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# A Review of Virtual Conferencing, Interaction and Collaboration in Virtual Reality

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**Abstract**—With the rapid advancement of technology, virtual conferencing, as a new communication medium, are changing people's traditional communication methods and work models. Through the Internet and advanced communication technology, virtual conferencing eliminates geographical distance and enable people to conduct various communication methods such as video conferencing, audio calls, and real-time chat, making communication easy regardless of time and space. Since COVID-19, there has been a wealth of research on virtual conferencing, especially augmented reality (AR) and virtual reality (VR) conferencing. They are either based on discussions of virtual conferencing technology, reflections on completed virtual conferencing events, or surveys on the user experience of virtual conferencing, but a comprehensive summary of the shared features of virtual conferencing is currently lacking. In this study, we will summarize the key features of virtual conferencing and propose existing issues and challenges in virtual conferencing based on these features, in order to provide directions for improving the quality of virtual conferencing.

**Keywords**—Virtual conferencing, Virtual Reality, Avatar, Collaboration

## I. INTRODUCTION

In the 1990s, the limited bandwidth of that era restricted the sharing of basic graphs related to molecules and data [1]. During this time, the concept of virtual conferencing, especially real-time interactions among participants, was considered virtually unattainable. However, as bandwidth capabilities have continually expanded, it is now feasible to share comprehensive visual information and execute more intricate renderings and animations [2]. Technological progress in transmitting audio and video to numerous interconnected

devices with minimal latency has paved the way for virtual conferencing to advance, approaching a state of real-time communication and offering nearly immersive experiences [3].

Virtual conferences have been heavily used since COVID-19, and user experience feedback about virtual conferencing has been mixed [4, 5]. Some people think that virtual conferencing is a very convenient way to hold conferencing, while some people are affected by improper organization of virtual conferencing due to lack of experience or unstable conferencing systems due to technology, network conditions, etc., resulting in bad conferencing experience. This paper organizes the timeline of the development of virtual conferences. Beyond technological feasibility and convenience, conferences fundamentally serve critical social and academic functions: knowledge exchange, professional networking, community building, informal social interaction, mentorship, and collaborative problem-solving. Face-to-face meetings naturally support these goals through spatial presence, nonverbal cues, and spontaneous interactions. Virtual conferencing, especially in immersive Augmented Reality (AR)/Virtual Reality (VR) environments, aims to preserve and enhance these core functions while overcoming geographic barriers. Clarifying these fundamental purposes strengthens the conceptual grounding of this review and justifies the focus on immersive technologies. With the ongoing maturation of computer vision technology, AR and VR conferences have garnered considerable attention due to their potential to offer immersive 3D experiences to participants [6]. For this form of virtual conferencing, we have amalgamated existing research and distilled three key features: "shared virtual environment", "representing the user's avatar" and "Interaction and collaboration". Based on these key features, the technical

issues and challenges of virtual conferencing are put forward, thereby offering valuable insights for the enhancement of virtual conferencing platforms.

## II. PREVIOUS WORKS

Face-to-face conferencing can provide an excellent setting for scientific discussion and communication, but the combined environmental cost of all the travel for participants is substantial [7]. The carbon footprint associated with attending academic conferences has become a widespread concern. Several studies have done research on the impact of face-to-face conferencing on the environment, showing that academic conferences produce a large amount of CO<sub>2</sub>, of which travel accounts for a large proportion [8]. With the outbreak of COVID-19, people have to turn many face-to-face conferencing into virtual conferencing [9]. These virtual conferencing are conducted online, assisted by social software and conference software [10, 11]. Virtual conferences can help people communicate in a cheap and eco-friendly form and overcome many of the accessibility barriers of traditional conferences. Until now, virtual conference is still widely used, it plays an important role in our work and communication. By delving into the context, strengths, challenges and implications of virtual conferencing, we can better understand its role in terms of society and communication modalities, and how to better address the problems and opportunities therein.

