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Interface metaphors in Industry 4.0 and their relationship with business competitiveness: a systematic literature review

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ABSTRACT: Industry 4.0 has increased the complexity of digital systems, making effective human–technology interaction essential for business performance. In this context, interface metaphors facilitate users' understanding and interaction with Industry 4.0 technologies. This study analyzes the relationship between interface metaphors in Industry 4.0 environments and business competitiveness through a systematic literature review. Relevant studies were identified and analyzed using established review protocols and academic databases. The results indicate that interface metaphors are mainly applied in human–machine interfaces, data visualization, cyber-physical systems, and digital twins, contributing to improved usability, efficiency and decision-making. These improvements positively influence business competitiveness by enhancing productivity and operational performance. The review also identifies research gaps related to the empirical assessment of interface metaphors and their direct impact on competitive outcomes.

Keywords: Interface metaphors, Industry 4.0, Digital transformation, Human – machine, Business competitiveness

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1. Introduction

The Fourth Industrial Revolution, known as Industry 4.0, has significantly transformed production and business processes through the incorporation of advanced technologies such as artificial intelligence, the Internet of Things (IoT), automation, and data analytics. These innovations have increased the complexity of digital environments and driven changes in organizational competitiveness, enabling companies to optimize operations, improve decision-making and develop new business models. However, the adoption of these technologies has not been uniform across sectors, and many organizations face barriers that limit their effective implementation [1].

In this context, interaction between users and technological systems becomes a central concern, particularly through the digital interfaces used to operate and monitor Industry 4.0 technologies. Interface design and specifically the use of interface metaphors, facilitates the understanding of complex systems by translating abstract technological functions into familiar concepts for users. Previous studies suggest that effective interface interaction can reduce resistance to change, improve technology adoption, and increase operational efficiency, thereby contributing to business competitiveness.

Despite the potential offered by Industry 4.0 many organizations continue to experience resistance or difficulties in its adoption, which may negatively affect their competitiveness in the global market. Factors such as limited technological infrastructure, a shortage of specialized talent, high implementation costs, and uncertainty regarding return on investment have been identified as key obstacles [2]. Beyond these structural and economic barriers, insufficient attention to human–technology interaction and interface usability may further hinder the effective implementation of Industry 4.0 technologies.

Given the relevance of this issue, this study conducts a systematic literature review to analyze the relationship between interface metaphors in Industry 4.0 environments and business competitiveness. Based on the review of 45 scientific articles, the following research questions are addressed: (1) What types of interface metaphors are used in Industry 4.0 environments? (2) In which Industry 4.0 technologies are interface metaphors most frequently applied? (3) How do interface metaphors influence usability, learning, and decision-making in Industry 4.0 systems? (4) What is the relationship between the use of interface metaphors and business competitiveness and innovation?

This systematic review follows a rigorous methodology based on predefined inclusion and exclusion criteria. Studies were selected from recognized academic databases in the fields of business management and technology. The results of the analysis are presented in Section 4, where the findings are classified and discussed in relation to the research questions posed. Finally, Section 5 presents the main conclusions and recommendations derived from the study.

2. Theoretical Overview of the Main Concepts

2.1 Industry 4.0

Industry 4.0 refers to the integration of advanced digital technologies into industrial and business processes, enabling smart, interconnected, and autonomous systems. It is characterized by the convergence of technologies such as the Internet of Things (IoT), artificial intelligence, big data analytics, cloud computing, and cyber-physical systems. These technologies allow real-time data exchange, decentralized decision-making, and increased flexibility in production and service operations. From a business perspective, Industry 4.0 is closely associated with digital transformation, innovation, and the pursuit of competitive advantage through enhanced efficiency, productivity, and responsiveness to market demands [3].

2.2 Interface Metaphors

Interface metaphors are conceptual tools used in human–computer interaction to represent complex or abstract system functions through familiar and easily recognizable concepts. By drawing on users' prior knowledge and everyday experiences, interface metaphors facilitate understanding, learning, and interaction with digital systems. Common examples include desktop metaphors, dashboards, and visual representations that mimic physical objects or processes. In Industry 4.0 environments, interface metaphors play a critical role in supporting user interaction with complex systems such as cyber-physical systems, data analytics platforms, and digital twins, where large volumes of information must be interpreted quickly and accurately [4]

2.3 Human–Computer Interaction in Industry 4.0

Human–computer interaction (HCI) focuses on the design and evaluation of interactive systems that are usable, efficient, and aligned with users' cognitive capabilities. In Industry 4.0 contexts, HCI becomes particularly relevant due to the increasing complexity of technological systems and the need for effective collaboration between humans and intelligent machines. Well-designed interfaces, supported by appropriate metaphors, can reduce cognitive load, minimize errors, and improve user satisfaction. As a result, HCI principles contribute to greater system acceptance and more effective use of Industry 4.0 technologies within organizations [5]

2.4 Business Competitiveness

Business competitiveness refers to an organization's ability to achieve and sustain superior performance in comparison to its competitors. It is commonly associated with factors such as productivity, innovation, operational efficiency, quality, and adaptability to changing market conditions. In the context of Industry

