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Hybrid options at conferences, which support in-person and remote attendance, have increasingly become the norm in order to broaden participation and promote sustainability. However, hybrid conferences are challenging, where in-person and remote attendees often have disjoint, parallel experiences with limited opportunity to interact with each other. To explore the potential for facilitating social interaction between in-person and remote conference attendees, we designed and built SocialMiXR, a research prototype that uses WebXR technologies to align the physical and virtual worlds into one hybrid space for socialization. We deployed SocialMiXR in a three-day field study with 14 in-person and remote attendees of an engineering conference. Our qualitative results demonstrate that participants felt they were together in the same conference experience, and formed meaningful connections with each other. At the same time, they faced difficulties balancing different realities and capabilities given their separate contexts. We discuss implications for the design of hybrid social experiences at conferences.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: hybrid conferences, WebXR, augmented reality, 3D virtual environments

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1 Introduction

As the world enters the post-pandemic era, hybrid formats for large events like conferences have become prevalent. Hybrid conferences usually involve holding the conference at a physical venue, with both in-person and remote attendance options. This shift has major advantages in diversity of participation and sustainability. For instance, travel to a physical venue is time-consuming, costly, and physically demanding, and is therefore especially difficult for people with disabilities, caregivers, and researchers from developing countries [20, 33]. Moreover, reducing air travel has implications for climate change by reducing the carbon footprint of conference attendance [9].

Despite these benefits, transitioning to hybrid models presents distinct challenges, which have been of prominent interest to the HCI community in the last few years [2, 10, 18, 37, 52]. Even with advancements in remote participation technologies, such as video conferencing and virtual immersive environments, in-person experiences are often viewed as the standard for optimal engagement and interaction. This preference is particularly noticeable in large-scale conferences, where the complexities of managing and synchronizing disparate experiences are amplified, leading to in-person and remote attendees engaging in parallel but separate activities [45, 52]. This division is especially prominent in attendees' ability to socialize with others, hindering important conference goals such as connecting with new people, learning from them, and generating new collaborations or professional relationships. While in-person attendees experience face-to-face interactions through organized social events, hallway chats, and post-presentation discussions, remote attendees are often limited to watching talks on video conferencing and livestreaming platforms with little to no presence in the conference space [5, 31]. There are few opportunities for meaningful and cohesive hybrid interactions, thereby increasing the difficulty of creating an integrated conference environment that is both equitable and engaging for all attendees.

In the present work, we explore how to address these issues in hybrid social connection at conferences through the design of a research prototype. We began with an iterative design process to understand the needs of conference organizers alongside known challenges from prior work, which revealed several key design goals. Based on these goals, we developed SocialMiXR, a WebXR prototype that creates a "hybrid space" – an aligned environment where in-person and remote attendees can interact with each other and view the same virtual objects at the same location. SocialMiXR integrates augmented reality (AR) interfaces on mobile phones for in-person attendees with virtual environments on desktop computers for remote attendees. Building on this foundation, SocialMiXR introduces three hybrid social experiences: Photo Wall, Scavenger Hunt, and Finale. Each component is designed to facilitate different modes of hybrid interaction, aiming to bridge the experiential divide between remote and in-person attendees and offer a comprehensive approach to enhancing engagement in hybrid conferences. We thus focus on the following research question: how do the hybrid experiences provided through SocialMiXR affect social connection between remote and in-person conference attendees?

To address this question, we deployed SocialMiXR at a three-day engineering conference, recruiting 14 in-person and remote attendees. Our findings highlight SocialMiXR's potential to facilitate an inclusive social networking experience that bridges the gap between in-person and remote participants. Participants reported that the prototype encouraged a sense of immersive engagement within a blended space, allowing them to feel as if they were together in a unified environment and connected through interactive hybrid activities, such as the Scavenger Hunt and Finale. We also identified challenges, including divergent experiences among participant groups and the necessity for more dynamic and expressive interactive elements. We describe design implications and recommendations that aim to harmonize the components of hybrid environments, and enhance the overall experience of hybrid conferences. In summary, our research contributions include:

(1) The design of SocialMiXR, a WebXR prototype that supports social activities between in-person and remote conference attendees within a hybrid, spatially aligned world.
(2) Results from deploying SocialMiXR at a three-day conference with in-person and remote participants.
(3) Design implications for systems that facilitate social interactions in hybrid spaces, such as for conferences.

2 Related Works

2.1 Remote Attendance at Conferences

Conference organizers have employed a number of tools to support remote participation in conferences. Perhaps most common are video conferencing and livestreaming platforms, such as Zoom and Twitch, primarily oriented towards watching presentations. Text platforms such as Slack and Discord can also support Q&A for presentations, backchannels, and general chatting. While these tools are valuable for events such as keynotes, talks, and panels, they provide limited capabilities for socialization amongst conference attendees, and minimal sense of presence at a conference.

One line of research explores the use of telepresence robots to enable remote attendees to physically move around an in-person conference. Neustaedter and colleagues studied the use of Beams, telepresence robots remotely controlled by a person shown in a live video display, in the Ubicomp/ISWC 2014, CHI 2016, and CSCW 2016 conferences. Remote attendees embodied the Beams and felt empowered to explore the conference and socialize with others. At the same time, they experienced challenges in navigating and conveying social cues through the Beams, as well as limitations in customizing them for self-presentation [40, 41]. Telepresence robots can also require a lot of overhead and be difficult to scale, where a limited set of physical devices need to be shared amongst remote attendees. In our work, we aim to similarly provide a sense of immersion and empowerment for remote attendees, while enabling them to control their own avatar and attend with their own devices through the use of AR and 3D virtual environments.

Conferences have experimented with the use of 3D virtual environments in combination with extended reality (XR) technologies for over a decade, with events held in virtual worlds that remote attendees can navigate through an avatar. IBM researchers studied a 500-person internal conference held in Second Life, an online virtual world, that included keynotes, social events, and poster sessions that users could attend on their desktop computers. They found that the virtual environment was most successful at supporting structured formats like poster sessions and round tables with one conversation at a time, given limited availability of spatial audio and social cues [17].

Due to the COVID-19 pandemic, recent years have seen more conferences held in virtual worlds similar to Second Life. Ahn and colleagues compared the use of Mozilla Hubs, a web-based immersive virtual platform, to tools such as Twitch, Discord, and social media sites during the IEEE VR 2020 conference. They found that Hubs was the most effective for supporting social presence and interaction with other attendees, but faced difficulties achieving the critical mass necessary to instigate those interactions due to the many other platforms participants were using. As such, conference attendees felt they had limited networking and socialization opportunities. The authors further highlight the importance of adding value to the virtual space to encourage participation, such as leveraging the ability to fly in Hubs to support navigation and spontaneous meetings [1]. Williamson and colleagues similarly observed the value of flying in an academic workshop held in Hubs, where people flew to manage their personal space and attract attention [61]. Building on these works, Moreira and colleagues studied engagement metrics for IEEE VR 2021, which moved to Virbela for its social events. The authors describe several new socialization events added to engage more people in the platform, including puzzle games and scientific speed dating. These events helped

increase social interactions and collaboration between participants, as well as their perceptions that they were at a conference [36]. Overall, these works demonstrate the value of virtual environments for facilitating social interactions between conference attendees through structured and playful events. However, these events were held in fully virtual conferences; we expand on these works by focusing on hybrid socialization with both in-person and remote attendees.

A few researchers have explored hybrid events specifically. Shirmohammadi and colleagues created a virtual environment in web.alive for remote people to attend the in-person MMVE 2010 workshop. Their setup enabled remote attendees to view in-person presenters giving talks, and in-person attendees to view remote attendees in a virtual world projected on a screen next to the presenter's slides. While this setup worked well for viewing the presentations, the physical and virtual worlds were disconnected in terms of socialization and presence [53]. HyWay is a recent prototype that showed success in triggering unstructured socialization at demos and informal events. It used large-screen displays placed at designated zones in a physical space, which remote users could navigate through a 2D virtual map to encounter in-person users over video on the displays. HyWay was able to create awareness and engagement between in-person and remote attendees, but faced some limitations in interactions due to remote attendees' small video tiles [60]. HybridMingler aims to more directly connect the two worlds, aligning a physical environment with a 3D virtual replica to create a hybrid space in which in-person and remote attendees can mingle. In-person attendees scan a physical hub to view remote attendees in AR around the device, while remote attendees can view the in-person attendees at the corresponding location in the virtual world in virtual reality (VR). However, HybridMinglr has not yet been evaluated in a event setting [32]. Inspired by these works, we designed and built a hybrid space for people to interact through structured social activities across XR platforms, and evaluated its potential through an empirical study with remote and in-person attendees of an actual conference.

