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User-centered Augmented Reality

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ABSTRACT

Augmented Reality (AR) is one of the emerging technologies with the greatest potential to transform interaction processes between individuals and digital information. Unlike virtual reality, which immerses users in fully simulated environments, AR combines virtual elements with the real world, enhancing perception and experience. This article aims to analyze Augmented Reality from a theoretical perspective, grounded in a user-centered methodology. Through a literature review, the main design principles, the most relevant applications in fields such as education, medicine, and industry, as well as the technical and ethical challenges associated with its implementation are identified. A user-centered methodology was applied to structure the analysis, dividing it into phases of research, design, prototyping, testing, and evaluation. The results show that the success of AR directly depends on its usability and on the harmonious integration between hardware, software, and user needs. The discussion compares findings from different studies, identifying trends such as the incorporation of artificial intelligence and the development of more immersive interfaces. It is concluded that Augmented Reality, conceived under a user-centered approach, has the potential to become a fundamental driver of technological, social, and educational innovation in the coming decade.

KEYWORDS

Information technology; Innovations; Educational technology; Basic education; Medical sciences.

INTRODUCTION

Augmented Reality (AR) has become one of the most influential disruptive technologies of the digital era. Its relevance lies in its ability to superimpose virtual information onto the physical environment in real time, expanding possibilities for learning, training, communication, and entertainment. From its early developments in the 1990s to contemporary

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applications on mobile devices and smart glasses, AR has evolved toward increasingly accessible and diverse scenarios. [1] [2]

In the scientific and technological domain, AR has gained importance by being integrated into innovation processes applied to education, medicine, industry, and marketing. Its implementation improves the understanding of complex concepts, assists in surgical procedures, optimizes production chains, and offers personalized consumer experiences [3][4]. However, these advances also raise challenges related to usability, accessibility, data privacy, and technological dependence.

The problem addressed in this study focuses on the lack of a systematic approach that ensures AR solutions respond to the real needs of end users. Although multiple projects exist across different fields, many of them fail due to inadequate consideration of user experience. Hence, the importance of adopting user-centered methodologies that enable more inclusive, effective, and sustainable design.

This article seeks to provide a theoretical analysis that systematizes the principles of design and application of Augmented Reality under a user-centered approach, highlighting both its benefits and challenges, and offering insight into the trends that will guide its future development.

DEVELOPMENT

Augmented Reality (AR) is based on the integration of virtual elements into physical environments, generating hybrid experiences that enrich user perception. To achieve this, AR requires three essential components: a capture device (camera, sensors), processing software, and a display medium (screens, headsets, or smart glasses). These elements work together to overlay graphics, sounds, or data onto reality. [5]

DIFFERENCES BETWEEN AR, VR, AND MR

A clear understanding of AR requires differentiating it from related technologies such as Virtual Reality (VR) and Mixed Reality (MR).

Table 1.

Comparison between Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR)

Characteristic			
	Augmented Reality (AR)	Virtual Reality (VR)	Mixed Reality (MR)
Environment	Combines real and virtual world	100% virtual	Seamless integration between both worlds
Main device	Smartphone, Tablet, camera and screen	VR headset/visor	Advanced glasses (e.g., HoloLens)
Immersion level	Medium	High	High with contextual interaction
Interaction	Through gestures, camera and screen	VR controllers and sensors	Natural interaction with real and virtual objects
Example	Pokemon Go, IKEA Place	Oculus Rift, Meta Quest	Microsoft HoloLens in medicine and industry

Source: Author’s own elaboration based on Azuma (1997) and Craig (2013).

Main Applications of Augmented Reality

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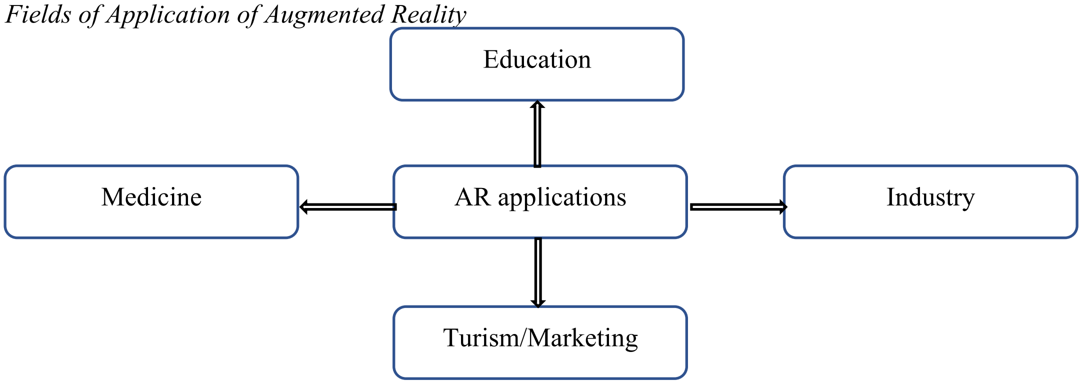
Augmented Reality (AR) has been successfully applied across multiple sectors:
• Education: AR promotes meaningful learning by enabling the visualization of three-dimensional models of scientific, historical, and biological phenomena.
• Medicine: It is used in assisted surgeries, medical training, and rehabilitation processes.
• Industry: AR optimizes maintenance procedures, assembly processes, and technical training.
• Tourism and Culture: It facilitates virtual tours in museums and archaeological sites.
• Marketing: AR provides immersive consumer experiences through virtual fitting rooms and interactive catalogs.
Principales aplicaciones de la RA

