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REVIEW

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Virtual and Augmented Reality Applications: A Broader Perspective Review

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Abstract: Over the past few years, the topics related to alternate realities seem to ponder significant discussion in engineering as well as in general studies. However, in the wake of increasingly diverse and complex research in major domains including education, medical, and& defense among others, the topics of augmented and virtual reality seem to gather attention on a global scale. This paper surveys the emerging trends of such technologies and their correlation with the wide application spectrum as an important aspect of human civilization. Moreover, the purpose of this paper is to distinctively formulate the role of such technologies by closely examining and describing the available approaches along with practical competencies through a detailed literature review of more than 70 technical papers. This review further aims to discuss the topic based on an empirically oriented study carried out through an experimental approach and practical vision. Lastly, the existing technologies in every domain along with the related issues and bounded limitations have been discussed to reveal the possible solutions as a future scope perspective of the work.

Keywords: augmented and virtual reality, application spectrum, empirically oriented study, experimental approach

1. Introduction

Augmented reality (AR) and virtual reality (VR) has completely redefined our perspective to look at the world and its relation with our body, mind, and actions by greatly influencing the sense of modern understanding. Due to the recent technological advancements in integrated body tracking, both AR and VR systems have become highly versatile, portable, realistic, and better to navigate in real-time, thus adding various elements to the range of sensations [1]. However, the increased availability of these devices tends to slowly close the gap between the level of alternate realities and the reality in the life world. Even after immense research on these tools within the cyber-physical environment, we cannot still accurately map multiple applications with today's state-of-the-art AR/VR authoring tools due to various obstacles encountered [2]. The findings from the initiatory reviews, discussions, literary texts, and work from global creators are mostly concerned with the isolated aspects and the verbalized paradigms of AR/VR interactive tools.

We are well aware that the terms AR and VR make sense only when linked to the human perception of the real world. Since we cannot alter the reality we live in, tremendous resources and research over the past few decades have been invested to change the initial landscape of reality to spawn the perceptions of an alternate reality. A distinction between the real world and the alternate worlds triggers the need to holistically study various distinguishing factors by applying various test principles to them and thus, observing their impacts from ground zero.

Through this detailed review, a structured interpretation of AR and VR technology has been presented considering diversified approaches for design and implementation. Domain-specific problems have also been addressed through an empirical segmented approach. The pluralism of perspectives being vivid has helped mankind to practice it among wider areas of interest, thereby encouraging research and innovation. Furthermore, the concepts of different realities revolve around the degree of immersion, the level of interaction, and the extent of dynamic nature serving as the factors of prime consideration [1]. The proposed review on applications of AR and VR technology is intentionally planned to reduce the gap between the application techniques by establishing a representation pattern that can be applied over multiple domains with minimal changes.

The generalized idea of AR/VR technology has been described via contrasting methodology in Section 2 of the paper. Section 3 provides insights on the major application scenarios along with knowledge-governed alternatives wherever possible. What comes up for discussion via literature is simply describing, understanding, correlating, and codifying the application models and establishing a link between the respective practices, which has been highlighted in Section 4. It is finally followed by derived conclusions covered in Section 5 of this review.

2. The Virtuality Continuum

The term "virtuality continuum" was first devised by research scholars Paul Milgram and Fumio Kishino in 1994 to affirmatively portray the concept of alternate realities in that era [3]. The modern interpretation of the virtuality continuum is, however, a spectrum of technological possibilities that exist between the actual physical

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world and an entirely digital world. It embraces all the technological advancements that recast reality by dissolving the boundaries between the living world and the digital elemental world through computerized graphical interventions. The contemporary adaptive version of the virtuality continuum is shown in Figure 1.

The continuum can be split open into multiple subsets. The real environment only accounts for actual physical elements and the environment we live in. With the slight tint of digital elements imposed upon the physical environment, we get the extended version of the physical world known as AR. Augmented virtuality (AV) on the other hand is the juxtaposed class of AR where the physical elements are included in the absolute virtual environment. VR being regarded as the new normal follows rather dominant digital criteria for each of its elements, thus pushing the concept of reality to its absolute maximum.

Mixed reality (MR) being a collective term encompasses all the environments where both the physical and virtual elements coexist. It often generates materially physical experiences, which remain formally categorized as alternate realities with little too highly integrated digital elements. The extreme nodes of the continuum are excluded from the MR terminology. The exact differentiation between the elements of the continuum is accurately not possible as proportional boundaries seem to misfit this theoretical framework. Extended reality (XR) is another related term, which embraces AR, AV, and VR techniques. This term was coined to adequately deal with the relationship between esthetic and life-world levels of reality. When additional sensory impulses like the taste, smell, touch, etc., are introduced into the VR, it gives rise to hyper reality (HR). Therefore, an alternate reality is not only perceived as a concrete term linked to verbal, textural, or basic media; it is also a process that can transcend text and pictorial boundaries to exceed the level of human imagination and act as an impactful tool in shaping the world around us.

2.1. Augmented reality and virtual reality

The term “augmented reality” was primarily coined by researcher Tom Caudell at Boeing in the early 1990s as a form of improved data visualization aid for shop floor workers, thus following a modified approach toward the traditional concept of text and images [4]. Hence, AR plays an esthetic and decisive role and contributes to shaping works of art and texts by demonstrating a multifaceted interplay between the real and virtual world as well as real-time interaction, which is registered in three dimensions enabling the coupling of text and images.

The major building blocks of any AR-based system involve tracking and registration systems, display technology, and real-time rendering. When presenting a reasonable augmented element in the real world, pin-point tracking and registration permit a sense of directness and simultaneity of elements by precisely matching the perspectives of both environments. Superior augmentation also needs an appropriate display medium and refined rendering to attain a precise layer of graphical elements in the real environment in an instantaneously realistic manner. The differentiation between the actual, augmented, and virtual realities can be best observed in Figure 2.

Also, known by the names “synthetic reality” and “cyberspace,” VR is concerned with interactive multidimensional simulations reproducing various environments and real situations [5]. The nexus of any VR-based application includes simulation for representation, interaction for control, and perception for artificial sensing [6]. Despite being developed in the late 1950s, the key components of any VR system still include vision devices for visualization, software for managing the immense virtual data, and interaction devices to facilitate the consistent involvement of the body and its motions in the virtual sphere to strongly emphasize the user experience.

3. Applications of AR and VR

As this review solely revolves around the applications of AR and VR technologies, most of the major domains where such instrumentation and differential scope can be defined have been ensembled in Figure 3. The document covers well-established application sectors like education, military, manufacturing, medical, and entertainment among others. Also, emerging applications in the fields of marketing, fashion, tourism, construction, logistics, etc., have been considered. The following paradigms of sub-sections cover the recent trends in the respective fields, which are explored to date.