4.0, competitiveness is increasingly influenced not only by technological adoption but also by how effectively technologies are integrated into organizational processes and daily operations. Interface metaphors, by enhancing usability and supporting decision-making, can indirectly strengthen competitiveness by improving employee performance, reducing operational risks, and facilitating innovation [6]

2.5 Relationship between Interface Metaphors, Industry 4.0, and Competitiveness

The relationship between interface metaphors and business competitiveness in Industry 4.0 can be understood through their impact on usability, learning, and decision-making. Interface metaphors enable users to interact more effectively with complex digital systems, leading to higher adoption rates and more efficient use of Industry 4.0 technologies. This improved interaction supports operational efficiency, faster response times, and better-informed decisions, which are essential elements of competitive performance. Despite this potential, the literature reveals a fragmented understanding of how interface metaphors contribute to competitiveness, highlighting the need for systematic analysis, as addressed in this study [7].

3. Methodology

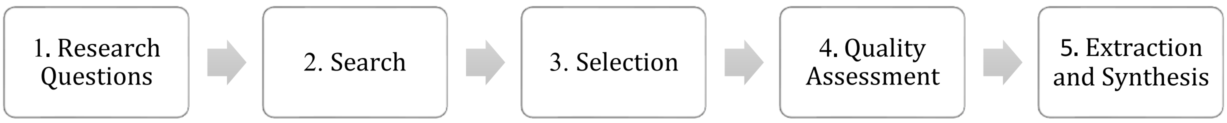
This study adopts a rigorous and structured approach based on the Systematic Literature Review (SLR) methodology, widely used across different fields to consolidate scientific evidence, identify research trends, gaps, and future research directions [8]. To manage and select the articles, the Rayyan tool was employed, a web-based platform designed to support the systematic screening of scientific literature. After removing duplicate records, the retrieved articles were imported into Rayyan, where a blinded review process was conducted. This procedure enabled the independent application of predefined inclusion and exclusion criteria, reducing selection bias and strengthening the reliability of the review process.

The purpose of this review is to analyze the role of interface metaphors in Industry 4.0 environments and their relationship with business competitiveness, considering their influence on usability, technology adoption, decision-making, and organizational performance.

The development of this systematic literature review was carried out through five main stages, which are illustrated in Figure 1. These stages provide a structured and transparent methodological framework, ensuring the rigor and reproducibility of the review process. Each phase is described in detail in the following subsections, offering a clear and systematic view of the approach adopted in this study.

Figure 1

Phases of the methodological process for the development of the review



3.1 Research Questions

The objective of this study is to analyze the findings derived from a systematic review of the scientific literature on the use of interface metaphors in Industry 4.0 technologies and their impact on business competitiveness. To structure the analysis and establish the state of the art, the following research questions were formulated:

- **RQ1:** What types of interface metaphors are used in Industry 4.0 environments?
- **RQ2:** In which Industry 4.0 technologies are interface metaphors most frequently applied?
- **RQ3:** How do interface metaphors influence usability, learning, and decision-making in Industry

4.0 systems?

- **RQ4:** What is the relationship between the use of interface metaphors and business competitiveness and innovation?

The structuring of these questions was carried out using PICO with its variant PIPOH, a widely recognized methodology for structuring research questions in systematic reviews, since it allows incorporation of key variables such as context, population and expected results [9]. Their definitions are described in Table 1.

Table 1
Defining analysis categories using the PIPOH framework

Criterion	Description
Population	Companies and productive sectors that have adopted Industry 4.0 technologies with digital user interfaces.
Intervention	Use of interface metaphors in human–computer interaction within Industry 4.0 systems.
Results	Studies analyzing usability, technology adoption, decision-making, business competitiveness, and innovation outcomes.
Professionals	Experts and researchers in human–computer interaction, interface design, Industry 4.0, digital transformation, and business management.
Context	Business and industrial environments where Industry 4.0 technologies are deployed.

3.2 Search

In this phase, search criteria were defined to identify relevant studies within the scope of the systematic literature review. The main objective was to ensure comprehensive coverage of the scientific literature addressing interface metaphors in Industry 4.0 environments and their relationship with business competitiveness, guaranteeing the inclusion of relevant, recent, and scientifically validated documents. To this end, key terms related to Industry 4.0, interface metaphors and interface design, and business competitiveness were identified, along with their corresponding synonyms or related terms. Table 2 presents the main terms used to construct the search string.

Table 2

Main terms, synonyms, and related concepts used to construct the search string

Main Terms	Synonyms/related terms
Industry 4.0	Fourth Industrial Revolution Intelligent Industry
Interface metaphors	User interface metaphors; Interface design; Human–computer interaction
Business competitiveness	Business Performance Organizational Performance

Based on these terms, the following search string was constructed:

("Industry 4.0" OR "Fourth Industrial Revolution" OR "Intelligent Industry")
AND ("Interface Metaphor*" OR "User Interface Metaphor*" OR "Interface Design" OR "Human–Computer Interaction")
AND ("Business Competitiveness" OR "Business Performance" OR "Organizational Performance")

The search was conducted in scientific databases of recognized academic prestige, including ACM Digital Library, IEEE Xplore, Scopus, and ScienceDirect. These databases were selected due to their extensive coverage of research in engineering, human–computer interaction, digital technologies, and business management, ensuring the inclusion of high-quality and relevant studies for the analysis.