2.2 Hybrid Collaboration

Beyond hybrid events, there are several works that investigate hybrid collaboration more broadly. Drawing from Johansen's time-space matrix [26], Neumayr and colleagues describe hybrid collaboration as a continuum in location (co-located and remote) and synchronicity (asynchronous and synchronous), with multiple groupings formed and various devices used during collaboration [39]. Much of the prior work on hybrid collaboration focuses on hybrid meetings, where co-located and remote team members participate in a meeting or shared task together. This setting faces major challenges such as limited social awareness and presence of remote attendees, which can lead to their exclusion during the meeting [7, 8, 15, 49, 50, 63]. This can be exacerbated by audio subgroup territories formed amongst co-located team members during hybrid collaboration [38].

Researchers have created various prototypes to address these challenges. These include prototypes to enhance video tools in meetings, such as MirrorBlender, which creates shared frames of reference with users' video feeds and screens to enable deictic referencing [29], as well as Perspectives, which digitally composites users' video feeds to give the illusion that they are sitting at the same table [56]. ACME is a prototype that similarly simulates a hybrid meeting at a shared table, where in-person users wear see-through head-mounted displays (HMDs) to view remote users' avatars at a physical table, while remote users would see in-person users' avatars at a virtual replica of the table in Second Life [29]. Researchers have also combined XR technologies with telepresence tools. Through VROOM, an in-person user could view a remote user's avatar overlaid on a Beam robot through an AR headset, while remote users could view the in-person user through a 360° camera attached to the robot [27]. Rather than robots, ChameleonControl uses a telepresence human surrogate, who physically carries out tasks for a remote instructor of an in-person class. The

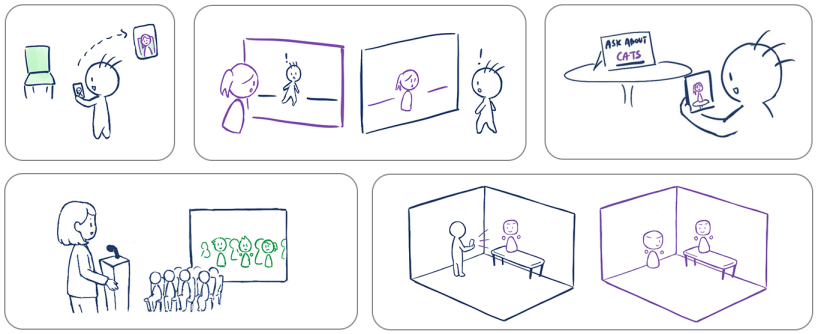

Fig. 1. Example storyboard sketches.

surrogate wears a VR headset to view the instructor's hands for the task, while a tablet attached to the headset displays the instructor's face to the class [19].

Taken together, these prototypes demonstrate the potential to engage remote participants in hybrid meetings through novel interactions, and ultimately enhance collaboration through the creation of shared spaces and consistency across physical and virtual worlds. At the same time, these prototypes are developed for very specific meeting structures and tasks which may not apply to conference settings or goals of socialization. For instance, hybrid experiences need to account for the size and space of conferences, where attendees require flexible movement to meet new people and engage in various events held over time. We address the gap of collaboration in hybrid events, specifically in the context of conferences, through a research prototype that enables a shared space for socialization between in-person and remote attendees.

3 Design Goals

To explore the potential for supporting hybrid socialization at conferences, we engaged in an iterative design process with organizers of an internal conference at JPMorganChase. The organizers were interested in providing remote options for their conference, which is typically held in-person. Following the need validation phase of the Speed Dating design method [16], we held multiple design sessions with the conference organizers in order to understand their needs for hybrid conferencing. In these sessions, we used storyboards that the research team created to encourage discussion and reveal opportunities (see Figure 1). The storyboards described potential solutions inspired by prior work, such as social networking badges [30] and spatial alignment [32, 56], as well as by the authors' personal experiences with networking events at both virtual and in-person conferences. We explored various form factors that ranged from tablets to wall-size displays for asynchronous and synchronous interactions, and discussed mechanisms such as scavenger hunts and sharing stories that could best align with organizers' needs. From these sessions, the research team discussed and reflected on the most salient needs, determining the following design goals to support hybrid conferencing:

(DG1) Ensuring that in-person attendees would not feel that they are "leaving" the conference to join another platform, and that remote attendees feel they are "at" conference. This was important to the conference organizers, given the resources they were already spending on planning for the physical conference venue.

(DG2) Connecting in-person and remote attendees *throughout* the conference, and not just once. We wanted to ensure that remote participants felt like they were engaging in a conference and not a one-time meeting.

(DG3) Enabling meaningful interactions between in-person and remote attendees, where meaningful interactions are those that enhance their (work) lives [34]. From the perspective of the conference organizers, this meant building work relationships and collaborative learning.
(DG4) Enabling attendees to network with a variety of people across the physical and virtual worlds, as networking is one of the key activities of any conference and should be *blended*, not segregated [52].

The research team brainstormed ideas that could address these goals, detailing them in a final set of storyboards that walked through the remote and in-person attendee experience side-by-side. For example, to address (DG2), we included a "mission list" concept, where in-person attendees are assigned a daily list of tasks to engage with the remote attendees, such as taking photos and leaving messages for them about the conference. We presented this idea to the conference organizers, who expressed interest in photo sharing as a major conference activity but were concerned about attendees feeling like they had homework. Based on their feedback, we iterated on the concept, which evolved into a social media-like hybrid "Photo Wall" for in-person attendees to post photos of the conference for everyone to see (described in more detail in Section 5.1). We further discussed with the conference organizers how to integrate the Photo Wall with the conference, such as making it available in the reception area where attendees tend to linger and could thus be more likely to engage.

Once the conference organizers approved our ideas, we consolidated them into a prototype called SocialMiXR, aiming to foster connections between in-person and remote attendees in a shared space. We tested this prototype for usability with members of our broader research team within our research lab, as well as at the conference venue where the organizers were planning their conference (where we would later deploy SocialMiXR, described in in Section 6). We detail the SocialMiXR system and the social activities that it supports in the following two sections.

4 SocialMiXR: System

SocialMiXR is designed to bridge the gap between in-person and remote attendees at hybrid conferences by creating a unified and interactive social experience. Through SocialMiXR, attendees join a "hybrid space" that aligns the physical and virtual worlds. Drawing inspiration from prior work [32], we decided on a hybrid space as the foundation for interactions to accomplish our design goal **(DG1)** of ensuring both sets of attendees felt they were at the conference in the same space.

In-person attendees can access the hybrid space through AR on their mobile phones, enabling them to visualize and interact with remote attendees, who are represented as virtual avatars overlaid on their physical conference surroundings. In-person attendees can see these avatars moving and interacting in real-time, as if they are physically present. We chose mobile AR to leverage the physical surroundings in a lightweight manner, such that in-person attendees would still feel present at the conference and not transported to another world, per **(DG1)**.

Conversely, remote attendees participate via a laptop or desktop interface. This setup allows them to view and engage with in-person attendees who are using the AR experience and are represented as avatars within a virtual 3D model that replicates the conference environment. This model mirrors the physical location and is spatially consistent. That is, remote attendees can view in-person attendees at the same location in the virtual environment as in the physical environment and vice versa, aiming to provide a sense of all attendees being present in the same space.

4.1 Avatars and Virtual Environment

SocialMiXR uses Ready Player Me[1] avatars to represent conference attendees. We chose Ready Player Me as it is a popular avatar creation system used in many social XR platforms, such as VRChat[2] and Spatial[3], with wide customization options. As a first step, we opted for half-body avatars with no facial expressions, which are common in social XR platforms used in prior research on virtual conferences, e.g., Mozilla Hubs [1]. While tracking hands, legs, and faces can enrich user interactions, these features were not central to our research objectives and thus were not included in our mobile AR and laptop/desktop settings.

For the virtual environment, we decided to recreate the conference venue as much as possible to enhance feelings of being in the same conference world, per **(DG1)**, and to better align the physical and virtual worlds. This "digital twin" approach has been used in prior work to simulate being in an existing environment [28]. To create a digital twin, we contacted the conference organizers for a 2D floor plan with accurate measurements of the conference venue, and visited the space in-person to take photos. We then precisely recreated the environment in Blender, with a focus on accurately replicating objects and textures for floors and walls using these references.

4.2 Aligning Virtual and Physical Environments

A critical component of our system is the accurate alignment of virtual and physical spaces, to enable synchronous interaction between remote and in-person attendees. For calibration purposes, we have selected the spatial frame of the virtual environment as the primary reference system.

We utilize a marker-based calibration approach for simplicity, which corresponds physical AR markers, placed at predetermined locations within the conference venue, with virtual markers at the same locations in the virtual environment. When an in-person attendee scans a physical marker using an Android mobile device, ARCore detects the marker and calculates its 3D pose relative to ARCore's established world coordinate system. Given the known pose of the corresponding marker in the virtual world coordinate system, our system computes the transformation necessary to align ARCore's world coordinate system with the virtual environment's coordinate system. We then apply the subsequent alignment matrix to transform coordinates from ARCore's system, and congruently represent in-person and remote attendees across worlds.

