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Systematic Literature Review on Augmented Reality with Persuasive System Design: Application and Design in Education and Learning

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Abstract— **Augmented Reality (AR) is an innovative technology that has gained significant scholarly attention. It uses computer-generated sensory inputs like visuals, sounds, and touch to enhance how we perceive the real world, providing a transformative impact on human sensory experiences. Motivated by the possibilities of augmented reality (AR) in the realm of the educational learning environment, this research aims to document the evolving landscape of augmented reality (AR) applications in education and training, with a specific emphasis on the incorporation of persuasive system design (PSD) elements. The study also explores the diverse technologies and methodologies for developing these applications. A systematic literature review was conducted, analyzing 44 articles following the protocol for PRISMA assessments. Four research questions were formulated to investigate trends in AR applications. Between 2016 and 2023, publications on AR applications doubled, with a significant focus on the educational field. Marker-based AR methods dominated (68.49%), while markerless methods constituted 31.51%. Unity and Vuforia were the most used platforms, accounting for 77.27% of applications. Most research papers assessed application effectiveness subjectively through custom-made questionnaires. University students were identified as the primary target users of AR applications. Only a few applications integrated persuasive elements, even for adult users. This highlights the need for further studies to fully grasp the possibilities of combining persuasive system design with augmented reality applications in education.**

Keywords— **Augmented reality; AR; education; persuasive system design; PSD.**

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I. INTRODUCTION

Augmented Reality (AR) is a groundbreaking technology that has garnered significant attention and interest in recent years, transcending its initial niche applications and expanding into various domains, including education, healthcare, gaming, and industry [1]. This technology represents a paradigm shift in how humans interact with the digital world, offering a seamless fusion of the physical and virtual realms [2]. AR leverages computer-generated sensory input, such as visual, auditory, and haptic, to enhance the perception of the real world, thus augmenting our sensory experiences in profound ways.

Ivan Sutherland's groundbreaking work with the "Sword of Damocles" in the 1960s began the conception of AR [3]. A head-mounted display system laid the foundation for modern AR devices. Since then, AR has evolved significantly, benefiting from advancements in hardware, software, and computer vision techniques. Here are the intricacies of augmented reality, exploring its historical evolution, underlying technologies, diverse applications, and the challenges it presents.

The origins of AR can be traced back to the early efforts in virtual reality (VR) and computer graphics. In 1968, Ivan Sutherland introduced the concept of AR with his head-mounted display system, marking a pivotal moment in the history of human-computer interaction [3]. Subsequent decades he witnessed incremental progress in AR technology, with notable contributions from researchers and industry pioneers. Key milestones include the development of ARToolKit by Hirokazu Kato in the late 1990s, which allowed real-time tracking of markers for overlaying virtual content onto the physical world [4]. However, the true transformation of AR emerged with the advent of smartphones and wearable devices, such as Google Glass and Microsoft HoloLens. These devices combined advanced sensors, cameras, and processing power [5], making AR accessible to a broader audience and sparking a surge in AR applications.

Driven by the potential of AR in education and training, this paper aims to 1) provide a comprehensive review of existing AR application system design approaches within domains such as e-commerce, medicine, engineering, computer science, and education and 2) critically analyze the challenges and opportunities surrounding the integration of persuasive system design elements for enhanced educational efficacy. Framed *by* specific research questions, this paper meticulously examines the multifaceted landscape of AR applications in education and training. The analysis explores critical aspects such as target audience, educational focus, assessment strategies, learning outcomes, technological approaches, and the emergent convergence between AR and persuasive system design.

AR relies on a synergy of several core technologies, including computer vision, spatial mapping, sensor fusion, and display systems [5]. Computer vision algorithms play a pivotal role in AR by enabling the recognition of objects and surfaces in the real world [6]. Simultaneous Localization and Mapping (SLAM) techniques create and update a spatial map of the environment, allowing AR devices to position virtual objects within physical space [7] accurately.

Data from multiple sensors, such as cameras, accelerometers, gyroscopes, and GPS, is combined via sensor fusion to comprehensively understand the user's surroundings. AR display systems, ranging from heads-up displays (HUDs) to handheld devices and augmented reality glasses, project virtual information into the user's field of view, maintaining spatial alignment with the natural world [8].

The versatility of AR technology is reflected in its broad spectrum of applications across various domains. AR is transforming traditional learning methods by providing interactive and immersive educational experiences [9]. Medical professionals use AR for surgical navigation, aiding in precise procedures and reducing risks [10]. The gaming industry has embraced AR with popular titles like Pokémon GO, seamlessly integrating virtual creatures into the real world through smartphone cameras.

In the business realm, AR is enhancing productivity and efficiency in industries like manufacturing and logistics by providing real-time information and guidance to workers. Moreover, AR has proven helpful in marketing and retail, enabling customers to see things in their actual settings before buying [11]. These applications, among many others, underscore the transformative potential of AR across diverse sectors. In recent years, researchers and practitioners have recognized the immense potential of AR as a persuasive tool for facilitating behavior change across various domains, including education, healthcare, marketing, and entertainment.

In today's dynamic digital landscape, software applications are ubiquitous. From e-commerce platforms to e-learning, these applications are critical communication, collaboration, and service delivery tools. Their success hinges on a well-conceived design—a blueprint that guides development and ensures the system meets its intended purpose with optimal efficiency and resilience.

A deep commitment to user-centricity lies at the heart of successful application system design. Every aspect, from the initial architecture to the final interface, must cater to the needs and expectations of those interacting with the system daily. User requirements must be considered when designing user interfaces so that features and functionalities can be tailored to the unique qualities of each user [64]. Intuitive navigation and straightforward functionalities are paramount, guiding users through their tasks effortlessly. The user interface, the touchpoint between the user and the system, is meticulously crafted to be inviting and self-explanatory, ensuring anyone can confidently and efficiently engage with the system. Only by prioritizing user experience at every stage can we genuinely design applications that empower and delight their users [16].

