [MSDs] represent one of the main causes of disability, and their burden has increased significantly in recent decades. According to estimates from the Global Burden of Disease 2021, between 1990 and 2021, the YLDs attributable to MSDs increased by 57.3%, rising from 1,458.4 to 2,293.7 per 100,000 inhabitants. Low back pain ranked as the most disabling condition, with 840.6 YLDs per 100,000 inhabitants, while osteoarthritis showed the greatest proportional increase [Clark et al., 2024].

Additionally, musculoskeletal injuries particularly those affecting the knee joint represent a significant problem in both clinical and sports settings. These injuries can considerably limit mobility, cause chronic pain, and reduce patients' quality of life if they are not diagnosed and treated in a timely manner. Diagnosis often implies high costs, prolonged evaluation times, and variability in outcomes depending on the clinician's experience [Padilla-Rojas et al., 2024; López et al., 2023]. According to the World Health Organization [WHO], access to advanced imaging diagnostic technologies is concentrated in countries and centers with high resource availability, creating a significant gap in educational institutions and secondary-level hospitals [World Health Organization, 2022]. Similarly, the Pan American Health Organization [PAHO] reports that Latin America faces considerable limitations in the availability of automated technologies and specialized diagnostic software, which delays early clinical assessment and increases health system costs [Health Technology Assessment, 2025].

In Mexico, recent studies indicate that timely diagnosis of these conditions is hindered by the lack of accessible technological tools, particularly in public hospitals and training environments, where interpretation depends solely on the clinical judgment of specialists [Clark et al., 2024].

Given this context, the development of an intelligent software prototype is proposed for the early diagnosis of muscular knee injuries by means of automated analysis of magnetic resonance imaging supported by deep learning techniques. The implementation of Convolutional Neural Networks [CNNs] using a U-Net architecture enabled high diagnostic precision and a reduction in required evaluation time.

This article is structured into five sections. First, the Theoretical Framework describes AI and CNNs as key tools in medical diagnosis, highlighting architectures such as U-Net, ResNet-18, and MobileNetV3-Small for their effectiveness in biomedical imaging. The State of the Art presents recent applications of AI across various medical specialties, including studies on knee injury diagnosis using magnetic resonance imaging. The Methodology covers data acquisition and preprocessing, CNNs model training, and the implementation of a web prototype using React and Flask. The Results show that U-Net achieved the highest accuracy and segmentation performance compared to ResNet-18 and MobileNetV3-Small, confirming its suitability for clinical environments. Finally, the Conclusions emphasize that the system contributes to faster and more accurate diagnoses, although the need to expand the dataset is recognized, along with future improvements aimed at extending the prototype to other musculoskeletal injuries.

2. Theoretical Framework

AI a branch of computer science focused on logic and learning, enables the design of systems capable of simulating human cognitive processes such as learning, reasoning, and self-correction [Ruibal-Tavares et al., 2023]. Driven by advances in infrastructure and computing capacity, including in low- and middle-income countries,

AI has gained momentum and has emerged as a key tool to address global health challenges [Schwalbe & Wahl, 2020].

This scenario opens opportunities for diagnostic support through automated analysis of clinical data and medical imaging, contributing to more timely decision-making and improved resource allocation.

In the healthcare sector, AI-based approaches have become consolidated as crucial tools, providing innovative solutions in diagnosis, prognosis, and treatment. In particular, deep learning and CNNs]have demonstrated high effectiveness in the interpretation of medical images with high precision, even in resource-limited settings, thus promoting equity in healthcare access. These networks, inspired by the connectivity of the human visual cortex, have been widely used in medical image processing and clinical diagnostic support [Craig & Awati, 2024].

The structure of CNNs consists of:

- Convolutional layers, which detect specific features through filters that generate activation maps.
- Pooling layers, which reduce dimensionality and preserve key information.
- Fully connected layers, responsible for the final classification by integrating all extracted features.

One of the milestones in the evolution of these networks was AlexNet, developed by Krizhevsky and Hinton, which significantly outperformed other techniques in image recognition competitions and marked a turning point in the field of deep learning [Badillo et al., 2021].

In this work, three CNNs architectures widely used in biomedical domains were considered: U-Net, ResNet-18, and MobileNetV3-Small.

U-Net

U-Net is a biomedical segmentation architecture based on an encoder–decoder scheme with skip connections that preserve spatial information, making it particularly effective in environments with limited datasets. Recent reviews have confirmed its flexibility and high performance across multiple medical imaging modalities such as magnetic resonance imaging, computed tomography, and microscopy, even when the number of annotated samples is limited [Isensee et al., 2020].

A recent taxonomy has classified U-Net variants according to image modality and clinical application, including their use in brain tumor segmentation, lung cancer, Alzheimer’s diagnosis, breast cancer, and COVID-19 detection [Ali et al., 2021]. Among proposed improvements, Sharp U-Net stands out, incorporating depthwise convolutions and sharpening filters to effectively combine extracted features in the encoding and decoding stages, achieving more precise segmentations without significantly increasing the number of parameters [Rahman et al., 2021].

ResNet-18

ResNet-18 is a deep residual network that uses shortcut [residual] blocks to mitigate the vanishing gradient problem and enable stable training in deeper architectures. Recent medical applications have demonstrated strong performance, such as in the classification of lesions in multiparametric prostate MRI, including those categorized as intermediate [PI-RADS 3, indeterminate probability of clinically significant cancer], achieving high precision and competitive area-under-curve metrics in multi-category classification scenarios [Wang et al., 2024].

MobileNetV3

MobileNetV3 is an architecture optimized for devices with limited computational resources, based on depthwise separable convolutions and squeeze-and-excitation blocks, enabling reduced training time and memory usage. Its combined version with U-Net, called MobileUNetV3, has shown outstanding results in spinal cord gray matter segmentation, demonstrating that high precision can be maintained with a lightweight architecture [Zhou et al., 2022]. Additionally, MobileNetV3 has been used as an efficient classifier in histopathological breast cancer imaging, achieving high accuracy in malignant pattern identification with reduced computational cost [Kumar et al., 2024].

3. State of the Art

Several recent studies highlight the application of AI in different medical specialties, as shown in Table 1, extracted from the review by Ruibal-Tavares et al. [2023]. The techniques used range from Deep Neural Networks [ANN], machine learning, to specialized CNNs, depending on the application field and the type of clinical data analyzed.

Box 1**Table 1**

Relevant applications of AI in medicine.