Figure 1.
Fields of Application of Augmented Reality



Source: Author's own elaboration based on Craig (2013) and Billinghurst et al. (2015)

User-Based AR Challenges

1. Usability: Development of interfaces that prioritize ease of use and intuitive interaction.

2. Accessibility: Inclusion of individuals with visual or motor impairments.

3. Privacy and Security: Protection of data collected through sensors and tracking systems.

4. Cost and Adoption: Devices and software continue to represent economic barriers to widespread implementation.

General Objective and Specific Objectives

The general objective of this study is to analyze Augmented Reality from a theoretical and methodological user-centered perspective, identifying its foundations, applications, benefits, and challenges for effective implementation across different social and technological domains.

Specific Objectives (Bloom's Taxonomy)

Cognitive Domain (analyze, evaluate, create):
• To comparatively analyze the characteristics of AR in relation to Virtual Reality (VR) and Mixed Reality (MR).
• To evaluate the benefits and limitations of AR in education, medicine, and industry.
• To propose user-centered design guidelines applicable to AR projects.

Psychomotor Domain (manipulate, practice, execute):
• To identify, through visual schemes, the interaction among devices, software, and users within AR environments.
• To design graphical representations illustrating the phases of a user-based methodology in AR projects.

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Affective Domain (value, respond, organize):
• To assess the social and ethical impact of AR across various sectors.
• To promote critical and responsible attitudes toward the use of immersive technologies.

Object of Study

The object of study of this research is Augmented Reality conceived under a user-centered approach. This implies analyzing the phenomenon not only as an emerging technology, but also as a human–computer interaction system that responds to cognitive, emotional, and social needs. The study focuses on the processes of design, implementation, and evaluation of AR experiences, considering that the success of these applications largely depends on their usability, accessibility, and cultural relevance.

METHODOLOGY

This study is framed within the User-Centered Design (UCD) methodology, which represents an interactive design approach focused on the needs, characteristics, and limitations of end users [6]. Unlike traditional technology-centered methodologies that prioritize technical aspects, UCD places the user as the key element throughout all stages of development.

This approach is particularly relevant for Augmented Reality (AR), as human–computer interaction occurs in hybrid environments where usability and perceptual experience are decisive factors for the success of the application. The applied methodology follows four fundamental principles [7]:

1. Understanding and specifying the context of use: identifying who the users are, their tasks, and the environment in which AR will be used.

2. Specifying user and organizational requirements: establishing the functions and characteristics that the application must include.

3. Producing design solutions: developing iterative low- and high-fidelity prototypes.

4. Evaluating designs against requirements: validating solutions with users and making adjustments to ensure satisfaction and effectiveness.

DEVELOPMENT PHASES

In applying the user-centered methodology to the analysis of Augmented Reality, the following phases are identified:

1. Context-of-use research
   - Collection of information about users and their cognitive, motor, and emotional needs.
   - AR example: analysis of secondary school students using a 3D anatomy educational application.

2. Requirements definition
   - Establishment of functional requirements (e.g., 360° visualization) and non-functional requirements (e.g., accessibility on mobile devices).
   - AR example: in medicine, a surgical headset must be compatible with sterile gloves.

3. Design and prototyping
   - Creation of initial prototypes (sketches, storyboards, digital models) and iterative testing.
   - AR example: prototype of a museum tour with 3D models superimposed on sculptures.

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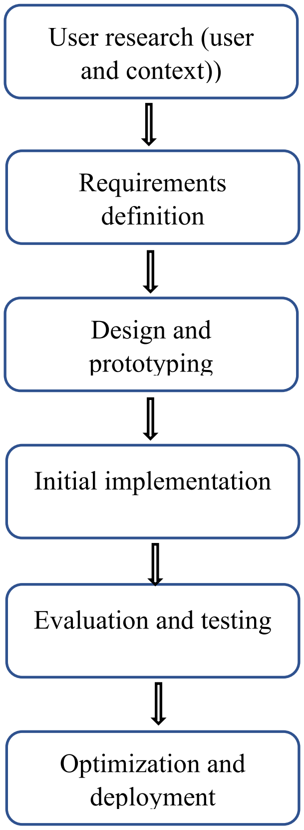
4. Initial implementation
   - Development of a preliminary version of the AR application, integrating hardware and software.
   - AR example: beta version of an industrial training application with instructions projected onto real machinery.

