

Evaluating a Live Holographic XR Opera Experience for Remote Attendees

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Abstract—This paper presents the design and evaluation of a work-in-progress live holographic Extended Reality (XR) opera experience, deployed in February 2026 as a small-scale pilot within the broader XR Opera pilot of the Horizon Europe HEAT project. The performance featured a singer, dancer, and pianist, who were captured in separate locations using multi-camera volumetric capture setups based on three Orbbec Femto Bolt depth cameras per performer. The resulting 360-degree holographic representations were streamed into a Unity-based XR application, enabling remote audiences to experience the performers as co-located within a shared virtual environment. While the pianist was represented through audio only, the singer and dancer appeared as live holograms situated inside a virtual reconstruction of the Interfaith Centre at Dublin City University. Live video and audio feeds from the venue were also integrated into the experience. The paper describes the system architecture, volumetric capture and streaming pipeline, and the virtual venue implementation. User experience was assessed through post-experience questionnaires. The results provide preliminary insights into the usability of the prototype and identify aspects to be investigated before the full XR Opera pilot is deployed.

I. INTRODUCTION

Extended Reality (XR) technologies are transforming the way audiences experience cultural events by enabling immersive participation beyond the physical venue [1]. Advances in virtual reality (VR), augmented reality (AR), volumetric capture, and real-time rendering have made it possible to recreate performances within shared virtual environments, allowing geographically distributed audiences to experience live events with an increased sense of presence and engagement. These developments have particular relevance for performing arts,



Fig. 1. XR Opera Experience

where preserving the spatial relationship between performers and audiences is fundamental to the overall experience.

For musical applications, remote participation also requires the delivery of live audio and its coordination with visual content. The Internet of Musical Things (IoMusT) describes connected ecosystems involving musical devices, services, performers, and audiences [2]. The broader Internet of Sounds (IoS) includes both musical and non-musical applications of networked sound sensing, processing, and communication [3]. Networked Music Performance (NMP), ubiquitous music, and IoMusT address related aspects of distributed musical

activities, although their scopes differ [4]. Musical XR brings these concerns into virtual and mixed-reality environments, where musical audio, performer representations, and remote audience access need to be considered together.

Recent progress in volumetric video, point-cloud streaming, and networked musical XR has enabled geographically distributed performers to be represented together within shared virtual environments [5], [6]. Unlike conventional video streaming, holographic representations preserve three-dimensional structure and support six degrees-of-freedom (6DoF) viewing, allowing audiences to freely observe performances from different viewpoints. Combined with modern game engines such as Unity and low-latency streaming technologies, these capabilities provide new opportunities for remote participation in concerts, theatre productions, and opera performances, as illustrated in Fig. 1. Such applications are also relevant to the Musical Metaverse, which considers musical creation, performance, and participation within shared virtual environments [7].

Existing work has investigated remote musical collaboration [5], [6], holographic telepresence [8], [9], social VR media consumption [10], [11], and distributed artistic performances [12]–[14]. The present study considers how these technologies can be integrated into a live operatic experience for remote attendees. The contribution lies in the design and preliminary deployment of the combined capture, streaming, and audience application, using existing reconstruction and communication technologies.

The experience was developed in preparation for the XR Opera pilot of the Horizon Europe Hybrid Extended reAliTy (HEAT) project [15]. The full XR Opera pilot has not yet been deployed. This paper reports a smaller pre-pilot experiment conducted in February 2026, together with a formative usability evaluation. Although the application supports VR visualization, the evaluation was conducted using standard screen monitors.

This work investigates two research questions:

- RQ1: How can geographically distributed performers be integrated into a common live holographic XR performance using real-time volumetric capture and streaming?
- RQ2: How do participants perceive the usability of the resulting prototype during a preliminary remote evaluation?

The contributions of this paper are:

- The design and implementation of an end-to-end prototype for live holographic XR opera experiences based on real-time volumetric capture and streaming.
- A small-scale pre-pilot deployment involving distributed performers integrated into a shared virtual environment for remote attendees.
- A preliminary user evaluation investigating system usability with seven participants viewing the experience on standard monitors.

The remainder of this paper is organised as follows. Section II presents related works, Section III describes the XR Opera

pilot and the overall system architecture. Section IV presents the deployment details, while Section V discusses the user evaluation results. Finally, Section VI concludes the paper and outlines directions for future work.