3.1. Education sector

The conjugation of real and virtual elements in education permits the learners to visualize complex structural relationships and hypothetical concepts [7], experience phenomena that are not

Figure 1
Modified virtuality continuum

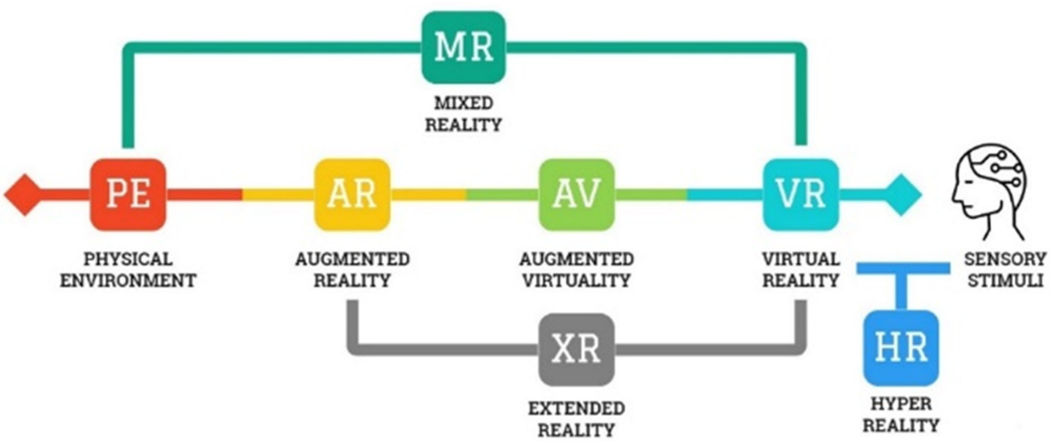


Figure 2
Different perspectives of reality

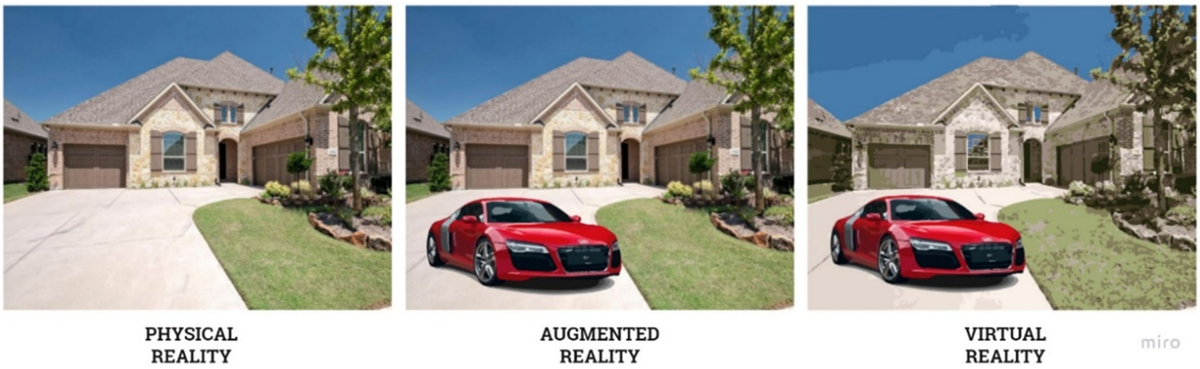
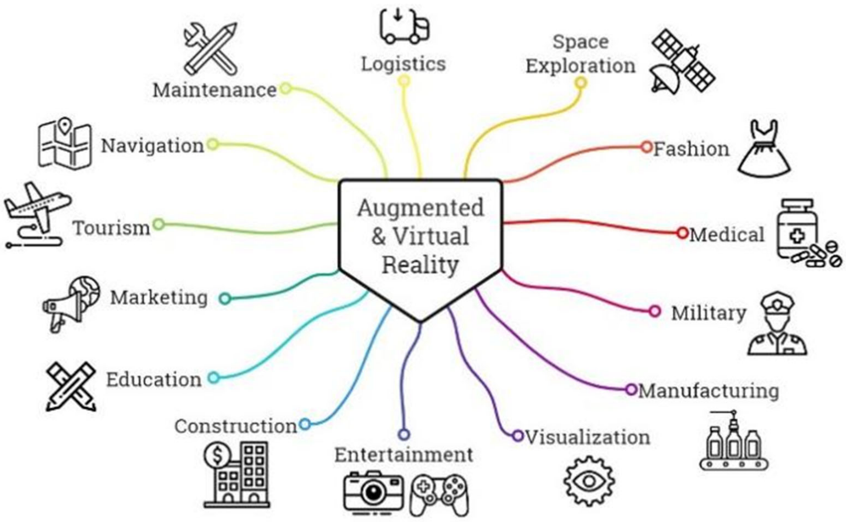


Figure 3
Application domains of AR and VR



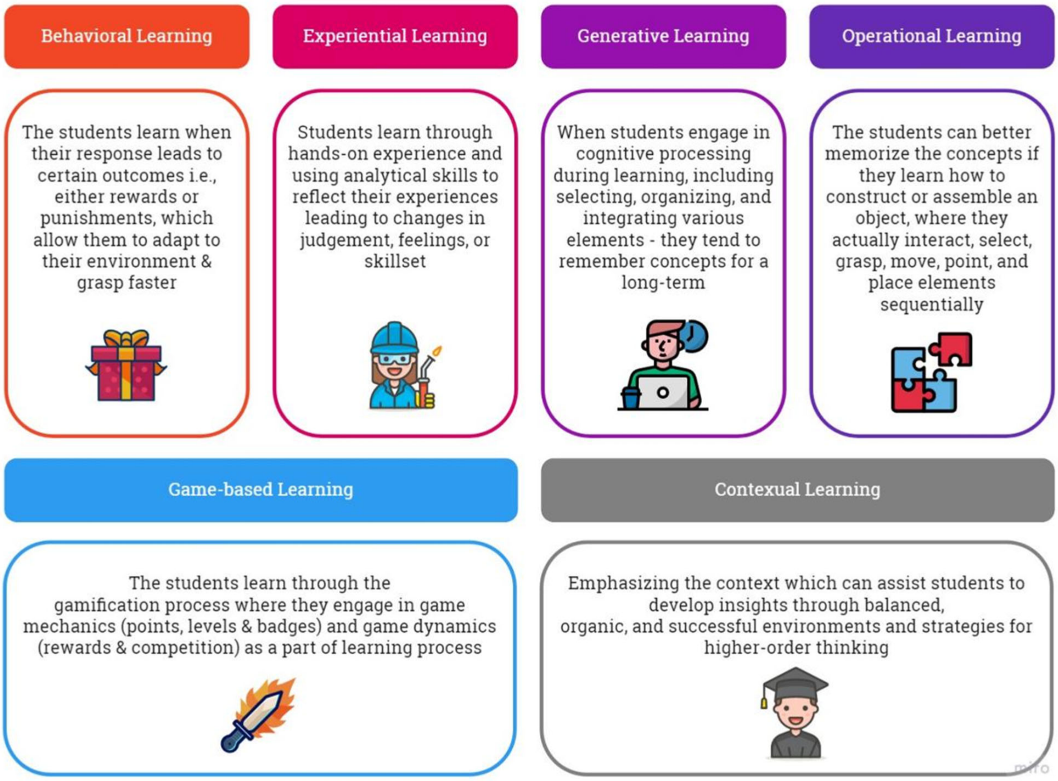
practical in the real world [8], interact with multi-dimensional artificial objects [9], and develop key practices which cannot be enacted in any other environment. There are numerous advantages of AR and VR in education, which are listed in Figure 4. These technologies prove to be of great assistance in creating a comprehensively blended e-learning environment [10], which enables the development of critical thinking, problem-solving skills, and mutually cooperative communication skills by merging digital objects with the physical world [11].

