Simulating Virtual Environment and Experience for Training, Exergaming, and Edutainment in eXtended Reality (XR): A Survey

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(a) Virtual Reality (VR) (b) Augmented Reality (AR) (c) Mixed Reality (MR)

Fig. 1. Teaser. This teaser shows the concepts of eXtended Reality (XR) technologies including (a) Virtual Reality (VR) technologies [1], (b) Augmented Reality (AR) technologies [2], and (c) Mixed Reality (MR) technologies [3].

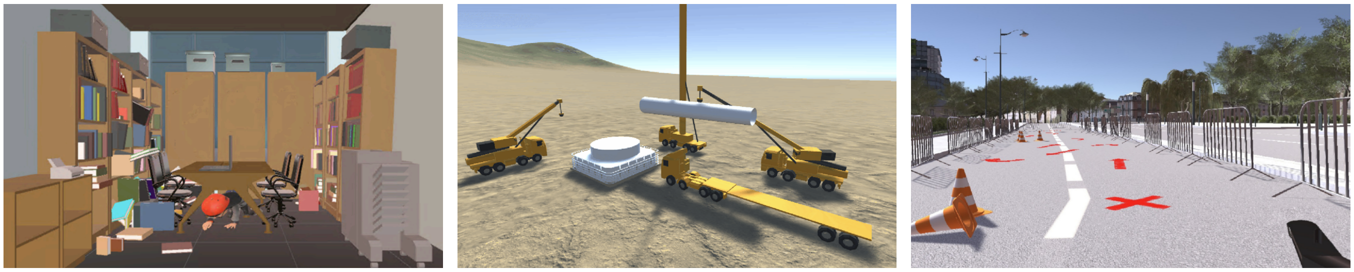
***Abstract*—In recent years, eXtended Reality (XR) technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), have emerged as transformative technologies in various domains and have revolutionized the fields of training, exergaming, and edutainment. These immersive XR technologies offer unique opportunities to simulate virtual environments and experiences that facilitate interactive learning and engaging physical activities. The simulation of virtual environments and experiences plays a crucial role in delivering high-quality and effective XR programs. This survey explores existing research and advancements in simulating virtual environments and experiences for training, exergaming, and edutainment in XR. This survey aims at providing an overview of the current state of research and development, discusses the challenges and opportunities in virtual environment and experience simulation, and highlights their future directions. By clarifying the advancements in virtual environment and experience simulation, this survey helps researchers discover the potential of XR in enhancing training, promoting physical activity, and revolutionizing education.**

***Keywords*—eXtended Reality, Virtual Reality, Augmented Reality, Virtual Experience simulation, Virtual Content Synthesis, Training, Exergaming, Edutainment**

I. Introduction

As an umbrella term, eXtended Reality (XR) [4] is the one that encompasses various immersive technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Figure 1 is a teaser that offers a glimpse into the world of eXtended Reality (XR) technologies, each of these XR technologies has its unique characteristics and applications, showcasing the vast potential for creating captivating and transformative experiences for users. Virtual Reality (VR) [5] refers to a simulated environment that is completely computer-generated. It immerses users in a virtual world, isolating them from their physical surroundings. VR typically involves wearing a head-mounted display (HMD) [6] or using projection systems to give users a sense of presence and immersion within the virtual environment. Users can interact with the virtual world using specialized input devices, such as handheld controllers [7], [8] or motion-tracking systems. Augmented Reality (AR) [9]–[11] overlays digital content onto the real-world environment, blending virtual elements with real-time sensory input. AR applications can be experienced through mobile devices, smart glasses, or headsets equipped with transparent displays. AR enhances the user's perception of reality [12] by providing additional information, context, or interactive elements in real time. It enables users to interact with both virtual and physical objects, often using gestures or voice commands. Mixed Reality (MR) [13] combines elements of both VR and AR, allowing digital objects to interact with the real world and vice versa. MR seamlessly blends virtual content with the user's physical environment, creating a cohesive and interactive experience [14]. Users can see and interact with virtual objects while maintaining awareness of their real-world surroundings. MR systems often employ advanced sensors, cameras, and spatial mapping technologies [13], [15] to enable real-time spatial understanding and accurate alignment of virtual objects with the physical environment.