The concept of Persuasive System Design (PSD) has gained prominence in human-computer interaction (HCI) to systematically engineer technology-driven interventions that encourage users to adopt desired behaviors or attitudes. PSD uses persuasive techniques, such as feedback, social influence, and personalization, to motivate and guide users toward specific goals, as in Table 1 [13]. When applied within the context of AR, PSD takes on a new dimension, harnessing the immersive and context-aware nature of AR experiences to influence users' behaviors and beliefs.

TABLE I
TEN MOST USED PERSUASIVE DESIGN TECHNIQUES IN APPLICATIONS FROM 2006 TO 2010 [13]

Technique	Domain Application						
	Commerce	**Education**	**Environment**	**Health**	**Leisure**	**Security**	**Total**
Feedback	1		9	9			19
Self-monitoring	1		2	11	1	1	16
Suggestion	1	2	4	8		1	16
Social role	1	1	1	7		1	11
Simulation			5	4	1		10
Tailoring	1	1		7		1	10
Tunneling	1	1		6	1	1	10
Reminders		1		7	1		9
Reduction				5	1	1	7
Reward			2	5			7

We aim to explore the unity of Persuasive System Design and Augmented Reality, shedding light on the unique opportunities and challenges this unification of immersive technology and persuasive strategies presents. To grasp the significance of this interdisciplinary intersection, we must first understand the foundational concepts of Persuasive System Design before delving into their integration and how AR can be harnessed to shape human behavior and drive positive outcomes.

The concept of Persuasive System Design (PSD) stems from the field of HCI. It focuses on creating technology that motivates users to engage in desired behaviors, adopt attitudes, or make informed decisions. Rooted in persuasion, psychology, and communication theories, PSD seeks to employ interactive systems as persuasive agents. The fundamental premise is to design interfaces, applications, or technologies that influence users subtly yet impactfully. The compelling power of these systems may manifest in various forms, such as providing feedback, offering rewards, invoking emotions, or employing social influence [14]. In the context of traditional digital interfaces, PSD has found practical applications in domains such as e-commerce, health and wellness, environmental conservation, and education. Classic examples include fitness apps that encourage users to exercise regularly. These e-commerce websites utilize scarcity tactics to boost sales and social media platforms that employ persuasive techniques to engage and retain users. Applying PSD principles has proven effective in driving specific behaviors and achieving desired outcomes. With augmented reality (AR) technologies gaining popularity and becoming more widely available, they present a fresh platform for persuasive strategies. The combination of AR and PSD opens new possibilities for HCI, allowing persuasive strategies and digital material to work together seamlessly with the real world. This combination creates opportunities for creating augmented reality experiences that inspire and convince people in real-world circumstances and educate and engage them.

An in-depth understanding of both domains is necessary for the challenging task of integrating AR and PSD. It involves exploring how digital information can be strategically presented within the user's field of vision to influence behavior and attitudes. For example, an AR application could encourage users to make healthier food choices by superimposing nutritional information onto restaurant menus [13]. It could promote environmental awareness by overlaying digital simulations of the consequences of pollution on a polluted riverbank. It could also enhance learning experiences by gamifying educational content within a historical museum. While the marriage of AR and PSD holds immense promise, it raises important ethical questions. The persuasive power of AR systems, when misused or unchecked, could potentially lead to undesirable consequences, such as manipulation, addiction, or privacy infringements. Hence, responsible design practices and ethical considerations are paramount in developing and deploying persuasive AR technologies [15].

The research paper aims to explore the potential of augmented reality (AR) applications in education and training, focusing on integrating persuasive system design (PSD) elements. The paper conducts a systematic literature review of existing AR applications across various domains, such as e-commerce, medical, engineering, computer science, and education. The paper analyzes AR applications' characteristics, challenges, and opportunities and the emerging trends of AR and PSD convergence. The paper also proposes key aspects for potential research studies in this field. The importance of the research paper lies in its comprehensive and interdisciplinary approach, which provides valuable insights and guidance for developers, instructors, and scholars who harness the power of AR and PSD to create effective and engaging learning experiences.

To facilitate reader comprehension, the paper adopts a clear organizational structure. The Methodology section thoroughly outlines the systematic review's approach, including the search strategy for the keywords, selection and exclusion criteria, guiding research questions, and quality assessment parameters for selected articles. Building upon this foundation, the "Results" section meticulously deconstructs the selection process and presents findings aligned with the established research questions. This section delves into each study's technological fundamentals, assessment strategies, quality outcomes, and key takeaways (encompassing scope, achievements, limitations, and future directions). Subsequently, the "Discussion" section provides a comprehensive analysis of the findings, illuminating opportunities, knowledge gaps, potential obstacles, and emerging trends in the application of AR for educational purposes. Finally, the "Conclusion" section summarizes the significant findings of the systematic review and offers valuable insights to guide future research endeavors in this domain.

II. Material and Method

A comprehensive analysis of the extant literature spanning 2016 to 2023 was undertaken to clarify the defining characteristics of augmented reality (AR) applications within the educational domain and assess their potential for effective integration across diverse sides of the learning process. The PRISMA statement was the foundation for the selection criteria [12]. The primary objective of the search was to map the body of knowledge regarding Augmented Reality system design in e-commerce, health and wellness, medicine, engineering, computer science, and education.

We created a search technique to find appropriate data for this systematic search. This particular search approach was designed for datasets like Scopus, Google Scholar, Web of Science, IEEExplore, and Science Direct, which were searched for scientific articles using keywords:

- “Augmented Reality” AND “education”
- “Augmented Reality” AND “persuasive system design”

A precise method of selection, informed by criteria of comprehensiveness, interdisciplinarity, publication quality, global inclusivity, and user access, identified vital databases. These databases, in concert, offer a gateway to peer-reviewed literature and conference proceedings from diverse academic backgrounds, ensuring a rich and reliable foundation for AR system design research exploration. Integrating Google Scholar expands the investigation to open-access sources, its recognized standing, interdisciplinary view, and advanced search tools, further supporting a thorough and reliable analysis of the subject matter. The curated databases, known for their consistent and timely updates, guarantee the inclusion of the most recent research and ensure the review remains level to the dynamic field of AR in education. Data collection commenced in September 2023; the study's inclusion/exclusion criteria are outlined below.