In addition, we implement WebXR anchors that specify the tracked marker poses, enabling the continuous update of the detected marker's pose. This maintains a stable relationship in terms of position and orientation with the physical world, adapting as the understanding of the world coordinate system evolves. This strategy effectively mitigates drift errors and stabilizes device movements. Importantly, this method also streamlines the user experience, necessitating only a single marker scan initially and removing the requirement for further recalibrations.

4.3 Networked Multiuser WebXR Application

SocialMiXR adopts a client-server architecture, leveraging Babylon.js, Colyseus, and Azure Communication Services to facilitate multiuser WebXR experiences.

4.3.1 Server-Side Synchronization. On the server side, SocialMiXR utilizes Colyseus, an open-source multiplayer framework that integrates with Node.js and employs WebSocket-based communication. To ensure a cohesive experience for all users, the system synchronizes the real-time state of the virtual environment and the movements of avatars within it. In addition to Colyseus, we use an SQL Database for managing authentication, user profiles, and application data. We use Azure

[1]https://readyplayer.me/
[2]https://hello.vrchat.com/
[3]https://www.spatial.io/

Communication Services to facilitate voice communication between in-person and remote attendees, and replicate the conversational interactions of a physical conference setup. To reduce overlapping conversations, we include audio circles throughout the virtual world, where users can only hear other users in the same circle. Outside of the circle, they can hear all other users.

4.3.2 Client-Side WebXR Experience. On the client side, we implemented the interactive 3D experience with Babylon.js, a web-based 3D engine, for rendering immersive virtual environments, avatars, and interactive virtual objects. Leveraging the capabilities of WebXR, we designed SocialMiXR to be cross-platform, enabling seamless experiences across various devices. For laptop and desktop users, users can control their avatars through a first-person perspective similar to social XR platforms (e.g., Spatial), using the standard WASD key setup along with mouse controls to change the viewing direction. Mobile phone users simply walk around the physical space to move their avatars.

While SocialMiXR is also compatible with VR headsets, our primary focus in this paper is the hybrid interaction between in-person AR users on their mobile phones and remote users on their laptops or desktops. We focused on these platforms to enable users to interact through their own devices and thus access the prototype in their own time, using input modalities that they are already familiar with as part of their everyday work activities.

5 SocialMiXR: Interactive Experiences for Hybrid Engagement

To create opportunities for in-person and remote attendees to connect with each other in the shared hybrid space, we designed three interactive social experiences for SocialMiXR: the Photo Wall, Scavenger Hunt, and Finale. Each of these experiences were designed to achieve the goals listed in Section 3.

5.1 Photo Wall: Asynchronous Sharing

The Photo Wall enables in-person attendees to share moments from the physical conference with other in-person attendees and remote attendees, displayed on a virtual "wall." We created this feature to accomplish our design goal of connecting in-person and remote attendees throughout the conference **(DG2)**, as attendees would be able to add to and view the Photo Wall at any point during the conference. The Photo Wall aimed to support attendees' connections with each other and to the broader conference experience, similar to hashtags and photos shared on social media during conferences [35], or bulletin boards at physical conference venues. This primarily supports asynchronous interactions, such that attendees can engage regardless of their time zone, which is often a major challenge for global participation [1, 31]. At the same time, this feature provides opportunities for simultaneous viewing, i.e., encountering other attendees viewing the Wall. This design was inspired by prior work in virtual museums [44] and cultural heritage [13], where shared viewing can cultivate a sense of togetherness that could enhance feelings of connection and inclusivity at the conference.

To interact with the Photo Wall, in-person attendees can use SocialMiXR to capture photos, append captions, and upload them to the Photo Wall as shown in Figure 2 (a). This feature is accessible via a mobile AR interface, allowing in-person attendees to view the Photo Wall by scanning a marker (Figure 2 (b)). This interaction not only makes the Photo Wall available but also aligns the virtual world with the physical environment, ensuring a coherent shared space. Conversely, remote attendees are able to view the same Photo Wall within the virtual environment. When accessed simultaneously by in-person and remote attendees, both groups can see each other as well as the Wall in this hybrid space (Figure 2 (c)(d)). Thus, attendees can not only share their

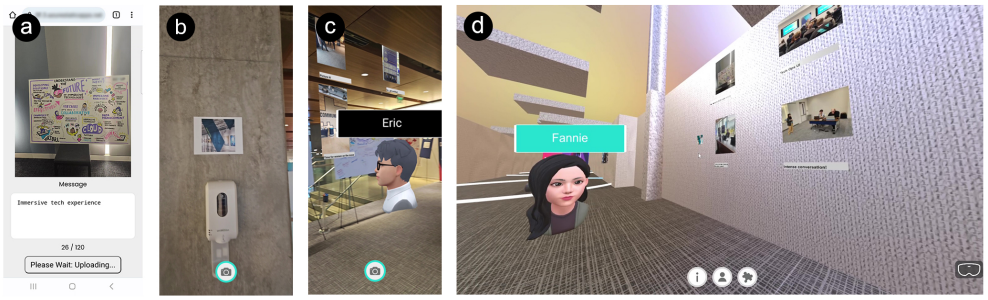

Fig. 2. **Photo Wall. (a) Upload Photo:** An in-person attendee takes a photo and writes a short caption, uploading it to the Photo Wall using the mobile interface. **(b) Scan Marker:** An in-person attendee scans an image marker at the conference venue, which aligns the virtual and physical environments. **(c) View Photo Wall (AR):** The in-person attendee views the Photo Wall in the physical environment, and sees a remote attendee's avatar. **(d) View Photo Wall (desktop):** A remote attendee views the same Photo Wall in the virtual environment, and sees the in-person attendee's avatar.

conference experiences through the Photo Wall, but also have the option to view them together with other attendees.

5.2 Scavenger Hunt: Collaborative Exploration

In the Scavenger Hunt, users engage in a synchronous activity that blends the physical and virtual worlds. To accomplish our design goal of meaningful interactions between in-person and remote attendees **(DG3)**, we created a structured, playful social experience, based on the success of similar events held in virtual environments [1, 17, 36]. Specifically, we designed a collaborative task in which attendees could work with each other while learning together and getting to know each other. Further, to encourage attendees to utilize and explore the hybrid space, the task involves movement and coordination. In this task, in-person and remote attendees pair up to find virtual puzzle pieces (Figure 3 (a)), hidden in balloons distributed evenly across the hybrid space (Figure 3 (b)), and collect them by answering questions together. To facilitate deeper connection through one-to-one interaction, pairs of attendees hear each other over audio communication and see each others' avatars, but do not hear or see other participants through the system.

Attendees have different abilities to find the balloons with puzzle pieces – an approach commonly used in cooperative games to prompt collaborative interactions and strategic discussions [24, 25]. We assigned abilities to balance and leverage attendees' different contexts. In particular, we were concerned that remote attendees might find the balloons too easily on their own given their mobility and larger view of the conference space, compared to in-person attendees who would be restricted by their physical abilities. Therefore, remote attendees can only detect balloons within a specified radius (i.e., balloons do not show up unless they are close enough). However, they have the unique ability to "fly up" to balloons positioned high up in the air. We specifically chose floating balloons, over other objects like treasure boxes that are typically grounded, to promote flying, as flying is valuable for navigating virtual conference environments [1, 61]. In contrast, in-person attendees can view and interact with the balloons regardless of their location (i.e., they can view balloon objects in mobile AR even if they are far away). Once an in-person attendee locates a balloon, they can guide their remote partner to the balloon's location. Attendees can then click on the balloon to pop it, an interaction we chose for its simplicity.

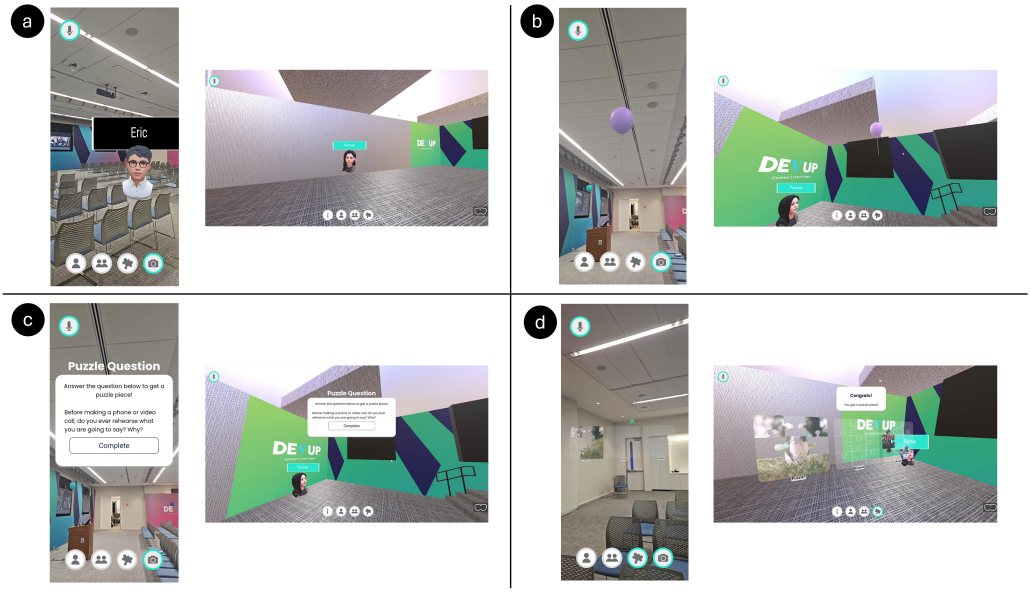

Fig. 3. **Scavenger Hunt. (a) Pairing:** An in-person and remote attendee pair up to collaborate on the Scavenger Hunt. **(b) Search for Balloons:** Attendees work together to find and pop virtual balloons that contain puzzle pieces, hidden throughout the hybrid space. **(c) Puzzle Question:** After popping the balloon, attendees answer a technical or personal question together. **(d) Puzzle Reward:** Both in-person and remote attendees receive a puzzle piece after successfully answering the question.