XR technologies have gained significant traction in various



(a) Earthquake Safety Training [19]   (b) Construction Safety Training [20]   (c) Wheelchair Training [21]

Fig. 2. Examples of XR Training: (a) Earthquake Safety Training, (b) Construction Safety Training, and (c) Wheelchair Training.

domains [16], including training, exergaming, and edutainment. Those technologies combine real-world and virtual elements to create interactive and immersive experiences for users. The ability of XR to create immersive and interactive experiences in virtual environments opens up new possibilities for enhancing learning, physical exercise, and entertainment. The key objective of XR is to provide users with immersive, interactive, and engaging experiences that go beyond traditional forms of human-computer interaction. XR technologies find applications across various industries [17], including entertainment, gaming, education, training, healthcare, architecture, and more. By enabling users to perceive and interact with virtual elements, XR delivers a new multimedia platform [18] for simulation, visualization, learning, communication, entertainment, etc. In these contexts, the simulation of virtual environment and experience plays a crucial role in creating immersive and interactive experiences. There are several topics covered in this survey including:

- Exploring the current state of research and development in simulating virtual environment and experience for training, exergaming, and edutainment in XR.
- Providing an overview of recent XR technologies in virtual environment and experience simulation technologies for training, exergaming, and edutainment.
- Presenting recent works on synthesizing virtual environments to deliver meaningful experiences in XR.
- Demonstrating latest technologies in combining XR with procedural modeling for improved engagement, enhanced learning outcomes, and increased physical activity.

II. Simulating Training Scenarios in XR

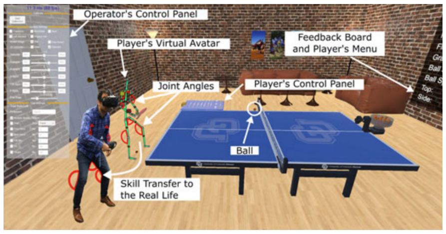
XR-based simulations have proven to be valuable tools for training across various domains. Virtual training simulations in XR involve creating realistic environments, lifelike avatars, and accurate physics simulations. Training simulations in XR offer realistic and immersive environments for professional development across industries such as safety training [22]–[24], healthcare [25], [26], surgery [27], [28], palpation [29], aviation [30], driving [31], and manufacturing [32]. This section discusses the use of XR for training purposes, such as physics-based simulations, virtual environment synthesis, personalized training synthesis, etc. and explores the benefits of simulating virtual environments and experience for training, including cost-effectiveness, risk mitigation, and scalability.

A. Earthquake Safety Training in XR

Earthquakes pose a significant threat to human lives and infrastructure. To mitigate the devastating impact of earthquakes, it is crucial to provide effective and immersive training to individuals and communities. Research works [33]–[36] explore the utilization of VR as a powerful tool for earthquake safety training. Zhang et al. [19] propose the use of VR technology to create an immersive and interactive simulation for evaluating and training occupants in earthquake safety actions. As shown in Figure 2 (a), the VR-based evaluation aims to assess occupants' response to simulated earthquake scenarios, identify areas for improvement, and promote effective safety behaviors in indoor settings. Li et al. [35] examine the advantages of VR in creating realistic simulations, promoting experiential learning, and enhancing the overall effectiveness of earthquake safety training programs through virtual drills. Lovreglio et al. [36] further discuss the potential challenges and future directions for VR-based earthquake safety training, emphasizing the importance of collaboration between researchers, developers, and educators to harness the full potential of this technology. To date, there is an absence of existing research or studies that demonstrate a focused endeavor in synthesizing virtual environment and experience for personalized earthquake safety training in XR.

B. Construction Safety Training in XR

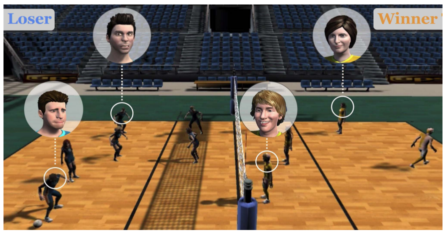
Construction sites are known for their high-risk environments, requiring comprehensive safety training to mitigate potential hazards and protect the well-being of workers. With the rapid advancements in XR technologies, recent research works [24], [37]–[40] show a growing opportunity to revolutionize construction safety training in XR. Li et al. [41] explore the application of synthesizing personalized construction safety training scenarios for VR training. Jeelani et al. [42] examine the benefits, challenges, and potential solutions associated with implementing stereo-panoramic environments-based training programs for construction workers. Additionally, Norris et al. [43] discuss the impact of XR on worker competence, safety awareness, and hazard recognition. Through a review of existing literature, case studies, and expert opinions, Li et