TABLE I. PREVIOUS WORK VIRTUAL CONFERENCING

<i>Classification</i>	<i>Title</i>	<i>Year</i>
Technology	Virtual meetings with desktop conferencing [12]	1998
Technology	Video realistic avatar for virtual face-to-face conferencing [13]	2002
Organization	Form of Academic Exchange on Information Era—Virtual Meeting [14]	2010
Experience	Ten simple rules for organizing a virtual conference—anywhere [15]	2010
Experience	Synchronous interaction among hundreds: An evaluation of a conference in an avatar-based virtual environment [2]	2011
Experience	Mixing real and virtual conferencing: lessons learned [16]	2013
Technology	Virtual Reality Conferencing: Multi-user immersive VR experiences on the web [17]	2018
Technology	Virtual Reality Conferencing [18]	2018
Experience	Virtually in this together—how web-conferencing systems enabled a new virtual togetherness during the COVID-19 crisis [4]	2020
Experience	Virtual science conference tries to recreate social buzz [19]	2020
Experience	Virtual conferences raise standards for accessibility and interactions [5]	2020
Organization	Online conferences—Towards a new (virtual) reality [20]	2020
Organization	Maximizing virtual meetings and conferences: a review of best practices [21]	2020

<i>Classification</i>	<i>Title</i>	<i>Year</i>
Experience	Lessons of COVID-19: virtual conferences [22]	2020
Experience	Enhancing the experience of virtual conferences in social virtual environments [23]	2020
Organization	Academic conferencing in 2020: A virtual conference model [24]	2021
Experience	IEEEVR2020: Exploring the first steps toward standalone virtual conferences [25]	2021
Experience	Virtual conference participant's perceptions of its effectiveness and future projections [26]	2022
Experience	Virtual conference design: features and obstacles [27]	2022
Experience	Going virtual: Academic conferences in the age of COVID-19 [28]	2022
Experience	Facilitating virtual conferences: reflections and lessons learned in two global communities [11]	2022

From the 1990s to the present, it can be observed through the study of various papers (Table I) that virtual conferences have undergone decades of development and evolution. We divide the papers about virtual conferencing into three classifications: (1) Technology: describe the technology related to virtual conferencing. (2) Organization: sort out how to organize a virtual conferencing. (3) Experience: review the successful or failed experience of virtual conferencing to propose the future development direction of virtual conferencing. It is evident that before the COVID-19 outbreak, research into virtual conferencing technology was already underway, which provided technical support for large-scale conversion of face-to-face conferencing into virtual conferencing the pandemic. After COVID-19, there has been a heightened focus on collating and summarizing the lessons learned from the organization of numerous virtual conferences, with the aspiration of enhancing the outcomes of future virtual conferences.

Although people can return to face-to-face conferences after the end of COVID-19, the advantages of virtual conferences were evident during the COVID-19, and many conferences continue to choose the virtual conferences format. This suggests that while virtual conferences cannot completely replace face-to-face conferences at this stage, they have become an important form of gatherings in people's lives. Consequently, it is imperative to comprehensively explore the features and issues associated with virtual conferencing for its continued development. Paper [27] undertakes a systematic literature review study and identifies 67 key features and 74 obstacles that users encounter when interacting with virtual conferencing (including 2D and 3D virtual conferencing) technologies. This paper will further summarize the key features unique to 3D virtual conferences represented by AR/VR conferences, and propose current issues and challenges regarding these features

## III. COMPARISON BETWEEN 2D VIDEO CONFERENCING AND AR/VR CONFERENCING

Mainstream 2D video conferencing platforms (e.g., Zoom, Microsoft Teams, Webex) are widely adopted for their

simplicity and accessibility, but they lack immersive and spatial qualities compared with AR/VR conferencing. Table II summarizes key differences across critical dimensions.