The educational use of AR and VR is being defined at each level of education right from elementary schooling to the university levels, thus including a wide range of learners [12]. Combining alternate realities with the education framework facilitates the adoption of a variety of learning methodologies with a great degree of flexibility for the user [13] as summarized in Figure 5. As the virtuality continuum can be experienced through a variety of mediums, it can be made portable and adaptive to a variety of scenarios – to enhance the contents and instruction sets within a traditional classroom, supplement instructions in special classrooms for disabled individuals,

Figure 4
Advantages of augmented and virtual reality in the education sector

extend content beyond the classroom as well as combine it with other technologies to enrich their applications [14]. Various image-based and location-based application techniques can be included to provide a rather authentic learning experience in the real world by improving the performance of the student and reducing the instructor's workload at the same time [15].

Figure 5
Different types of learning



The use of these emerging technologies eliminates the traditional separation between the user and the machine and hence provides increasingly direct access to information as shown in Figure 6 [16]. The use of hands-free devices to overlay visuals and facilitate real-time interaction via voice recognition, hand gestures, and other similar techniques with a greater level of sensory integration gives the best possible dynamic learning experience, interactive manipulation, and topic immersion [17].

Figure 6
AR-based multitasking

3.2. Medical sector

The necessity to explicitly stage the medical data as well as the patient in the same physical environment serves to be the foremost motivation to use AR and VR technologies in the medical sector. The base of these techniques is the instantaneous in-situ visualization of superimposed and diversified data with reality associated with the physical world [18]. The camera-tracked head-mounted displays (HMDs) acting as an interfacing medium with sight-angle-focused visualization can be of great assistance in surgical operation routines [19]. AR can be specifically used for visual assistance-based systems for ultrasound imaging applications [20] projecting see-through graphical elements, which are sufficiently rendered to provide a perception of depth. Acting as constitutive elements in collaborative surgeries, such display-based systems guided by hand gestures and voice recognition algorithms can help to control the extent of visual information while operating [21]. VR procedures are increasingly being used for the simulation of digital spaces designed with real-world resemblance as visual assistance aids for the training of medical professionals. Trainees practicing these systems learn tasks and procedures at a much faster pace while constantly exploring and troubleshooting the possibilities [22–24] to improve the accuracy of their medical knowledge in a professionally safe environment [25].

Teleoperated robot-served surgery proved to be highly advantageous to the operators over minimally meddling surgery by refining the extent of tool precision, agility, and the scale of visualization. Bichlmeier et al. [26] developed an AR-based system for observing human anatomy through the skin using polygonal surface models as shown in Figure 7 [26]. Various VR-enabled complex distraction techniques can be utilized for acute pain management procedures [27]. Different forms of sensors can also be used to provide an intuitive form of haptic feedback to the user [28]. Virtual environments using VR wearables are rated helpful for mentally unfit patients suffering from depression, anxiety, eating disorders, substance abuse, stress syndromes, phobias, and much more [29, 30].

Figure 7
Bichlmeier AR system

All these technological advancements in the medical sector have led to improvements in patient safety and cost reductions [31] up to a certain extent through the use of enhanced professional training, better surgical navigation and tooling, enhanced data visualization, and finally as a therapeutic tool in the treatment of patients [32–34]. Though all these outcomes are on the positive side, they need to be adapted on regular basis as per the ever-changing true-to-life environments [35] and medical settings to maintain flexibility and ease of use. On the contrary, they also tend to restrict the surgeon's natural skillset [36].

3.3. Military sector

As the military and defense sectors are based upon the formal and concrete approach agendas most of the time, there are quite a few options explored to date considering the concept of alternate realities. AR and VR can be collectively used as augmented virtual reality [37] to simulate complex battlefield scenarios [38] and provide a superior augmented visual experience to soldiers. Immensely narrow but significant efforts have been put up by multiple firms in the development of artificial terrains using AR and VR for the sole purpose of military training and intervention planning [18]. Real-time and hyper-realistic enemy combat scenarios can be simulated in VR for large-scale training programs of military personnel as shown in Figure 8. The battlefield augmented reality system (BARS) developed by Julier et al. [39]. Mao and Chen [40] uses similar technological tools for precise and highly scaled simulation of war-like conditions and is also equipped with environment-authoring tools to display updated 3D information status at all times.

Figure 8
Battlefield AR headset similar to BARS

Hybrid inertial and optical trackers using miniaturized sensors have been increasingly used in the armors of soldiers to track the movement of body parts in real time [41] as a part of urban military training under variable conditions [42]. Digitized superimposed elements combined with night vision technologies are being used to extend the pilot's visibility and facilitate navigation in degraded visual conditions [43]. VR-based environmental simulations and models are used as tools to find answers to forensic psychiatry concerning how individuals' behaviors are organized in various combat conditions [44] to develop physically as well as mentally fit soldiers. Soldiers are constantly subjected to complex and stressful activities under various cognitive and emotional factors like wars, which act as multifaceted, uncertain, and ambiguous contemporary operating spaces [45, 46].

Maintaining the operational effectiveness, performance, as well as mental state of soldiers has become a factor of prime consideration [47] and can be achieved up to a certain extent using augmented and virtual experiences. Serving as a novel approach toward improving stress resilience [48], the development of increasingly innovative and efficient training programs [49] integrated with alternate perspectives seems to have a promising future.

3.4. Manufacturing sector

Considering the current dynamic and competitive business environment, the manufacturing industry is engaged with new challenges every other day, which require an all-round perspective on the basic yet important classes of manufacturing attributes, i.e., time, cost, quality, and flexibility among others [50]. Unlike traditional times, the present era is focused on high production mix, variable production scaling, extreme customization of products, environmental soundness, and many more demanding criteria, thereby increasing the degree of complexity while manufacturing. Hence, globalized manufacturing environments require enhanced production practices, better product development, real-time information exchanges between the functional units on the shop floor, superior production scheduling, and seamless collaboration [18] while maintaining shorter lead time, reduced costs, and improved quality [51]. Due to innovative advancements in information technology, manufacturing processes have become more responsive, systematic, efficient, as well as economically competitive.