Upon popping a balloon, each pair collaboratively answers a question to secure a puzzle piece (Figure 3 (c)(d)). Pairs answer one of three types of questions: 1) an open-ended question to discuss one of the pictures on the Photo Wall, aiming to encourage discussion about the conference activities; 2) an open-ended self-disclosure question (modified from [3] for work contexts), aiming to increase interpersonal closeness; and 3) a technical question about a topic of interest at the conference, aiming to promote learning, one of the goals of the conference.

Each scavenger hunt session lasts ten minutes, after which participants switch partners so that they could collaborate with new people. Every session introduces a new puzzle, contributing to continuous engagement and discovery throughout the activity. Through the Scavenger Hunt, we aimed to create fun opportunities for collaboration and connection between in-person and remote attendees that would also encourage them to explore the hybrid space.

5.3 Finale: Network Expansion Activity

We designed the Finale to provide more opportunities for attendees to connect, as per our design goal of helping attendees meet new people across worlds **(DG4)**. Specifically, we aimed to provide a "speed networking" experience, similar to scientific speed dating used in prior work on virtual conferences [36], so that all users would have a chance to meet each other through the prototype. The Finale takes place after all the Scavenger Hunt sessions, such that attendees first meet others one-to-one for a longer collaborative activity, and then have the chance to meet them again during a networking session. This allows attendees to meet both new and old connections, akin to how networking typically takes place at conferences. Thus, in this concluding segment, we enabled all attendees to converse with other.

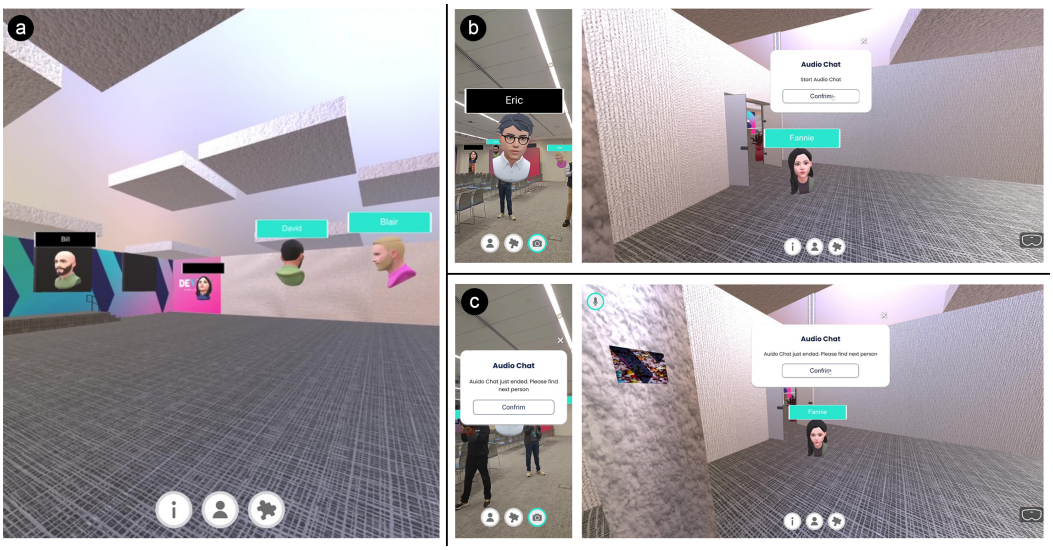

Fig. 4. **Finale. (a) Hybrid Networking:** All attendees, both in-person and remote, are visible within the hybrid conference space, with color-coded name labels for easy identification. **(b) Audio Chat:** An in-person attendee initiates a one-on-one conversation with a remote attendee by tapping on their avatar, and the remote attendee responds to the conversation invitation. **(c) Find New Partner:** Following a 30-second chat, both in-person and remote attendees can seek new partners for subsequent conversations.

In the Finale, all attendees, both in-person and remote, are visible to each other within the hybrid conference space as shown in Figure 4 (a). Participants can initiate one-on-one conversations with as many different individuals as they want. We color-coded name labels above the avatars to help with identifying attendee type: black for in-person and blue for remote (Figure 4 (a)). In-person attendees can initiate 30-second audio conversations with remote attendees by tapping on their avatar on their phone screen, and vice versa (Figure 4 (b)(c)). If the user had not connected with that person before, they are awarded a puzzle piece from any puzzle they had not completed in the Scavenger Hunts at the end of the 30-second chat. We chose 30 seconds, as well as included the puzzle pieces, to motivate people to engage in numerous brief yet impactful conversations, as well as to minimize wait times if everyone was already engaged in conversation. As such, attendees can use the Finale session to meet many other people in the hybrid space over a short period.

6 Methods

To evaluate the potential for the design of SocialMiXR to support hybrid conference interactions, we deployed SocialMiXR at a three-day conference with 14 in-person and remote attendees.

6.1 Research Context

We conducted our research at DEVUP, JPMorganChase's internal conference for software engineers, in November 2023. Over 500 employees are invited to attend the conference, either by application or nomination from their team. The conference is typically held for three days in-person in the United States, but attendees travel from around the world. The conference includes keynote talks, technology sessions (i.e., presentations, panels, and guided discussions on technology topics from selected employees), an expo for demoing technology, and networking events. Our team collaborated with the conference organizers to deploy our system as a pilot for including remote attendees

for the first time. Since the conference did not yet have a remote option, but did provide online talks post-conference, we focused on providing hybrid networking opportunities based on our research scope. Attendees participated in our research by interacting with SocialMiXR throughout the conference, including during scheduled sessions, explained further below.

6.2 Participants

We recruited participants who were attending the conference in-person or were engineers at the company who were not attending but willing to participate remotely during the three days the conference was held. To recruit in-person attendees, the conference organizers included recruitment text in the conference information newsletter in the weeks leading up to the conference. We recruited remote attendees by advertising our study on a mailing list for an internal career development program for software engineers early in their career, focused on the New York tri-state area in the United States. We chose this program as it aligns with the population that the conference targets: engineers interested in connecting with others to build their career. To incentivize participation, we stated in our recruitment messages that participants would have the opportunity to receive company swag. Fourteen people total (7 in-person and 7 remote) volunteered to participate in the study, including follow-up interviews. All participants had some prior experience interacting with augmented or virtual reality, such as through phone app filters or video games. All participants were attending the conference for the first time.

6.3 Procedure

6.3.1 Onboarding. The week before the conference, we scheduled a 30 minute onboarding meeting with each set of participants over Zoom (i.e., one meeting with in-person attendees and one meeting with remote attendees). During the video call, participants first signed a consent form and then provided information for their user profile in SocialMiXR, including selecting an avatar, a technology topic they were interested in learning at the conference, and a hobby. Users would be able to view their own profile anytime they used SocialMiXR, as well as the profile of other users they paired with. Participants could select their avatar from a diverse set of pre-created Ready Player Me avatars or ask one of the researchers to create an avatar for them based on their photo[4].

Next, we gave an overview of SocialMiXR and its features. We provided login credentials to ensure that participants could access SocialMiXR through a web browser on their Android phone or laptop computer. We also ensured that in-person attendees had AR enabled on their phones, and that all attendees were able to use the system's audio communication features. We told remote attendees that they could access SocialMiXR's virtual world at anytime during the conference. We told all attendees that the Photo Wall would be available throughout the conference, both to add photos (for in-person attendees) and view photos (for both in-person and remote attendees). Finally, we asked all attendees to join four 30 minute evaluation sessions scheduled during the conference (in Zoom for remote attendees or at a specific conference room for in-person attendees), where they would use SocialMiXR as part of a hybrid networking experience. Participants were all added to an internal chat group where they could ask questions and view the onboarding information and announcements.

6.3.2 Evaluation Sessions. We scheduled four evaluation sessions during the three-day conference: one for each day except for the last day which had two sessions. In the first three sessions, participants engaged in the Scavenger Hunt activity (described in Section 5.2), where SocialMiXR would randomly pair remote and in-person participants who had not yet been partners with each other. The last session functioned as the Finale (described in Section 5.3), where remote participants could

[4]due to organization restrictions, only the researchers were approved to create avatars on readyplayer.me

openly talk with any other in-person participant, and vice versa. Members of the research team were both onsite at the conference and online in a video call and in the virtual world during the sessions in order to provide instructions and assistance. At the start of each session, participants checked-in with a research team member and received instructions. Throughout each session, we kept a Zoom video call open for remote attendees in case they ran into issues while they were in the virtual world and needed to communicate with the research team. Researchers did not interfere during sessions unless participants needed help with technical issues, such as connecting to audio or scanning the AR marker.

