Exploring Challenges of Hybrid Collaboration in Mixed Reality

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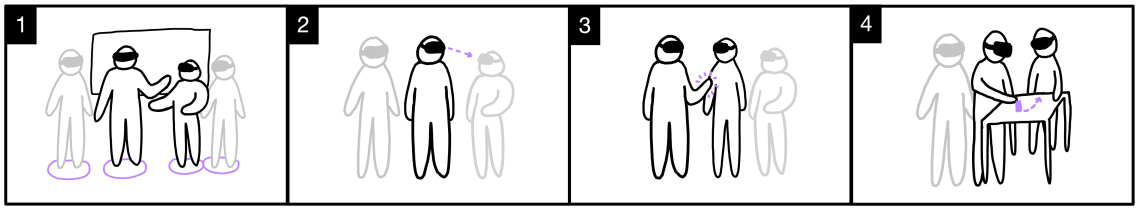

Fig. 1. We discuss key challenges in hybrid collaboration in MR. The hybrid setting engages multiple co-located users (black) and remote users (grey) in synchronous collaboration. (1) Spatial Congruency: Co-located and remote users experience different spatial configurations, which are unfeasible to merge with more than one remote participant. (2) Social Cues: Gaze and gestures may not be accurately conveyed between remote and co-located spaces. (3) Embodiment and Representation: Co-located users perceive each other physically, while remote users only have access to avatars and vice versa. (4) Tangible Interactions: Asymmetries in access to tangible interactions create asymmetries in control.

Mixed Reality (MR) is transforming remote collaboration by reintroducing spatial and embodied interactions that traditional video conferencing tools lack. While MR research has primarily focused on fully remote scenarios, real-world collaboration is increasingly hybrid, with some participants co-located and others remote. Hybrid meetings, however, often suffer from participation asymmetries, where remote attendees feel excluded while co-located participants dominate discussions. MR offers potential solutions, yet challenges remain in maintaining spatial congruency, balancing social dynamics, ensuring equitable embodiment, and facilitating tangible interactions across locations. In this position paper, we examine these asymmetries and explore how MR can create more inclusive hybrid collaboration environments.

CCS Concepts: • **Human-centered computing** → **Computer supported cooperative work**.

ACM Reference Format:
Juan Sánchez Esquivel and Julia Kleinau. 2025. Exploring Challenges of Hybrid Collaboration in Mixed Reality. In *Proceedings of CHI Conference on Human Factors in Computing Systems (CHI '25).* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 Introduction

As Mixed Reality (MR) becomes more prominent in the consumer electronics space, it is opening new possibilities for collaboration. Tasks that were once complex, such as 3D collaborative sketching or visualizing and manipulating 3D models, are now easily achievable [8, 15]. Early research on MR collaboration approaches, such as [1], create a sense of virtually "being there" together and enable deictic gestures with spatial referencing. One of the key advantages of MR collaboration is its ability to reintroduce physicality to remote interactions – supporting non-verbal cues, gesturing, pointing, turn-taking, and spatial formations, which are often lost in traditional online videoconferencing tools. This is

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Manuscript submitted to ACM

what I (JSE) focus on in my research on MR collaboration, investigating spatial alignment, shared interaction techniques, and co-presence in distributed MR environments. In my previous work, I explore how distributed collaborators can effectively work together on shared whiteboard tasks [7, 16].

Current MR collaboration research primarily focuses on fully remote scenarios, where all participants are distributed and interact through virtual environments. However, real-world collaboration is increasingly hybrid, with some participants sharing a physical space while others join remotely. Hybrid meetings have become common practice for knowledge workers [12–14], yet they often suffer from participation asymmetries. Remote attendees frequently feel isolated and excluded, while co-located participants dominate interactions [2, 3]. This imbalance creates significant challenges in ensuring equal visibility, participation and engagement.

Traditional hybrid meeting setups typically rely on fixed spatial configurations, constrained to meeting rooms equipped with videoconferencing technology [11]. These setups limit flexibility, reinforcing rigid structures that further disadvantage remote participants. In my (JK) research, I investigate asymmetries in hybrid meetings and how collaboration unfolds beyond traditional meeting rooms, such as in mobile and flexible settings [10]. My key focus lies in the role of multimodal feedback for mitigating participation inequalities and enhancing engagement in hybrid collaboration scenarios. Thus, thinking about flexible hybrid collaboration, MR presents an opportunity to break free from screen-based meeting structures, offering more immersive and fluid hybrid collaboration experiences.

Our interest in this topic stems from our respective research areas, which highlight key challenges in MR and hybrid collaboration. By bringing together our perspectives, we aim to contribute to the workshop's discussion on distributed MR collaboration, identifying both challenges and potential research directions of hybrid collaboration in MR. We believe that MR-based hybrid meetings hold promise for mitigating asymmetries of hybrid collaboration. However, substantial challenges remain, which we explore in the following, and hope to discuss in the workshop.

2 Asymmetries in MR Hybrid Meetings

As MR collaboration evolves, hybrid collaboration has emerged as a critical research challenge. Ens et al. [4] highlight hybrid collaboration as a central theme for future research in collaborative MR. They emphasize the challenge of taking advantage of the benefits of co-location while at the same time enabling effective presence of remote participants. Unlike traditional distributed MR setups, hybrid meetings introduce spatial, social, and interaction asymmetries that impact collaboration. While MR holds potential to enhance remote presence, current systems still struggle to provide equal participation, embodiment, and agency across hybrid settings.