Taking finite resources and limited energy options into consideration, using AR and VR approach toward manufacturing seems to be a valid option [52]. Moving on to the era of digital manufacturing, various graphical assembly instructions and animated procedures can be pre-coded at the design stage for a particular process or equipment. These sequences can then be transmitted when needed and virtually projected on real products [53] using AR annotation for better understanding and error-less assembly/production. This approach can reduce information overload and facilitate better instructional understanding for assembly operators. Technology has advanced a long way ahead from industry 1.0 to the current state of 4.0, and so has the information access mediums as shown in Figure 9. Expert authors also found that by overlaying instructions on actual components, the rate of error for an assembly task can be reduced by up to 82% [54].

Figure 9
Journey of information access mediums use in industries

Over the past few decades, novel advancements in the digital manufacturing community have been highly promising in reducing product development times and cost, as well as addressing the need for customization [55], better product quality, and faster response to ever-changing market conditions. As AR and VR can be coupled with human abilities and intelligence using AI techniques, they can be used to provide efficient and contemporary tools to assist the various manufacturing tasks and reduce data handling errors through superior decision-making. Various challenges faced by the manufacturing domain are mostly due to a lack of fluid interaction and physical experience, which can be eliminated by a combination of HMDs, handheld devices, projectors, user trackers, haptic feedback, and software systems in close connection to AR and VR acting as a mutually beneficial system as shown in Figure 10 [56]. The extent of intervention by these technologies in manufacturing activities has been summarized in Figure 11. Also, the success of VR in these applications largely depends on the level of immersive feeling and the degree of fidelity of the virtual environments [57].

3.5. Entertainment sector

As there is immense information to access at the fingertips of human civilization, the use of AR and VR technologies has not been limited to professional domains only. These techniques are also implemented in gaming and entertainment as a part of human life. These can be used to create immersive games and to increase the visibility of important game aspects in life sports broadcasting [18]. Using virtual tooling, anything and everything from swimming pools to F1 tracks and complex gaming environments have been created in conjugation with various accessories that can be used to obtain better immersion into these games.

Whether it be AR or VR-based gear, camera and sensor-based tracking systems [58] still play a major role to enhance the experience of the user. One of the best examples of these games is virtual golf in a confined environment as in Figure 12(a) where the posture, movement, and force exerted by the player are evaluated to make the virtual golf shot possible [59]. Most of us have also experienced the annotations on the football, cricket, or rugby fields within an ongoing game possibly due to superior computerized software-based augmentation algorithms [60]. Using them frequently can help individuals to master unknown sports as in Figure 12(b) and other complex activities like dancing, singing, and physical actions in a short period by allowing them to transfer their skills to the physical world acting as hands-on virtual training experience.

3.6. Other domains

Besides the major application domains, AR and VR have been tried and tested with other domains as well. Indoor navigation technologies using marker-based AR using hand-held cameras for position tracking [61] have been around for a long time now. Modern and portable sleek AR-enabled glasses based in Figure 13 on refined and tested paradigms for outdoor navigation are being used for pedestrians and automobiles under outdoor conditions with facial recognition and smart tracking sensors [62]. The data regarding the surrounding elements, route to be followed, highway signs, fuel status, danger zones, etc., are

Figure 10
VR-based interactive gear for simulation in industries

Figure 11
Extent of AR and VR immersion in manufacturing tasks

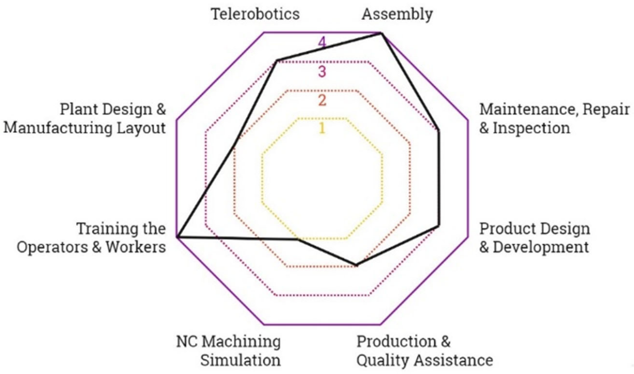


Figure 12
(a) Virtual indoor golf. (b) Multiplayer VR action PvP game players with virtual gear

(a)
(b)

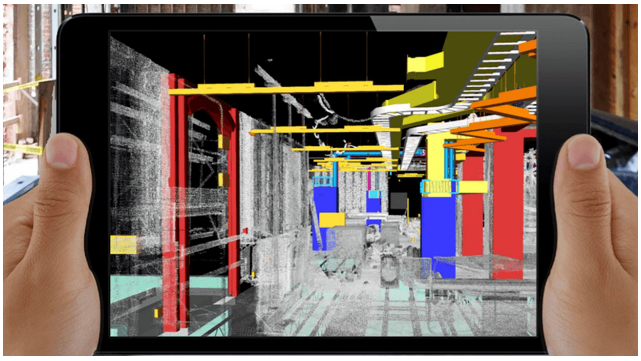

being displayed these days in modern vehicles on the windshield via heads-up displays. These techniques when coupled with IoT and path-planning algorithms are capable of analyzing the flow of traffic and possible congestion [63]. These navigation techniques lead to significant reductions in navigation errors and enable focused attention.

VR-based navigation is used for training the workers and guards in virtual industrial environments to make them acquainted with unfamiliar plant and warehouse layouts [25]. Additional

Figure 13
View through the AR navigation glasses

information through path-finding systems, coordinate-based regions, and IoT enablers can facilitate faster object location on huge floor plans [64]. Visualization of the located objects in the form of 3D models on an HMD or tablet PC is more realistic and provides an increasingly realistic environment. With the increasing capabilities of smartphones and tablets, virtual element-based apps are becoming popular tools for creating immersive customer experiences and satisfying their needs [65]. Various popular retail businesses using such techniques to influence customer behavior are shown in Figure 14. Decision support tools as shown in Figure 15 in architecture and construction are developed to explore the relationships between structural systems and perceived architectural space [66] using VR as a focal element. Improved construction, renovation, and inspection [67] plans for architectural sites and monuments are mostly AR-based. Besides normal annotation and visualization, these can provide calibration-free urban planning, tangible interfacing, and projection-based simulation along with construction management [68] at a single click.

Figure 14
Virtual warehouse planning through a tablet



Virtual elements can be dragged into the advertisement and marketing industry by introducing special flyers and QR codes, which when scanned by cameras will cause a 3D model in Figure 16 of the specified item [69]. Such techniques have been used for quite a few years in the automotive industry on a global scale. A similar technique can be implemented at cultural heritage sites as a virtual tourist guide to access archaeological and historical information through multimedia sketches [70] as a better knowledge exploration experience via mobile devices [71].