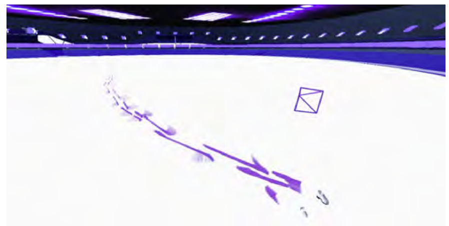
(a) Ping-Pong [48]

(b) Soccer [49]

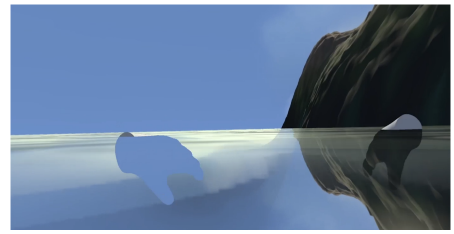
(c) Basketball [50], [51]



(d) Volleyball [52], [53]



(e) Ice Skating [54]



(f) Swimming [55]

Fig. 3. Examples of Sports in XR: (a) Ping-Pong, (b) Soccer, (c) Basketball, (d) Volleyball, (e) Ice Skating and (f) Swimming.

al. [44] aim to shed light on the transformative potential of XR in enhancing construction safety training methodologies. Li et al. [20] propose the use of simulation technology to create a virtual environment for construction safety training and active learning in wind tower construction. As shown in Figure 2 (b), the simulated wind tower construction environment aims to enhance trainees' understanding of safety protocols, promote hazard recognition, and develop effective safety behaviors. Xu et al. [45] propose the incorporation of VR technology as a solution for safety training on construction sites in urban cities. Harichandran et al. [46] propose a conceptual framework for construction safety training using dynamic virtual reality games and digital twins. Li et al. [47] presents a framework for simulating virtual construction scenes on OpenStreetMap and explores potential applications and future developments in the field. The integration of XR aims to create immersive training simulations that simulate real-world construction scenarios, enhance hazard recognition, improve safety behaviors, and ultimately reduce accidents and injuries.

C. Wheelchair Training in XR

Wheelchair mobility plays a critical role in the lives of individuals with mobility impairments, providing them with independence and facilitating their participation in various activities. However, training individuals to maneuver wheelchairs effectively can be challenging and time-consuming. Arlati et al. [56], [57] presents an overview of XR-based wheelchair simulators, and discusses their potential benefits, challenges, and future directions. Inman et al. [58] use VR technology to develop wheelchair simulators that provide immersive and interactive training experiences. Vailland et al. [21] conducted a pilot study to explore the integration of vestibular feedback into a VR wheelchair driving simulator to enhance the training experience. As shown in Figure 2 (c), this pilot study aims to investigate the impact of vestibular feedback on user performance, engagement, and spatial awareness during wheelchair driving simulations. Ktena et al. [59] propose a gaze-based wheelchair simulation platform with a safe and controlled environment for users to practice wheelchair navigation skills, enhance their spatial awareness, and improve overall mobility in VR. Li et al. [60] propose an automatic synthesis approach for generating virtual wheelchair training scenarios. By leveraging stochastic optimization techniques, the synthesis process aims to generate diverse and adaptive scenarios that cater to users' specific needs and progressively challenge their wheelchair navigation skills.

D. Other Types of Training in XR

XR has revolutionized the field of training by providing immersive and interactive simulations on different domains such as fire fighting training [61]–[67], medical training [68]–[75], military training [76]–[83], social skills training [84]–[91], decision-making training [92]–[96]. Generally speaking, these research works explore the applications and benefits of simulating different types of training scenarios in XR, and discuss the potential of XR in creating engaging training environments across various domains.

III. Simulating Exergaming Experience in XR

Exergaming refers to the integration of gaming elements with physical exercise, promoting physical activity and health. Simulating virtual environments and experiences for exergaming involves creating engaging and motivating virtual worlds that encourage users to perform physical movements. Researchers explore various approaches, including gesture recognition, motion tracking, and real-time feedback systems, to develop immersive exergaming experiences. This section focuses on the integration of XR with physical exercise through

(a) Treadmill [97]   (b) Elliptical [98]

Fig. 4. Examples of Optimizing Personalized Gym Activities in XR such as (a) Treadmill Exergame and (b) Elliptical Exergame.