At the end of the last session, we handed out conference tote bags as gifts for participating (shipping them to remote attendees after the conference). We had additional prizes (vest, water bottle, hat) for three in-person and three remote attendees who collected the most puzzle pieces; however, since most participants were able to finish their puzzles, we randomly selected winners for these prizes. We included prizes to reduce potential drop-off throughout the study. While participants mentioned feeling competitive while they gathered puzzle pieces during the sessions, our results did not indicate that the prizes were their primary motivation to participate.

6.3.3 Post-Conference Interviews. The research team conducted semi-structured interviews the week after the conference to learn about participants' experience using SocialMiXR. Interviews lasted 30 minutes on average. During the interview, we asked about participants' overall experience, whether or not they interacted with different features of the system and what their subsequent thoughts were (e.g., "Did you view the photo wall at all? If so, what did you think when you saw it?"), their experience in the scheduled sessions (e.g., "Did you talk with your partner during the scavenger hunt? What did you talk about?"), their perception of hybrid interactions with other attendees (e.g., "What did you think of seeing the other attendees' avatars in AR/in the virtual world?"), and their feedback on using this type of system for future hybrid conferences or events (e.g., "Is there anything you would want to change about the experience for next year's conference?"). We designed the interview protocol to probe participants on how they engaged with each other through SocialMiXR (if at all), and their ability to connect with each other through the hybrid experience, per our overarching research question.

6.3.4 Adjustments During the Study. Since SocialMiXR is a research prototype, we ran into a few technical issues during deployment. In particular, we were unable to pair participants during the first session due to a technical bug, which was fixed for the following sessions. Therefore, participants only participated in up to three sessions. Additionally, since we had multiple evaluation sessions, participants could skip sessions if they had conflicts. In the case of in-person attendees who would miss sessions, we allowed in-person passersby at the conference to participate for single sessions in order to have enough pairings for the Scavenger Hunt or people available to meet for the Finale. In the case of remote attendees who would miss sessions, we had remote members of our research team on standby to join. Since these were temporary participants, we did not include their data in our analysis. One in-person and two remote participants skipped one session each.

7 Analysis

The primary data that our resarch team collected was participants' self-report through their interviews. We transcribed audio of the 14 interviews and analyzed them using an inductive approach [57]. Two researchers generated initial codes from a subset of in-person and remote interview transcripts. They discussed and defined these codes in a codebook (example codes including "spatial interactivity" and "embodied togetherness"). Then, they validated the codebook by independently coding a new subset of transcripts, and meeting afterwards to discuss any improvements to the codebook as well as to ensure high inter-rater reliability. After achieving

Cohen's kappa [14] above 0.7, one researcher coded the rest of the transcripts. We then grouped and analyzed the codes to form higher level themes (e.g., "together at the same time/place") and subthemes (e.g., "natural interactions as if in-person"), which we refined in the paper writing process and discuss in the following section.

8 Results

During the conference, participants made a total of 35 unique connections with each other, based on the total number of audio communication sessions between unique pairs of participants during the Scavenger Hunt and Finale (as tracked in SocialMiXR). Overall, all participants stated that the experience was fun and that they enjoyed meeting others who were physically distant from them through a novel WebXR environment. Participants appreciated that the experience was inclusive of people who could not attend the conference in-person, and were excited by the possibilities of using XR technologies for future hybrid work settings such as town halls, team meetings, demos, and training. The analysis of their interview transcripts revealed several opportunities and challenges for designing hybrid social interactions for conferences in particular. Below, we structure our results according to these opportunities and challenges, with themes and subthemes under each.

8.1 Opportunities for Hybrid Interactions

8.1.1 Establishing Presence in the Hybrid Space. Both in-person and remote attendees perceived that they were "there" in a hybrid space at the conference, despite being in different U.S. states from each other. This feeling of presence, or a sense of "being there" [6], was accomplished through the design of the environment and how participants could interact within it.

Providing a Realistic Experience. Remote attendees highlighted the realism of the virtual world as key to feeling present. We had designed the environment as a semi-digital twin of the physical conference space, matching the dimensions and textures of a subsection of the event area but using pre-created models to represent office furniture. Remote participants appreciated the level of detail in the environment, including "how the tables had outlets for charging" (P12), how the audio circles allowed you to hear people near you and not "on different sides of the building" (P10), and how "the textures resembl[ed] a real space [without being] uncanny or uncomfortable" (P9). Even though the remote attendees had never been to the physical conference building, they felt the environment was "very appropriate and very precise to [how it would look] in the real world" (P13). Remote attendees also described using the Photo Wall to get a view into the conference as a whole through the experiences that in-person attendees were sharing.

Providing a Dynamic, Spatially Interactive Experience. The dynamic nature of the environment also contributed to participants' feelings of presence. This included the ability to interact with virtual objects such as the balloons and puzzles during the Scavenger Hunt. In comparison to a video call, one in-person attendee mentioned the value of touching objects in a hybrid space that are accessible to others across the world:

> "In [a video call], I cannot react to any objects on the other side of the world...I cannot touch them. In [SocialMiXR] you can give it an additional feeling [that] you are as good as in the room itself and whatever objects are there you can feel it virtually, you can touch it." - P6 (in-person)

Participants also felt compelled to move around and explore the hybrid space, which helped them "think a little bit differently" (P11-remote). One in-person attendee noticed this in their search for balloons, describing how it forced them to be more aware of the space:

> "It allows people to not...have tunnel vision, just trying to get from point A to point B in the conference.... It makes them kind of have the need to look around and be aware of their surroundings.... You may come across something you weren't particularly looking for and it could add to the experience, which I think is definitely pretty cool." - P2 (in-person)

Remote attendees particularly enjoyed the agency to flexibly move anywhere they wanted, including flying in the air. The 3D movement and "superhuman" abilities helped them go *beyond* the screen or a traditional 2D interface or even the physical world, with more autonomy to interact the way they wanted:

> "You had more degrees of freedom...it's not constrained to a screen on a UI...[moving around] that 3D space...helps with the immersiveness of that experience, especially for people who might not be able to make it there." - P9 (remote)

> "[Controlling the different perspectives] gave me a good idea of...people gathering here, or...people who were looking at the photo wall and all of that.... And that higher perspective [gave me] a better view of something that I would not be doing if I was on my own two feet in the room in person." - P13 (remote)

These results align with prior work, where more realistic, immersive environments contribute to individual feelings of presence [54]. We demonstrate similar possibilities through hybrid experiences that forefront spatiality, and empower all attendees with greater interactivity and mobility.

8.1.2 Together at the Same Place and Same Time. Participants not only felt present in the hybrid space, but also felt that they were present *together*. Based on Johansen's time-space matrix [26], despite being in different physical places, participants actually perceived that they were in the same place at the same time – which is typically only associated with face-to-face interactions. Key to this experience was aligning the virtual and physical environments to feel like one space, and subsequently promote more natural, face-to-face-like interactions.

Aligning Two Worlds for People to Come Together. We aligned the virtual and physical worlds by replicating the actual conference rooms in the virtual world and using image markers to ensure spatial consistency in participants' locations. Participants perceived they were in one shared space, and felt connected just by seeing each other's real-time movements and having a shared experience:

> "I think it's just knowing...we're in the same place and we have a connection there.... We're both managing our way through it. And I just think...it's a really good platform that could be used to help people learn more and get to know each other better, even though we're not physically next to each other." – P11 (remote)

Moreover, by following each other's avatars, participants were able to coordinate with each other, move around together, and ultimately collaborate across the two worlds:

> "The [avatars] were moving along with me.... It gave you the feeling that you're talking to someone who's next to you." - P6 (in-person)

> "[Seeing their avatar] made it clear that we're on the same page at least, and not just lost in the two different worlds. So it was a good indication that we were successfully communicating with each other." - P7 (in-person)

Promoting Natural Ways to Interact with Each Other. Moving and seeing each other's avatars in the aligned space also helped participants interact with each other more naturally. Participants were able to see where people were and approach when they wanted to speak with them. One remote attendee described how this was possible with the audio circles, where they could view and join sidebar conversations, unlike on video conferencing platforms:

> "If you're on [a video call], you can't...see somebody's in breakout room, and like wander over there. So I guess that's the added benefit here." - P10 (remote)

Another participant was particularly conscious of others' space, such as when several participants were crowding around the Photo Wall to view the photos:

> "[It's] a tiny photo wall and there are like three or four people looking at one thing, you don't often get the angle or the right point of view to see the photos...I don't know why something in me was like don't bump into other avatars." – P13 (remote)

Participants also used the direction that avatars were facing as a cue for whether they were engaged in conversation. This was important during the Finale in order for participants to gauge who was available to chat:

> "I liked getting to see especially the facial direction. [In the Finale] it was more important because you could see which two people are talking to each other since they're typically facing each other." - P12 (remote)

One in-person attendee used the avatar cues to force a more natural interaction. When a remote attendee's avatar was hovering above them, this participant sat down and angled their phone up towards where the avatar was facing down at them to feel like they were talking face-to-face.