Medical Specialty	Tecnologías de IA	Relevant Applications
Radiology	Deep ANN	Detection of pulmonary nodules, coronary calcium scoring in CT
Cardiology	ANN, XGBoost	ECG-based diagnosis, hypertension prediction
Ophthalmology	CNN	Detection of retinal neovascularization and macular degeneration
Dermatology	Deep learning	Diagnosis of melanoma and basal cell carcinoma using dermatoscopic images
Neurology	Machine learning	Prediction of ischemic stroke and epilepsy risk
Pathology	Deep learning, machine learning	Classification of neoplasms by DNA methylation, hepatic steatosis
Genetics	Deep ANN	Analysis of pathogenic genetic variants
Gastroenterology	CNN, machine learning, 5G recognition	Diagnosis of celiac disease using endoscopic imaging

Source: Ruibal-Tavares et al., 2023

Qiu et al. [2021] developed a model called CNNss, which combines two convolutional networks to identify meniscal injuries. Their results show that the use of magnetic resonance imaging significantly outperforms the diagnostic accuracy of traditional computed tomography.

Similarly, Trejo-Chávez et al. [2022] proposed a methodology that includes data augmentation, robust image preprocessing [such as rotation, noise, and brightness adjustments], and training of CNNs under different configurations. This approach strengthens the model's adaptability to real-world conditions.

Finally, Cueva et al. [2022] presented a computer-assisted diagnostic system based on Siamese networks and ResNet-34 to simultaneously evaluate X-ray images of both knees, allowing the classification of osteoarthritis severity with high accuracy.

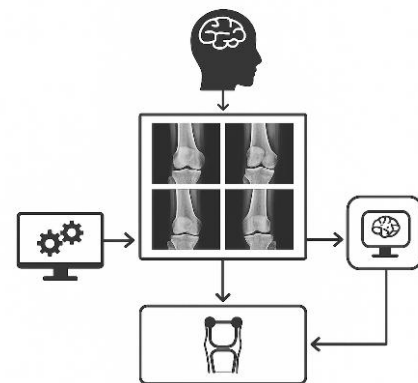
These studies demonstrate the applicability of AI, particularly CNNs, in the automated diagnosis of joint and musculoskeletal injuries, establishing a solid foundation for their integration into clinical systems.

4. Methodology

The methodology was structured into two main components:

- Development of the AI model for the segmentation and classification of muscular knee injuries.
- Development of the web prototype and clinical database.

The development of this model comprises four stages:

Box 2**Figure 1**

Development diagram of the AI models

Source: Author's elaboration

The first stage is the acquisition of medical images: MRI or radiographic images are collected to form the database that will feed the AI model. These images may be obtained from clinics, hospitals, or specialized repositories.

For this research, the MRNet-v1.0 dataset was used, composed of a total of 1,370 MRI studies divided into three modalities: T1 sequence, T2 sequence, and proton-density images. These images were carefully selected and annotated by expert radiologists, ensuring quality and clinical relevance. Each image is associated with labels indicating the presence or absence of lesions, enabling classification and segmentation model training.

The second stage is preprocessing, through which the images undergo normalization, segmentation, noise reduction, and data augmentation, ensuring they are in optimal condition for training.

Preprocessing included:

- Pixel intensity normalization.
- Resizing and padding to 256×256 pixels.
- Data augmentation through rotations, cropping, and brightness adjustments.
- Organization by anatomical view: coronal, sagittal, and axial.

In the third stage, the AI model is trained. A Convolutional Neural Network or specialized architecture such as U-Net is applied to learn patterns and detect possible lesions in the knee.

- Training and Evaluation Environment
- Platforms: Google Colab [GPU Tesla T4] and Intel i7 CPU for local tests.
- Data split: 70% training, 15% validation, 15% testing.

Training Functions and Optimization:

- U-Net \rightarrow BCEWithLogitsLoss, AdamW optimizer, mixed precision using GradScaler[] for GPU acceleration.
- ResNet-18 and MobileNetV3 \rightarrow Configured in environments optimized for binary classification.
- Metrics: Accuracy, IoU, Dice Score, training time.

The models were trained for a maximum of 20 epochs, using validation at each iteration. An early stopping strategy with a patience of 10 epochs was implemented, such that training would stop automatically if no improvement was observed in the validation metric [Dice Score].

This approach prevented overfitting and optimized computational resource usage, ensuring that the model reached a stable performance without unnecessarily extending the training process.

Additionally, a decision threshold of 0.5 was defined for classifying each pixel as lesion or healthy tissue. Values equal to or greater than the threshold were classified as lesion, while those below were classified as healthy.

This criterion enabled the calculation of complementary metrics, including the number of False Positives [FP] and False Negatives [FN], as well as the confusion matrix to evaluate prediction quality.

The final stage corresponds to results generation: The system produces a visual or diagnostic output, such as lesion detection or segmentation in the knee, which can support medical decision-making.

Development of the Web Prototype and Clinical Database

Development Methodology

An agile approach based on the Kanban methodology was adopted. Short iterations and periodic reviews by clinical personnel allowed functionalities to be adjusted according to real project needs. A project schedule was defined and roles were assigned, supported by the Jira project management tool.

Frontend

The interface was developed in React.js with responsive design, enabling:

- Uploading MRI images.
- Display of segmentation results generated by the model.
- Registration of clinical observations xzsaq linked to each patient.

Backend

The backend was implemented in Flask [Python] with the following functionalities:

- Execution of the U-Net segmentation model.
- Generation and processing of segmentation masks.
- Communication with the frontend using Flask-CORS.
- Integration with PyTorch, OpenCV, and NumPy.

Box 3

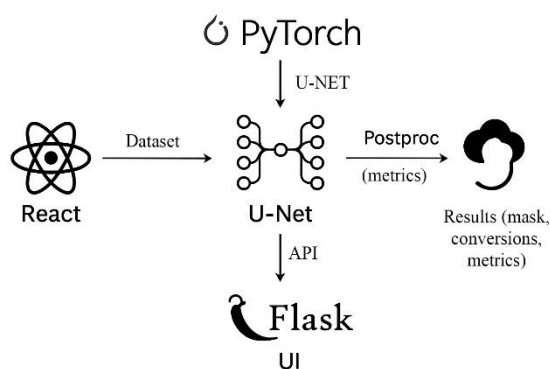


Figure 2

System architecture diagram

Source: Author's elaboration

Purpose

To develop an MRI-based software prototype for the early detection of muscular knee injuries, facilitating identification and diagnostic support through automated image analysis.

Scope

The project aims to provide a tool that enables early diagnosis of muscular knee injuries using MRI image processing and deep learning, adaptable to clinical and academic environments.

5. Results

Development of the AI Model

The results obtained during the experimental phase allow for the evaluation of the performance of the three CNNs architectures: U-Net, ResNet-18, and MobileNetV3-Small, trained for the detection of muscular knee injuries using magnetic resonance imaging, as shown in Table 2.

Box 4

Table 2

Training results of the evaluated models.

Model	Accuracy	Training Time [Colab]	Training Time [PC]
U-Net	91%	1 hour 36 minutes	30 minutes
ResNet-18	89%	14 minutes	14 minutes
MobileNetV3	88%	12 minutes	10 minutes

Source: Author's elaboration

The U-Net model demonstrated the best performance in terms of accuracy and segmentation quality, proving particularly useful in simulated clinical environments where diagnostic precision is prioritized. Its encoder-decoder structure with skip connections allows for more precise segmentation of muscular structures.