A. *Selection Criteria*

- Articles involving the use of Augmented Reality applications system design.
- Articles published between 2016 and 2023.
- Journals and conferences
- Published in the English language.

B. *Exclusion Criteria*

This review excluded several categories of research studies, including reviews, summaries, workshops, and lecture notes. Additionally, research locked behind paywalls or requiring on-site access was not included in this investigation's view. Four research questions, developed before data extraction, were the guiding principles for the subsequent analysis phase.

- RQ1. What tools and technology were utilized to create the augmented reality application?
- RQ2. What augmented reality recognition method is used in AR application development?
- RQ3. What assessment criteria were used to measure the success of the final solution?
- RQ4. Is there any evidence of the integration of persuasive system design elements with the development of the augmented reality application?

III. Results and Discussion

Figure 1 displays the inclusion and exclusion of literature at each step, adhering to the recommendations made by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) statement [12]. The updated, internationally recognized version of the QUORUM (Quality of Reporting of Meta-analysis) statement is PRISMA. This study presents the methodology's fundamental phases.

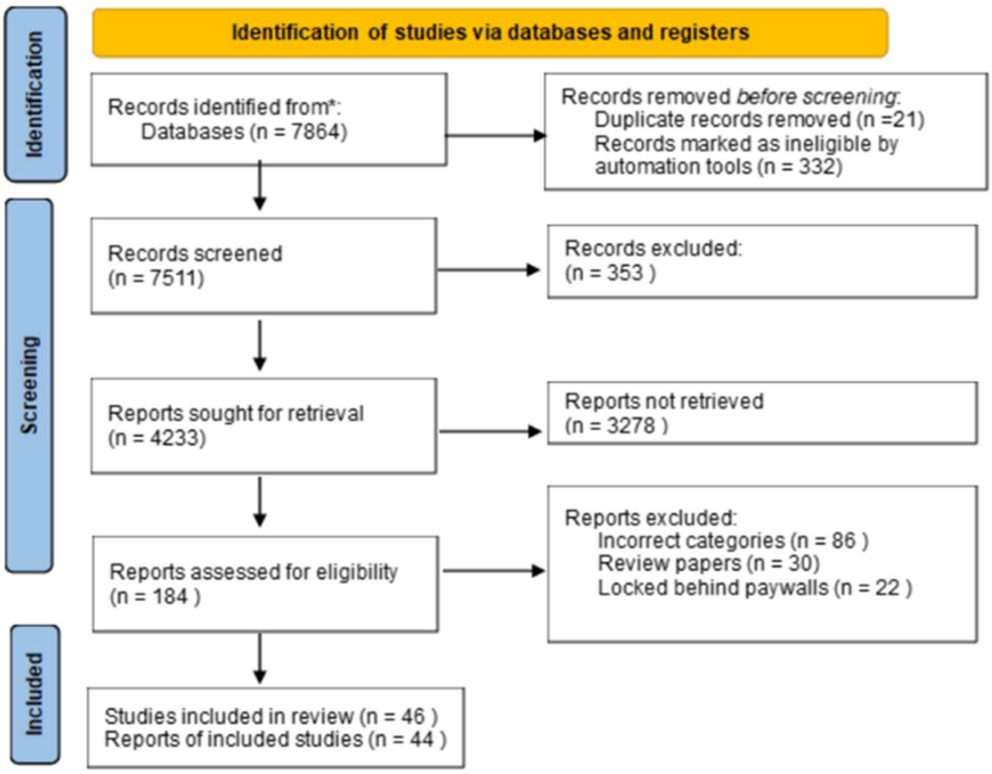

Fig. 1 PRISMA flowchart

The initial stage of the research identified 7,864 relevant publications. Subsequently, a data refinement stage was undertaken, encompassing several sequential procedures. Following an initial data cleansing phase, the dataset was refined by removing redundant entries and non-English publications, yielding 7,511 articles. Next, a comprehensive screening of article titles and abstracts was conducted, identifying 4,233 potentially relevant studies for further evaluation. Furthermore, articles that were inaccessible through established channels and those categorized as reviews or theoretical works not directly about the research topic were excluded, bringing the set to 184 papers. Following rigorous inclusion criteria, a final set of 44 studies was identified for in-depth analysis. Figure 1 offers a comprehensive visual representation of the workflow. Figure 2 sheds light on the public's interest in "Augmented reality in education" by illustrating the search volume for this keyword on Google Trends.

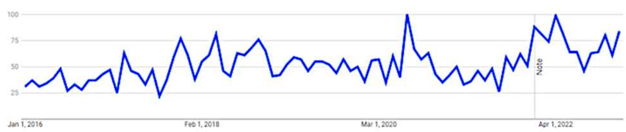

Fig. 2 Google trends for the keyword “Augmented Reality in Education” from the year 2016-2023