3.3 Selection

All studies included in this review were examined in detail. During their evaluation, aspects such as the title, keywords, abstract, introduction, background, state of the art, methodology, results, and conclusions were considered. Additionally, predefined inclusion and exclusion criteria were established to ensure the quality and relevance of the selected studies. These inclusion (I) and exclusion (E) criteria allowed for filtering the articles according to their relevance to the analysis.

Inclusion Criteria (I)

I1: Articles published in the last five (5) years.

I2: If several articles correspond to the same study, the most recent version is selected.

I3: Articles available in full-text format.

Exclusion Criteria (E)

E1: Technical documents, abstracts, or conference presentations were excluded.

E2: Articles written in languages other than English or Spanish were not considered.

E3: Articles not related to Industry 4.0, interface-related aspects, or business competitiveness were excluded.

The selection process of primary sources was carried out in three phases. The first phase involved the elimination of duplicate records. In the second phase, titles and abstracts were reviewed to assess their relevance. Finally, in the third phase, the full text of the remaining articles was examined to determine their suitability for inclusion.

As a result of the initial search conducted in the selected databases, 504 studies were identified. After applying the inclusion and exclusion criteria and completing the full-text review, the final number of documents selected for analysis was 45 articles. The distribution of the initial set of primary studies retrieved from each database is presented in Table 3.

Table 3

Number of primary education levels obtained

Databases	Amount
ACM Digital Library	**103**
IEEE Xplore	7
Scopus	294
ScienceDirect	100
Total	504

3.4 Quality assessment

The quality assessment process for the selected documents considered seven fundamental criteria: the origin and credibility of the sources, relevance of the content to interface metaphors and Industry 4.0 contexts, impact of the study, clarity of the research objectives, context of the study, objectivity of the methodological design, and scientific rigor in data analysis. These criteria are aligned with the three core pillars of quality management, planning, organization and control as proposed by Jiménez Ávila et al. (2021).

Furthermore, the evaluation process involved the complete reading and systematic analysis of the 45 selected studies. This process included the verification of full-text availability, the elimination of duplicate and non-accessible articles, and the rigorous application of the predefined inclusion and exclusion criteria. The quality assessment procedure and the resulting classification of studies are summarized in Table 4.

3.5 Data Extraction and Results Synthesis

This section presents the findings derived from the systematic analysis of the 45 selected articles, with the aim of structuring relevant information on the relationship between interface metaphors, Industry 4.0 environments, and business competitiveness. For this purpose, key data were extracted from each study, including publication year, research objectives, methodological approach, industrial context, type of Industry 4.0 technologies involved, and the role of interface-related concepts such as usability, visualization, user interaction, and metaphor-based design. This process enabled the identification of recurring patterns, dominant research trends, and prevailing analytical perspectives across the literature. Subsequently, the extracted evidence was synthesized and organized into thematic categories aligned with the research questions. These categories facilitate a comprehensive understanding of how interface metaphors support user interaction with complex Industry 4.0 systems, influence technology adoption and decision-making processes, and contribute to organizational performance, innovation, and competitive outcomes. This synthesis provides a solid foundation for the discussion of results and the formulation of conclusions presented in the following sections.

4. Discussion

The results of this systematic literature review highlight the relevance of interface metaphors as a key enabling factor in the effective use of Industry 4.0 technologies and their contribution to business competitiveness. While most studies emphasize technological infrastructure and automation, the findings show that the human–technology interaction dimension plays a essential mediating role. Interface metaphors support users' understanding of complex Industry 4.0 systems by reducing cognitive load, improving usability, and facilitating learning. These effects positively influence technology acceptance, system adoption, and decision-making processes, which are recurrent challenges in digital transformation initiatives. From a competitiveness perspective, the reviewed literature suggests that interface metaphors contribute indirectly to improved organizational performance by enabling faster responses, better use of real-time data, and more informed strategic and operational decisions. However, the analysis also reveals that the role of interface metaphors is often addressed implicitly, indicating a fragmented theoretical treatment within Industry 4.0 research. Overall, the discussion underscores the need to integrate interface metaphors more explicitly into Industry 4.0 frameworks, as they represent a strategic link between advanced technologies, user cognition, and competitive outcomes.

5. Synopsis of the Main Research Outcomes

5.1 Industry 4.0: Technological transformation, interface interaction, and opportunities

Industry 4.0, also known as the Fourth Industrial Revolution, represents a disruptive transformation of production systems and business management. Introduced in Germany in 2011 as part of a national strategy to digitize the manufacturing industry, this concept encompasses the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, advanced robotics, additive manufacturing, and cloud computing [1]. These technologies operate within highly digitalized environments in which human–machine interaction and digital interfaces play a central role, shaping how users understand, control, and interact with complex industrial systems.