Box 5

```

def load_data_from_npy(
    npy_dir: str,
    csv_dir: str,
    img_height: int,
    img_width: int,
) -> tuple[ndarray, ndarray]:
    """Function to load .npy images and labels from subdirectories"""
    def load_data_from_npy(base_dir, csv_path):
        df = pd.read_csv(csv_path, header=None, names=["index", "label"])
        x, y = [], []

        for _, row in df.iterrows():
            sub_dir = row["index"]
            img_path = os.path.join(base_dir, sub_dir, f"{row['index']:04d}.npy")

            if os.path.exists(img_path):
                # Load image
                img = np.load(img_path)

                # Resize image if dimensions are inconsistent
                if img.shape[-1] != (img_height, img_width):
                    print(f"Resizing image from {img.shape} to {(img_height, img_width)}")
                    img = np.resize(img, (img_height, img_width))

                # Expand dimensions for grayscale images
                if len(img.shape) == 2: # Grayscale
                    img = np.expand_dims(img, axis=-1)

                # Normalize image
                img = img.astype(np.float32) / 255.0

                # Create binary mask
                mask = np.full((img_height, img_width, 1), row["label"], dtype=np.float32)

                X.append(img)
                y.append(mask)

    # Convert lists to numpy arrays
    X = np.array(X)
    y = np.array(y)
  
```

Figure 3

Model development

Source: Author's elaboration

Desarrollo e Implementación del prototipo Web

Frontend: A responsive interface developed in React.js enables clinical personnel to:

- Upload MRI scans.
- Visualize segmentation outputs generated by the model.
- Record clinical observations linked to each patient.

Box 6

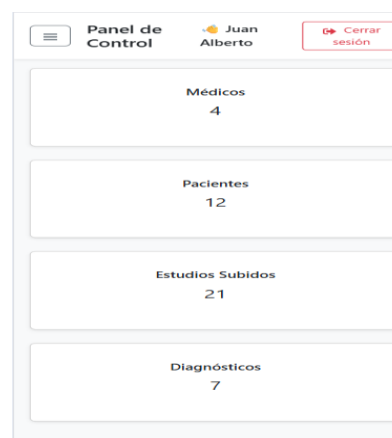
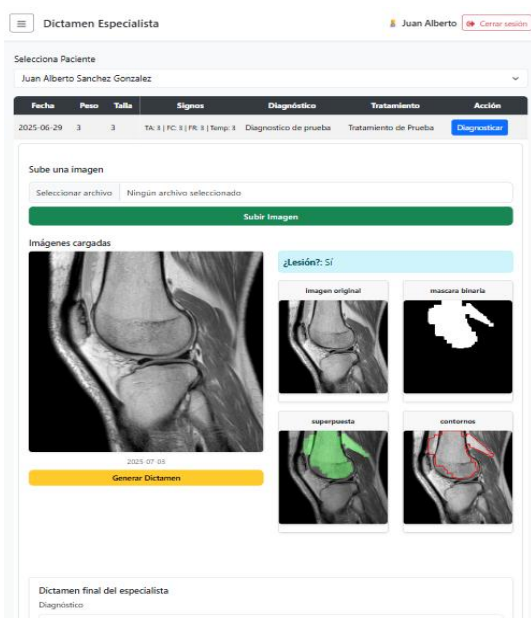


Figure 4

Prototype dashboard

Source: Author's elaboration

Box 7**Figure 5**

Lesion prediction output

Source: Author's elaboration

Backend: Implemented in Flask [Python], responsible for:

- Executing the U-Net model.
- Generating segmentation masks.
- Returning predictions to the user interface.

Prototype Performance Evaluation

The web prototype with the U-Net model was evaluated on a set of 20 knee MRI studies uploaded directly through the interface. The results are summarized in Table 3.

Box 8**Tabla 3**

Prototype performance on 20 MRI studies.

Metric	Mean [±SD]	95% CI	Minimum	Maximum
Accuracy	91.0 % ± 2.1	[89.7 – 91.9]	87.2 %	94.1 %
Dice Score	0.87 ± 0.03	[0.85 – 0.89]	0.83	0.91
IoU	0.85 ± 0.04	[0.83 – 0.87]	0.80	0.90
Avg. time per study	4.6 ± 0.5	[4.4 – 4.9]	3.9	5.4

Source: Author's elaboration.

Interpretation of results:

- The system maintained an average accuracy of 91.0%, confirming consistent predictions in a simulated clinical environment.
- The Dice Score of 0.87 and IoU of 0.85 indicate a high level of agreement between automatic segmentations and expert references.
- The average analysis time per study was approximately 4.6 minutes, confirming the system's efficiency for real clinical workflows.

Analysis of False Positives, False Negatives, and Decision Threshold

In addition to the global metrics reported in Table 4, a detailed analysis was conducted on the 20 magnetic resonance imaging studies evaluated with the web prototype. The U-Net model assigns each pixel a probability value between 0 and 1 of corresponding to a lesion, establishing a decision threshold of 0.5.

Values equal to or greater than the threshold were classified as lesions, while values below the threshold were considered healthy tissue.

Using this criterion, the following results were obtained: 15 True Positives [TP], 2 True Negatives [TN], 1 False Positive [FP], and 2 False Negatives [FN]. Table 4 shows the distribution of the cases, while Figure 11 presents the corresponding confusion matrix.

Box 9**Table 4**

Classification results across 20 evaluated studies.

Study	Actual Lesion	AI Prediction	Result
1–15	Yes	Yes	TP
16–17	Yes	No	FN
18–19	No	No	TN
20	No	Yes	FP

Source: Author's elaboration

Box 10**Table 5**

Confusion matrix for the 20 evaluated studies.

Study	Predicted Lesion	Predicted Healthy
Actual Lesion	TP = 15	FN = 2
Actual Healthy	FP = 1	TN = 2

Source: Author's elaboration.

Based on these values, the following additional metrics were calculated: a precision of 85%, a sensitivity of 88.2%, a specificity of 66.7%, a Dice Score of 0.87, and an average IoU of 0.85, results that are consistent with those obtained in the experimental phase.

Regarding the decision threshold, it was observed that a value of 0.5 achieves a balance between sensitivity and specificity. A higher threshold [0.7] reduces false positives but increases false negatives, while a lower threshold [0.3] increases sensitivity at the expense of more false positives.

Therefore, the threshold of 0.5 is considered the most suitable for initial clinical scenarios, as it maintains an appropriate balance between lesion detection and the reduction of classification errors.

6. Conclusions

The findings of this research demonstrate the technical and clinical feasibility of implementing artificial intelligence-based tools for the early diagnosis of muscular knee injuries.