> "So that time...there [was] a platform. I sat down. I was trying to find the right angle...at which they were looking down like they were looking [at me] — I sort of forced an angular connection with them." – P3 (in-person)

P3 further described how having that natural interaction was key to forming a meaningful connection with their partner. Another in-person attendee detailed a similar experience, where being able to face their remote partner through their phone helped them bond with them personally:

> "I think it was a good idea to get the in-person and [remote] attendees bonding in a way.... Because although we didn't see them in person, we did see the avatar. So, it was weird because I'm looking at my phone but there was an avatar literally standing in front of me. So, it seems like we're talking...I remember one of the attendees was a dad and I'm a mom...so we started talking about age groups and how they change, kids change, and all that...learning more about them even though I may never meet them in person. It was just nice to talk to someone." - P7 (in-person)

Overall, the cues that the avatars conveyed in their movement and orientation were important for establishing a sense of togetherness as well as deeper connections between participants. These results align with prior work on face-to-face communication, where nonverbal behaviors like facing towards each other and coordinating movements are important factors in building rapport with other people [59]. In the following section, we describe how this "bonding" between participants was facilitated by not only the hybrid setting, but also the social activities we designed.

8.1.3 Bonding Through Hybrid Networking Activities. SocialMiXR enabled two types of synchronous hybrid social activities: a paired collaborative Scavenger Hunt, and a speed networking Finale. Most participants stated that both types events are valuable but serve different purposes. Participants viewed the Scavenger Hunt as a way to make deeper connections with their partner, since they had to work together towards a shared goal and could spend more time with each other. They also appreciated switching partners in order to collaborate with new people. On the other hand, the Finale was useful to broadly make connections. All participants felt that 30 seconds was too short to have a full conversation in the Finale, but enjoyed being able to meet many people at once. Both activities functioned as icebreakers that facilitated conversation in a hybrid setting, and served as a basis for follow-up interactions that could help people form relationships.

Encouraging Conversation Through Shared Tasks. All of the participants enjoyed the gamification of the hybrid experience and the friendly competition of collecting puzzles as they interacted with other people. The Scavenger Hunt provided a way to work as a team with a remote coworker and encouraged moving around together in the shared space, while describing what they were seeing:

> "[My partner] was kind of guiding me, saying, 'I think there's one over there, there's one off to the right, move a little to the left,' just to help me get to where the balloons were if I didn't actually see it right away." - P11 (remote)

When participants burst the balloons, they had to answer technical and personal questions together. Participants described these questions as conversation starters, where they were able to learn together and connect with each other over work, technology, and their personal lives.

> "One question was, 'what are your professional goals?' And it gave me...some time to reflect...[on] my time at [the conference], seeing all the new things people are working on, [on] the direction I want to take my career in. And then hearing a different perspective from my virtual buddy to see...what they were looking to do in the near future. Yeah, that's definitely one I remember." - P2 (in-person)

Along the same lines, one participant noted that the collaborative navigation of Scavenger Hunt helped them feel more comfortable with their partner. As a result, when they had extra time after finishing their hunt early, they were able to have more personal conversations with their partner:

> "We've...practically been yelling at each other for the past 10 minutes to find balloons. So I think we can talk about how life's been going in general and where you are at the company and stuff like that." - P13 (remote)

Extending the Relationship. Participants formed meaningful connections with each other as they were able to meet people with specific knowledge and experiences they were interested in learning from, or simply because they got along with each other. Participants also enjoyed bumping into their previous Scavenger Hunt partners at the Finale and being able to catch up with each other:

> "It was good seeing them...especially on the last [session], when we just casually ran into each other and we were able to talk about the previous days." - P14 (remote)

P7 and P11 independently mentioned how they hoped to reconnect after the conference because they had spent the most time with each other, both as Scavenger Hunt partners and running into each other during the Finale, and enjoyed the experience together:

> "P11 and I, we definitely talked the most...I probably would connect with them again...it was just a nice conversation, felt like something organic enough to just continue and see how they're doing post-[conference]." - P7 (in-person)

> "I talked with P7 more than anyone else, she's at the top of my list, we get along pretty well...but everyone was good, we were going through the same experience together and it was fun." - P11 (remote)

Most other participants were also interested in following up with the people they met to continue their conversation after the conference, learn from each other's work area, or because their office locations were actually close to each other:

> "I'd love to follow-up [with] at least one person I talked to [who] knows our team. And he works on [a product I'm interested in]...so I'd love to get to know more about what his team is doing. So I'd like to follow-up." - P8 (remote)

Indeed, all of the participants had mentioned that their major goal for the conference as a whole was to meet new people, particularly to learn from others and to search for opportunities for internal mobility. The remote attendees, who were all junior engineers in the firm, were especially

happy for the opportunity to meet in-person attendees of various levels of seniority. In-person attendees likewise enjoyed collaborating with people from different offices with whom they might otherwise have never connected. Overall, the hybrid social experience was successful in helping people expand their networks in new ways.

8.2 Challenges for Hybrid Interactions

8.2.1 Unbalanced Realities. Though participants perceived that they were in the same hybrid space, they had different controls for interacting in that space. In-person attendees used their Android phone to view virtual objects and physically walk around, whereas remote attendees would view it through their laptop screen and move using their keyboard. These controls ultimately affected the way they appeared to each other and could interact with each other, leading to unbalanced realities.

Remote attendees appreciated their degrees of freedom in movement; however, too much freedom sometimes made it difficult for in-person attendees to keep track of them. Remote attendees could fly around and generally move faster than in-person attendees, sometimes moving too far away:

> "We weren't on...the same playing field, like I was able to fly and she had to walk.... It seemed different because we weren't in the same type of situation...she was moving slow." - P10 (remote)

Additionally, since remote attendees were flying around, a few in-person attendees found it difficult to coordinate with their height level, since they had to point their phone upwards and look around. Though the aforementioned P3 was able to force a natural interaction by sitting and looking up at their remote partner, they had trouble connecting with other remote attendees outside of that moment. They described it as an unrealistic, comic book-like experience:

> "I saw avatars floating up like balloons. I'm like, well, why is the avatar doing up there? When in real – I'm not walking around at that level...it was more like a comic book experience at that point.... I would try to walk around to the other side of the avatar, but the avatars now move to a different angle. Things were not really happening in the...same time scale." – P3 (in-person)

Finally, one in-person attendee brought up concerns around holding their phone to converse with remote attendees. While in-person attendees generally enjoyed seeing the remote attendees through their phone as if they were standing by them, holding a phone can be tiring:

> "I guess holding up a phone for a while talking is fine for an experiment. But longer term, doing that, walking around, will ultimately get tiring, right?" - P4 (in-person)

The physical restrictions of the physical world were not balanced with the openness of the virtual world, thus creating a disconnected experience for some attendees. In these cases, participants were on different "playing fields" or "time scales," as described in the quotes above, and therefore faced challenges in being able to collaborate with each other.

8.2.2 Limited Social Cues. Though participants were able to connect with each other through their avatars and audio communication, they described challenges in understanding the other participants' perspectives and emotions due to the lack of several social cues.

As previously mentioned, participants would sometimes describe what they were seeing to each other to navigate the space together; however, several people mentioned they were not 100% sure of the other person's view. In-person attendees did not ever enter the virtual world , and remote attendees likewise did not have a live feed of what the conference venue actually looked like.

> "I didn't know what she was looking at. So I could see stuff, I could see her. I know what she was looking at, like, could she see me somehow? I didn't quite understand how that worked." - P10 (remote)

Participants also felt the avatars were not expressive enough. Though the avatar's orientation was a cue for conversation, they wished that the avatars had more body language and facial expressions in order to understand each other better, and have a more realistic experience rather than "disembodied heads" (P14-remote). P14 further described how having a "moving picture," or video feed on top of the avatar would be an improvement, since it otherwise felt like a phone call:

> "Because you can see the other person's facial expressions...you'd be able to put a voice to a face instead of a voice to an avatar.... [It] feels very similar to a phone call. Like you could put the avatars face-to-face, quote unquote, but you wouldn't really see the other person [or] really meet them other than your voice." - P14 (remote)

The telephone-like experience was exacerbated when participants were stationary, which was often the case for conversations during the Finale. At these moments, participants would mainly focus on each other's voice, since the avatar was essentially a "static icon," as P4 further describes:

> "Once we started talking we didn't move around too much. We just sort of stayed in one place...I guess you're at a party and you would meet somebody, you stop and you talk...like you might walk side-by-side in real life with them or something...but I don't know that you'd be able to do that in a virtual [world] and still stay together, if you will." - P4 (in-person)

Thus, while the avatars were able to convey enough cues for people to start conversations, they did not convey all of the necessary cues to fully engage people once they started talking. Nonverbal cues like facial expressions and gestures play an important role in establishing understanding and connection with each other during conversation [59] as well as presence in remote contexts [12], including through avatars [42]. Though participants could still communicate through voice and bond while facing each other, additional nonverbal cues would have been helpful in strengthening those bonds.