The literature highlights that these technologies, when combined with intuitive and well-designed interfaces, create interconnected ecosystems that optimize production processes, increase productivity, stimulate innovation, and enhance organizational adaptability in competitive global markets [11]. In this context, interface metaphors such as dashboards, digital twins, or visual representations of physical processes serve as cognitive bridges that facilitate user interaction with complex technological infrastructures.

Among the most fundamental components of Industry 4.0 is IoT, which enables communication between devices through intelligent networks and supports real-time data visualization via digital interfaces. This capability transforms production processes by enabling predictive maintenance, reducing operational failures, and optimizing resource use, while making system behavior more comprehensible to users [12]. Similarly, AI automates decision-making through advanced algorithms and is frequently mediated through interface metaphors that support interpretation, control, and trust, thereby improving customization and supply chain management [13].

Big data and advanced analytics further enhance these capabilities by processing large volumes of information and presenting insights through visual and interactive interfaces. These representations support strategic decision-making by revealing patterns and trends essential for competitive positioning, particularly in manufacturing environments where real-time monitoring and adaptive control are required [3]. Likewise, technologies such as 3D printing redefine manufacturing paradigms and are increasingly supported by digital interfaces that simplify design processes and enable mass customization.

However, the effective implementation of Industry 4.0 depends not only on technological acquisition but also on organizations' capacity to integrate these systems into everyday operations through usable and meaningful interfaces. Challenges such as high initial investment, continuous staff training, and the need to develop digital competencies remain significant barriers [2]. Consequently, companies must adopt strategies that address both technological infrastructure and interface design, fostering organizational cultures that support user-centered digital transformation [14].

As companies progressively adopt Industry 4.0 technologies, a profound shift in their relationship with consumers is also evident. Digital technologies, in this sense, facilitate greater interaction and product personalization, which in turn enhances customer experience. The use of AI and big data allows companies to gain a deeper understanding of consumer needs and preferences, offering more tailored and precise solutions. Thus, this approach not only improves companies' competitiveness but also generates lasting value that extends beyond simply selling products, establishing long-term relationships with consumers [15].

In this context, Industry 4.0 is positioned as a key driver for long-term business sustainability. By incorporating technologies such as advanced robotics and 3D printing, organizations have the opportunity to optimize resource use, reduce waste, and minimize the environmental impact of their operations [16]. Furthermore, digitalization enables the implementation of business models based on the circular economy, which promote the reuse and recycling of materials. This approach, therefore, not only contributes to environmental sustainability but also responds to the growing expectations of consumers and regulators regarding corporate social responsibility [17]. Consequently, the synergy between sustainability and technology has become a fundamental aspect for companies seeking to remain competitive and relevant in a market increasingly focused on sustainability.

5.2 Business Competitiveness in digital and interface-mediated environments

Business competitiveness refers to an organization's ability to generate value, respond to market demands, and sustain long-term performance. This concept includes operational efficiency, innovation capacity, adaptability, product and service quality, and effective human talent management [18]. In the context of a globalized and technologically advanced environment, business competitiveness is increasingly linked to the adoption and implementation of disruptive technologies.

The literature emphasizes that digitalization and automation, supported by data-driven decision-making and user-friendly interfaces, are critical factors for organizational success in highly competitive markets [19]. In this sense, interface metaphors contribute to reducing system complexity, improving usability, and accelerating technology adoption, which directly impacts productivity and performance.

Sustainability also emerges as a key dimension of competitiveness. Companies that integrate responsible practices and transparent digital systems enhance their reputation and strengthen stakeholder trust. Interface design plays a supporting role by making sustainability indicators, resource consumption, and environmental impact more visible and understandable to decision-makers [20].

From a theoretical perspective, mod els such as Porter's Diamond and the resource-based view (RBV) highlight the importance of internal capabilities, knowledge, and innovation in achieving competitive advantage [21]. Within Industry 4.0, interface metaphors can be considered strategic intangible resources, as they support knowledge integration, organizational learning, and effective use of technological assets.

5.3 Research findings overview

This This section presents an overview of the findings obtained after applying the search and selection protocol defined for this systematic literature review, focused on interface metaphors in Industry 4.0 and their relationship with business competitiveness.

The initial search conducted in the selected academic databases—IEEE Xplore, ACM Digital Library, Scopus, and ScienceDirect—yielded a total of 504 records, as summarized in Table 4. These records were identified using search strings that combined terms related to Industry 4.0, business competitiveness, and digital industrial environments.

In the first stage of the selection process, 97 duplicate records were identified and removed across the databases, resulting in a refined set of unique studies. Subsequently, a screening process was carried out based on predefined exclusion criteria, during which 241 articles were excluded due to lack of thematic relevance, document type limitations, language restrictions, or insufficient methodological rigor.

After applying all inclusion and exclusion criteria and completing the screening and eligibility assessment phases, a total of 45 relevant articles were selected for final analysis. These studies met the established quality standards and directly addressed aspects related to Industry 4.0 and business competitiveness, while also incorporating—either explicitly or implicitly—elements associated with interface design, interaction mechanisms, or user–system communication within digital and industrial contexts.