The U-Net model achieved an accuracy greater than 90%, proving to be the most robust architecture under simulated clinical conditions. In addition, the analysis time was significantly reduced, contributing to faster and more timely diagnostic support.

The prototype offers an economical, accessible, and adaptable solution for institutions with limited resources, such as public hospitals or university clinics.

The combination of an intuitive web interface, trained AI models, and a structured database makes this tool a complete and functional system. Consequently, the system has high scalability potential, allowing it to be adapted to other types of musculoskeletal injuries.

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Future work and improvement opportunities

- Expand the database with locally acquired clinical images to improve the model's generalization capacity.
- Integrate additional models to differentiate degrees of lesion severity.
- Implement and evaluate the prototype in the Clinical Training Center at the Universidad Tecnológica de Xicotepec de Juárez.

Declarations

SECIHTI Contribution Area

This project contributes to the axis Development of strategic cutting-edge technologies and open innovation for social transformation, by proposing an artificial intelligence-based system for the early detection of muscular knee injuries through magnetic resonance imaging, strengthening diagnostic capacity and medical care in institutions with limited resources.

Conflict of interest

The authors declare that they have no conflict of interest.

They have no known competing financial interests or personal relationships that could have influenced the results, interpretation, or presentation of this article.

Author contribution

Sánchez-González, Juan Alberto: Methodological design, development of the U-Net model, training and validation, interpretation of results, manuscript writing, and development of the web prototype.

Hernández-Reyes, José Manuel: Results analysis, model validation, technical support in implementation, and final manuscript review.

Escorza-Sánchez, Yolanda Marysol: Academic supervision, methodological guidance, and final manuscript review.

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Abbreviations

AI	Artificial Intelligence
ANN	Artificial Neural Network
BCE	Binary Cross-Entropy
CI	Confidence Interval
CNN	Convolutional Neural Network
CT	Computed Tomography
Dice	Dice Similarity Coefficient
ECG	Electrocardiogram
FN	False Negative
FP	False Positive
IoU	Intersection over Union
MRI	Magnetic Resonance Imaging
MSD	Musculoskeletal Disorder
PAHO	Pan American Health Organization
ReLU	Rectified Linear Unit
SD	Standard Deviation
TN	True Negative
TP	True Positive
WHO	World Health Organization
YLD	Years Lived with Disability

References

Antecedents

Clark, P., Contreras, D., Ríos-Blancas, M. J., Steinmetz, J. D., Ong, L., Culbreth, G. T., Lenox, H., Mendoza, C. F., & Razo, C. [2024]. [Analysis of musculoskeletal disorders-associated disability in Mexico from 1990 to 2021](#). *Gaceta Médica de México*, 159[6].

Padilla-Rojas, L. G., Tamayo-Cosio, J., Garín-Zertuche, D. E., Rojas-Herrera, C. A., Vallejo, L., Leal, J. A., Soarez-Hungria, J. O., Caiero, M. T., Tabares-Neyra, H., Roig, J. L. G., & Giordano, V. [2024]. [Trauma center rehabilitation systems in Latin America](#). *OTA International*, 7[5S].

World Health Organization. [2022]. [Global Health Estimates 2022: Disease burden and disability by cause, age, sex, by country and region, 2000–2021](#).

Health Technology Assessment. [2025]. [Artificial intelligence in medical imaging in Latin America: Opportunities and challenges](#). Pan American Health Organization.

Basics

Badillo, F. L., Hernández, C. A. R., Narváez, B. M., & Trillos, Y. E. A. [2021]. [Redes neuronales convolucionales: un modelo de Deep Learning en imágenes diagnósticas](#). Revisión de tema. *Revista Colombiana de Radiología*, 32[3], 5591–5599.

Craig, L., & Awati, R. [2024, January 11]. [Convolutional neural network \[CNN\]](#). Enterprise AI.

Isensee, F., Jaeger, P. F., Kohl, S. A. A., Petersen, J., & Maier-Hein, K. H. [2020]. [nnU-Net: A self-configuring method for deep learning-based biomedical image segmentation](#). *Nature Methods*, 18[2], 203–211.

Parada, M. [2021, May 19]. [Qué es React](#). OpenWebinars.net.

Prot-Mandelbrot, B. B. [2020]. Negative dimensions and Hölders, multifractals and their Hölder spectra, and the role of lateral preasymptotics in science. *Journal of Fourier Analysis and Applications Special*, 409–432.

Schwalbe, N., & Wahl, B. [2020]. [Artificial intelligence and the future of global health](#). *The Lancet*, 395[10236], 1579–1586.

Supports

Ruibal-Tavares, E., Calleja-López, J. R., Rivera-Rosas, C. N., & Aguilera-Duarte, L. J. [2023]. [Inteligencia artificial en medicina: panorama actual](#). *REMUS - Revista Estudiantil de Medicina de la Universidad de Sonora*.

Trejo-Chávez, O., Amezcua-Sanchez, J. P., Huerta-Rosales, J. R., Morales-Hernandez, L. A., Cruz-Albarran, I. A., & Valtierra-Rodriguez, M. [2022]. [Automatic knee injury identification through thermal image processing and convolutional neural networks](#). *Electronics*, 11[23], 3987.

Differences

Cueva, J. H., Castillo, D., Espinós-Morató, H., Durán, D., Díaz, P., & Lakshminarayanan, V. [2022]. [Detection and classification of knee osteoarthritis](#). *Diagnostics*, 12[10], 2362.

Wang, X., Zhang, Y., Chen, J., Liu, Y., Zhang, Y., & Li, W. [2024]. [Deep learning based on ResNet-18 for classification of PI-RADS 3 lesions in multiparametric prostate MRI](#). *Academic Radiology*.

Discussions

Ali, M., Ali, A., Farooq, A., & Khan, M. U. G. [2021]. [U-Net variants for medical image segmentation: A review of theory and applications](#).

Article

Kumar, R., Gupta, A., & Sharma, M. [2024]. [MobileNetV3 for breast cancer histopathological image classification](#). *Applied Sciences*, 14[17], 7564.




Rahman, M. M., Islam, M. M., Sarker, A., & Hasan, M. K. [2021]. [Sharp U-Net: Depthwise convolutional network for biomedical image segmentation](#). *Computers in Biology and Medicine*, 136, 104699.

Zhou, Y., Chen, M., Ma, J., Wang, H., & Chen, Q. [2022]. [MobileUNetV3—A combined U-Net and MobileNetV3 architecture for spinal cord gray matter segmentation](#). *Electronics*, 11[15], 2388.