TABLE II. COMPARISON BETWEEN 2D VIDEO CONFERENCING AND AR/VR CONFERENCING

Aspect	2D Video Conferencing	AR/VR Conferencing
Sense of presence/immersion	Low (flat screen, limited spatial cues)	High (3D space, spatial audio, embodied avatars)
Social interaction and networking	Limited (face-to-camera, small groups, hard to "walk around")	Rich (spatial proximity, spontaneous grouping, natural gaze/gesture)
Ease of use and accessibility	Very high (browser/app, low hardware demand)	Moderate - low (requires VR HMD/AR device, learning curve)
Technical requirements	Low (stable internet, basic PC/laptop)	High (VR-ready GPU, high bandwidth, tracking sensors)
Scalability	Excellent (hundreds - thousands of participants)	Limited (current platforms support tens to hundreds with optimization)
Key added-value scenarios	General meetings, lectures, interviews	Spatial collaboration, 3D object manipulation, training simulations, virtual labs, creative workshops

2D video conferencing remains practical for most daily communication due to its low cost and ease of use. AR/VR conferencing offers clear advantages for tasks requiring spatial presence, embodied interaction, and collaborative 3D work, making it particularly valuable in education, engineering, healthcare simulation, and creative industries.

#### IV. TIMELINE

As network communication technology and computer hardware equipment continue to advance, the evolution of virtual conferences has led to various forms of popularity during different periods. To provide a comprehensive overview, we can categorize the evolution of virtual conferencing into distinct stages, which are visually depicted in Fig. 1.

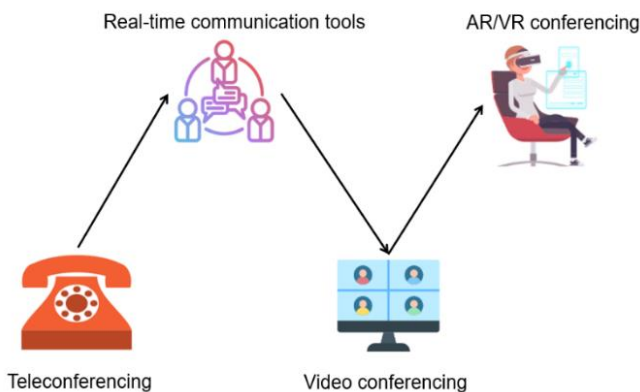


Fig. 1. The timeline of virtual conferencing

**Teleconferencing:** Teleconferencing is an early form of virtual conferencing. It has its origins in the development of telephone technology, allowing people in different

geographical locations to be connected together by telephone lines for conferencing. Although this way is capable of voice communication, it cannot deliver images or other multimedia content, which is quite limited [29].

**Real-time communication tools:** With the popularity of the Internet, real-time communication tools such as Skype, MSN Messenger, Yahoo Messenger and so on emerge as The Times require. These tools allow users to make text chats, voice calls, and video calls on their computers. They offer more ways of multimedia communication, but are still limited by bandwidth and technical constraints [12].

**Video conferencing:** With the popularity of broadband Internet and the improvement of video codec technology, platforms dedicated to video conferencing have emerged, such as Zoom, Webex, etc. These platforms provide high-quality video and audio communication, as well as additional features such as screen sharing, chat capabilities, and cloud storage [13, 16]. They make virtual conferences more practical and convenient, and are widely used in enterprises, education and medical treatment and other fields [30].

**AR/VR conferencing:** With the development of AR and VR technologies, virtual conferences have been taken to a whole new level, allowing participants to interact in the same way as face-to-face conferencing. AR conferences make use of augmented reality to superimpose virtual elements onto the real world [31], while VR conferences are completely placed in a virtual environment. This technology can improve the immersive feel of teleconferencing and facilitate deeper collaboration and interaction. With the popularity of hardware devices such as depth cameras and VR glasses, this form of conferencing has been used by more and more people [18]. However, the lack of immersion and interactivity like real face-to-face conferencing still restricts the development of AR/VR conferences. In recent years, many researchers have devoted themselves to solving this problem.

In general, the development of virtual conferencing has experienced the evolution from teleconference to real-time communication tools, to video conferencing platforms, and finally to AR/VR conferencing. Each stage is improving the quality and convenience of remote conferencing, enabling people to better collaborate and communicate remotely