II. RELATED WORKS

A. Networked Music and Musical XR

Networked XR technologies are creating new opportunities for remote musical performance and collaboration. IoMusT considers the communication between devices and services involved in producing or receiving musical content, including connections between performers and audiences [2]. IoS extends this approach to sound applications beyond music [3]. Turchet and Rottondi discuss the relationships between NMP, ubiquitous music, and IoMusT, identifying common concerns and differences in their technical and musical scope [4].

Turchet introduced the concept of the “Musical Metaverse”, describing virtual environments in which musicians, audiences, and other stakeholders can participate in musical activities, while also identifying technical and artistic challenges that must be addressed to support such experiences [7]. In this context, the representation of geographically separated performers through volumetric content has received increasing attention. Schlagowski *et al.* investigated remote musical collaboration in mixed reality, where musicians viewed a remote partner as a real-time point-cloud representation through a head-mounted display [6]. Compared with an audio-only condition, the mixed-reality condition resulted in significantly higher co-presence, illustrating the potential of volumetric representations to strengthen the feeling of performing together remotely. Turchet *et al.* similarly investigated networked musical XR by combining point-cloud representations of geographically separated musicians with low-latency audio communication [5]. Their technical evaluation highlighted that, despite advances in communication technologies, latency and the computational and networking requirements of point-cloud transmission remain important constraints for real-time networked musical interaction. These works provide evidence that real-time volumetric communication can support geographically distributed musical experiences, while also highlighting the technical challenges involved in achieving convincing and synchronous remote performances.

B. Holographic Telepresence and User Representation

Storytelling forms such as theatre and opera offer rich expressive potential, yet they remain predominantly in-person visual and auditory experiences [13], [14], [16]. This limits accessibility for remote audiences and reduces the sense of presence typically associated with live performances. Recent advances in Extended Reality (XR), volumetric capture, and holographic communications have enabled increasingly immersive telepresence experiences for geographically distributed users. One of the earliest end-to-end demonstrations of live holographic communication was Microsoft’s *Holoportation*, which introduced a real-time system for capturing, recon-

structing, compressing, and transmitting full three-dimensional human representations for mixed reality interactions [8].

Building upon these foundations, Fernández *et al.* proposed a lightweight social VR platform supporting real-time volumetric holographic representations of multiple users captured using commodity RGB-D cameras. Their evaluation demonstrated that realistic point-cloud representations can improve presence and interaction quality while remaining feasible with low-cost hardware [9].

More recently, Montagud *et al.* highlighted the potential of holographic communications as a key enabler for future Social VR applications, emphasizing the importance of realistic user representations, low-latency communication, and synchronization for achieving high levels of presence and engagement in collaborative immersive environments [10]. Earlier work by Fernández *et al.* also explored hyper-realistic social VR experiences for live television scenarios by integrating volumetric users, immersive media, and low-latency interaction within shared virtual environments [11].

User representation is an important factor in collaborative XR, particularly when spatial communication and social presence are required. Gamelin *et al.* compared a streamed 2.5D point-cloud avatar with a pre-constructed 3D avatar replicating the remote user's movements during collaborative spatial tasks [17]. Irlitti *et al.* presented a real-time volumetric mixed-reality telepresence system supporting multiple users and cross-modality collaboration across AR, VR, and face-to-face settings [18]. The system generated full-body and environmental volumetric representations in real time over a local enterprise network. An evaluation conducted in a remotely delivered training scenario indicated that volumetric telepresence can facilitate co-presence and support communication between geographically separated participants.

Yu *et al.* compared RGB-D point-cloud reconstruction-based avatars with personalised virtual characters driven by body, face, and gaze tracking [19]. Their work demonstrates that the choice of avatar embodiment technique can affect user perception in 3D telepresence and reinforces the importance of considering how remote participants are visually represented. More broadly, Weidner *et al.* systematically reviewed 72 studies comparing avatar and agent representations in AR and VR using head-mounted displays [20]. Their findings highlight that avatar design involves trade-offs between visual fidelity, technical complexity, and user experience, and that the appropriate representation depends on the application and interaction context.