Smart Phil Dispenser - SPD**Dispensador de Pastillas Inteligente - DPI**

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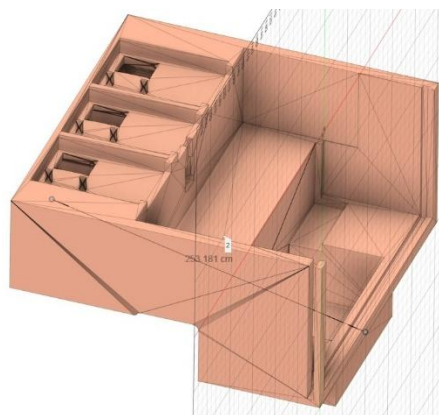
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**Abstract**

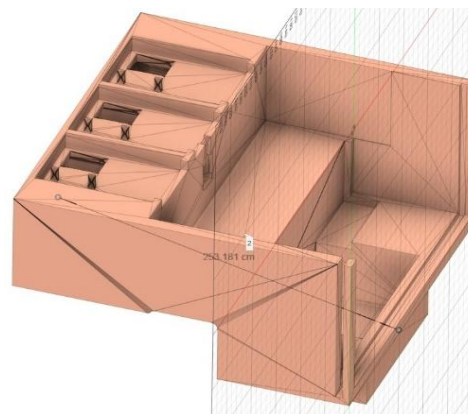
This article presents the development of a Smart Pill Dispenser called Phil by a team from the Technological University of San Juan del Rio called IoT Connection. Following the Scrum methodology, a prototype was designed to medication schedule, ensuring accurate and timely administration. Functional tests demonstrated the device's effectiveness and realism. This innovative approach to healthcare offers a practical and safe solution for medical care, promoting better daily management focused on well-being and health. To this end, a mobile application and a website were developed, and database and the MQTT protocol were implemented to communicate with our physical prototype.

Resumen

Este artículo presenta el desarrollo de un Dispensador de Pastillas Inteligente llamado Phil por parte de un equipo de la universidad Tecnológica de San Juan del Río llamado IoT Connection. Siguiendo la metodología Scrum, se diseñó un prototipo para programar la medicación, garantizando una administración precisa y oportuna. Las pruebas funcionales demostraron la eficacia y el realismo del dispositivo. Este innovador enfoque en la atención médica ofrece una solución práctica y segura para la atención médica, promoviendo una mejor gestión diaria centrada en el bienestar y la salud por lo cual se desarrolló una aplicación móvil y una página web así como se implementó una base de datos y el protocolo MQTT para tener comunicación con nuestro prototipo físico.



Automatic, Innovation, Health



Automatic, Innovation, Health

Area: Dissemination and universal access to science

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Peer review under the responsibility of the Scientific Committee MARVID®- in the contribution to the scientific, technological and innovation Peer Review Process through the training of Human Resources for continuity in the Critical Analysis of International Research.



Introduction

The Smart Phil dispenser represents an innovative solution that integrates advanced technology with the need to improve adherence to medical treatments. This device was created to facilitate daily medication management, ensuring that patients take their medications on time and with the correct dosage, without requiring constant intervention from a caregiver.

Its main objective is to offer a reliable, safe, and easy-to-use tool, specially designed for people who must follow a strict medication regimen. This includes those suffering from chronic illnesses, prolonged treatments or conditions that require continuous monitoring of medication use.

One of the dispenser's most notable features is its ability to organize medications into individual compartments, which can be programmed to release pills at specific times, according to medical indications. This automation reduces the risk of human error, improves treatment effectiveness, eliminating the need to remember exact schedules or doses.

The device automatically dispenses the correct medication at the right time, providing the user with peace of mind and confidence in their treatment. It also incorporates a secure locking mechanism that prevents unauthorized access or accidental consumption, a feature especially useful in homes with elderly people, children, or patients with cognitive impairment.

Smart Phil also features visual, audible and mobile notification reminders that alert the user when it's time to take their dose. These reminders are fully customizable, adapting to each user's needs and preferences, improving their experience and commitment to medication.

Unlike traditional pillboxes, Smart Phil integrates into the smart device ecosystem [IoT], allowing synchronization with mobile applications or medical platforms to keep a digital record of treatment adherence. This way, family members, caregivers, or healthcare professionals can monitor patient adherence in real time, receive alerts in case of omission, and access detailed reports on their progress. In addition to its individual benefits, the project seeks to reduce healthcare costs associated with medication errors and improve patient's quality of life through the responsible use of technology.

With this initiative support tool, but also represents a step toward the digitalization of healthcare combining technological innovation with human well-being.

Problematic

In the healthcare field, one of the greatest challenges is proper medication management, especially for older adults who must follow long-term treatments.

Factors such as forgetfulness, confusion about schedules, or lack of supervision lead to medication-taking errors, which can lead to medical complications and reduce treatment effectiveness.

Given this situation, we identified the need for an automated technological solution that facilitates medication control, ensures the correct dosage and schedule, and provides users with security, autonomy, and confidence in their daily treatment.

Therefore, we decided to develop a pill dispenser to improve health adherence among older adults.

Justification

The Smart Phil project is justified by its ability to automate the medication administration process, allowing the user to receive the correct dose at the right time, without relying on memory or the constant assistance of a caregiver. This automation not only increases the accuracy and safety of treatment, but also promotes patient independence and confidence, improving their physical and emotional well-being.

Furthermore, the dispenser offers added value in the medical and family setting, as it allows medication intake times to be recorded, generates personalized alerts, and provides remote access to caregivers or healthcare professionals thus facilitating continuous monitoring of therapeutic adherence. This contributes to strengthening the relationship between patient and healthcare system, favoring risk prevention and the early detection of irregularities.

Furthermore, from a technical perspective, it promotes the use of automation, IoT connectivity, and user-centered design as key tools for innovation in the healthcare sector.

In conclusion, Smart Phil not only represents a technological advance, but also a tool with a social and healthcare impact, aimed at reducing medication errors, increasing patient safety, and strengthening personal autonomy. Its implementation directly contributes to the goal of achieving more efficient, humane, and sustainable healthcare.

Methodology

The Scrum methodology is a widely used agile framework for the management and development of technology projects, aimed at improving collaboration, adaptability, and the continuous delivery of functional results. In the Smart Phil project, this methodology allowed the team's work to be efficiently organized, promoting constant communication and continuous improvement at each stage of the smart phil dispenser's development.

Scrum is structured in short work cycles called sprints, which have a defined duration [usually one to four weeks]. Each sprint begins with planning, in which the team establishes clear and achievable objectives, defines priority tasks, and assigns specific responsibilities to each member. At the end of each sprint, a review of results and feedback are provided, allowing for errors to be detected, improvements to be implemented, and the project's course to be adjusted flexibly and quickly. The use of Scrum at Smart Phil allowed for a clear view of progress, fostering team autonomy and accountability, and ensuring that each partial delivery added tangible value to the project. Thanks to this methodology, a process focused on the user's real needs was achieved, thus ensuring a functional and high-quality result.

Development

We made the sketch of our prototype ourselves, which is the Smart Pillbox, we designed it in SolidWorks and sent it to be 3D printed.