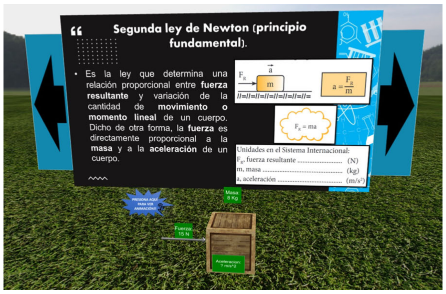
exergaming and highlights the potential of simulating virtual environment and experience to create engaging fitness tasks.

A. Sport Activities in XR

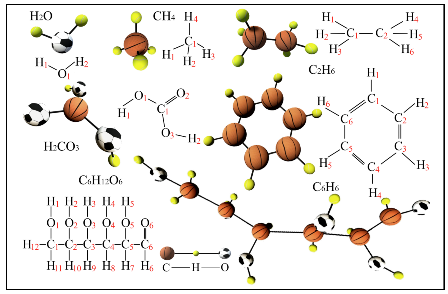
XR offers exciting opportunities for simulating sports activities and enhancing the training and immersive experiences in sports. Neumann et al. [99] explore the applications and potential benefits of simulating sports activities in VR and discuss the utilization of VR technologies in recreating realistic sports environments, enabling athletes to practice and improve their skills, and providing fans with immersive and interactive experiences. Putranto et al. [100] highlight the advantages of VR in sports training, including enhanced performance analysis, injury prevention, and adaptive training scenarios. Nor et al. [101] present a review of gamification in VR sport to discuss challenges and considerations in designing VR-based sports simulations, such as capturing realistic player movements, simulating real-time interactions, and ensuring user comfort and safety. By conducting research on college physical education and sports training in VR, Li et al. [102] contributes to the understanding of how VR can revolutionize sports training, engagement, and spectator experiences. Kim et al. [103] and Li et al. [104] present immersive interactive, multi-player, virtual ping-pong games that leverages VR technology to create an engaging and realistic ping-pong simulation. Pietschmann et al. [105] focuses on matching levels of task difficulty for different modes of presentation in a VR table tennis simulation. Oagaz et al. [48] explore the impact of training in VR on performance improvement and skill transfer in ping-pong. As shown in Figure 3 (a), this game simulator enables players to compete against each other in a virtual ping-pong match, mimicking the physical aspects of the sport, including ball physics, racket movements, and player interactions. By providing an immersive and interactive environment, VR enables players to practice and refine their techniques, simulate real game scenarios, and enhance their overall performance. Rojas et al. [49] presents a novel approach to skill assessment using a full-body immersive VR soccer simulation. As shown in Figure 3 (b), by providing a realistic and interactive soccer environment, this VR simulation enables players to experience game-like scenarios and make real-time decisions based on the actions of virtual opponents and teammates. Tsai et al. [50], [51] explore the use of VR technology as a training tool for enhancing basketball tactic skills. As shown in Figure 3 (c), by creating immersive and interactive virtual environments of basketball courts, VR simulations provide players with realistic game scenarios to practice and refine their tactical decision-making abilities. Bai et al. [52], [53] explores the concept of building emotional virtual characters in VR volleyball games to create a more immersive and engaging gameplay experience. As shown in Figure 3 (d), by simulating human-like emotions and reactions, virtual characters can generate a dynamic and responsive environment that elicits emotional responses from players. Li et al. [54] explore the simulation of ice skating experience in VR as shown in Figure 3 (e), focusing on the design and development of physics-based VR simulation that mimic the sensations and challenges of ice skating. Ginja et al. [106] explores the applications of VR in para-badminton practice, including skill development, tactical training, and enhancing the overall player experience. Li et al. [107] explores the simulation of skydiving experience in VR by employing motion tracking devices to create a realistic and thrilling skydiving simulation within indoor settings. Tsai et al. [108] focuses on the design and development of interactive software using a digital glove for virtual reality baseball pitch training. Li et al. [55] presents a procedural marine landscape synthesis approach for creating swimming exergames in VR. As shown in Figure 3 (f), by leveraging procedural generation techniques, this paper generates realistic underwater environments through a novel procedural modeling approach.