Figure 15
Examples of popular retail brands using virtual customer experience tools

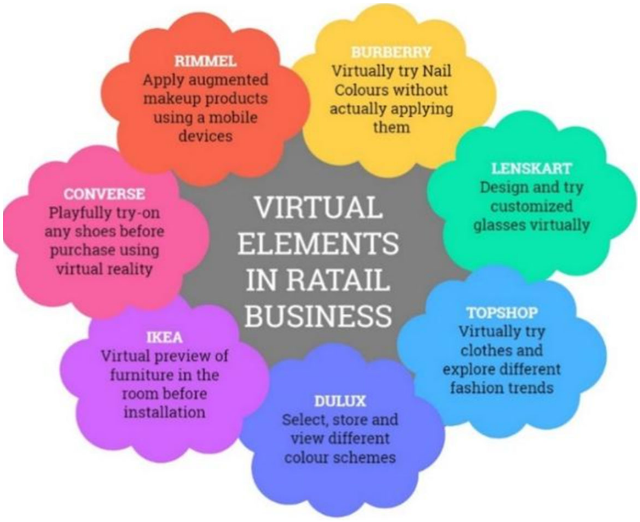


Figure 16
Automotive AR showroom

4. Discussion and Future Scope

AR and VR devices are increasingly being modified to suit the different application areas in terms of the extent of immersion and the degree of human involvement. Considering the emerging interest in these techniques backed by advanced research and implementation, several limitations still need to be worked upon. The primary observations to be drawn from this review are the differences between the levels of user interactions that occur inside the synthetic virtual environments and the hardware interactions in the physical world. While considering the augmentation of virtual elements or even the virtualization of the real space, accurate tracking of the surrounding data using any of the vision-based or marker-based techniques still needs improvement in connection with the outdoor environmental conditions. To overlay the digital elements or place them appropriately, these systems need to switch toward better edge computation services as the amount of data to be processed is simply huge in real time. Once the environment is mapped appropriately, these diverse applications require pin-point registration of virtual data through suitable hardware for an appropriately immersive experience. Being unable to represent all of the data instantaneously, many of the hardware options lead to distorted 3D representations and projections. Much of these limitations are also due to the current portability requirements for devices incorporating batteries, computing power, communication capabilities, memory modules, and resolution variability altogether. Implementation of haptic devices alongside sensory technology sure adds some promising future to these technologies in terms of application flexibility extended beyond specific domains. Table 1 provides a systematically organized representation of the various techniques implemented in this field along with their application based on their nature and other factors.

Another important observation from this review is that the same technology with a similar base is being tweaked to comply with the specific application. The same technology can be used for image capturing, data processing, and data projection without many changes if it is designed with a universal functionality purpose. If the scope of these devices is extended to a global scale through the integration of IoT and smart sensors coupled with refined hardware, it can prove to be universal application-oriented. IoT enablers like WiFi, radio frequency tags, and QR codes can play a crucial role to make the technology more universal. Such devices with better memory capabilities and advanced computational power can be equipped with machine learning algorithms to make them self-learning and of better practical predictability. The amalgamation of AR and VR broadens the application spectrum beyond human perception. Trends related to the transfer of information to the user from the hardware kit apart from the traditional vision medium need to be explored. This would also help humankind to achieve immersion beyond human perception by introducing the concepts of XR and HR. More focus should be aimed toward improving the flexibility of current techniques and devices, making them lighter, faster, precise, and more compact with the slightest continuous improvements over the future.

AR and VR are booming and promise to transform many aspects of our lives, such as education, entertainment, health care, tourism, social interaction, and more. Some of the future predictions include: LiDAR technology will bring more realistic AR creations to our phones by creating a 3D map of surroundings and allowing for occlusion, VR headsets will get smaller, lighter, and incorporate more features such as hand detection, eye tracking, and haptic feedback, we will also have new XR accessories to deepen the experience further, such as gloves, suits, treadmills, and chairs, and we will see more immersive and interactive content creation and consumption in the metaverse, such as gaming, art, music, and sports.

Some of the opportunities and challenges that AR/VR/MR will create include: closing the skills gap by using VR for training employees and staff remotely and effectively, lowering maintenance and service costs by using AR/VR/MR for remote service and support, improving design and production efficiency by using AR/VR/MR for digital prototyping and testing before manufacturing, enhancing customer engagement and satisfaction by using AR/VR/MR for personalized and immersive experiences, etc. But considering the current state of these technologies, the biggest hurdles include lack of standardization and interoperability among different platforms and devices, high cost and low availability of quality hardware and software, limited battery life and processing power of mobile devices, ethical and legal issues such as privacy, security, and content regulation, user acceptance and comfort issues such as motion sickness, and social stigma, and content creation and distribution issues such as quality, diversity, and accessibility.

Table 1
Analysis of reference research material

Reference	Technique AR	Technique VR	Degree of immersion and realism	Scalability	Remodeling time	Social acceptance	Application
Palmarini et al. [1]	✓		M	L	L	M	Mechanical maintenance
Caudell and Mizell [72]	✓		L	H	L	M	Manufacturing processes
Lerma-Castaño et al. [5]		✓	H	L	H	L	Education for disabled students
Nee and Ong [73]	✓	✓	M	M	M	M	Digital manufacturing
Chang et al. [74]	✓		L	H	L	M	Contextual e-learning
Billinghurst and Duenser [75]	✓		M	M	L	H	Visualization of non-practical learning concepts
Yuen et al. [9]	✓		H	L	H	H	2D to 3D visualization
Thomas et al. [76]	✓		M	H	L	H	Anatomical medical education
Dunleavy et al. [77]	✓	✓	H	H	H	H	Immersive participatory e-learning
Scrivner et al. [78]	✓		H	H	L	L	Foreign language teaching
Radianti et al. [13]		✓	M	H	H	M	Virtual laboratory
Sutherland [79]	✓		M	H	L	M	Medical data superimposition
Bajura et al. [80]	✓	✓	H	M	L	L	Ultrasound imagery
Wen et al. [21]	✓		L	M	M	L	Gesture-guided robot surgery
Sielhorst et al. [81]	✓		M	H	L	M	Advanced medical displays
Bharathan et al. [22]		✓	M	M	H	L	Surgery simulator
Schout et al. [23]		✓	M	M	H	M	VR-based simulator trainer kit
Bichlmeier et al. [26]	✓		H	H	M	H	Depth-based image projection
Ahmadpour et al. [27]		✓	H	H	H	M	Acute pain management
Akinbiyi et al. [28]	✓		M	L	M	M	Robot-assisted surgery
Freeman et al. [29]		✓	H	L	M	M	Mental disorder treatment
Graafland et al. [31]	✓	✓	M	M	L	M	Medical education games
Carmigniani et al. [36]	✓		L	L	M	M	Multimedia tools
Neumann and Majoros [37]	✓	✓	M	M	H	M	Industrial maintenance
Julier et al. [39]	✓		L	M	L	L	Information filtering
Foxlin et al. [41]			H	M	M	H	Enhanced vision guidance systems
Livingston et al. [82]	✓		H	H	M	H	Military training and mapping
Benbouriche et al. [44]		✓	M	L	H	H	Forensic psychiatry
Nee et al. [56]	✓		M	M	M	M	Design engineering
Chryssolouris et al. [52]	✓	✓	L	L	M	L	Lean manufacturing
Tang et al. [54]	✓		M	M	H	M	Object assembly
Cavallaro et al. [83]	✓		H	H	L	H	Live broadcast augmentation
Rolland and Fuchs [84]	✓	✓	H	H	L	H	Medical visualization
Cirulis and Ginters [85]	✓		M	M	L	M	Logistics control
Watson et al. [65]	✓		H	H	H	H	Retail business
Feiner et al. [66]	✓	✓	H	H	H	L	Architecture and construction
Spies et al. [69]	✓		H	M	M	M	Automotive inspection
Martínez and Muñoz [70]	✓	✓	M	H	M	H	A virtual tourist guidance system
Feiner et al. [86]	✓	✓	H	M	M	H	3D prototyping tools