Table 4 summarizes the distribution of search results, duplicate records, excluded studies, and relevant articles across the four academic databases. Notably, ACM Digital Library and Scopus contributed the highest number of relevant studies, while IEEE Xplore provided a limited but focused contribution. In contrast, no relevant articles were retained from ScienceDirect after the application of all selection criteria.

Finally, Figure 1 illustrates the overall filtering and selection process, visually representing each stage from the initial identification of studies to the final inclusion of the 45 articles that constitute the empirical basis of this systematic literature review.

Table 4

Quality assessment in search and selection processes

Main term	Search results	Duplicate files	Excluded Files	Relevant files	Databases
Industry 4.0 Business competitiveness	7	0	6	1	IEEE Xplorer
	103	4	75	24	ACM Digital Library
	294	85	189	20	Scopus
	100	8	93	0	Science Direct
Total	504	97	241	45	

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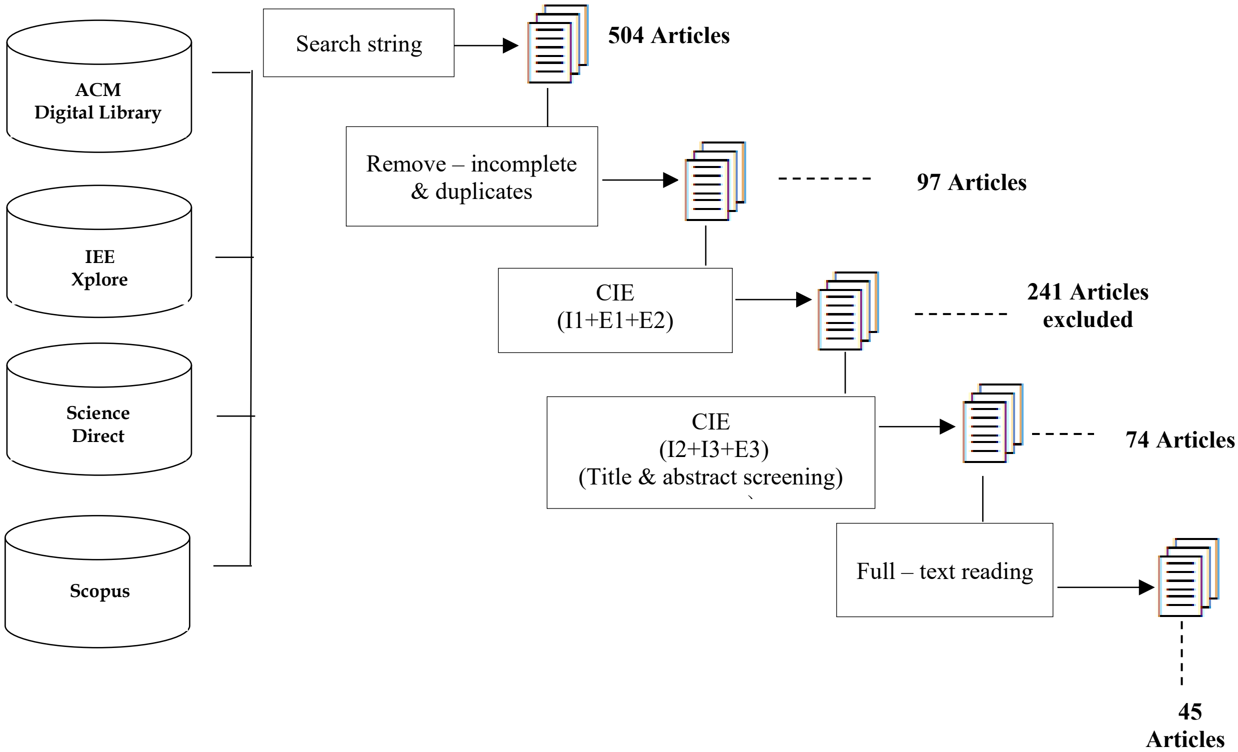
Figure 1

Overview of the article filtering process



4.1 Impact of Industry 4.0 technologies and interface metaphors on business competitiveness

The results obtained from the systematic literature review indicate that the adoption of Industry 4.0 technologies has a profound and multifaceted impact on business competitiveness. However, the findings also highlight that this impact is not determined solely by the technological infrastructure itself, but significantly influenced by how these technologies are presented, interpreted, and managed through interface design and interaction mechanisms. In this context, interface metaphors play a critical role as cognitive bridges between complex digital systems and human users.

Technologies such as the Internet of Things (IoT), artificial intelligence (AI), Big Data analytics, advanced robotics, and process automation generate large volumes of data and complex operational environments. The reviewed studies consistently emphasize that effective interface metaphors such as dashboards, digital twins, visual workflows, and symbolic representations enable users to understand, control, and trust these systems, directly influencing organizational performance and competitiveness [22].