While there are studies demonstrate the feasibility of holographic telepresence and collaborative XR, they primarily focus on communication, meetings, or media consumption scenarios [21]–[23]. In contrast, relatively little work has investigated complete live artistic performances involving multiple geographically distributed performers captured volumetrically and integrated into a shared virtual venue. This paper addresses this gap by presenting the design, deployment, and user evaluation of a live holographic XR opera experience developed within the Horizon Europe HEAT project.

III. XR OPERA PILOT AND PRE-PILOT EXPERIMENT

The XR Opera pilot explores advanced technologies to enable immersive live holographic operatic experiences demonstrated through a live performance deployed in February 2026. The performance featured a singer, dancer, and pianist captured from separate locations using multi-camera volumetric capture systems based on three Orbbec Femto Bolt depth cameras per performer. The resulting holograms were streamed into a Unity-based XR environment, where remote audiences perceived the performers as co-located inside a virtual reconstruction of the Interfaith Centre at Dublin City University. Live video and audio feeds from the physical venue were also integrated into the experience.

The primary goal of the pilot is to create an immersive live operatic experience for remote audiences while demonstrating the potential of holographic XR technologies for cultural and artistic performances. The pilot explores whether live volumetric capture, holographic streaming, and immersive virtual environments can support audience engagement, social presence, and perceived immersion by allowing geographically distributed performers to appear together within a shared virtual space. The preliminary evaluation reported here does not aim to establish a causal improvement over conventional streaming. It combines real-time volumetric communication, synchronized audiovisual streaming, and virtual venue reconstruction, enabling new forms of remote participation in live artistic performances.

IV. SYSTEM ARCHITECTURE

The XR Opera pilot is centred on a live holographic opera performance combining distributed performers and remote audiences within a unified XR environment. The architecture consists of three interconnected domains: the physical performance venue, the remote performer environments, and the remote audience environment, as illustrated in Fig. 2.

The physical venue hosts the live performance, with audiovisual feeds captured and transmitted to remote participants. The singer and dancer are captured in separate locations using volumetric capture systems composed of three Orbbec Femto Bolt depth cameras per performer, generating real-time 3D holographic representations. These holograms are streamed into a Unity-based XR application together with live audio, allowing remote participants to experience the performers as occupying the same virtual space.

The solution is designed to allow remote audiences to access the performance through devices running the Unity application. Within the virtual environment, users observe the live holographic representations of the singer and dancer positioned inside a virtual reconstruction of the Interfaith Centre at Dublin City University. The pianist participates through live audio only, while synchronized live video from the venue provides additional contextual awareness of the performance. Communication and synchronization between all sites ensure consistent audiovisual delivery throughout the experience. For the preliminary evaluation presented in Section V, participants