8.2.3 Lack of Asynchronous Experiences. Finally, participants wanted more ways to engage with the hybrid space and each other asynchronously. Participants appreciated the ability to interact asynchronously through the Photo Wall, which in-person attendees enjoyed contributing to in a social media-esque way, and remote attendees enjoyed viewing to get a broader sense of the conference. However, most remote attendees only viewed the Wall once, and primarily viewed it at the beginning of evaluation sessions while waiting for the session to start. Participants generally did not enter the virtual world outside of the scheduled evaluation sessions, even though they were told they could if they wanted to (only three participants viewed the Wall outside of the sessions). As realistic to the conference venue as the world was, people lacked the incentive to come back with limited activities to do and low expectation of others being there:

> "There was not much to do, like maybe...if the conference was being...presented in that space or there were certain virtual elements that I could interact with live during the conference." - P9 (remote)

> "[I didn't return because] I didn't think anybody would be there." - P10 (remote)

Along the same lines, two in-person attendees felt that asynchronous experiences would be important for a remote attendee to fully engage in a conference. While many remote attendees praised the realism of the virtual world, these participants were doubtful that a 3D model could be a satisfactory proxy for what they were experiencing physically at the conference. They felt that a live feed would be more beneficial than a purely virtual world:

> "If they find something they want to...lock in on, they could flip from that virtual world to...the actual presentation feed of that. So they're not trying to [look through] a camera

or something steady to look at a screen from an angle that they could actually get a real, you know, to kind of switch between worlds." - P1 (in-person)

The liveness of the scheduled sessions, where people had to gather and collaborate in real-time for the Scavenger Hunt/Finale, helped participants achieve a sense of presence during those events. But outside of those sessions, there was no impression of liveness in the world, which was devoid of people or conference activities. Thus, while the planned synchronous experiences were successful at creating a hybrid space for in-person and remote attendees, the asynchronous ones remained relatively separate conference worlds.

9 Discussion

Overall, our results demonstrate the potential for the design of SocialMiXR to support meaningful hybrid social interactions between in-person and remote attendees. By aligning the physical and virtual worlds, SocialMiXR created a shared hybrid space, which participants could use to explore and feel present together, and collaborate with each other through structured social activities. This suggests promising new directions for improving hybrid conferences and creating blended social experiences for networking. At the same time, we found several limitations in our hybrid setup. In-person and remote attendees were ultimately in different contexts with different controls, leading to experiences that did not always align even though their two worlds were spatially aligned. Moreover, participants sought more features, including expressive avatars and asynchronous activities, in order to have richer interactions with each other and a fuller conference experience overall.

In the following sections, we discuss design implications based on these findings and future directions for exploring hybrid social interactions at conferences, summarized in Table 1.

Table 1. Summary of Design Implications

Component	Finding	Implication
Mobility	Participants felt like they were together in the hybrid space when they moved together (8.1.2); however, their ability to move was unbalanced, as their controls were too different (8.2.1, 8.2.2).	Tightly coupled tasks, such as the Scavenger Hunt, may facilitate togetherness, while loosely coupled tasks may better leverage asymmetrical inputs. Flexible controls for mobility that adjust according to task type could empower users to explore and interact within the hybrid space.
Perspective	Participants experienced uncertainty about each other's capabilities and view into the hybrid space (8.2.2).	Asymmetric modalities can limit establishing common ground. Possible directions include providing similar input/output modalities, extended displays for perspective sharing, more experiential onboarding, and mirrors for self-awareness and live views.
Social Activities	Participants felt they could form deeper connections with each other through the Scavenger Hunt, as they could learn about the technical content together, as well as learn about each other (8.1.3). However, participants did not engage with the system outside of these scheduled sessions, as they did not expect others to be engaging as well (8.2.3).	Structured, playful, synchronous activities are conducive to relationship-building, learning, and exploring in hybrid spaces. Balanced asynchronous activities, that could lead to spontaneous synchronous activities through presence cues, might motivate greater engagement. All activities should be well-connected to the broader conference.

9.1 Mobility in a Hybrid Space

Perceiving movement in the space was critical to enhancing people's feeling of presence, where seeing other attendees move around in real-time helped participants feel they were *in* the space, i.e., physical presence (see Section 8.1.1), and *together with others* in that space, i.e., co-presence (see Section 8.1.2) [6]. However, this feeling was lost at moments where users were too stationary (e.g., during Finale conversations, see Section 8.2.2), or not able to see each other (e.g., when remote attendees flew too fast or high for in-person attendees, see Section 8.2.1).

These findings suggest that the task type can have an important impact on people's expectations for movement, particularly in their need for *collaborative coupling* [55], or how dependent collaborators are on each other's work. Collaborative coupling can be complex in hybrid, cross-platform environments due to asymmetrical inputs and outputs [51]. In our case, in-person attendees had to physically move to view AR content on their mobile phone, while remote attendees used their keyboard and laptop/desktop computers. Both the Scavenger Hunt and Finale are tightly coupled tasks, where users guide each other to find puzzle pieces or converse directly with each other. Perceptions of moving side-by-side with others during such tasks might facilitate feelings of togetherness, as P6 describes in Section 8.1.2. While researchers are actively investigating techniques for shared movement in VR, such as walking and teleporting in groups [11, 47, 62], future work might explore what that would mean in the hybrid space.

On the other hand, loosely coupled tasks may not require side-by-side movement, and may provide opportunities for leveraging the affordances of users' different inputs. For example, a search task would leverage the high mobility of remote users, while a gesture-based task would leverage the physicality of in-person users. This notion of leveraging diverse user inputs in loosely coupled tasks is supported by prior research on platform-specific task design [48]. Moreover, studies have shown that asymmetric designs, as opposed to symmetric ones, can lead to improved social presence and immersion in mixed reality environments [24, 25]. As such, interdependent roles and tailored tasks could significantly enrich player experiences in such contexts.

Taken together, we recommend providing flexible, dynamic controls for mobility that can adjust based on the task. For example, a flying remote user might automatically land next to the other user before they can start a conversation. A "follow me" option, where users can follow the movements of another user, could help mitigate issues of losing each other due to moving at different speeds. Future research should explore how to seamlessly shift between modes of mobility while still empowering users with the agency to explore hybrid spaces as desired.

9.2 Perspectives from Different Worlds

Interestingly, even though participants perceived they were in the same hybrid space, they were often unsure about what other people were seeing, which could subsequently affect their coordination with each other (see Section 8.2.2). Aligned with prior work on hybrid collaboration [27], participants were uncertain about each other's capabilities, and needed to explicitly communicate what they saw. The asymmetry of their modalities (i.e., mobile AR vs virtual desktop) may have affected their ability to find common ground in their display output [51]. One natural solution is to provide similar input/output modalities, such as both users wearing a head-mounted display (HMD). This could also address concerns around holding a phone for longer than a short task. However, the increasing accessibility and ease of use of XR platforms are guiding collaboration toward a cross-reality, platform-agnostic model [4]. This trend emphasizes the importance of integrating XR technologies in a way that accommodates all users, ensuring a unified and inclusive conference experience regardless of their chosen platform.

Though researchers have suggested some solutions to establishing common ground across platforms, establishing it in a hybrid space can be challenging. For example, P5 mentioned his desire for perspective sharing during the Scavenger Hunt, where users can simply see each other's view [22, 51, 58], but quickly brought up the limited screen space on his mobile phone. Drawing from research on asymmetrical interactions in XR, future work might consider extending displays for in-person attendees by incorporating projectors [23], or audio or haptic cues that could replace visual ones that take up screen space [46]. Another solution is to enable users to experience each other's modalities early on [27]. While we showed participants what each view would look like in the onboarding, experiencing it themselves could have strengthened their understanding. Researchers might explore creating trial versions for remote testing and simulation of in-person participation to substitute the need to travel to the physical conference venue.

Finally, future research might consider leveraging a popular feature of social VR platforms: mirrors. In social VR, users gather around mirrors to establish self-awareness and embodiment in the virtual space as their avatar [21]. Virtual mirror objects in the hybrid space could similarly help both in-person and remote attendees understand what they look like in the shared space, while also giving them a chance to see themselves side-by-side as their avatars. A mirror that flips into a live view, as P1 recommended, could also be an interesting way to see each other's faces if desired. At the same time, mirrors can be distracting and negatively impact people's ability to converse [21]. Our participants valued the perception that they were conversing face-to-face (see Section 8.1.2), so mirror placement and usage may not be appropriate during conversational or collaborative tasks, and would need to be carefully introduced and integrated.