Most studies agree that Industry 4.0 technologies contribute significantly to optimizing operational efficiency when supported by intuitive and well-designed interfaces. Automation of repetitive tasks, reduction of human error, and improved resource management are strongly linked to interfaces that reduce cognitive load and facilitate rapid decision-making. For instance, IoT-based systems supported by real-time visual dashboards allow managers to monitor supply chains, predict failures, and respond promptly to disruptions, thereby reducing costs and increasing operational agility [23].

Furthermore, AI- and Big Data-driven systems rely heavily on interface metaphors to translate complex analytical outputs into actionable insights. Visual analytics, predictive indicators, and scenario-based representations enhance strategic decision-making, allowing organizations to respond proactively to market changes. The literature highlights that companies with user-centered interface designs are more likely to fully exploit the competitive potential of Industry 4.0 technologies [24].

The findings also reveal that the impact of these technologies and their interfaces varies across sectors and depends on the level of digital maturity of organizations. In the manufacturing sector, cyber-physical systems and digital twins supported by spatial and process-based metaphors have significantly increased productivity, product quality, and cost efficiency. In contrast, service-oriented sectors emphasize interface personalization and interaction quality to improve customer experience and service innovation [7].

Despite these benefits, the literature also identifies challenges related to interface complexity, usability issues, and resistance to digital interaction. High initial investments, lack of interface design expertise, and organizational resistance to new interaction paradigms can limit the competitive benefits of Industry 4.0. Nevertheless, studies consistently conclude that organizations that invest in effective interface metaphors and human-centered interaction design gain sustainable competitive advantages by improving adaptability, efficiency, and decision quality [25].

la transición hacia la Industria 4.0 no debe centrarse exclusivamente en la automatización y la digitalización de los procesos productivos, sino en el fortalecimiento del rol del operador humano dentro de entornos industriales cada vez más complejos. A través del concepto de Operator 4.0, los autores proponen una tipología que integra tecnologías avanzadas —como sistemas ciberfísicos, inteligencia artificial y analítica de datos— con interfaces diseñadas para ampliar las capacidades cognitivas, físicas y decisionales del trabajador. En este contexto, el diseño de interfaces y el uso de metáforas visuales y funcionales resultan elementos clave para facilitar la interacción humano-máquina, reducir la carga cognitiva y mejorar la comprensión de los sistemas digitales. Este enfoque humano-céntrico contribuye directamente a una mayor eficiencia operativa, a la reducción de errores y a una mejor toma de decisiones, lo que se traduce en una ventaja competitiva sostenible para las organizaciones que adoptan modelos de Industria 4.0 orientados al usuario [26]

4.2 Contribution of interface metaphors to digital transformation in productive sectors

Industry 4.0 has played a central role in accelerating the digital transformation of productive sectors by introducing disruptive technologies that redefine traditional operational and managerial models. Beyond process digitization, these technologies enable the creation of intelligent, interconnected, and data-driven environments in which interfaces and interaction mechanisms act as key mediators between humans and complex industrial systems [1].

One of the main contributions of Industry 4.0 lies in process automation supported by cyber-physical systems and smart devices. These systems rely on advanced human–machine interfaces that use visual, spatial, and conceptual metaphors to represent production processes, system status, and performance indicators in real time. Such interfaces enhance situational awareness, improve resource optimization, and enable greater flexibility in production planning [27].

Additionally, Industry 4.0 has significantly improved information management through Big Data and AI. Predictive analytics and real-time monitoring systems depend on interface metaphors to communicate patterns, trends, and anomalies effectively. Dashboards, heat maps, and simulation-based interfaces allow users to anticipate operational issues and adjust strategies proactively, which is essential in highly competitive environments [28].

Digital transformation also extends to business model innovation. Interface-driven personalization of products and services allows organizations to better understand customer needs and respond more efficiently. In this sense, interfaces become strategic assets that shape customer experience, employee performance, and inter-organizational collaboration [29]. However, the literature emphasizes that successful digital transformation requires more than technological infrastructure. Challenges such as skills development, change management, and interface usability must be addressed to ensure effective human–technology integration and sustainable transformation over time [30].

Moreover, recent studies highlight that interface metaphors play a critical role in reducing the cognitive complexity associated with advanced industrial systems. As Industry 4.0 environments increasingly rely on autonomous and semi-autonomous processes, well-designed metaphors—such as digital twins, virtual dashboards, and spatial representations—help operators interpret system behavior and make informed decisions more efficiently. This cognitive support is particularly relevant in smart manufacturing contexts, where human oversight remains essential despite high levels of automation [31].

Another important contribution of interface metaphors to digital transformation lies in supporting human-centric and inclusive industrial systems. Research emphasizes that intuitive and adaptive interfaces enable a wider range of users, with varying skill levels, to interact effectively with complex technologies. By aligning interface design with human capabilities, organizations can enhance learning, reduce errors, and foster workforce acceptance of digital transformation initiatives, which directly impacts productivity and organizational performance [32]. The integration of emerging interaction technologies—such as augmented reality, virtual reality, and mixed reality—has expanded the scope of interface metaphors in productive sectors. These technologies enable immersive and context-aware representations of industrial processes, facilitating remote collaboration, training, and real-time decision support. Empirical evidence suggests that such immersive interface metaphors not only improve operational efficiency but also strengthen organizational resilience and competitiveness by enabling faster adaptation to dynamic industrial environments [33].