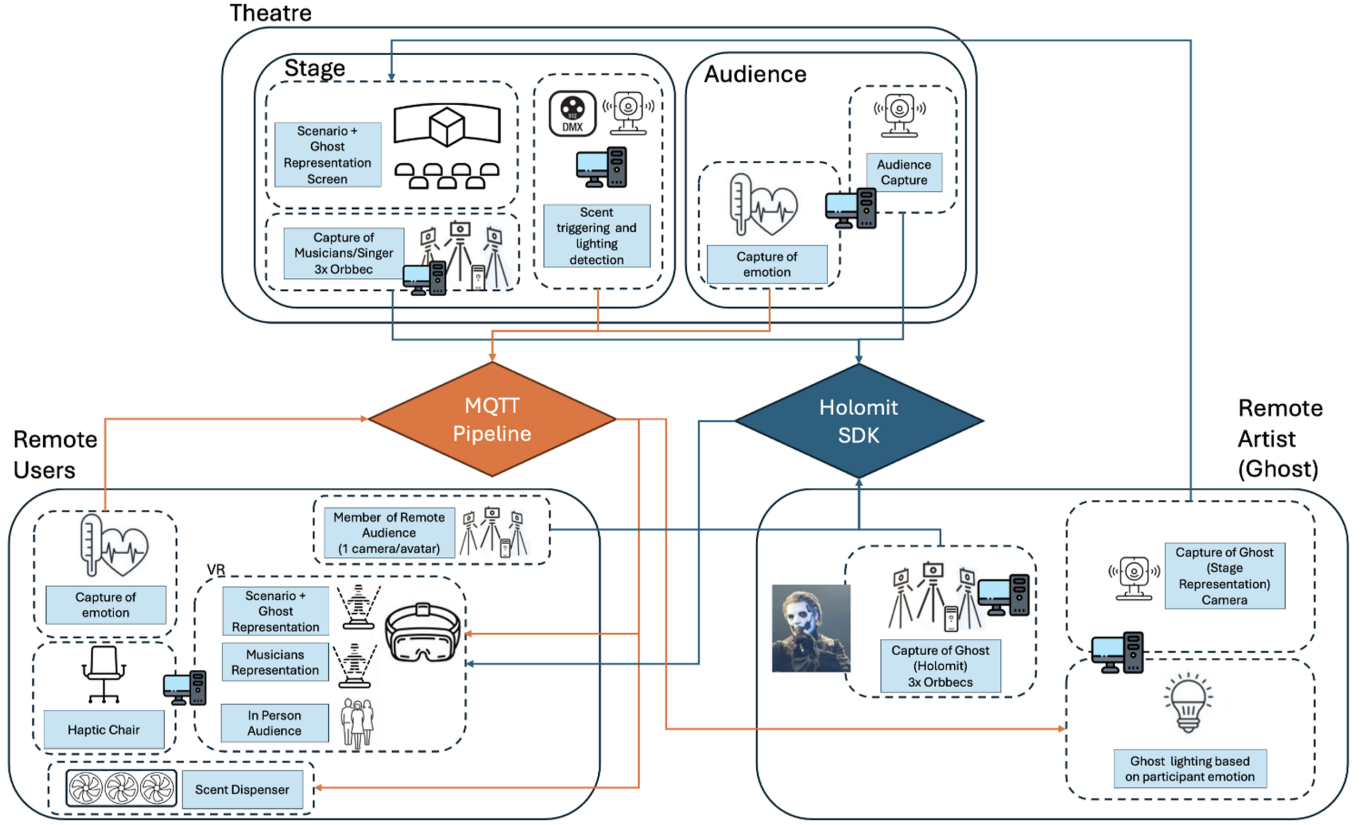


Fig. 2. Solution architecture for the XR Opera pilot. The pre-pilot experiment used volumetric capture, live holographic and audiovisual streaming, and Unity-based rendering. Scent and emotion integration are planned components and were not implemented or evaluated in the reported experiment.

viewed the performance on standard screen monitors rather than through VR headsets.

A. Pre-pilot Deployment

The deployment consists of three physically separated environments connected through a real-time communication and streaming infrastructure: the physical performance venue, the remote performer locations, and the remote audience environment. The physical venue hosts the live performance together with the audiovisual production equipment used to capture and distribute the event. Live video and audio from the venue are streamed to remote participants and integrated into the Unity application.

The remote performer environments host the singer and dancer, each captured using a volumetric capture setup composed of three Orbbec Femto Bolt depth cameras. The reconstructed holograms are transmitted in real time and rendered within the shared virtual environment. The pianist contributes through a live audio feed without volumetric representation.

Users experience the opera inside a virtual reconstruction of the Interfaith Centre at Dublin City University, where the live holographic representations of the distributed performers appear co-located despite being captured in different physical locations. The user evaluation described in this paper used the same content displayed on standard screen monitors.

The deployment employs Orbbec Femto Bolt cameras for performer acquisition, Unity for the XR environment and holographic rendering, support for VR visualization, live audiovisual streaming between all sites, and a real-time communication infrastructure responsible for synchronizing holographic, video, and audio content. Following the performance, participants completed post-experience questionnaires assessing presence, immersion, audience engagement, and overall quality of experience. The architecture also presents planned future features of the experience, such as scent and emotion integration. These components were not implemented or evaluated in the study reported in this paper.

V. RESULTS

A. Evaluation Methodology

The evaluation was conducted as a preliminary, formative study of the deployed prototype. After viewing the live performance on standard screen monitors, participants completed post-experience questionnaires. Participants also filled a demographics questionnaire and a consent form. System usability was assessed adapting the ten standard System Usability Scale (SUS) items, scored on a five-point Likert scale [24]. The XROpera pre-pilot experiment was conducted under the ethical approval of the Dublin City University Research Ethics Committee (DCU REC), approval number DCUREC2024/175.