#### V. KEY FEATURES OF VIRTUAL CONFERENCING

According to the paper [2, 5, 20], virtual conferencing is usually conducted in two forms: Live virtual conferencing and non-Live virtual conferencing. Live virtual conferencing help participants to discuss and exchange information in a timely, and it is easier to bring the same sense of presence as face-to-face conferencing. Non-Live virtual conferencing help to increase the flexibility of participants' time, participants can choose their own available time to participate, and it is also more inclusive of network broadband than Live virtual conferencing. According to the paper [20, 21, 24], we can summarize a complete conferencing into three phases (Fig. 2): the first phase is to develop a conferencing plan, such as determining the time, location, events, etc. of the conferencing. In the second phase, executing and completing the conferencing plan. In this phase, more manpower and funds are

invested in travel, accommodation, and conferencing venues for face-to-face conferencing, while virtual conferencing focus on technical support such as virtual environment construction, virtual avatar reconstruction, and virtual activity design. In the third phase, collect user feedback from participants in order to improve the quality of the conferencing in the future [21], such as setting a more reasonable schedule and organizing more effective events to attract attendees. Therefore, the essential difference between virtual conferencing and face-to-face conferencing lies in the second phase, during which we summarized the three key features of virtual conferencing: "Shared Virtual Environments," "Representing the User's Avatar," and "Interaction and Collaboration". This section will discuss these three features.

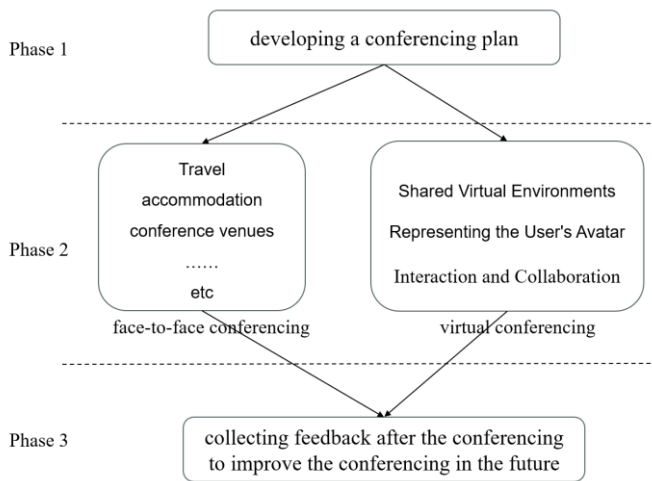


Fig. 2. Three phases for a conferencing

*A. Shared Virtual Environments*

Virtual conferencing allows people to meet and communicate in a common virtual environment. Depending on the conferencing size, conferencing format, and conferencing needs, providing different conferencing environments can often provide users with a better conferencing experience. Just like the conference model proposed in paper [2], three different conference environments are provided for different forms of conferences, as shown in Fig. 3.



Fig. 3. Different virtual conferencing environments [2]

These virtual environments are designed to be similar to the real world. The conference room used for a keynote has a podium and some seats. The conference room used for social events provides users with a relatively casual and free space where they can find who they are interested in to communicate. The poster session allows users to browse poster abstracts and

send them to interested posters to communicate with the authors. Paper [18] shows that the design of virtual environment details, such as trying a moving wall clock, the noise of passing cars outside the window, etc., can enrich the quality of the virtual environment and provide users with an immersive experience.

In addition, according to the paper [14], the virtual conferencing space should be composed of two parts: global conferencing space and local conferencing space. The global conferencing space is a virtual conference space that integrates the images of all participants, participants' gaze directions, venue background, physical objects and resource control. It mainly includes scenes, participant object collections and virtual entity object collections. The local conferencing space is the projection of the global conferencing space on the participant terminals according to the local participants' own spatial position and observation direction, and mainly includes local participants and corresponding external equipment.

*B. Representing the User's Avatar*

In virtual worlds, people design 3D anthropomorphic digital representations of themselves, called avatars [32]. Avatars can interact with others and the environment on behalf of the user. An avatar consists of two key features: appearance and movements. Although, many people think that it is a cool thing to use an appearance that they cannot have in real life to do some actions that cannot be completed in real life [33]. But in virtual conferencing, people's avatars that are similar to themselves are more attractive to some extent, because it can help familiar people more easily identify each other when they meet in a virtual environment, thereby enhancing the human connection in virtual conferencing.