5. Evaluation and feedback
   - Testing with real users to identify improvements in interaction, performance, and accessibility.
   - AR example: feedback from teachers after using AR in the classroom, identifying distractions or navigation issues.

6. Optimization and deployment
   - Final adjustments and release of the application in real environments.
   - AR example: launch of a marketing application with a virtual clothing fitting feature.

Flowchart

User-Based Methodology Applied to Augmented Reality (AR)



Source: Author's own elaboration based on Norman (2013) and ISO 9241-210:2019.

RESULTS AND DISCUSSION

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The theoretical review of Augmented Reality (AR) under the User-Centered Design (UCD) methodology made it possible to identify relevant results regarding its adoption, benefits, and limitations across different sectors. These results are organized into three main sections:

1. Results reported in previous studies

2. Comparison with other research approaches

3. Discussion of trends and future projections

1. Results reported in previous studies

Findings from the literature indicate that AR has a positive impact on content comprehension, process efficiency, and user experience. However, differences in effectiveness are observed depending on the sector of application.

Table 2.

Impact of AR across different sectors

Sector	Positive Outcomes	Identified limitations	Source
Education	Improves motivation and understanding of complex concepts.	Student distraction and high development costs	[8]
Medicine	Greater precision in surgeries; safe training in simulated environments.	Need for expensive equipment; learning curve.	[9]
Industry	Reduction of assembly errors; hands-on training.	Integration issues with existing machinery.	[10]
Tourism	Immersive experiences in museums and historical sites.	Requires constant connectivity.	[11]
Marketing	Enhances the shoppin experience; personalization	Risk of advertising saturation	[12]

2. Comparison with other research approaches

When comparing the User-Centered Design methodology with traditional technology-focused approaches, it is observed that AR projects incorporating usability testing achieve higher acceptance and sustainability.

Table 3.
Comparison of approaches in Augmented Reality projects.

Approach	Main Characteristics	Outcomes in AR

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Technological Classic Approach	Focused on hardware and software	Rapid advancements, but lower user acceptance.
User Centered Design	Considers user needs in all phases	Greater usability, accessibility, and adoption.
Delphi Method	Based on expert consensus	Provides a strategic perspective, but less focus on user experience.

Source: Author's own elaboration based on Norman (2013) and ISO 9241-210:2019

3. Discussion of trends and future projections

The results indicate that AR is transitioning from isolated applications toward integrated ecosystems that combine artificial intelligence (AI), the Internet of Things (IoT), and 5G connectivity. This integration enables more fluid experiences, reduced latency, and higher levels of personalization.

Research trends show exponential growth in AR-related studies, particularly in education and medicine due to their direct social impact. Industry and marketing research focuses primarily on efficiency optimization and consumer experience enhancement.

Overall, the User-Centered Design methodology emerges as a recommended standard, as it facilitates large-scale adoption and reduces early abandonment of AR applications.

Results and Discussion

The application of User-Centered Design (UCD) methodology in Augmented Reality (AR) projects has generated significant outcomes across various domains, including education, medicine, industry, and marketing. The following section presents key findings compiled from recent research, along with a critical discussion in relation to the existing literature.

Main Results in Education

The reviewed studies indicate that the integration of AR in classroom settings enhances student motivation and knowledge retention when designed from the learner's perspective. A meta-analysis conducted by Radu (2014) demonstrated that AR-based learning environments achieve average improvements of 15–30% in short-term memory tests compared to traditional instructional methods.

Table 4.
Comparison of the impact of Augmented Reality in educational environments

Author / Year	Educational context	User-Centered Design	Main Results
Radu (2014)	Natural Sciences	Yes	+29% in concept retention
Akçayır & Akçayır (2017)	Mathematics and Geometry	Yes	Higher reported motivation (surveys)
Ibáñez et al. (2020)	Physics	Yes	20% improvement in problem-solving skills