TABLE II
REVIEW OF PREVIOUS LITERATURE

ID	Author	Dev. Tools	Subject/domain	AR Type	Performance measurement instrument
1	Suzuki R. et al [18]	RealitySketch	Education (Physics, sports training)	markerless	Interviews, observation
2	Ashour Z. et al. [19]	BIMxAR	Architecture	markerless	Quasi-experimental
3	Arjun P.R. et al [20]	Unity,	History & civic	marker	Heuristic analysis
4	Hu X. et al [21]	VARS	Engineering	markerless	Quasi-experimental perception survey
5	Gupta N. et al. [22]	Unity, ARkit	medical	marker	Quantitative research
6	Abdullah N.A.S. et al [23]	Unity, Vuforia	medical	marker	Black box testing
7	Hemme C.L. et al [24]	UnityMol	medical	Markerless	Pre-Post test
8	Cai S. et al [25]	Unity	medical	marker	-
9	Villanueva A. [26]	ColabAR	engineering	marker	Questionnaires
10	Martin-Gomez A. et al [27]	Unity	medical	Markerless	Interviews, observation
11	Schnürer R. et al [28]	Unity, Vuforia	Science computer (cartography)	marker	Experiment, observation
12	Hertel J. et al [29]	Unity, MRTK	Engineering (petroleum)	Marker less	Qualitative research
13	Ishihara M. et al [30]	Unity	Science computer (programming)	Marker less	t-test, Mann-Whitney test, and ANOVA
14	In H. et al [31]	Draw2code	Science computer (programming)	Markerless	Observation
15	Song E. et al [32]	Unity, Vuforia	Education (mathematics)	marker	Experiment, questionnaires
16	Subandi et al [33]	AR-CoNDe	Science computer (network)	marker	Pre-Post test
17	Nguyen P. et al [34]	Unity, Vuforia	e-commerce	marker	survey
18	Sholikhah, B.U. et al [35]	Unity	Education (mathematics)	marker	Pre-Post test
19	Ariffin N.H.M. et al. [36]	Unity, AR Foundation	Education (tourism)	marker	-
20	Kumar A. et al [37]	Unity, Vuforia, Arduino IDE	engineering	marker	questionnaires
21	Reisinho, Pedro et al [38]	Unity, Vuforia	Interactive media (health)	marker	questionnaires
22	Ahmad N.I.N. et al [39]	Unity, Vuforia	Education (mathematics)	Marker	Observation, pre-posttest, questionnaire
23	Sundari A.M.A et al [40]	Unity, Vuforia	Engineering	Marker	-
24	Chiam B.S.I. et al [41]	Unity	Social science	Marker less	Feasibility evaluation checklist, questionnaire
25	Oberdörfer S. et al [42]	Unity, Vuforia	Education (anatomy)	marker	-
26	Huang H.-M. et al [43]	-	Education	Marker	Experiment, Pre-Post test
27	Velaora M. et al [44]	Unity, Clojure	architecture	Markerless	experiment
28	Avila-Pesantez D. et al [45]	Unity, Vuforia	medical	Marker less	experiment
29	Thongchum K. et al [46]	Unity	Science computer (language)	Markerless	experiment
30	Tang J.K.T. et al [47]	Unity, Vuforia	Science computer (computer graphics)	marker	Questionnaire, experiments
31	Deng X. et al. [48]	Vuforia	Science computer (programming)	marker	observation
32	Rodriguez-V. L. et al. [49]	Unity, Vuforia	Education (language)	marker	Experiment, observation, questionnaire
33	Pittman C. et al. [50]	Unity, MRTK	Education (physics)	Markerless	questionnaire
34	Daineko Y. et al. [51]	Unity, Vuforia	Education (physics)	marker	Interview
35	Joseph Dube T. et al. [52]	Unity, Vuforia	Media and arts (choreography)	marker	Experiment, questionnaire
36	Karambakhsh A. et al. [53]	Unity	Science computer (anatomy)	Markerless	Cross-subject, cross-validation method
37	Černý F. et al. [54]	Unity, Vuforia	Education	marker	Experiment, questionnaire
38	Murrell S. et al. [55]	Unity, Vuforia	Education (meteorology)	marker	Pre-Post test
39	Kouzi M.E. et al. [56]	Unity, Vuforia	Education (anatomy)	marker	Questionnaire
40	Rongting Z. et al. [57]	Unity, Vuforia	Education (science)	marker	Interview
41	Cook M. et al. [58]	Google ARCore	Education (anatomy)	marker	Questionnaire
42	Schiavi B. et al. [59]	-	History & Civic	marker	Experiment, Questionnaire
43	Jacob S. et al. [60]	Unity, Vuforia	Engineering	marker	Questionnaire
44	Protopsaltis A. et al [61]	Alvar, Visual Studio	Interactive media	marker	Black box, white box, SUS questionnaire