TABLE I
SYSTEM USABILITY QUESTIONNAIRE (1 = STRONGLY DISAGREE; 5 = STRONGLY AGREE)

Statement	Mean	SD	Median	Min-Max
I would like to use this system frequently	2.29	1.11	2	1-4
The system was unnecessarily complex	2.57	1.13	2	1-4
The system was easy to use	3.29	0.95	4	2-4
I would need technical support	1.57	0.53	2	1-2
Functions were well integrated	2.71	1.11	3	1-4
There was too much inconsistency	3.14	1.35	3	1-5
Most people would learn to use the system quickly	3.86	0.38	4	3-4
The system was cumbersome to use	2.29	0.95	2	1-4
I felt confident using the system	3.43	1.27	3	2-5
I needed to learn many things before getting started	1.86	0.38	2	1-2

B. Participants

A total of seven participants completed the evaluation following the live XR opera experience. Participants ranged in age from 29 to 46 years ($M = 35.1$, $SD = 7.2$). Four participants identified as men, two as women, and one preferred not to disclose their gender.

The sample consisted primarily of highly educated participants, with four holding a doctorate or higher and three holding a master's degree. Professional backgrounds included engineering and technology ($n = 3$), science and research ($n = 2$), arts and design ($n = 1$), and one additional science/research participant. Participants joined the study from a variety of locations, including university laboratories, offices, and home environments.

Previous familiarity with VR varied considerably, with self-reported experience ranging from 2 to 10 on a 10-point scale ($M = 8.3$, $SD = 3.0$). Six participants used a WiFi connection, while one used Ethernet. All participants viewed the performance on a standard screen monitor.

C. System Usability

The ten SUS items in Table I use a five-point scale from 1 (Strongly Disagree) to 5 (Strongly Agree). The mean SUS score was 60.4 on the 0–100 scale, using the standard scoring procedure for the adapted questionnaire.

Responses indicate that participants generally found the system straightforward to use. Most participants agreed that the system was easy to use and that users would learn to operate it quickly. For negatively worded SUS items, lower agreement indicates a more favourable usability response; these items are reverse-scored when calculating the SUS score. Participants generally reported feeling confident while using the system, although opinions regarding feature integration and consistency were more varied. Given the small sample, these results are interpreted descriptively as part of a preliminary evaluation.

The usability questionnaire results are presented in Table I. The statement “Most people would learn to use the system quickly” received the highest level of agreement ($M = 3.86$), while participants generally agreed that the system was easy to use ($M = 3.29$) and reported feeling confident while using it ($M = 3.43$).

Negative usability statements received comparatively low agreement for the need for technical support ($M = 1.57$), extensive learning before using the system ($M = 1.86$), and the system being cumbersome to use ($M = 2.29$). Responses regarding system complexity ($M = 2.57$), feature integration ($M = 2.71$), and inconsistency ($M = 3.14$) were more varied.

Given the small sample size ($n = 7$) and the ordinal nature of the five-point Likert-scale responses, median and minimum–maximum ranges are reported alongside the mean and standard deviation for each questionnaire item. These non-parametric descriptive statistics provide additional information about the distribution of responses and reduce reliance on mean values alone.

Overall, the results provide preliminary answers to the research questions of this study. Regarding the feasibility of delivering a live holographic performance with geographically distributed performers, the experiment demonstrated that real-time volumetric representations of the singer and actor could be integrated with the pianist's live audio within a shared Unity-based environment and delivered to remote attendees. Participants generally reported favourable responses regarding confidence in using the system, while also indicating room for improvement in making the navigation, controls, and visual presentation more user-friendly. Overall, the study demonstrates the technical feasibility of the proposed live holographic performance approach while identifying usability, presence, and immersion as areas for further development and evaluation.

D. Limitations

As an early stage pre-pilot activity, the study involved seven participants relatively familiar with VR; consequently, the findings are formative and should not be generalised to broader remote audiences. While the solution supports VR headsets participants used standard screen monitors. A baseline condition, such as conventional 2D streaming, was not included, preventing causal conclusions about whether holographic presentation improves the audience experience. Finally, objective technical measurements such as capture-to-render latency, streaming bitrate, frame rate, and packet loss were not included in the present evaluation. These aspects will be investigated alongside larger and comparative user studies in future work.