B. Gym Activities in XR

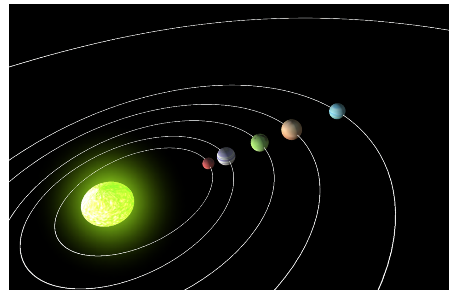
XR has the potential to transform traditional gym activities into immersive and interactive virtual training experiences. Recent research works explore the applications and benefits of integrating XR technology in various gym activities, including virtual workouts [109], strength training [110], fitness classes [111], and personalized training sessions [112]. By incorporating XR, users can engage in realistic simulations, receive real-time feedback, access personalized training programs, and track their progress in a more engaging and motivating manner. Rabbi et al. [113] discuss the design considerations, technological advancements, and user experiences associated with the Internet of Things (IoT) and VR-based gym activities. Amresh et al. [114] explores the potential impact of XR on user engagement, exercise adherence, and overall fitness outcomes for home-based VR game systems. Furthermore, Zhou et al. [115] address the challenges, ethical considerations, and future directions to promote physical ac-



(a) Physics Science [119].

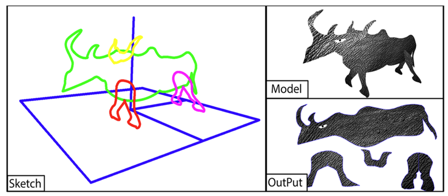


(b) Chemistry Science [120].

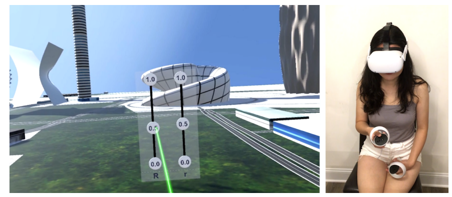


(c) Astronomy Science [121].

(d) Wire Art [122].



(e) Cardboard Toy Art [123].



(f) Architecture Art [124].

Fig. 5. Examples for Edutainment in XR such as (a) Physics Science, (b) Chemistry Science, (c) Astronomy Science, (d) Wire Art, (e) Cardboard Toy Art, and (f) Architecture Art.

tivity by leveraging the XR technologies in gym environments. Gao et al. [116] conduct a study to understand how can VR exercise promote the health and wellness of older adults during the COVID-19 pandemic and how can VR enhance fitness training experiences, making gym activities more enjoyable, effective, and accessible for individuals of all fitness levels. Kosmalla et al. [117] explore the concept of using everyday sports equipment as a proxy for immersive virtual reality workouts, allowing users to engage in VR fitness experiences without the need for specialized equipment. For synthesizing personalized VR fitness experiences and gym activities, Li et al. [118] introduce the concept of exertion-aware path generation specifically designed for VR bike exergames. This proposed approach aims to optimize the virtual path in the game environment based on the user's exertion preferences and fitness levels. Li et al. [97] focus on the synthesis of terrains specifically designed for treadmill exergaming in VR. As shown in Figure 4 (a), this proposed approach aims to create realistic virtual landscapes that align with the user's customized treadmill workout intensity and preferences. Li et al. [98] present an interactive exergame authoring tool designed specifically for creating personalized elliptical workout experiences in VR. As shown in Figure 4 (b), this authoring tool enables users to customize their elliptical VR exergames tailored to their fitness goals, preferences, and abilities.

IV. Synthesizing Edutainment Programs in XR

Edutainment combines educational content with entertaining elements to enhance learning experiences. Synthesizing edutainment programs in XR involves creating interactive and engaging virtual environments that facilitate knowledge retention. This section explores the fusion of education and entertainment in XR applications and discusses how to synthesize edutainment programs in XR that can create immersive educational experiences across various disciplines.