9.3 Hybrid Social Activities

Our findings show that designing for synchronous collaboration, such as in the Scavenger Hunt and Finale, helped participants feel as if they were in the same place at the same time despite being physically distant (see Section 8.1.2). We highlight several factors that contributed to this, which we recommend for future hybrid social settings. First, as suggested in prior work [36], providing structured, playful activities helped participants "break the ice" and approach people they did not know. The Scavenger Hunt was well-suited to deepening those connections, as people were able to spend time with each other working towards the same goal, while learning both together and about each other (see Section 8.1.3). Second, the Scavenger Hunt gave participants the opportunity to expand their perception of the hybrid space, where they were motivated to move around and explore. Finally, providing different abilities to match participants' different inputs was important for supporting coordination with each other (see Section 8.1.2).

At the same time, the hybrid space was relatively unused outside of the scheduled research sessions. Our findings suggest two reasons for this: 1) the lack of asynchronous activities, where participants sought opportunities for being in the same place at different times [26], and 2) the lack of people to interact with, or spontaneous opportunities to be in the same place at the same time, akin to hallway chats (see Section 8.2.3). In both cases, there was not enough value in the space for users to return outside of the structured activities. Asynchronous options are particularly important for remote attendees, as they need to manage different timezones from the in-person event and balance their attendance with their own in-person responsibilities [1]. While we included one social asynchronous experience, the Photo Wall, it had limited interactivity for remote attendees who could only view what in-person attendees added. Providing balanced roles for attendees might improve engagement, such as remote attendees being able to add their own virtual selfies (as in [36]) or leave recorded comments to start discussions around photos. Researchers might also consider asynchronous experiences beyond photos, such as virtual traces of activities that correspond to areas in the hybrid space (e.g., a 3D snapshot of avatars gathered in one of the conference rooms

engaged in discussion). Providing asynchronous activities may naturally build towards critical mass in the space, and therefore lead to spontaneous, synchronous interactions. Cues to let attendees know that others are present in the space and available to chat may further motivate them to join outside scheduled events. HyWay, for example, bridges awareness between in-person and remote attendees by showing nearby users in the shared space and enabling users to overhear their conversations, triggering spontaneous interaction [60].

Finally, the provided social activities should meet attendees' expectations and motivation to participate in a hybrid conference. All of our participants described meeting new people as their main goal for attending, and were happy to achieve that through the hybrid experience. Moreover, while in-person attendees were already meeting people through other conference activities, they were all excited meet, collaborate, and share experiences with a diverse set of people they otherwise would never have met. Thus, we recommend emphasizing the opportunities for people to diversify their networks, while sharing and reflecting on their experience, and learning with new people. These activities should be seamlessly integrated into the broader conference such that attendees do not feel as if they are "exiting" the conference for a different experience.

9.4 Lessons Learned for Future Hybrid Conferences

In this section, we highlight logistical recommendations for incorporating systems like SocialMiXR at hybrid conferences. We draw from our experience deploying SocialMiXR at a real-world, multi-day conference, and working closely with the conference organizers.

9.4.1 Scheduling Hybrid Experiences. Conference organizers should consider the order and timing in which to engage attendees in hybrid social experiences. In our case, Scavenger Hunts took place on each day of the conference, with the Finale on the final day. While attendees enjoyed running into prior Scavenger Hunt partners during the Finale, a few recommended providing a speed networking session before the Scavenger Hunts. Future conferences might schedule early sessions to help attendees "warm up" to each other and to interacting in a hybrid space, before diving into sessions with more involved tasks like the Scavenger Hunt. Additionally, holding longer, individual sessions for such tasks, e.g., 1-2 hours, with speed networking sections at the beginning and end, could mitigate fatigue that would arise from repeating the same task throughout the conference while providing time to meet several people. This longer session could still be scheduled each conference day for different groups of attendees. Alternatively, having a continuous experience that connects each session, such as subsequent sessions being the next "level" of the task, could be a fun way to engage the same attendees throughout the conference. For example, in the case of SocialMiXR, each Scavenger Hunt could increase in difficulty or introduce new mechanics, such as needing to search for answers to the questions that would pop the balloons, or having limited time/use of abilities (e.g., having the power to fly only for 30 seconds with a cooldown period).

Scheduling hybrid connection points throughout the conference is also important for attendees to flexibly participate based on their schedule for the rest of the conference. Due to scheduling constraints, we scheduled all of our sessions during the talk tracks. Therefore, participants could not attend talks that were scheduled at the same time. Conference organizers might instead integrate hybrid experiences into typical times for mingling, such as coffee breaks between talks, post-talks when attendees are lingering at the conference venue, or evening social events.

9.4.2 Scaling Up. As a first step in exploring hybrid social experiences, we limited study participation and focused primarily on one-to-one interactions in three social activities. To scale up to a whole conference, conference organizers need to provide a fuller conference experience for remote attendees, such that they have more opportunity to engage during the whole conference. This could

involve the addition of typical conference events in the virtual world, such as talks, panels, and expos/demos. Such events can be effective even if held fully remotely in 3D environments [1, 17], where organizers might use hybrid systems primarily for social networking activities. At the same time, researchers have also begun to consolidate best practices around the logistics and setup of these events for hybrid settings to improve their inclusiveness [31]. Further research could explore not only hybrid social interactions within these events, but also how attendees transition between hybrid and remote-only social interactions (and similarly, in-person-only to hybrid social interactions). Holistically providing virtual, hybrid, and in-person events could also promote more equal conference experiences. Awareness indicators for attendees' presence in the different spaces, as described in Section 9.3, could help with balancing attendees across platforms and reaching critical mass for socialization. Of course, supporting events on all platforms would require much upfront organization and preparation of content, volunteers, etc.

Future work might also consider systems that could support group interactions, and not just one-to-one. Prior work on telepresence robots has demonstrated teams' or research labs' interest in participating in conferences as a group (i.e., sitting next to each other to control a Beam) [40]. Further, satellite "unconferencing" events have emerged in recent years to support local gatherings in a more intimate networking setting [43]. Group interactions, where participants of different local satellite events can engage with each other, could help connect these events with the broader conference. Researchers might consider incorporating large displays to support hybrid groups, such that multiple attendees can be in view and interact at the same time.

10 Limitations

While our research demonstrates the potential for creating more connected hybrid social experiences, there are several limitations in our work. First, we designed a hybrid experience specific to a company's internal engineering conference, working closely with conference organizers to ensure it matched their overarching goals and was well-integrated with their conference tracks. While their goals generally aligned with that of most conferences, e.g., fostering collaboration and learning, future research might explore hybrid socialization in different sizes and formats of conferences, or similar types of events (e.g., workshops), and how to scale accordingly. In the same vein, given the exploratory nature of our work, our sample size was relatively small. The smaller size allowed us to easily obtain consent from each participant and ensure they were aware of how to participate, as well as provided more opportunities for participants to connect with each other within a smaller group. Future work would need to address how to scale hybrid experiences to all conference attendees, and how wider availability might affect attendees' interactions.

Additionally, for the purposes of our research, we focused on social networking for conference attendees. Though other common conference activities, such as watching talks or panels, were outside the scope of our work, they are an important aspect of conferences that could influence the way people interact. Thus, future work might consider how to further incorporate conference content into hybrid socialization activities. We also focused on social networking between early-career remote attendees and in-person attendees of various levels of seniority. Several remote participants mentioned that they enjoyed the opportunity to connect with senior colleagues who are otherwise difficult to meet. The conference organizers received similar feedback for early-career in-person attendees outside of our study. At the same time, future work should include attendees of diverse seniority levels for both remote and in-person options, in order to understand how the hybrid experience might change according to different backgrounds.

Finally, we deployed our prototype in a field study to explore hybrid social interactions in an actual conference setting, while allowing participants to use their own devices. While this setup achieves high ecological validity, it can be difficult to control. Indeed, a few participants did not

show up to all sessions, while some participants' devices faced audio connection issues during the social activities or issues connecting to the virtual world. Further, while all participants had some familiarity with immersive technologies through phone app filters or video games, they may have experienced novelty effects in using SocialMiXR in the context of a conference, given the short time frame of the experience. As a next step, future work should run more controlled studies on hybrid social experiences along with a larger number of participants over a longer study period to gauge impact on important outcomes such as social connection, presence, and engagement.

11 Conclusion

This paper presents a step towards addressing the inherent challenges of hybrid conference formats. SocialMiXR, a WebXR-based prototype, demonstrates the creation of a unified and interactive environment that integrates in-person and remote participants. Results from our three-day conference user study highlight the potential of the design of SocialMiXR to facilitate immersive engagement and meaningful connection between participants. However, challenges like the need for more dynamic interactions and accommodating diverse user experiences emerged, directing future research towards enhancing hybrid interaction platforms. Our findings contribute to the evolving understanding of hybrid conferencing, providing insights and practical solutions for these increasingly prevalent events. Ultimately, our research lays groundwork for further exploration in hybrid events, advocating for the effective use of XR technologies to foster more inclusive, engaging, and sustainable professional gatherings in a post-pandemic world.

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12 Disclaimer

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