VI. CONCLUSION

This paper presented the design, deployment, and evaluation of a live holographic XR opera experience developed within the Horizon Europe HEAT project. By combining real-time volumetric capture, holographic streaming, and a Unity-based virtual environment, the system enabled geographically distributed performers to appear together for remote audiences in a shared experience. The preliminary user evaluation achieved a mean SUS score of 60.4/100, indicating that further usability development is needed. The pre-pilot contributes a deployment case to Musical XR and IoS, while further evaluation is needed to assess audience experience and compare it with conventional streaming.

Future work will focus on evaluating the system using VR headsets, collecting objective network and streaming performance metrics, introducing comparison conditions, and conducting larger-scale user studies. Observed usability tasks and qualitative feedback should help investigate the responses concerning integration, consistency, and interest in frequent use. The integration and evaluation of additional multisensory components remain part of the planned XR Opera pilot.

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REFERENCES

- [1] A. A. Simiscuka, G. Barceló Orts, M. Picoreau, Á. E. Benavente, M. Montagud, and G.-M. Muntean, "HoloScent: an AI-Driven Multi-sensory IoT-XR Platform for Artistic Immersion Through Holograms, Lighting, and Olfaction," in *Artificial Intelligence and Cognitive Science*, T. T. Mai, A. L.-D. Tran, L. Zhang, L. Rossetto, H. Lee, G. Marks, L. Zhou, A. D. Jung, E. Rushe, T. Ward, and C. Gurrin, Eds. Cham: Springer Nature Switzerland, 2026, pp. 414–420.
- [2] L. Turchet, C. Fischione, G. Essl, D. Keller, and M. Barthet, "Internet of Musical Things: Vision and Challenges," *IEEE Access*, vol. 6, pp. 61 994–62 017, 2018.
- [3] L. Turchet, M. Lagrange, C. Rottondi, G. Fazekas, N. Peters, J. Østergaard, F. Font, T. Bäckström, and C. Fischione, "The Internet of Sounds: Convergent Trends, Insights, and Future Directions," *IEEE Internet of Things Journal*, vol. 10, no. 13, pp. 11 264–11 292, 2023.
- [4] L. Turchet and C. Rottondi, "On the relation between the fields of Networked Music Performances, Ubiquitous Music, and Internet of Musical Things," *Personal and Ubiquitous Computing*, vol. 27, pp. 1783–1792, 2023.
- [5] L. Turchet, N. Garau, and N. Conci, "Networked Musical XR: Where's the Limit? A Preliminary Investigation on the Joint Use of Point Clouds and Low-Latency Audio Communication," in *Proceedings of the 17th International Audio Mostly Conference*. Association for Computing Machinery, 2022, pp. 226–230.
- [6] R. Schlagowski, D. Nazarenko, Y. S. Can, K. Gupta, S. Mertes, M. Billingham, and E. André, "Wish You Were Here: Mental and Physiological Effects Of Remote Music Collaboration in Mixed Reality," in *Proc. of the 2023 CHI Conf. on Human Factors in Computing Systems*. Association for Computing Machinery, 2023, pp. 1–16.
- [7] L. Turchet, "Musical Metaverse: Vision, Opportunities, and Challenges," *Personal and Ubiquitous Computing*, vol. 27, no. 5, pp. 1811–1827, 2023.
- [8] S. Orts-Escolano, C. Rhemann, S. Fanello, W. Chang, A. Kowdle *et al.*, "Holoportation: Virtual 3D Teleportation in Real-Time," in *Proceedings of the 29th Annual ACM Symposium on User Interface Software and Technology (UIST)*, 2016.
- [9] S. Fernández, M. Montagud, G. Cernigliaro, and D. Rincón, "Multi-Party Holomeetings: Toward a New Era of Low-Cost Volumetric Holographic Meetings in Virtual Reality," *IEEE Access*, vol. 10, pp. 81 856–81 876, 2022.
- [10] M. Montagud, M. Martos, Álvaro Egea, and S. Fernández, "Social VR with Holographic Comms: Enablers for New Engaging Experiences Within the TV/Video Consumption Landscape," *IEEE Transactions on Broadcasting*, vol. 71, no. 3, pp. 793–807, 2025.