H – high; M – moderate; L – low.

5. Conclusions

Through this work, the major fields of application for AR and VR techniques with their current level of advancement have been highlighted. The suitability of these techniques for specific domains has been surveyed. Several approaches for the refinement of techniques have been studied from multiple research materials and the present challenges for the implementation have been discussed. To accelerate the implementation of virtual experiences, various hybrid approaches have also been studied up to a certain scale to effectively capitalize on the techniques' novel nature. Moreover, future research in this direction has also been proposed to bring forward the promising role of AR and VR with further refinement.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Nakul Chhabhaiya: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Bhumeshwar Patle:** Validation, Supervision. **Praveen Bhojane:** Methodology, Validation, Investigation, Writing – review & editing, Supervision, Project administration.

References

[1] Palmarini, R., Erkoyuncu, J. A., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing*, *49*, 215–228.

[2] Ashtari, N., Bunt, A., McGrenere, J., Nebeling, M., & Chilana, P. K. (2020). Creating augmented and virtual reality applications: Current practices, challenges, and opportunities. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, 1–13.

[3] Skarbez, R., Smith, M., & Whitton, M. C. (2021). Revisiting Milgram and Kishino's reality-virtuality continuum. *Frontiers in Virtual Reality*, *2*, 647997.

[4] Marshall, S. (2023). Augmented reality's application in education and training. *Springer Handbook of Augmented Reality*, 335–353.

[5] Lerma-Castaño, P. R., Chanaga-Gelves, M. V., Llanos-Mosquera, J. M., Castro-Serrato, L. E., & Romana-Cabrera, L. (2022). Virtual reality in gait rehabilitation in children with spastic cerebral palsy. *Revista Mexicana de Neurociencia*, *23*(1), 29–33.

[6] Bassyouni, Z., & Elhajj, I. H. (2021). Augmented reality meets artificial intelligence in robotics: A systematic review. *Frontiers in Robotics and AI*, *8*, 724798.

[7] Korkut, E. H., & Surer, E. (2023). Visualization in virtual reality: A systematic review. *Virtual Reality, 27*, 1447–1480.

[8] Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education*, *8*(1), 1–32.

[9] Yuen, S. C. Y., Yaoyuneyong, G., & Johnson, E. (2011). Augmented reality: An overview and five directions for AR in education. *Journal of Educational Technology Development and Exchange (JETDE)*, *4*(1), 11.

[10] Liberatore, M. J., & Wagner, W. P. (2021). Virtual, mixed, and augmented reality: A systematic review for immersive systems research. *Virtual Reality*, *25*(3), 773–799.

[11] Ozdemir, M., Sahin, C., Arcagok, S., & Demir, M. K. (2018). The effect of augmented reality applications in the learning process: A meta-analysis study. *Eurasian Journal of Educational Research*, *18*(74), 165–186.

[12] Zhang, W., & Wang, Z. (2021). Theory and practice of VR/AR in K-12 science education—A systematic review. *Sustainability*, *13*(22), 12646.

[13] Radianti, J., Majchrzak, T.A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778.

[14] Antonioli, M., Blake, C., & Sparks, K. (2014). Augmented reality applications in education. *The Journal of Technology Studies*, *40*(2), 96–107.

[15] Tzima, S., Styliaras, G., & Bassounas, A. (2019). Augmented reality applications in education: Teachers point of view. *Education Sciences*, *9*(2), 99.

[16] Tan, Y., Xu, W., Li, S., & Chen, K. (2022). Augmented and Virtual Reality (AR/VR) for education and training in the AEC industry: A systematic review of research and applications. *Buildings*, *12*(10), 1529.

[17] Oyelere, S. S., Bouali, N., Kaliisa, R., Obaido, G., Yunusa, A. A., & Jimoh, E. R. (2020). Exploring the trends of educational virtual reality games: A systematic review of empirical studies. *Smart Learning Environments*, *7*, 1–22.

[18] Mekni, M., & Lemieux, A. (2014). Augmented reality: Applications, challenges and future trends. *Applied Computational Science*, *20*, 205–214.

[19] Carpinello, A., Vezzetti, E., Ramieri, G., Moos, S., Novaresio, A., Zavattero, E., & Borbon, C. (2021). Evaluation of HMDs by QFD for augmented reality applications in the maxillofacial surgery domain. *Applied Sciences*, *11*(22), 11053.

[20] Qian, L., Barthel, A., Johnson, A., Osgood, G., Kazanzides, P., Navab, N., & Fuerst, B. (2017). Comparison of optical see-through head-mounted displays for surgical interventions with object-anchored 2D-display. *International Journal of Computer Assisted Radiology and Surgery*, *12,* 901–910.

[21] Wen, R., Tay, W. L., Nguyen, B. P., Chng, C. B., & Chui, C. K. (2014). Hand gesture guided robot-assisted surgery based on a direct augmented reality interface. *Computer Methods and Programs in Biomedicine*, *116*(2), 68–80.

[22] Bharathan, R., Vali, S., Setchell, T., Miskry, T., Darzi, A., & Aggarwal, R. (2013). Psychomotor skills and cognitive load training on a virtual reality laparoscopic simulator for tubal surgery is effective. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, *169*(2), 347–352.

[23] Schout, B. M., Ananias, H. J., Bemelmans, B. L., d'Ancona, F. C., Muijtjens, A. M., Dolmans, V. E., . . . , & Hendrikx, A. J. (2010). Transfer of cysto-urethroscopy skills from a virtual-reality simulator to the operating room: A randomized controlled trial. *BJU International*, *106*(2), 226–231.

[24] Xu, X., Mangina, E., & Campbell, A. G. (2021). HMD-based virtual and augmented reality in medical education: A systematic review. *Frontiers in Virtual Reality*, *2*, 692103.