4.3 Factors that limit the adoption of Industry 4.0 technologies

The adoption of Industry 4.0 technologies faces several challenges that affect their effective implementation in different productive sectors [34]. These limiting factors encompass technological, economic, organizational, and sociocultural aspects, creating barriers that hinder the realization of the potential of digital transformation. Table 5 below presents the main factors that obstruct this process:

Table 5

Critical Limitations in the Digital Transformation of Industry 4.0

Limiting Factor	Description
Insufficient Technological Infrastructure	Limited connectivity, equipment obsolescence, and a lack of robust digital platforms.
Shortage of Qualified Talent	Shortage of professionals with skills in data analysis, automation and cybersecurity.
Resistance to Organizational Change	Conservative attitudes, fear of failure and lack of digital culture in organizations.
High Initial Investment Costs	Difficulty in financing technological equipment, digital infrastructure and staff training.
Lack of Clear Policies and Regulations	Absence of government incentives, regulatory frameworks and interoperability standards.
Cybersecurity Risks	Concern about technological vulnerabilities, cyberattacks and protection of sensitive data.
Limited Access to Financing	Difficulty in obtaining credit or economic resources that facilitate investment in technology.
Low Awareness of the Benefits	of awareness of the positive impact of Industry 4.0 on business competitiveness and efficiency.
Interoperability Issues	Difficulties in integrating technologies from different providers due to the lack of common standards.
Weak Change Management	Lack of organizational strategies to effectively lead digital transformation processes.
Regional Digital Divide	Inequality in technology adoption between urban and rural areas due to infrastructure and connectivity limitations.
Implementation Complexity	Difficulty in integrating and managing advanced technologies due to their complex and dynamic nature.
Ethical and Legal Aspects	Concerns about data privacy, automation of work, and accountability in algorithmic decisions.

4.4 Relationship between the adoption of Industry 4.0 technologies and business innovation

The relationship between Industry 4.0 technologies and business innovation is a central theme in the reviewed literature. These technologies introduce new opportunities for innovation not only through automation and data analytics but also through novel forms of interaction enabled by digital interfaces and metaphor-based design [35]. Advanced tools such as AI, IoT, Big Data analytics, and additive manufacturing facilitate the development of innovative products, services, and business models. Interface metaphors enable organizations to translate technological complexity into accessible and actionable systems, supporting experimentation, rapid prototyping, and continuous improvement [14].

Furthermore, Industry 4.0 enhances firms' capacity to innovate by improving operational efficiency, reducing costs, and accelerating data-driven decision-making. Interactive platforms and visualization-based interfaces allow organizations to collaborate more effectively within digital ecosystems, fostering co-creation with customers, suppliers, and partners [36]. Innovation is also reflected in new business models based on servitization, mass customization, and platform-based strategies. These models rely heavily on interface design to support user engagement, personalization, and seamless interaction across digital touchpoints [37].

Nevertheless, the literature emphasizes that the innovative potential of Industry 4.0 depends on organizational culture, workforce skills, and strategic alignment. Companies that integrate interface design and interaction metaphors into their innovation strategies are better positioned to enhance learning, usability, and adaptability, thereby sustaining competitiveness in highly dynamic industrial environments [38]. Interface metaphors also support strategic alignment between technology and business objectives in Industry 4.0 environments. By translating complex processes and large data volumes into intuitive visual and interactive representations, such as dashboards and dynamic models, these interfaces enhance shared understanding and enable faster, more informed decision-making. As a result, organizations improve their responsiveness to competitive changes and strengthen sustainable competitive advantages [39].

4.5 Interface Metaphors and Human–Machine Interaction in Industry 4.0

Beyond the adoption of core Industry 4.0 technologies, recent research emphasizes the critical role of human–machine interaction (HMI) and interface metaphors in enabling effective collaboration between operators and digital systems [40] . Studies show that as manufacturing and cyber-physical systems become more complex, traditional static interfaces are no longer sufficient, and there is a clear trend toward adaptive, multimodal, and context-sensitive designs that support operators' decision-making, reduce cognitive load, and enhance competitiveness. For example, adaptive human–machine interfaces that leverage machine learning to personalize interaction have been proposed to improve user experience and reduce cognitive workload in industrial settings, highlighting the importance of contextual interaction data in interface design [41]. Multimodal interfaces combining visual, auditory, gesture, and other interaction channels have been shown to offer enhanced immersion and usability in digital production environments, suggesting that diversified interface metaphors can support complex tasks more effectively than traditional single-mode designs [42].

Furthermore, emerging research on extended reality (XR) visual guidance indicates that immersive visual metaphors significantly improve task performance and reduce errors in virtual assembly tasks, demonstrating the potential competitive advantage of integrating advanced visualization techniques in industrial operations [43]. Empirical work also suggests that the representation of prototypes and interface metaphors in simulated environments (e.g., VR) influences user perception, trust, and experiential aspects of human–machine interaction, which are key factors for user acceptance and system performance [44]. Editorial perspectives on human–media interaction emphasize that Industry-oriented interfaces are fundamental for bridging the gap between humans and machines in digitalized industrial systems, empowering workers to interact effectively with data-rich environments and fostering collaborative decision-making .