Box 1

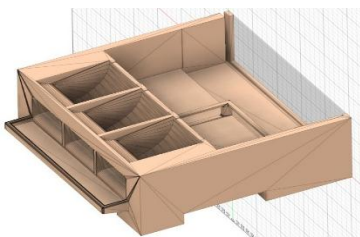


Figure 1

Dispenser model

Our sketch of how our dispenser would be made was created based on what each of us had in mind about how we wanted it to look, which was presented to the collaborative team beforehand to determine if the prototype was suitable for what we wanted.

Box 2

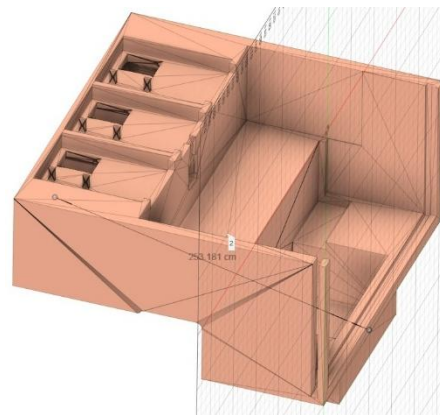


Figure 2

Top of the dispenser

Before starting our project, we made a diagram where we listed all the technologies to be used so we could clearly define what would be needed to carry out the project, since making this diagram made certain points easier for us.

Box 3

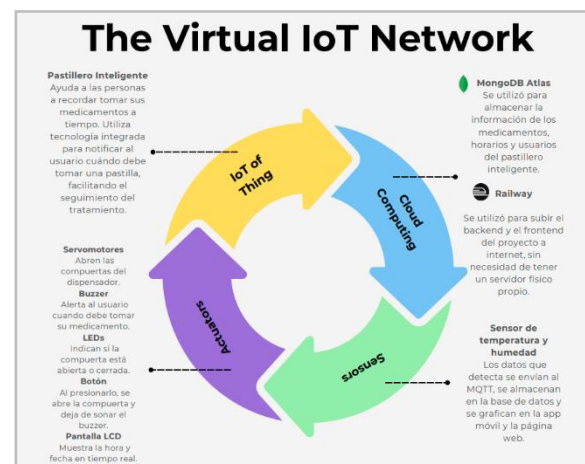


Figure 3

Technology diagram

Similarly, when we knew what was going to be stored in the database, a model was created to define how our database was structured.

Box 4

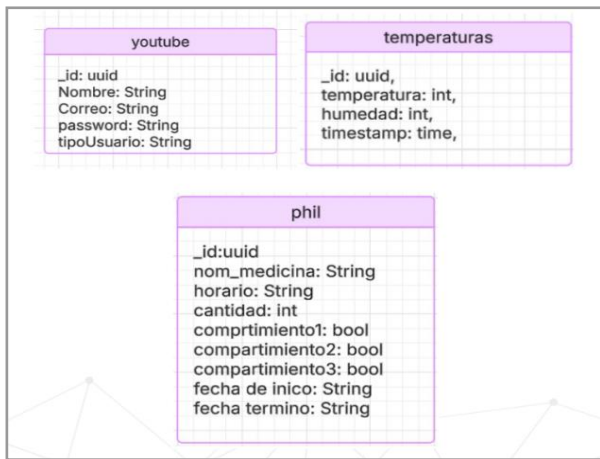


Figure 4 Database composition each table is a collection

Similarly, Mongo Atlas interfaces were created to store data from our website and mobile app.

Our Mongo Atlas interfaces have a collection called test, another called test.youtube, and another called test.temperature, each of which stores data from the website and mobile app.

Here is our test.youtube where there is an Id, Name, Email and password.

Box 5

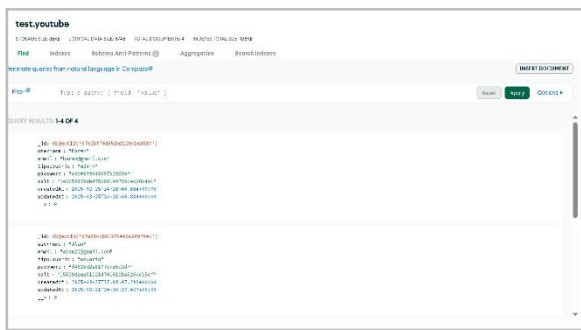


Figure 5 Mongo atlas interface TEST.YOUTUBE

Here is the test.temperature where the Id, Temperature, Humidity and Timestamp are saved.

Box 6

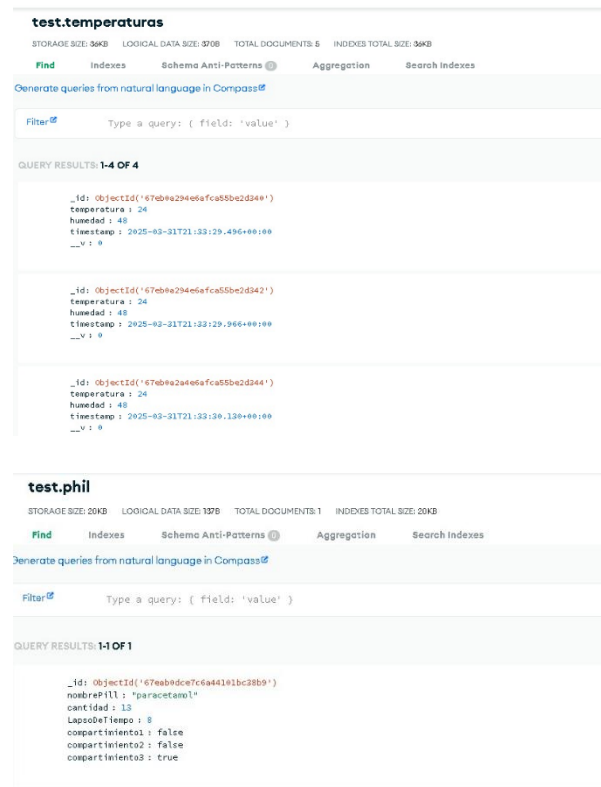


Figure 6 Mongo atlas interface Test.Temperature and Test Phil

We also have test.phil which shows Id, Name, Quantity and Time period.

On our website and mobile app, there's a section that shows us the temperature of the medications in our dispenser. We did this because sometimes medications need to be at a certain temperature.

Below, I'll show a screenshot showing the temperature of the medications on our website.

Box 7



Figure 7 Temperature History (Web Page)

Similarly, the mobile application was programmed to be able to display our graph.

Box 8

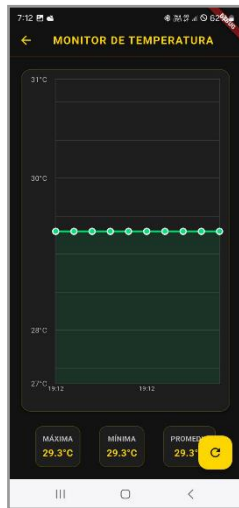


Figure 8

Temperature History (Mobile App)

Results

After implementing and testing the pill dispenser, the result was a functional device that fulfilled its purpose of alerting and dispensing pills at the scheduled time.