*a) Appearance:* Early avatars converted head images in 2D video streams into 3D facial models through model-based encoding. During this period, virtual avatars already had the ability to turn their heads and express specific expressions [13]. Later, half-body or full-body 3D virtual avatars began to gradually appear, just like the virtual world in "Second Life". Paper [34] conducted an evaluation of avatar appearance on current social virtual reality platforms. These social virtual platforms often provide virtual conferencing tools that allow users to meet and interact in a virtual environment. The study found that across the virtual social platforms investigated, there was no clear similarity between a user's avatar and their real appearance (Fig. 4).

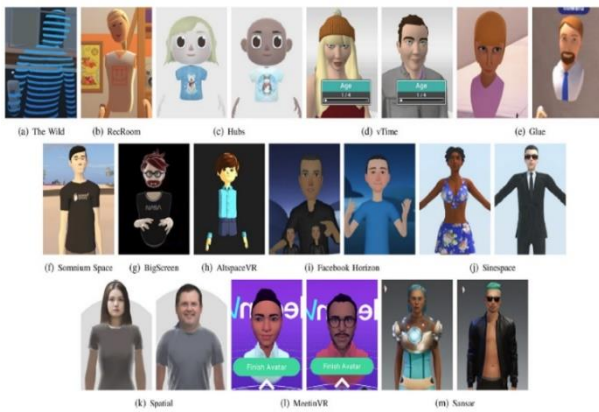


Fig. 4. Default/Representative characters of evaluated platforms [34]

The reason for this difference may be that many current techniques that attempt to use camera data (including RGB and depth information) to reconstruct virtual avatars are affected by environmental factors such as light. These factors may cause the appearance of the avatar to be unreal-istic, and sometimes the so-called "uncanny valley effect" may occur, making the avatar look abnormal or uncomfortable. This shows that avatar technology still needs further improvements to provide a more realistic and satisfying virtual appearance, especially in virtual conferencing applications.

b) *Movement*: We are all aware of the significance of nonverbal communication, which includes facial expressions and physical movements, in face-to-face conferences. For instance, in a traditional face-to-face conferencing, when we approach someone, they might greet us with a smile and offer the nearby seat, instantly creating a sense of closeness and initiating a conversation. Transitioning from a user's real-world movements to those of their virtual avatar is possible with the use of Head-Mounted Displays (HMDs) and motion control trackers. However, it's important to note that the occlusion resulting from the HMD's presence on the face introduces new challenges in capturing and reconstructing facial expressions [2].

## VI. INTERACTION AND COLLABORATION

Virtual conferences are facilitated through a web-conferencing system (WCS). This web-conferencing system encompasses a range of interaction features, including but not limited to audio and video calls, messaging, content and screen sharing, and the capability to record conferences [4]. Furthermore, virtual conferences are expected to enable seamless collaboration among virtual avatars, which includes real-time presentation uploading, drawing and annotating, tagging of shared content, and cooperative engagement with 3D objects [18].

### A. User Interaction in VR

VR is a technology that creates an alternate, computer-generated environment that users can explore and interact with. It supports immersive experiences through 3D visuals, intuitive

controls, and social interaction, allowing users to feel present in a simulated world and detached from physical reality. 3D avatar is a form of representation of human users in a VR environment. It represents the user's body and interaction with the surrounding environment and other users in the virtual world to enhance the realism of the overall experience.

VR in meeting space is while the user can interact with another user by using HMD. The meeting room can be created fully by using VR that makes the user of HMD cannot perceive the real world [35]. However, user can have the full experienced of the meeting space by wearing the HMD. The user of the HMD traditionally would be guided and instructed by a user sitting on a PC using a traditional GUI. The reason behind this so that the safety of the user can be fulfil because once the user wears the HMD, the user can be isolated from the real world. By having a guide, it can help them to not bum into other things that leads to safety issues and give negative experience for the user that wear HMD.

As in Fig. 5 (a), VR user will use the Oculus Touch to interact with the whiteboard by grabbing the marker pen 3D object and use the tip of the pen to draw to the whiteboard. The VR user will use press the VR keyboard (as in Fig.5 (b)) in the VR space to write the text for the sticky notes. If the user presses the submit button by using the raycast, a sticky note will be appeared at the left hand of the VR user with the text that has been type using the VR keyboard. The user then can drag the sticky note and placed it at the whiteboard.