[25] Vanderbilt, A. A., Grover, A. C., Pastis, N. J., Feldman, M., Granados, D. D., Murithi, L. K., & Mainous, A. G. (2015). Randomized controlled trials: A systematic review of laparoscopic surgery and simulation-based training. *Global Journal of Health Science*, *7*(2), 310.

[26] Bichlmeier, C., Wimmer, F., Heining, S. M., & Navab, N. (2007). Contextual anatomic mimesis hybrid in-situ visualization method for improving multi-sensory depth perception in medical augmented reality. In *6th IEEE and ACM international symposium on mixed and augmented reality*, 129–138.

[27] Ahmadpour, N., Randall, H., Choksi, H., Gao, A., Vaughan, C., & Poronnik, P. (2019). Virtual Reality interventions for acute and chronic pain management. *The International Journal of Biochemistry & Cell Biology*, *114*, 105568.

[28] Akinbiyi, T., Reiley, C. E., Saha, S., Burschka, D., Hasser, C. J., Yuh, D. D., & Okamura, A. M. (2006). Dynamic augmented

reality for sensory substitution in robot-assisted surgical systems. In *International Conference of the IEEE Engineering in Medicine and Biology Society*, 567–570.
[29] Freeman, D., Reeve, S., Robinson, A., Ehlers, A., Clark, D., Spanlang, B., & Slater, M. (2017). Virtual reality in the assessment, understanding, and treatment of mental health disorders. *Psychological Medicine*, *47*(14), 2393–2400.
[30] Maples-Keller, J. L., Yasinski, C., Manjin, N., & Rothbaum, B. O. (2017). Virtual reality-enhanced extinction of phobias and post-traumatic stress. *Neurotherapeutics*, *14*, 554–563.
[31] Graafland, M., Schraagen, J. M., & Schijven, M. P. (2012). Systematic review of serious games for medical education and surgical skills training. *Journal of British Surgery*, *99*(10), 1322–1330.
[32] Bretón-López, J., Quero, S., Botella, C., García-Palacios, A., Baños, R. M., & Alcañiz, M. (2010). An augmented reality system validation for the treatment of cockroach phobia. *Cyberpsychology, Behavior, and Social Networking*, *13*(6), 705–710.
[33] Chu, M. W., Moore, J., Peters, T., Bainbridge, D., McCarty, D., Guiraudon, G. M., . . . , & Daly, R. C. (2012). Augmented reality image guidance improves navigation for beating heart mitral valve repair. *Innovations*, *7*(4), 274–281.
[34] Lamounier, E., Lopes, K., Cardoso, A., Andrade, A., & Soares, A. (2010). On the use of virtual and augmented reality for upper limb prostheses training and simulation. In *Annual International Conference of the IEEE Engineering in Medicine and Biology*, 2451–2454.
[35] Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41–49.
[36] Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E., & Ivkovic, M. (2011). Augmented reality technologies, systems and applications. *Multimedia Tools and Applications*, *51*, 341–377.
[37] Neumann, U., & Majoros, A. (1998). Cognitive, performance, and systems issues for augmented reality applications in manufacturing and maintenance. In *Proceedings IEEE Virtual Reality Annual International Symposium,* 4–11.
[38] Vesa, C., Şorecău, E., Şorecău, M., & Vesa, T. A. (2022). Design, implementation and preliminary testing of a virtual reality system used to train military personnel on a simulated battlefield. *International Conference Knowledge-Based Organization*, *28*(3), 106–111.
[39] Julier, S., Lanzagorta, M., Baillot, Y., Rosenblum, L., Feiner, S., Hollerer, T., & Sestito, S. (2000). Information filtering for mobile augmented reality. In *Proceedings IEEE and ACM International Symposium on Augmented Reality,* 3–11.
[40] Mao, C. C., & Chen, C. H. (2021). Augmented reality of 3D content application in common operational picture training system for army. *International Journal of Human–Computer Interaction*, *37*(20), 1899–1915.
[41] Foxlin, E., Altshuler, Y., Naimark, L., & Harrington, M. (2004). Flighttracker: A novel optical/inertial tracker for cockpit enhanced vision. In *Third IEEE and ACM International Symposium on Mixed and Augmented Reality*, 212–221.
[42] Wu, Y., He, Y., Li, N., Wang, G., Zhang, L., Zhang, F., & Zhu, Y. (2023). A review of intelligent vision enhancement technology for battlefield. *Wireless Communications and Mobile Computing*, *2023*, 6733262.
[43] Yu, D., Jin, J. S., Luo, S., Lai, W. & Huang, Q. (2010). A useful visualization technique: A literature review for augmented reality and its application, limitation & future direction. *Visual Information Communication*, 311–337.
[44] Benbouriche, M., Nolet, K., Trottier, D., & Renaud, P. (2014). Virtual reality applications in forensic psychiatry. In *Proceedings of the Virtual Reality International Conference*, 1–4.
[45] Gomez, B. G., Winstead, J., Lopata, J., & McMahon, R. (2023). Closing the trauma and critical care gap: A paradigm shift through virtual reality and augmented reality. *Medical Journal, US Army Medical Center of Excellence, 23*(4–6). 20–24.
[46] Solomon, Z. (2013). *Combat stress reaction: The enduring toll of war*. Germany: Springer Science & Business Media.
[47] Kavanagh, J. (2005). *Stress and performance a review of the literature and its applicability to the military*. USA: Rand.
[48] Hackett, M., Makled, B., Mizroch, E., Venshtain, S., & Mccoy-Thompson, M. (2022). Volumetric video and mixed reality for healthcare training. *Interservice/Industry Training, Simulation, and Education Conference*, *22*, 22–24.
[49] Gaggioli, A., Pallavicini, F., Morganti, L., Serino, S., Scaratti, C., Briguglio, M., . . . , & Tartarisco, G. (2014). Experiential virtual scenarios with real-time monitoring (interreality) for the management of psychological stress: A block randomized controlled trial. *Journal of Medical Internet Research*, *16*(7), e3235.
[50] Machała, S., Chamier-Gliszczyński, N., & Królikowski, T. (2022). Application of AR/VR technology in industry 4.0. *Procedia Computer Science*, *207*, 2990–2998.
[51] Eswaran, M., & Bahubalendruni, M. R. (2022). Challenges and opportunities on AR/VR technologies for manufacturing systems in the context of industry 4.0: A state of the art review. *Journal of Manufacturing Systems*, *65*, 260–278.
[52] Chryssolouris, G., Papakostas, N. & Mavrikios, D. (2008). A perspective on manufacturing strategy: Produce more with less. *CIRP Journal of Manufacturing Science and Technology*, *1*(1), 45–52.
[53] Siedler, C., Glatt, M., Weber, P., Ebert, A., & Aurich, J. C. (2021). Engineering changes in manufacturing systems supported by AR/VR collaboration. *Procedia CIRP*, *96*, 307–312.
[54] Tang, A., Owen, C., Biocca, F., & Mou, W. (2003). Comparative effectiveness of augmented reality in object assembly. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 73–80.
[55] Akbari, M., Ha, N., & Kok, S. (2022). A systematic review of AR/VR in operations and supply chain management: Maturity, current trends and future directions. *Journal of Global Operations and Strategic Sourcing*, *15*(4), 534–565.
[56] Nee, A. Y., Ong, S. K., Chryssolouris, G., & Mourtzis, D. (2012). Augmented reality applications in design and manufacturing. *CIRP Annals*, *61*(2), 657–679.
[57] Chandra Sekaran, S., Yap, H. J., Musa, S. N., Liew, K. E., Tan, C. H., & Aman, A. (2021). The implementation of virtual reality in digital factory—A comprehensive review. *The International Journal of Advanced Manufacturing Technology*, *115*(5–6), 1349–1366.
[58] Biswas, P., Orero, P., Swaminathan, M., Krishnaswamy, K., & Robinson, P. (2021). Adaptive accessible AR/VR systems. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*, 1–7.
[59] Livitcuka, R., Alksnis, R., & Pladere, T. (2023). Impact of interpupillary distance mismatch on visual aftereffects of virtual reality gameplay. In *Optical Architectures for*