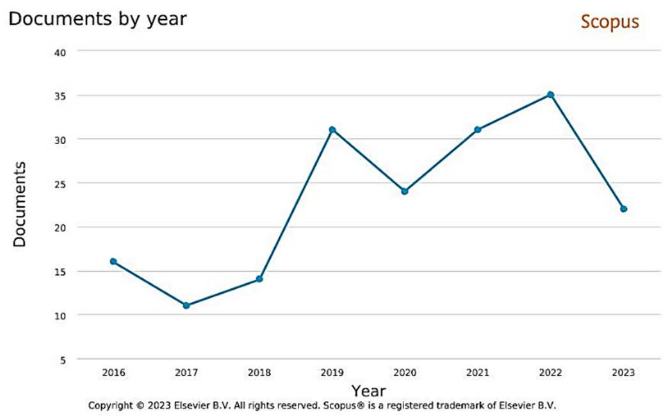

Fig. 3 Research paper by year under AR in education keyword

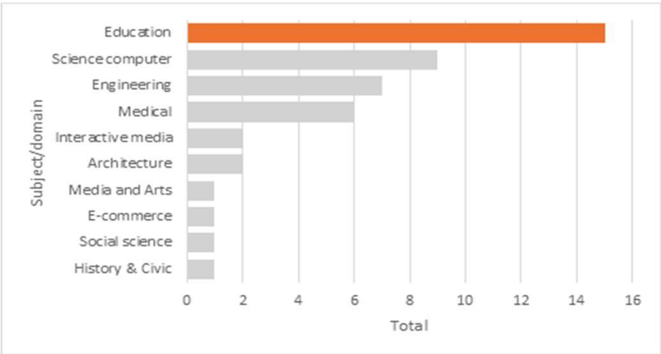

Fig. 4 Research paper by subject/domain

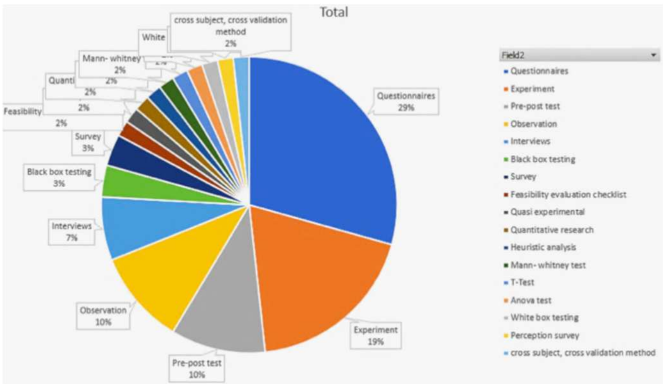

Fig. 5 Research evaluation methods

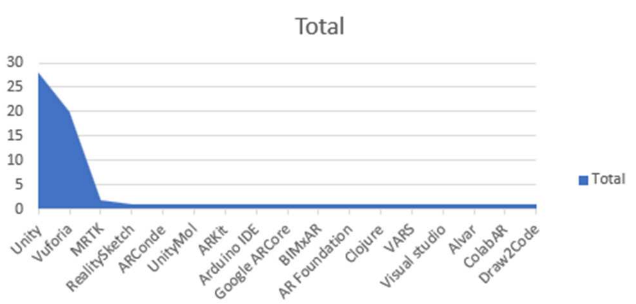

Fig. 6 Development Tools

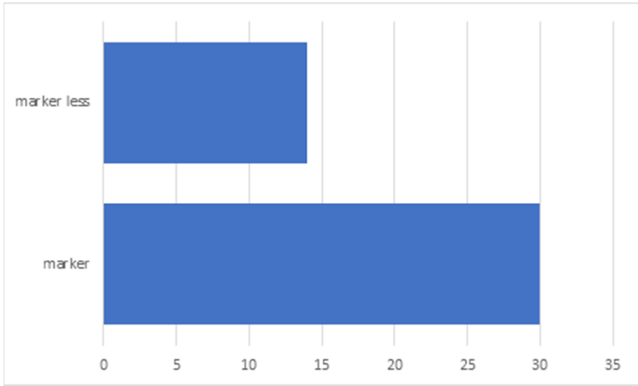

Fig. 7 Distribution of Augmented Reality Type

TABLE III
PERSUASIVE DESIGN ELEMENTS INFERRED FROM THE LITERATURE IN TABLE II

ID	Author	Persuasive design elements
1	Suzuki R. et al [18]	None
2	Ashour Z. et al. [19]	None
3	Arjun P.R. et al [20]	None
4	Hu X. et al (21)	Feedback, motivation, suggestion, simulation
5	Gupta N. et al. [22]	Simulation, tailoring, feedback
6	Abdullah N.A.S. et al [23]	Feedback, simulation, suggestion
7	Hemme C.L. et al [24]	None
8	Cai S. et al [25]	Simulation, feedback
9	Villanueva A. [26]	Feedback, reminder
10	Martin-Gomez A. et al [27]	Motivation, reward
11	Schnürer R. et al [28]	None
12	Hertel J. et al [29]	None
13	Ishihara M. et al [30]	None
14	Im H. et al [31]	Social Role, reduction, rewards
15	Song E. et al [32]	Rewards, motivation
16	Subandi et al [33]	Simulation
17	Nguyen P. et al [34]	Simulation
18	Sholikhah,B.U. et al [35]	None
19	Ariffin N.H.M. et al. [36]	None
20	Kumar A. et al [37]	None
21	Reisinho, Pedro et al [38]	Tunneling, self-monitoring, simulation, rewards, feedback, motivation, social role
22	Ahmad N.I.N. et al [39]	Tailoring, feedback, reward,
23	Sundari A.M.A et al [40]	Tailoring, simulation
24	Chiam B.S.I. et al [41]	Reduction
25	Oberdörfer S. et al [42]	Tunneling
26	Huang H.-M. et al [43]	Tunneling, Self-monitoring
27	Velaora M. et al [44]	Simulation, feedback
28	Avila-Pesantez D. et al. [45]	Simulation, tailoring, feedback
29	Thongchum K. et al [46]	None
30	Tang J.K.T. et al [47]	None
31	Deng X. et al. [48]	None
32	Rodriguez-Vizzuett L. et al. [49]	None
33	Pittman C. et al. [50]	Feedback
34	Daineko Y. et al. [51]	None
35	Joseph Dube T. et al. [52]	None
36	Karambakhsh A. et al. [53]	Feedback
37	Černý F. et al. [54]	Motivation, Feedback
38	Murrell S. et al. [55]	None
39	Kouzi M.E. et al. [56]	Feedback, social role, motivation
40	Rongting Z. et al. [57]	Motivation, feedback
41	Cook M. et al. [58]	Feedback, simulation, tailoring, suggestion
42	Schiavi B. et al. [59]	Motivation, reduction
43	Jacob S. et al. [60]	None
44	Protopsaltis A. et al [61]	Social role, suggestion, rewards, motivation

The outcomes of the review process for the chosen papers are summarized in Table 2, focusing on the tools used to develop the augmented reality application, the augmented reality recognition type, subject or domain, and the attributes of the evaluation phase for the end conclusion. Notably, most research papers employed varied assessment tools and methodologies, as shown in Figure 5, with 29% of the studies employing a questionnaire, 19% conducting experiments, 10% using pre-posttest and observing the participants, and 4% doing interviews. Questionnaires are the most popular instruments for collecting data due to their quick, effective, and affordable means of acquiring a lot of data from large samples of test subjects. It can also be conducted without the researcher's presence, making them less intrusive and less time-consuming than other instruments [17].

Other methods, such as black-and-white box testing [23] [61], Mann-Whitney test, T-test, ANOVA test [30], and cross-subject/cross-validation method [53], are below 3%. Some studies employed a combination of instruments, such as experiments, observation, pre-posttest, and questionnaire, to get more conclusive results [49][39].