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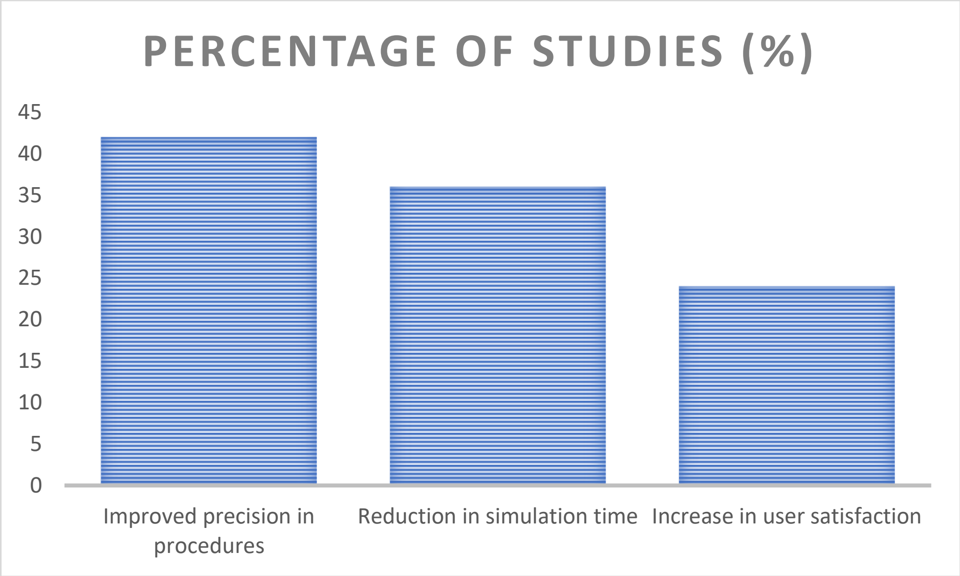
Outcomes in medicine

In the healthcare field, Augmented Reality (AR) has been applied to surgical training, anatomical visualization, and rehabilitation therapies. Studies such as that of Moro et al. (2017) indicate that AR reduces errors in simulated medical practice by providing real-time information and enabling natural interaction with three-dimensional models.

Figure 2.
Reported Benefits of AR in Medicine (percentage of studies that identify them).



Source: [9].

Results in Industry and Marketing

In industrial processes, Augmented Reality (AR) has demonstrated increased operational efficiency in assembly and maintenance tasks [8]. Studies report reductions of up to 25% in operation time when AR-based manuals are used instead of paper-based instructions. In marketing, AR applied to shopping experiences (e.g., virtual fitting rooms or product visualization) generates higher customer engagement and an average increase of 20–25% in purchase intention [13].

Table 5.
AR Results in Productive Sectors

Sector	Application	Beneficio reportado	Fuente
Industry	Assembly and maintenance	–25 % operation time	[8]
Marketing	Shopping experience	+22 % purchase intention	[13]
Tourism	Interactive guides	Higher satisfaction and return visits	[11]

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Discussion

The collected results confirm that the effectiveness of AR depends directly on user-centered design. Across all analyzed sectors, projects that implemented the User-Centered Design (UCD) methodology reported greater benefits compared to those that did not.

In education, AR increases motivation provided that content is aligned with learning styles.
In medicine, precision and safety improve when systems are adapted to the cognitive and psychomotor needs of clinical personnel.
In industry, error reduction depends on interface clarity and ease of interaction.
In marketing and tourism, AR has a positive impact when the experience is intuitive and emotionally engaging.

A consistent finding is that poorly designed AR systems may generate cognitive overload, visual fatigue, and user rejection, confirming the need to apply methodologies that prioritize usability and user experience [14].

In conclusion, the reviewed results demonstrate that a User-Based Methodology is essential for the success of AR. The benefits of this technology depend not only on technical advancements, but also on its proper integration into the end-user experience.

CONCLUSIONS

Augmented Reality (AR) is positioned as one of the most promising technologies within the context of digital transformation, with applications spanning education, medicine, industry, marketing, and tourism. The analysis conducted under the User-Centered Design (UCD) methodology demonstrates that the true potential of AR lies not only in technical advances in hardware and software, but also in its capacity to adapt to the cognitive, psychomotor, and affective needs of end users.

The reviewed results support the following main conclusions:

1. Educational relevance:
AR increases motivation and knowledge retention when content is designed according to learners' age, learning styles, and educational context.

2. Impact in medicine:
AR enhances precision in medical practice, reduces errors, and supports the acquisition of complex skills, provided that interfaces are intuitive and easy to manipulate.

3. Industrial and commercial applications:
AR improves efficiency in productive processes and increases purchase intention in retail environments, confirming its strategic value for business innovation.

4. Importance of a user-centered approach:
Successful AR projects prioritize user experience and apply methodologies such as UCD to design, test, and evaluate solutions prior to large-scale implementation.

5. Remaining challenges:
Technical limitations (device weight, battery life, development costs) and risks of cognitive overload persist and must be mitigated through continuous iterations with real users.

In summary, AR should not be understood solely as a technological advancement, but as a socio-technological tool whose success depends on its alignment with the people who use it. Its future will be shaped by the ability of researchers and developers to integrate usability, accessibility, and user experience principles throughout all stages of design.

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