Displays and Sensing in Augmented, Virtual, and Mixed Reality (AR, VR, MR) IV, 12449, 377–380.

[60] Heller, B., & Bar-Zeev, A. (2021). The problems with immersive advertising: In Ar/VR, nobody knows you are an ad. *Journal of Online Trust and Safety*, *1*(1), 3.

[61] Kaimaris, D., Roustanis, T., Karolos, I. A., Klimantakis, K., & Patias, P. (2021). Aligning positioning and navigation of smart mobile devices to AR/VR environments. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *46*, 347–353.

[62] Lakehal, A., Lepreux, S., Efstratiou, C., Kolski, C., & Nicolaou, P. (2023). Spatial knowledge acquisition for pedestrian navigation: A comparative study between smartphones and AR glasses. *Information*, *14*(7), 353.

[63] Kim, S., Kim, H., Eom, S., Mahalik, N. P., & Ahn, B. (2006). A reliable new 2-stage distributed interactive TGS system based on GIS database and augmented reality. *IEICE Transactions on Information and Systems*, *89*(1), 98–105.

[64] Safikhani, S., Keller, S., Schweiger, G., & Pirker, J. (2022). Immersive virtual reality for extending the potential of building information modeling in architecture, engineering, and construction sector: Systematic review. *International Journal of Digital Earth*, *15*(1), 503–526.

[65] Watson, A., Alexander, B., & Salavati, L. (2018). The impact of experiential augmented reality applications on fashion purchase intention. *International Journal of Retail & Distribution Management*, *48*(5), 433–451.

[66] Feiner, S. K., Webster, A. C., Krueger III, T. E., MacIntyre, B., & Keller, E. J. (1995). Architectural anatomy. *Presence: Teleoperators & Virtual Environments*, *4*(3), 318–325.

[67] Zollmann, S., Hoppe, C., Kluckner, S., Poglitsch, C., Bischof, H., & Reitmayr, G. (2014). Augmented reality for construction site monitoring and documentation. *Proceedings of the IEEE*, *102*(2), 137–154.

[68] Guo, Y., Du, Q., Luo, Y., Zhang, W., & Xu, L. (2008). Application of augmented reality GIS in architecture. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *37*, 331–336.

[69] Spies, R., Ablaßmeier, M., Bubb, H., & Hamberger, W. (2009). Augmented interaction and visualization in the automotive domain. In *Human-Computer Interaction. Ambient, Ubiquitous and Intelligent Interaction: 13th International Conference Proceedings,* 211–220.

[70] Martínez, M., & Muñoz, G. (2004). Designing augmented interfaces for guided tours using multimedia sketches. In *Proceedings of the IUI-CADUI*04 Workshop on Exploring the Design and Engineering of Mixed Reality Systems.*

[71] Fan, X., Jiang, X., & Deng, N. (2022). Immersive technology: A meta-analysis of augmented/virtual reality applications and their impact on tourism experience. *Tourism Management*, *91*, 104534.

[72] Caudell, T. P., & Mizell, D. W. (1992). Augmented reality: An application of heads-up display technology to manual manufacturing processes. In *Hawaii International Conference on System Sciences, 2.*

[73] Nee, A.Y., & Ong, S. K. (2013). Virtual and augmented reality applications in manufacturing. *IFAC Proceedings Volumes*, *46*(9), 15–26.

[74] Chang, H. Y., Wu, H. K., & Hsu, Y. S. (2013). Integrating a mobile augmented reality activity to contextualize student learning of a socioscientific issue. *British Journal of Educational Technology*, *44*(3), E95–E99.

[75] Billinghurst, M., & Duenser, A. (2012). Augmented reality in the classroom. *Computer*, *45*(7), 56–63.

[76] Thomas, R. G., John, N. W., & Delieu, J. M. (2010). Augmented reality for anatomical education. *Journal of Visual Communication in Medicine*, *33*(1), 6–15.

[77] Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, *18*, 7–22.

[78] Scrivner, O., Madewell, J., Buckley, C., & Perez, N. (2016). Augmented reality digital technologies (ARDT) for foreign language teaching and learning. In *Future Technologies Conference,* 395–398.

[79] Sutherland, I. E. (1968). A head-mounted three dimensional display. In *Proceedings of the December 9–11, Fall Joint Computer Conference, Part I*, 757–764.

[80] Bajura, M., Fuchs, H., & Ohbuchi, R. (1992). Merging virtual objects with the real world: Seeing ultrasound imagery within the patient. *ACM SIGGRAPH Computer Graphics*, *26*(2), 203–210.

[81] Sielhorst, T., Feuerstein, M., & Navab, N. (2008). Advanced medical displays: A literature review of augmented reality. *Journal of Display Technology*, *4*(4), 451–467.

[82] Livingston, M. A., Rosenblum, L. J., Julier, S. J., Brown, D., Baillot, Y., Swan, J. E., . . . , & Hix, D. (2002). An augmented reality system for military operations in urban terrain. In *Interservice/Industry Training, Simulation, and Education Conference, 89.*

[83] Cavallaro, R., Hybinette, M., White, M., & Balch, T. (2011). Augmenting live broadcast sports with 3D tracking information. *IEEE MultiMedia*, *4*(18), 38–47.

[84] Rolland, J. P., & Fuchs, H. (2000). Optical versus video see-through head-mounted displays in medical visualization. *Presence*, *9*(3), 287–309.

[85] Cirulis, A., & Ginters, E. (2013). Augmented reality in logistics. *Procedia Computer Science*, *26*, 14–20.

[86] Feiner, S., MacIntyre, B., Höllerer, T., & Webster, A. (1997). A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. *Personal Techonologies*, *1*, 208–217.

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