As in Figure 4, the domain education and its allied disciplines accounted for the largest share (33%) of the represented publications, followed by science computer (22%). Engineering-related research comprised a smaller segment of the analyzed literature, as evidenced by the low number of represented journals (16%) followed by medical (13%). An analysis of the publication domains reveals a balanced focus on architecture and interactive media (5%). The rest of the domains, such as media & arts, social science, e-commerce, and history & civics, are distributed at (2%). The specific technological tools and frameworks utilized by each project are defined in Table 2. The distribution of AR approaches in the reviewed literature revealed a dominance of marker-based methods (68.49%) and marker-less-based methods distributed at (31.51%) as shown in Figure 7.

Vuforia and Unity combined were the most popular augmented reality development tool used in most studies (77.27%). In contrast, two studies employed a Mixed Reality Toolkit (MRTK) [29][50] for Microsoft Holo-lens AR development as shown in Figure 6. Educational contexts emerged as the primary focus of the reviewed studies, with the majority targeting university students (31.8%). Subsequent representation was observed in secondary and primary schools. Studies investigating early childhood education [57] constituted a smaller portion.

In this study, data from several publications—both qualitative and quantitative—were analyzed. The decisions and actions made by developers when creating educational and non-educational augmented reality applications, as well as the degree to which these applications have been used, could be identified thanks to the qualitative data gathered. Significantly, the study's exploration of augmented reality applications transcended the confines of learning environments. It started a more extensive inquiry, examining the changing field of augmented reality applications in formal and informal settings. The present study takes a thorough methodology that sets it apart from previous research, offering a comprehensive overview of the developments in AR application design and deployment documented between 2016 and 2023.

Given the diversity of publication sources, it is likely that there aren't many journals or conferences dedicated to the topic of interest: the integration of persuasive system design in AR development. However, the most developed AR applications between 2016 and 2023 were those related to education or training with no or few integrations with persuasive system design elements.

The physical environment and augmented reality (AR) technology coexist, but a complex interaction of hardware elements supports this seamless integration. All of the components, from strong GPUs to accurate spatial positioning algorithms, work together to create attractive AR overlays.

Persuasive design significantly impacts human behavior by leveraging the features of a product or service. In this study, it's interesting to note that out of the 44 papers identified, most authors did not explicitly mention any persuasive techniques in the application design and development of their product or service. However, this study identified some possible persuasive elements that can be inferred from the papers, which have been tabulated in Table 3. These four elements – Tunneling, Feedback, Self-monitoring, and Suggestion – have been identified as the most commonly employed persuasive design elements based on insights from the paper. Tunneling in AR education apps involves guiding students step-by-step through different educational concepts. For example, a new AR learning app could gradually introduce historical events, scientific principles, or math problems. Each step helps students understand better, ensuring a smoother and more effective educational AR experience.

Feedback is essential in AR education apps. Picture an AR learning app overlaying educational info in the real world. Students stay on track and feel confident by giving instant feedback on correct answers and explanations. This real-time guidance improves the AR educational experience, making it more effective and student-friendly.

Self-monitoring is another crucial persuasive element in AR education apps. Consider a language learning AR app that encourages students to track progress in virtual language environments. The app could log learned vocabulary, explore cultural aspects, and overall language proficiency. Visualizing achievements motivates students to continue learning AR language, creating a more engaging and rewarding experience.

AR educational apps can subtly suggest learning activities. For example, an AR science app detecting a student near a botanical garden might discreetly recommend exploring plant life and conducting virtual experiments related to botany. These subtle nudges enhance student engagement, providing helpful hints without strict rules. Students feel empowered to analyze and make educational choices, creating a personalized and enjoyable AR learning experience.

A. Research Questions

To answer RQ1, we identify the fundamental technology that allows for smooth AR interactions. The creation of augmented reality (AR) requires a complex interplay of multiple hardware, each contributing to a different aspect of the immersive experience. From the research, we found that most AR applications use strong graphics processing units (GPUs) and application processors to do the heavy lifting of complex visual renderings, real-time data processing, and 3D object manipulation. Complex spatial positioning systems are required to achieve sensory immersion. A mix of inertial, magnetometers, and depth-sensing technologies is required to enable the AR application to precisely track user movement and ambient context. The ability to precisely localize things is essential for smoothly integrating virtual objects into the physical world. Display technologies are essential to create visual canvases for augmented reality material. High-resolution optics—often liquid-crystal display (LCD) or micro-OLED (AMOLED) technology—are used to provide crisp images and reduce latency. This promotes a seamless and continuous presentation of the augmented elements. Different user input devices are needed for different interaction modalities, and each is customized for a particular AR application. Voice control, hand gestures, and stylus interaction are constantly used to allow users to naturally operate virtual items within the actual environment.

Mobile phones, our companions in our pockets, have become readily available AR platforms. Their integrated sensors—cameras, accelerometers, and gyroscopes, among others—provide crucial information for real-time monitoring and comprehending the surroundings. They also have high-resolution monitors that show the augmented material alongside the actual world. Well-known frameworks like ARKit from Apple and ARCore from Google enable developers to take advantage of these features, promoting the development of various AR applications on easily accessible devices.

Mobile augmented reality has various benefits. It is a well-liked entry point for both individuals and corporations due to its accessibility and affordability. Portability and ease make spontaneous AR experiences in a variety of locations possible. The vast number of smartphone users also guarantees a broader audience for augmented reality applications.

Yet, there are drawbacks to mobile augmented reality. Complex augmented reality experiences that require a lot of computational power or visual data may be limited by phones' processing power and display size. Comparing the experience to specialized AR headsets, the reduced field of view may further lessen its immersiveness.

Microsoft's HoloLens, a specialized AR headset, provides an alternative method. It uses advanced technology, such as MEMS micro-mirror-powered spatial mapping technologies, to accurately map the surrounding area. This complex spatial awareness makes accurate virtual object overlays into the user's actual space possible. Its wide-field-of-view, high-resolution screens also make blending the real and virtual worlds easier, creating a more immersive experience.

HoloLens has several advantages. Demanding AR applications like industrial design, medical training, or complex simulations are made possible by its specialized hardware, which provides robust computing and spatial awareness. Expanding the area of view further enhances the immersive experience by immersing consumers in augmented reality. But HoloLens has its share of difficulties. Its more significant price tag, when compared to mobile phones, restricts its usability and prevents mass adoption. The more prominent form factor may also be less comfortable to wear for lengthy periods, affecting usability and practicality.