The field of human–computer interaction (HCI) within smart factories continues to expand, with special issues and systematic reviews underscoring the need for user-centered and context-aware interfaces to support human roles in digital manufacturing and improve competitive outcomes[5]. Classic studies of human-centred design in Industry 4.0 reinforce that interactive interfaces must account for cognitive ergonomics, task complexity, and user variability to achieve effective human–technology synergy and competitive productivity gains [32]. Additionally, research in interactive systems points to the potential of tangible and enactive interfaces to reorganize human engagement with industrial processes, suggesting that physical and multimodal metaphors can enhance intuitive interaction and operator performance.

Finally, systematic reviews of multimodal human–computer interaction show that immersive technologies such as VR, haptics, and other display modalities are increasingly relevant across domains including industry indicating that interface metaphors leveraging these technologies could shape future competitiveness paradigms [45]. Collectively, these studies demonstrate a growing research trend toward understanding how interface metaphors and advanced interaction techniques can mediate the relationship between technological complexity and human performance, ultimately contributing to enhanced organizational competitiveness in the era of Industry 4.0.

6. Conclusions

This systematic literature review highlights that the adoption of Industry 4.0 technologies significantly contributes to business competitiveness; however, its impact is strongly mediated by the design and implementation of effective human–machine interfaces. In particular, interface metaphors emerge as a critical element for enabling meaningful interaction between users and complex digital systems, facilitating understanding, usability, and decision-making in industrial environments. Organizations that strategically integrate interface metaphors into their digital transformation initiatives are better positioned to optimize processes, reduce operational errors, and enhance responsiveness to market demands, thereby achieving sustainable competitive advantages.

The findings also indicate that interface metaphors play a key role in supporting the digital transformation of productive sectors by bridging the gap between advanced technologies—such as artificial intelligence, the Internet of Things, and data analytics—and human operators. Well-designed interfaces contribute to improved cognitive support, increased system transparency, and more effective use of real-time information across the value chain. This human-centered approach not only improves operational efficiency but also strengthens organizational learning and innovation capabilities.

Despite these benefits, the literature identifies persistent challenges that limit the effective adoption of interface metaphors within Industry 4.0 contexts. High initial investment costs, limited availability of skilled personnel in interface and interaction design, resistance to organizational change, and concerns related to interoperability and cybersecurity remain significant barriers. Addressing these challenges requires comprehensive strategies that combine technological investment with user training, change management, and a strong emphasis on usability and user experience.

In conclusion, the relationship between interface metaphors in Industry 4.0 and business competitiveness is both direct and strategic. Beyond technological adoption alone, competitive advantage increasingly depends on how organizations design, implement, and manage interfaces that support human interaction with digital systems. Future research should further explore empirical evidence on the effectiveness of specific interface metaphors across sectors, as well as their long-term impact on innovation, performance, and sustainable growth.

7. Limitations, Implications, and Further Directions of Research

Lorem Despite the contributions of this systematic literature review, several limitations must be acknowledged. First, the analysis was restricted to articles published in English and Spanish and indexed in four major academic databases (IEEE Xplore, ACM Digital Library, Scopus, and ScienceDirect). Although these sources ensure high-quality and peer-reviewed content, relevant studies published in other languages or indexed in alternative databases may have been excluded. Second, the review focused on a five-year publication window, which, while ensuring the inclusion of recent and relevant research, may have limited the consideration of foundational or earlier studies related to interface metaphors and human–machine interaction in industrial contexts. Additionally, the diversity of methodological approaches across the selected studies made it challenging to conduct direct quantitative comparisons.

From a practical perspective, the findings of this review have important implications for both industry and academia. For practitioners, the results emphasize that business competitiveness in Industry 4.0 environments depends not only on technological adoption but also on the effective design of human–machine interfaces. Interface metaphors play a crucial role in supporting usability, operator understanding, and decision-making, suggesting that organizations should integrate human-centered design principles into their digital transformation strategies. For policymakers and managers, these findings highlight the need to invest in training programs that combine technical skills with competencies in interface and interaction design. In terms of theoretical implications, this study contributes to the literature by linking interface metaphors with business competitiveness, an area that has received limited explicit attention in previous research. By framing interface metaphors as a mediating factor between advanced technologies and organizational performance, this review extends existing discussions on Industry 4.0 beyond purely technological or operational perspectives.

Future research should address the identified gaps by conducting empirical and longitudinal studies that evaluate the direct impact of specific interface metaphors on productivity, innovation, and competitive performance across different sectors. Comparative studies between industries and organizational contexts could provide deeper insights into how interface design influences technology adoption and user acceptance. Furthermore, future work should explore emerging technologies such as augmented reality, digital twins, and adaptive interfaces, examining how new forms of interface metaphors can enhance human–machine collaboration and support sustainable competitiveness in Industry 4.0 environments.

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