The audible and visual alerts were successful, and the user servomotor-operated opening mechanism operated accurately.

The timer programming remained stable, allowing the system to operate error-free.

As general conclusions, it is highlighted that the project demonstrated the feasibility of applying IoT technologies to solve everyday problems and improve user's quality of life.

Opportunities for improvement were identified, such as the integration of an app for remote management.

The project represented an enriching experience that combined programming, electronics, and design knowledge.

The results obtained in our mobile application included Login, Administration User, Management, Registration [if they do not have an account], and graphics.

Box 9



Figure 9

Login (Mobile App)

Here's our login page, which you can use if you already have a Username and Password.

Here's a section where you can register if the user doesn't have an account and can create one in this section.

Box 10

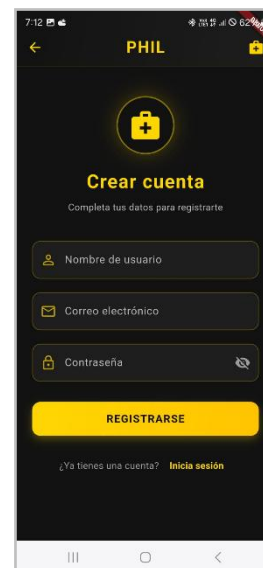


Figure 10

Account registration for login (Mobile App)

Here we see registered users, medications, reports, patients, user management, and settings in our application. This is the main screen that appears when you log in and where the administrator can make changes to medications and users.

Box 11

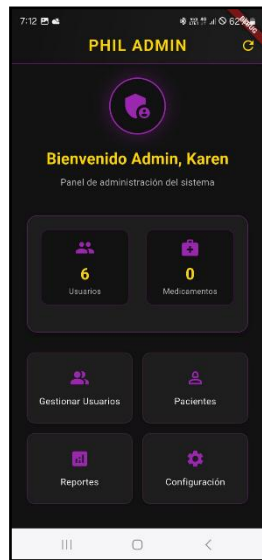


Figure 11

Administrator screen (Mobile App)

Our app also features a user management system that lists users who have logged in and those who are registered

Box 12



Figure 12

User management (Mobile App)

Website

On our website, you can also find several sections:

- Home Page
- Patient Management
- Patient List
- Temperature History
- My Medications

The first section's four websites contain three sections: medications, charts and the compartments of our dispenser.

Box 13

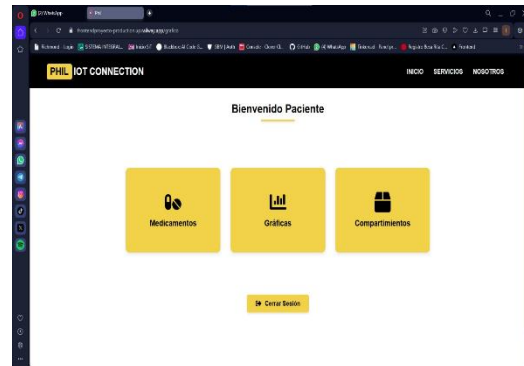


Figure 13

Patient welcome screen (Website)

As the next section we have a patient management in which there are 3 sections in which the first is for patients, the second for patient management and another one which is the reports.

Box 14

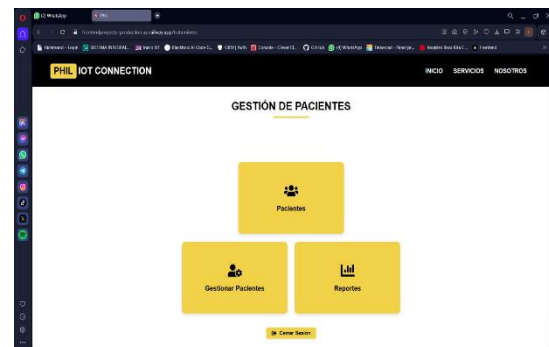


Figure 14

Patient management (Website)

In another section of the page, there is a list of discharged patients, which is the person who will take the medication.

We enter the type of pill, the treatment to be administered, the date and time it should be taken, the dose to be taken, and finally the compartment through which that type of pill will be dispensed.

Box 15

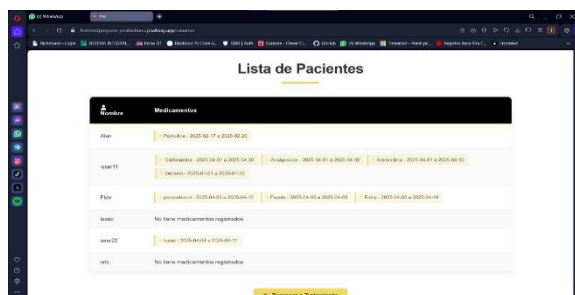


Figure 15

List of patients with details (Website)

Another section on our website is My Medications, which has three sections indicating the prototype's three compartments, as well as the dosage and time the pill will be released from the assigned compartment.

Box 16

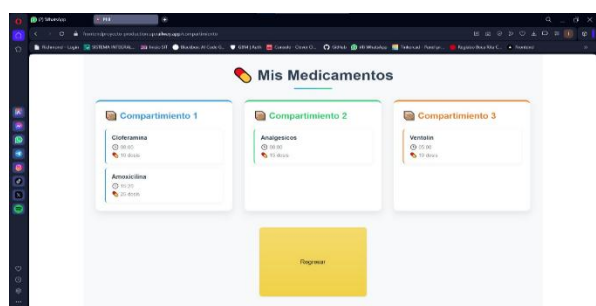


Figure 16

My Medications (Website)

Base de datos

The database created to store all the data generated by both the mobile app and the website also includes a function to create a temperature graph for the tablets.

Box 17

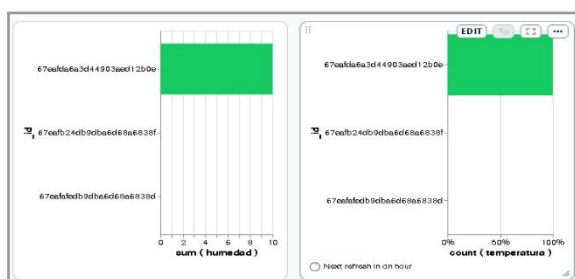


Figure 17

Graph in database (Database)

Our project implemented the MQTT protocol, a lightweight messaging protocol designed for machine-to-machine communication. This allows us to communicate between our dispenser and our project's website and mobile app.

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The dispenser publishes a message in the dispenser/status topic indicating that a pill has been dispensed or if there was an error.

The web/mobile app we have for our project will receive the notification instantly and update the user's status.