A. Science Edutainment in XR

XR technologies revolutionize science education through immersive and interactive experiences [125]. Recent research works explore the applications and benefits of science edutainment in XR, focusing on how XR technologies can enhance science learning, stimulate curiosity, and promote active engagement. Durukan et al. [126] present a systematic review on science education to examine the potential of VR for visualizing complex scientific concepts, conducting virtual experiments, exploring virtual worlds, and fostering collaborative learning. Pirker et al. [127] presents a systematic review of the design considerations, pedagogical approaches, and technological advancements in creating VR-based computer science education experiences. Liou et al. [128] conduct study to explore how can VR classroom be applied to science education and how can VR transform science education, making it more accessible, immersive, and enjoyable for learners. Fabris et al. [129] explore the VR in higher education and addresses the challenges and future directions in implementing science education in VR. Barrow et al. [130] explores the applications and benefits of AR in the context of life science education. Sermet et al. [131] explores the applications and benefits of VR and AR in the context of environmental science education. Bogusevschi et al. [132] present a case study that explores the implementation and effectiveness of a combined VR and Virtual Laboratory (VL) approach in a secondary school physics classroom and investigates how the integration of a 3D virtual learning environment can enhance student engagement, conceptual understanding, and practical skills in physics class. As shown in Figure 5 (a), Zatarain et al. [119] explores the experiences and benefits of using web-based XR technologies in physics education and discusses the design considerations, implementation strategies, and pedagogical approaches associated with web-based XR applications for physics education. As shown in Figure 5 (b), Li et al. [120] explore the concept of creative molecular model design as a means of enhancing chemistry education through engaging and interactive edutainment experiences on XR game engine. Li et al. [121] present a text-based planetary system VR simulation interface as a tool for astronomy edutainment. As shown in Figure 5 (c), by leveraging text-based interfaces and procedural generation techniques, users can explore simulated planetary systems in immersive virtual environment.

B. Art Edutainment in XR

Art education plays a vital role in fostering creativity, critical thinking, and cultural appreciation. The emergence of XR presents exciting opportunities to transform art education through immersive and interactive experiences [133]–[135]. Gonzalez et al. [136] explore the concept of art edutainment in XR, examining how XR technologies can be harnessed to engage learners and enhance their understanding and appreciation of art in the context of higher education. Kim et al. [137] examine the effect of socially engaged art education with VR platforms and discuss the design considerations, pedagogical approaches, and technological advancements in integrating VR into art education. Li et al. [122] present a smart pen tool interface designed specifically for wire art design in VR to enhance art education via immersive and interactive experiences. As shown in Figure 5 (d), this smart pen tool leverages the capabilities of VR technology, allowing users to design virtual wire sculptures with precision and creativity. Li et al. [123] focus on the design and creation of drawing animal cardboard toys as a means of promoting art education and entertainment for children. As shown in Figure 5 (e), this cardboard toy design process encourages children to engage in hands-on activities, express their artistic abilities, and develop spatial awareness. Li et al. [124] present a scriptable parametric modeling interface designed specifically for conceptual architecture design in VR for architecture art education. As shown in Figure 5 (f), this interface allows architects and designers to understand parametric art designs via manipulating and iterating on design parameters, generating architectural forms, and visualizing them in virtual 3D space.

V. CONCLUSION

Synthesizing virtual environment and experience for training, exergaming, and edutainment in XR holds tremendous potential for enhancing learning, physical activity, and skill development. The simulation of virtual environment and experience plays a pivotal role in the success of XR applications for training, exergaming, and edutainment. Researchers are focusing on inclusive design practices, adaptive interfaces, and user customization options to cater to users with varying abilities, preferences, and specific needs for the XR applications. This survey highlights the importance of creating immersive, interactive, and engaging virtual experiences through techniques such as 3D modeling, gesture recognition, gamification, and adaptive feedback systems. The advancements in content synthesis techniques, such as geometric processing, physics simulations, procedural generation, and machine learning, offer exciting opportunities to enhance the effectiveness and immersion of XR experiences. However, challenges related to realism, scalability, computational complexity, and accessibility remain. Future research need to focus on addressing the challenges and exploring innovative approaches to further improve the simulation of virtual environments and experience in XR applications. Efforts need to focus on addressing these challenges to unlock the full potential of simulating virtual environments and experiences in XR for training, exergaming, and edutainment. Additionally, the integration of artificial intelligence and machine learning algorithms can enable adaptive and personalized virtual environments and experience simulation, tailoring experiences to individual preferences.

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