In augmented reality hardware, mobile phones and HoloLens represent different paths. HoloLens prioritizes specialized hardware for immersive and computationally demanding AR experiences, while mobile phones offer affordability, accessibility, and portability. The best option depends on the AR project's particular requirements, considering things like the intended application's complexity, budget, and user experience. As augmented reality technology develops, we may expect more mobile and specialized hardware breakthroughs, expanding the realm of possibilities and opening truly immersive AR experiences to a larger audience.

The rapidly developing field of augmented reality (AR) development requires a strong set of tools to close the gap between imagination and immersive experiences [65]. This study examines the features and benefits of two well-known AR development platforms, Unity and Vuforia, for the creative process. The flexible gaming engine Unity has become a potent tool for AR production. Both inexperienced and seasoned developers can benefit from its user-friendly interface and extensive ecosystem of pre-built components and extensions. Unity's primary advantage is its ability to combine physics simulations and real-time rendering seamlessly, making it possible to create dynamic and engaging augmented reality experiences. Furthermore, accessibility is increased by its cross-platform compatibility, which guarantees that created apps may be easily installed on a range of mobile devices and augmented reality headsets.

Unity's capabilities are enhanced with Vuforia, a software development kit (SDK) designed exclusively for AR creation. Robust computer vision features including object and picture identification, marker less tracking, and spatial mapping are provided by Vuforia to developers. Because of this, augmented reality experiences that smoothly merge virtual aspects with the real world may be created by identifying and interacting with tangible items, surfaces, and environments. With the help of cloud identification capabilities, Vuforia's reach may be further increased, and an extensive library of items and locations can be recognized without the need for physical markers [66].

Nonetheless, the requirements of the augmented reality project frequently determine which of Unity and Vuforia is best. Developers unfamiliar with augmented reality principles may find Unity's learning curve more challenging, even though it allows more creative freedom and flexibility. Though Vuforia's customization choices may not be as comprehensive as Unity's, it does offer a speedier entry point for beginners with its concentrated AR functionalities.

Apart from these two popular development tools, ARKit (for Apple devices) and ARCore (for Android devices) are other noteworthy tools influencing AR creation. Every platform has distinct advantages and disadvantages, and the best choice depends on the project's requirements, the proficiency of the developers, and the degree of customization required.

There are two ways to define augmented reality: marker-based and markerless. Each method has trade-offs; markerless systems excel in versatility but demand expensive hardware, while marker-based systems offer cost and accuracy but lack immersion. Understanding these distinctions guides decisions for engaging AR experiences, which answers RQ2.

Marker-based augmented reality systems use easily recognized visual cues, or markers, to place and activate virtual material. These markers are anchors that the AR system detects using computer vision techniques. These markers are frequently printed images or QR codes. The method correctly superimposes the digital material onto the marker's real-world position once recognized. AR with markers has various benefits. Beginners or low-budget projects will find it excellent due to its price and simplicity. Accurate placement of virtual elements is ensured by the exact marker identification, which is especially helpful for applications requiring great spatial accuracy. Still, there are drawbacks to marker-based augmented reality. Using physical markers might be cumbersome and interfere with the experience's fluidity because users must carry or print them. The AR experience may also be hampered by occlusion or marker damage. Moreover, the immersive experience of augmented reality may be diminished if markers don't always blend in with the surroundings.

On the other hand, marker-less AR disregards the usage of tangible markers. Instead, it uses advanced computer vision algorithms to identify and evaluate the actual world environment. Planar surfaces, particular items, or even generic environmental aspects may be recognized this way. Without markers, the AR system can smoothly incorporate virtual features by comprehending the context of the natural environment. Markerless augmented reality has many benefits. Doing away with the necessity for tangible markers and enabling spontaneous interaction with the augmented environment provides a more realistic and immersive experience. Its capacity to identify various real-world features also opens more creative options, allowing AR experiences to adapt to various environments dynamically.

Depending on the project's needs, marker-based or markerless augmented reality solutions should be selected. While markerless AR works best in situations requiring flexibility, adaptability, and a seamless, immersive experience, marker-based AR is best in controlled environments or applications requiring great precision. Both strategies are expected to advance as augmented reality technology develops, obscuring distinctions and opening even more fascinating possibilities for augmented interactions with our surroundings.

RQ3 focuses on assessment criteria to measure the success of the research conducted. A research paper by Hu X. et al. [21] assesses how well undergraduate non-engineering students can meet learning objectives and how they see augmented reality (AR) as a tool for learning. They developed Virtual and Augmented Reality for Structures (VARS),, an AR program that teaches structural systems to test their experiments. Using pre and post-tests and quizzes, it was discovered that the perceived attainment of learning outcomes and change in quiz scores were unaffected by prior knowledge or AR experience.

One of the most important trends is the diversification of AR applications across many subjects and learning levels. AR enables immersive experiences beyond the confines of textbooks and still images, from studying ancient civilizations in history classes to dissecting virtual frogs in biology classes. Furthermore, the popularity of mobile augmented reality (AR) democratizes access to this technology even further by making it widely available outside of classrooms.

In RQ4, this study tries to find some evidence of integration in AR development and persuasive system design. Although not many were found using such a combination, some papers show promising results. There is no denying that AR technology has the power to revolutionize traditional learning by encouraging participation, visualization, and involvement. The combination of AR with gamification components is another significant trend. Teachers may increase student engagement and retention by incorporating game concepts like points, rewards, and challenges—which are also components of persuasive system design. There have been numerous seminar studies on the application of augmented reality (AR) in education. Children's learning can be accelerated by AR technology. Augmented reality improves children's motivation and interest in learning, making it more enjoyable [63]. Today, augmented reality is used in education by combining the real world with digital learning resources. This enhances user perception and interaction using simulations in the real world [62].