Our MQTT protocol showed us that when sending a message, it responds correctly. This step involves entering the time the pill will be dispensed, as well as the compartment.

Box 18



Figure 18

MQTT message sending protocol

Our results regarding our prototype were what we expected, and it resulted in something satisfactory since during testing everything turned out as we had planned in several Scrum meetings.

Box 19



Figure 19

3D Prototype

Cortés-García, Alicia, Valencia-García, Alejandro Cesar, Rodríguez-Miranda, Gregorio and Feregrino-Martínez, Luz María. [2025]. Smart Phil Dispenser - SPD. ECORFAN Journal Bolivia 12[22]1-10: e71222110.

<https://doi.org/10.35429/EJB.2025.12.22.7.1.10>

Our prototype contains several components, one of them is an LCD screen that shows us the time and date, this helps us to check what time our medication is due, we also have two LEDs that indicate when the compartment is going to open and when it indicates that it will close, as well as we have a buzzer that we use as an alarm that tells us when our pill is due and lastly and most importantly we have a button whose function is that when pressed the alarm is deactivated and the compartment is opened through which the pill that corresponds to us will come out, in this case we have 3 different compartments.

Box 20



Figure 20

Prototype with everything implemented

During the assembly process of our prototype, a Raspberry Pi was used to control everything integrated into the prototype, from the operation of the button to the LEDs.

Two fans were also installed on our Raspberry Pi. When everything was connected, the Raspberry Pi temperature rose, causing it to shut down and taking several minutes to restart. So, when it was time to implement everything, it lasted a little longer with the fans.

Box 21

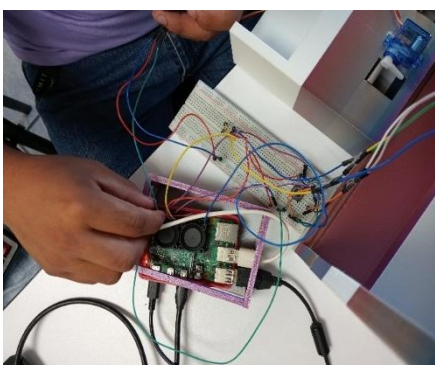


Figure 21

Wiring on the Raspberry

User Tutorial

Step 1: Go to our website

Step 2: Search the website under “My Medications”. Enter the name of the medication and which compartment the pill will be in.

Box 22



Figure 22

My medications screen

Step 3: Send a message using our MQTT protocol.

Box 23

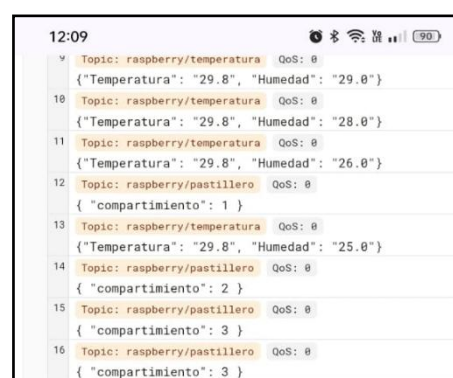


Figure 23

MQTT

Step 4: Verify that the LED and buzzer light up so you can press the button and receive the pill. Tables and adequate sources.

Box 24



Figure 24

LED and buzzer on so they can give me the pill

Step 5: Press the button to open the compartment where the pill will come out.

Box 25**Figure 25***Button*

Step 7: Check where the pill will come out of the compartments that are available in the prototype.

Box 26**Figure 26***Prototype compartments*

And this is how you can use our prototype quickly and safely for your senior health care.

Conclusions

The development of a smart Pill dispenser with integration into web and mobile applications was an exciting and multidisciplinary challenge.

Through a combination of hardware engineering, software development, and user experience design, we were able to create a comprehensive system that facilitates medication management, allowing users to configure and monitor their medication easily and efficiently.

The collaboration of the eight-member team, with clearly defined roles, was key to the project's success. The collaborative work between backend and fronted developers, designers, hardware engineers, and testestr allowed for a comprehensive approach to the technical and functional aspects. Through an agile approach, the research, development, and testing phases were completed in reasonable timeframe components.

The use of technologies such as MongoDB Atlas, Node.js, Flutter and Visual Studio, along with integration with a physical prototype using microcontrollers, provided a robust and scalable solution. Furthermore, the implementation of push notifications and the ability to access the system are both seamless and accessible.

In terms of results, the system meets the proposed objectives, providing a Smart Pill dispenser that not only reminds users when to take their medication but also offers historical usage reports.

However, as with any technology project, there is room for improvements. Future updates may include integration with other health devices or the addition of advanced features such as medication pattern analysis.

Reference**Basic**

Abdulkadhim, F. G., Yi, Z., & Khalid, M. [2020]. SMART PHARMACY MONITORING SYSTEM BASED ON MQTT PROTOCOL USING RFID AND RASPBERRY PI. EUREKA: Physics and Engineering, [2], 98–104.

¿En qué consiste Scrum? - Explicación sobre la metodología Scrum - AWS. [s. f.]. Amazon Web Services, Inc.

Jareño, B. G., Jareño, B. G., & Jareño, B. G. [2024, 27 septiembre]. Los 10 mejores pastilleros para organizar tu medicación semanalmente. El País.

Martins, J. [2025, 15 febrero]. Scrum: conceptos clave y cómo se aplica en la gestión de proyectos [2025]. Asana.

Murphy, J., & Murphy, J. [2025, 11 junio]. A Smart Pill Box to Increase Medication Adherence. Tenovi.

Pastilleros inteligentes e IoT | Casos prácticos | INCE. [s. f.]. INCE.

Tareq, R. W., & Khaleel, T. A. [2021]. Implementation of MQTT Protocol in Health Care Based on IoT Systems: A Study. International Journal of Electrical and Computer Engineering Systems, 12[4], 215–223.

Tsao, Y.-C., Cheng, F.-J., Li, Y.-H., & Liao, L.-D. [2022]. *An IoT-Based Smart System with an MQTT Broker for Individual Patient Vital Sign Monitoring in Potential Emergency or Prehospital Applications. Emergency Medicine International*, 2022, Article 7245650.

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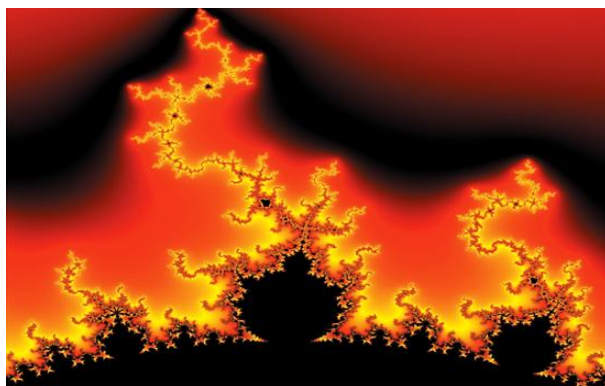


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