- [11] S. Fernández, M. Montagud, G. Cernigliaro, and D. Rincón, "Toward Hyper-Realistic and Interactive Social VR Experiences in Live TV Scenarios," *IEEE Transactions on Broadcasting*, vol. 68, no. 1, pp. 13–32, 2022.
- [12] D. L. Williams, I. C. Kegel, M. Ursu, P. Cesar, J. Jansen, E. Geelhoed, A. Horti, M. Frantzis, and B. Scott, "A Distributed Theatre Experiment with Shakespeare," in *Proceedings of the 23rd ACM International Conference on Multimedia*, ser. MM '15, 2015, p. 281–290.
- [13] M. A. Togou, A. A. Simiscuka, R. Verma, N. E. O'Connor, I. Tamayo, S. Masneri, M. Zorrilla, and G.-M. Muntean, "An Innovative Adaptive Web-Based Solution for Improved Remote Co-Creation and Delivery of Artistic Performances," *IEEE Transactions on Broadcasting*, vol. 70, no. 2, pp. 719–730, 2024.
- [14] R. Verma, A. A. Simiscuka, M. A. Togou, M. Zorrilla, and G.-M. Muntean, "A Live Adaptive Streaming Solution for Enhancing Quality of Experience in Co-Created Opera," *IEEE Transactions on Broadcasting*, pp. 1–12, 2025.
- [15] M. Murrioni, G. Muntean, M. Montagud, and V. Popescu, "Toward Interactive and Distributed Hybrid Extended Reality Experiences," in *Proceedings of the 2024 ACM International Conference on Interactive Media Experiences Workshops*, ser. IMXw '24, New York, NY, USA, 2024, p. 127–130.
- [16] K. Pietroszek, M. Rebol, and B. Lake, "Dill Pickle: Interactive Theatre Play in Virtual Reality," in *Proc. ACM Symposium on Virtual Reality Software and Technology (VRST)*, 2022.
- [17] G. Gamelin, A. Chellali, S. Cheikh, A. Ricca, C. Dumas, and S. Otmane, "Point-Cloud Avatars to Improve Spatial Communication in immersive collaborative virtual environments," *Personal and Ubiquitous Computing*, vol. 25, no. 3, pp. 467–484, 2021.
- [18] A. Irlitti, M. Latifoglu, Q. Zhou, M. N. Reinoso, T. Hoang, E. Velloso, and F. Vetere, "Volumetric Mixed Reality Telepresence for Real-Time cross modality collaboration," in *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, 2023, pp. 1–14.
- [19] K. Yu, G. Gorbachev, U. Eck, F. Pankratz, N. Navab, and D. Roth, "Avatars for Teleconsultation: Effects of Avatar Embodiment techniques on user perception in 3d asymmetric telepresence," *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, no. 11, pp. 4129–4139, Nov. 2021.
- [20] F. Weidner, G. Boettcher, S. Arévalo Arboleda, C. Diao, L. Sinani, C. Kunert, C. Gerhardt, W. Broll, and A. Raake, "A Systematic Review on the Visualization of Avatars and agents in AR & VR displayed using head-mounted displays," *IEEE Transactions on Visualization and Computer Graphics*, vol. 29, no. 5, pp. 2596–2606, May 2023.
- [21] A. A. Simiscuka, D. A. Ghadge, and G.-M. Muntean, "OmniScent: An Omnidirectional Olfaction-Enhanced Virtual Reality 360° Video Delivery Solution for Increasing Viewer Quality of Experience," *IEEE Trans. on Broadcasting*, vol. 69, no. 4, pp. 941–950, 2023.
- [22] I. Tal, L. Zou, A. Covaci, E. Ibarrola, M. Bratu, G. Ghinea, and G.-M. Muntean, "Multimedia in Telecommunication and Networking Education: A Novel Teaching Approach that Improves the Learning Process," *IEEE Commun. Mag.*, vol. 57, no. 11, pp. 60–66, 2019.
- [23] A. A. Simiscuka, M. A. Togou, M. Zorrilla, and G.-M. Muntean, "360-ADAPT: An Open-RAN-Based Adaptive Scheme for Quality Enhancement of Opera 360° Content Distribution," *IEEE Transactions on Green Communications and Networking*, pp. 1–14, 2024.
- [24] V. L. Tiase, J. M. Fritz, J. Ferraro, G. Bayles, A. Alsalem, G. Del Fiol, K. Kawamoto, D. Brodke, B. Martin, and R. Altizer, "Advancing Digital Access to Physical Therapy via Virtual And Extended Reality Technology: Prototype Development and Usability Evaluation," *JMIR Formative Research*, vol. 9, 2025.