Collaborative augmented reality (AR) experiences are also becoming more popular. They allow students to collaborate on shared augmented worlds in real time, promoting communication and teamwork skills. ColabAR is a toolset that Villanueva A. et al. [26] introduced; it allows users to manipulate virtual items in Tangible Augmented Reality (TAR) labs via physical proxies. To encourage student remote cooperation, ColabAR offers configurable, haptic-based interaction options. The AR toolkit provides haptic feedback-enabled gear and software to improve user experience and promote cooperation during learning.

In another project by Gupta N. et al. [22], they want to create and assess an augmented reality application that gives medical students a dynamic and immersive learning environment by using the quantitative methodology to develop and evaluate the AR application's capacity to enhance learning results. The study examines how the augmented reality application affects students' performance on tests, information retention, and engagement. The findings demonstrate that the AR application significantly improves learning outcomes. Augmented reality (AR) technology enhances student performance on tests, retention of material, and engagement. It was discovered that the application's functionality and design were straightforward and easy to use, making it suitable for both instructors and students. The study shows how AR technology can improve learning outcomes in medical education and offers insights into this potential.

Another novel approach to teaching medicine and carrying out neurosurgery outside of the operating room is to use patient medical data to create augmented reality. To help trainees grasp the various situations of pituitary tumors and surrounding blood vessels, especially arteries, an AR application for surgical training of pituitary tumor excision has been developed by Cai S et al. [25]. Pituitary tumors and surrounding arteries and veins are represented as virtual objects using image segmentation from numerous patients' MRI data. With the AR application, trainees have an immersive learning environment, which motivates them to comprehend the various situations of pituitary tumors and surrounding vessels, particularly arteries.

A practical AR system has been developed by Oberdörfer et al. [42] to teach frog anatomy. The learning environment is created based on a plush frog with detachable markers. The organs' 3D models replace the markers after they are detected. Learners can examine the organs up close and gain insight into their activities by extracting individual organs. To increase overall motivation, they also integrate a gamification system and a quiz for self-assessment of learning progress.

There are several possible restrictions brought up by PSD and AR convergence. A significant concern is that AR systems can trick users without their knowledge or agreement. For instance, an entity may utilize augmented reality (AR) to subtly market products to customers. At the same time, an agency of government could use it to track users' locations and gather behavioral data.

The possibility that "filter bubbles" could be created by AR systems, in which people are only exposed to data supporting their previous beliefs, is another problem. Personalized news headlines might be projected over users' worldviews by a social network firm, for instance, using augmented reality. Lastly, a decrease in user autonomy may result from merging PSD and AR. AR systems can potentially restrict users' access to information or influence them to make decisions that are not in their best interests, for instance.

B. *Specific Limitations*

Teachers' imaginations have been captured by augmented reality (AR), a technology that has the potential to transform education completely. AR aims to improve comprehension, encourage active learning, and boost engagement by placing digital content over the real world. However, despite its obvious persuasiveness, augmented reality in education has several disadvantages that prevent its wide adoption and success.

C. *Technological hurdles*

The field of view, display resolution, and processing power of current AR devices, like smartphones and headsets, might not be sufficient for smooth and engaging learning environments. Furthermore, the price of these gadgets may be too high for individual students and institutions, increasing existing gaps in education.

D. *Technical glitches and limitations*

AR applications tend to face problems related to surroundings, latency, and tracking accuracy. Errors and inconsistencies have the potential to disrupt the flow of learning, lead to frustration, and compromise the entire experience.

E. *Connectivity and infrastructure*

Strong internet connections are usually necessary for AR to download content and keep accurate overlay tracking. This poses a challenge for communities and schools with poor or restricted internet connectivity.

F. *Pedagogical Challenges*

AR material must be thoughtfully created to support the present curriculum and align with learning objectives. Gains in learning might not always be guaranteed by merely superimposing digital items onto natural environments. Training and assistance are needed for educators to create successful AR-based lesson plans. For students, the constant stream of sensory input in augmented reality settings can be disorienting and mentally taxing. Information density and interactivity must be carefully evaluated to ensure AR promotes learning rather than distraction. It might be challenging to assess the effectiveness of AR-based learning. The complex learning processes that AR offers may be beyond the scope of traditional assessment techniques. It will take new frameworks and methods to assess how much-augmented reality affects student learning results.

G. *Social considerations*

Inequalities in social and economic status may affect opportunities for learning if certain people have less access to AR technology and training. To guarantee that every kid has fair access to AR's potential benefits, educators and schools must devise solutions. The collection and use of user data by AR apps raises privacy concerns. In AR contexts, schools need to teach children about responsible online behavior and have robust data protection mechanisms in place. Excessive use of augmented reality (AR) in education might lead to social isolation and a decline in real-world engagement. A healthy mix of traditional interactive activities, interaction with others, and AR-based learning is essential.

IV. CONCLUSION

The vast possibilities presented by the convergence of Augmented Reality (AR) and Persuasive System Design (PSD) technologies must be carefully assessed against any possible disadvantages. The following essential suggestions can direct the convergence's ethical and responsible development: First and foremost, it is important to set strong ethical standards. It is essential that these guidelines identify and restrict negative behaviors such as privacy invasions, manipulation, and social discrimination. These actions are crucial to safeguarding people's well-being and promoting societal cohesiveness. Second, it's critical to empower users. Users must oversee the AR information they view and its presentation. As opposed to passive exposure, ensuring informed engagement involves transparency and customizable options. Thirdly, it's essential to inform users about potential risks. Thorough information on possible dangers connected to augmented reality systems must be easily accessible. Possible risks are reduced by enabling users to make educated choices and use technology securely. Lastly, it is pretty valuable to investigate how AR affects behavior. By examining the ways in which AR affects human behavior, we can learn a great deal about the advantages and disadvantages of the technology. This information can protect against unforeseen harmful effects and guide the creation of appropriate apps.

By implementing these suggestions, we will ensure that the convergence of PSD and AR technologies occurs in a responsible and ethical manner, optimizing its potential to positively impact society.

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