Despite the promise of MR hybrid collaboration, it introduces new challenges that must be addressed. We discuss four key areas that are closely related to our previous research, and require further investigation: (1) Spatial Congruency – How can MR maintain coherence between virtual and physical spaces for both co-located and remote users? (2) Social and Group Dynamics – How do we prevent co-located subgroups from forming, ensuring equitable participation? (3) Embodiment and Representation – How should MR systems balance avatar-based and physical presence to maintain parity in interaction? (4) Tangible Interactions Across Locations – How can remote and co-located participants meaningfully engage with shared objects?

These challenges hinder the integration of MR technology into hybrid collaboration and must be addressed to pave the way for more inclusive and effective future MR collaboration setups.

2.1 Spatial Congruency

MR collaboration technologies can enhance spatial awareness for remote participants, allowing them to better perceive co-located interactions [6, 7]. Research has explored MR systems that acknowledge users' physical spaces and integrate them into the virtual environment [7, 9]. These approaches allow users to engage with their physical surroundings. However, in hybrid settings, co-located participants share one consistent space, while remote users operate in divergent physical environments. This raises fundamental challenges, as visualised in Figure 1(1). To maintain meaningful co-presence, avatars and spatial representations need to be positioned in a specific way, while considering what happens when co-located participants move and remote users remain fixed in virtual space. This results in the challenge of blending spaces when multiple remote users join a hybrid meeting.

2.2 Social and Nonverbal Cues

MR systems, besides approaching the challenge of bringing people together, should further aim to preserve and transform the nonverbal cues of users so these are not lost in the medium. A user looking or pointing at something should be perceived in the same way as all other participants, so that communication remains effective. In MR hybrid collaboration, challenges raise regarding the transmission of nonverbal cues, where representations are distinct between users, yet pointing or looking in a specific direction might carry important meaning for effective collaboration (see Figure 1(2)). When replicating real-world interactions to digital feedback, the question of scope of nonverbal cues arises; as it needs to be determined which cues should be translated to which extent.

2.3 Embodiment and Representation

In fully distributed MR collaboration, the virtual representation of meeting participants can provide equal embodiment, ensuring remote users are represented and integrate naturally into the space [8]. A key challenge in hybrid MR environments however, where both co-located and remote participants interact, is ensuring parity in representation. While co-located participants perceive each other visually, auditory and haptic through their physical presence, remote participants only have access to representations, and are displayed as avatars themselves (as visualized in Figure 1(3)). This potentially adds to the asymmetries already prominent in hybrid meeting settings. In prior work we explore how multimodal feedback mechanisms can enhance remote participants' sense of presence and engagement in flexible hybrid collaboration scenarios [10]. By integrating multimodal tools, hybrid MR systems could better bridge the sensory gap between co-located and remote users, fostering a more balanced interaction experience. This results in the discussion of how MR systems should balance avatar-based and physical presence to foster equality and inclusion among all participants. The choice of representation impacts engagement, social dynamics, and the ability to interpret non-verbal cues.

2.4 Tangible Interactions across Locations

By allowing users to engage with virtual and tangible objects in shared MR environments, dynamic interaction can be supported [5]. Yet, in hybrid settings, co-located participants may have multimodal access to physical objects that are integral to collaboration, while remote participants lack direct interaction with these shared artifacts (see Figure 1(4)). A key challenge is ensuring that both co-located and remote participants can interact meaningfully with shared objects, regardless of their physical presence. This is either achieved by having all participants interact with either fully virtual representations, or introducing physical synchronized artifacts to the remote space. This further creates obstacles

regarding synchronization – How can tangible interactions be synchronized across locations to maintain a coherent experience, preventing co-located participants from having an advantage in manipulation and control? Multimodal interactions, including multiple sensory modalities, such as haptic feedback, spatial audio, or visual augmentation can potentially play a role in enhancing remote users' perception and interaction with shared objects.

3 Opportunities

MR presents an opportunity to bridge the gap between remote and co-located collaboration by enabling dynamic, immersive interactions. However, as outlined in previous sections, hybrid MR meetings introduce unique asymmetries in spatial congruency, non-verbal communication, embodiment, and tangible interaction. To address these challenges, we propose an in-depth investigation of MR hybrid meetings that seeks to explore and analyze the complexities to develop a deeper understanding for MR hybrid collaboration. Future work should focus on:

- Investigating the role of multimodal feedback: How can haptic, auditory, or adaptive visual cues enhance the sense of presence and participation for remote users?
- Studying social dynamics in hybrid MR collaboration: How do hybrid MR settings influence group formation, participation equity, and nonverbal interactions compared to traditional hybrid meetings?
- Evaluating hybrid MR collaboration in different contexts: Most MR collaboration studies take place in controlled environments. How do these findings translate to real-world settings, such as mobile and flexible hybrid work scenarios?
- Designing for adaptive spatial configurations: How can MR systems dynamically adjust spatial representations based on user movement, group size, and task demands?

By pursuing these directions, we aim to contribute to a broader understanding of how hybrid MR meetings can be designed to support inclusive and effective hybrid collaboration.

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Received 14 March 2025; accepted 24 March 2025