(a) Virtual Whiteboard



(b) Virtual keyboard

Fig. 5. Users' interaction in VR [35]

### B. User Collaboration

Collaborative interface is an interface that provide shared environment that will bind the users so that users will have common task. In this section, the use of collaborative interface to the project will be explained. This setup will have more than two users. All users will be in the same virtual space and single scene.

For an example, the AR/VR application will integrate the user interactions for both VR and AR user. The application to run and execute both user interactions by using the Oculus Quest 2 for the VR user and handheld device by using Touch-based interaction for AR user. Users should also be able to communicate with the object through the UI and implement all the interaction technique included in the project. Fig. 5 demonstrates the flow of application systems for this project creation.

VII. ISSUES AND CHALLENGES

Although virtual conferencing has been tested for a long time, especially during the COVID-19 period, it has developed relatively mature. However, a large amount of experience in using virtual conferencing shows that there are still some technical issues and challenges. Table III summarizes these issues and challenges.

TABLE III. ISSUES AND CHALLENGES

Key Features	Issues and Challenges
Virtual Environment	How to enhance user interaction with virtual environments?
Avatar	How to achieve personalization of avatar reconstruction based on user?
	How to reconstruct avatar expression in real time in virtual conferencing?
	How to achieve accurate movement synchronization between avatars and users in virtual conferencing, including direction control?
Collaboration	How to achieve more effective and richer user collaboration in virtual conferencing?
Hardware & Accessibility	How to reduce VR hardware cost and bridge the digital divide for global participation?

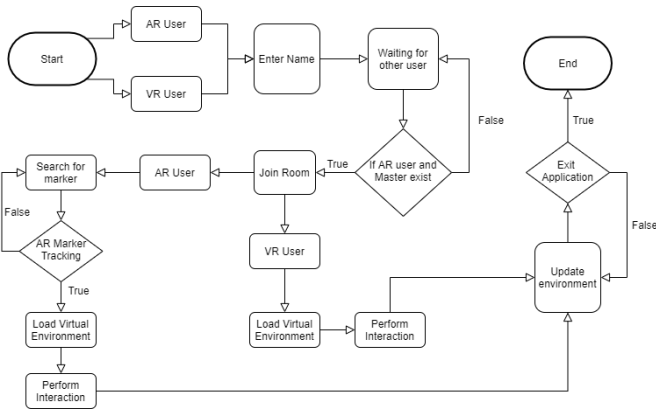


Fig. 6. Collaboration between AR and VR users in shared environment [35]

As in Fig. 6, the application system flow defines the mechanism that allow virtual meeting room to be enabled. The application will start by both users will enter name first before joining the room. The VR user will be the master. Thus, the VR user must join the room first before AR user. Next, by successfully joining the room, virtual environment will load for both users. But, before the AR user can load the virtual environment, the AR user must search the marker first to allow the AR tracking to be done. If each user performs any interaction, the application will update the virtual environment via real time. If both users exit application, the process will end. AR tracking is a fundamental to enable AR, there marker tracking is one of the tracking methods that could quickly place the VR object to overlay on the top of the real world.

AR user will interact with the collaborative tools by using interaction metaphor such as Joystick, Mouse-clicking, or touch-based. The virtual meeting rooms could contain the whiteboard, virtual keyboard or the sticky note. As mentioned in [35], if whiteboard writing allows the user to draw anything on it which are then will also draw on the 3D whiteboard object at real-time. In collaboration setup, all users should be able to see what have been written on the whiteboard simultaneously. Fig. 7 shows the live pointing on virtual slideshow, and object manipulation.

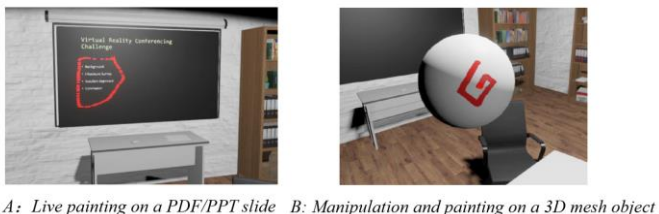


Fig. 7. Collaborative Interface for virtual meeting

The degree of realism of the virtual conference environment is an important factor affecting the effectiveness of virtual conferences [18]. Current virtual conference platforms have provided users with different numbers of virtual conference environments to meet different conference needs. However, enhancing the interaction between users and the virtual environment is still an issue worth thinking about, because lack of interaction will make users feel bored in the virtual environment and choose to leave [2, 11].

The user's avatar performance is very important to the user because it is an important bridge for transmitting information between users. Most of the avatars in current virtual conferences platforms are manually customized, and the reconstruction of user-based personalized avatars is necessary for virtual conferencing [33]. The non-verbal communication of avatars still needs to be further strengthened [11]. Real-time reconstruction of facial expressions and user motion tracking and synchronization can give users greater control over their avatar, enabling more non-verbal communication in virtual conferencing [18, 27].

High hardware cost and limited accessibility represent major barriers to widespread adoption of VR conferencing. Head-mounted displays (e.g., Meta Quest, HTC Vive), motion trackers, and high-performance computing equipment remain expensive for individual users and many institutions, particularly in developing regions. This creates a digital divide, limiting participation and exacerbating economic inequality in global academic and professional communities. Potential mitigation strategies include: hybrid VR – desktop participation models that allow non-VR users to join via standard computers; web-based or lightweight VR solutions that reduce hardware requirements; and shared institutional VR

facilities to lower individual costs. Addressing these accessibility challenges is critical for inclusive and equitable immersive conferencing.

Prolonged VR conferencing also raises significant health, safety, and human-centered concerns. Common issues include cybersickness/motion sickness (dizziness, nausea, disorientation), eye strain and visual fatigue from prolonged HMD use, and physical discomfort due to poor ergonomics. These problems reduce user comfort and productivity, especially in long meetings. Potential solutions include: improved hardware ergonomics (lighter HMDs, adjustable fit, better ventilation); optimized rendering and frame rates to reduce motion artifacts; and adaptive session design with regular breaks and shorter segments for VR sessions. Prioritizing user well-being is essential for sustainable long-term adoption of immersive conferencing.

Effective interaction and collaboration in virtual conferencing is an important technical factor in the potential for virtual conferencing to surpass face-to-face conferencing [2, 26, 28]. Because such collaboration may not be possible at face-to-face conferencing, such as a virtual surgery for observation and learning.

### VIII. CONCLUSION

Virtual conferencing may not completely replace face-to-face conferencing, but it provides highly adaptable and efficient communication channels that foster collaboration and creativity among business, academia, and society. It is currently quickly becoming a widely accepted alternative. This paper organized the timeline of virtual conferencing, and by summarizing a large number of research papers on virtual conferencing, proposes three key features of AR/VR virtual conferencing: "shared virtual environment", "representing the user's avatar" and "interaction and collaboration". An excellent shared virtual environment can give users a more realistic conferencing experience, making participants feel as if they are in a real conferencing. Personalized user-based avatars help users express themselves more authentically in virtual conferencing and develop an emotional attachment to that persona. Interaction and collaboration can enhance the cohesion of participants in virtual conferencing, and more importantly, through the collaborative operation of virtual 3D objects, people can achieve better learning effects while saving resources, which is an advantage that face-to-face conferencing can't provide.

With the development of computer vision technology, the maturity of AR/VR virtual conference is inevitable, which is expected to bring people a profound and rich conferencing experience. Just as it is in line with globalization trends, changing work dynamics and increasing environmental awareness, the trajectory of virtual conferences has the potential to promote cooperation and innovation in different areas. This paper proposes the key features of AR/VR virtual conferencing, while also clarifying the problems and challenges, providing a strong direction for accelerating the development of virtual conferencing

Future research directions include: developing AI-driven avatar expression reconstruction to enable real-time, natural

facial and emotional communication; establishing standardization of VR conferencing platforms for cross-platform interoperability; and designing rigorous evaluation frameworks to quantitatively and qualitatively measure conferencing effectiveness, user engagement, and collaboration quality. These efforts will advance the maturity, usability, and impact of immersive virtual conferencing.

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### CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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