Towards Immersive Mixed Reality Street Play

Understanding Collocated Bodily Play with See-through Head-Mounted Displays in Public Spaces

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Figure 1: A research-through-design game probe series, Multiplayer Omnipresent Fighting Arena (MOFA), for studying social implications of Immersive Mixed Reality Street Play in a potential MRHMD-dominated future. From left to right: gameplay screenshots from a third-person spectator view of our three MOFA game prototypes, showing *The Training* – Single-player play (1 player) occurring in the public park under the Brooklyn Bridge in DUMBO, Brooklyn; *The Duel* – Competitive play (2 players) occurring on the urban streets of SoHo, Manhattan; *The Dragon* – Puppeteering play (3 or more players) occurring in public atrium at the World Trade Center Transportation Hub of New York City.

ABSTRACT

We're witnessing an upcoming paradigm shift as Mixed Reality (MR) See-through Head-Mounted Displays (HMDs) become ubiquitous, with use shifting from controlled, private settings to spontaneous, public ones. While location-based pervasive mobile games like Pokémon GO have seen success, the embodied interaction of MRHMDs is moving us from phone-based screen-touching gameplay to MRHMD-enabled collocated bodily play. Major tech companies are continuously releasing visionary videos where urban streets transform into vast mixed reality playgrounds—imagine Harry Potter-style wizard duels on city streets. However, few researchers have explored the social implications of such Immersive Mixed Reality Street Play (IMRSP) in public spaces in an MRHMD-dominated future. Through empirical studies on a research-through-design game probe called Multiplayer Omnipresent Fighting Arena (MOFA), we gain initial understanding of this under-explored area by identifying the social implications, challenges, and opportunities of this new paradigm.

CCS CONCEPTS

• **Human-centered computing** → Interaction design theory, concepts and paradigms; **Mixed / augmented reality**; Collaborative and social computing systems and tools.

KEYWORDS

Social Augmented Reality, Social Implications, Collocated Mixed Reality, Bystander Inclusion, Social Acceptance, Game design, Urban Games, Pervasive Games, Collocated Bodily Play, See-through Head-mounted Display, Public Spaces, Spontaneous Encounters, Social Awkwardness, Safety Issues

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1 INTRODUCTION

Several big tech companies such as Apple and Meta now suggest that the evolution of Mixed Reality Head-Mounted Displays (MRHMDs) is poised to revolutionize personal computing and social interaction. For example, Meta[1] and Niantic[2] now envision a future where MRHMDs are replacing smartphones as a ubiquitous part of our mundane lives. The year 2024 has been pivotal in this trajectory in terms of advances in related technology, with Apple releasing the Vision Pro[3], a video see-through MRHMD in the form factor of a headset, and Meta introducing Orion[4], an optical see-through MRHMD in the form factor of eyeglasses. Meta Chief Mark Zuckerberg's bold claim that MRHMDs *"Smart Glasses Will Replace Phones By 2030"*[5] underscores the potential significance of this technological shift.

The advancement of MR see-through technology, both video and optical, has been crucial in expanding the potential applications of MRHMDs. As Itoh et al. [44] demonstrate, this technology allows wearers to perceive their surroundings and move freely, extending usage scenarios from private, controlled environments to public, ubiquitous, and spontaneous settings. This expansion raises important questions about how widespread MRHMD adoption might transform our interactions in public spaces. Some scholars even predict that AR could become indistinguishable from reality to some degree, further blurring the boundaries between what is real and what is augmented [50, 71, 81]. These predictions underscore the importance of understanding the dynamics and perceptions of users engaged with MRHMDs.

In the current augmented reality landscape, Pokémon GO stands as the most successful application, generating $6 billion over eight years [42]. While promotional videos depict a future where people engage in device-free bodily play on public streets, the game in today's market still primarily relies on traditional smartphone screen-touching interactions. Moreover, some scientific studies estimate that less than 10% of active Pokémon GO players use the game's AR features [50]. Despite this, Niantic, the company behind Pokémon GO, continues to release promotional videos [6] showcasing a future where people engage in MRHMD-based bodily play on public streets, interacting directly with nearby friends [7]. We term this vision "Immersive Mixed Reality Street Play" (IMRSP)—a form of collocated bodily play in public spaces using MRHMDs that primarily involves body movements as the main mode of interaction. Although the technology to implement such games exists, there's a significant research gap regarding empirical studies for MRHMD-based bodily play in the wild. Therefore, in this study, we explore the feasibility of this vision through the following research question (RQ):

> **(RQ)** *What are the social implications if immersive mixed reality street play becomes a prevalent form of play in public spaces in an future with ubiquitous mixed reality HMDs?*

To address this, we developed a research-through-design game probe called Multiplayer Omnipresent Fighting Arena (MOFA). MOFA is a series of multiplayer collocated bodily play experiences using MRHMDs, going beyond pervasive AR location-based, button-pressing mobile gaming. The probe comprises three research gameplay probes: The Training, The Duel, and The Dragon. We chose 'magic' as the theme for all three gameplays for two reasons: (1) it leverages popular culture references, making the rules and settings intuitively understandable for many, even when the behaviors might seem unusual, and (2) it allows for the exploration of various levels of social interaction, from single-player to multiplayer scenarios.

Our methodology involves in-the-wild research to capture participants' authentic reactions, following by desktop research of online reviews. We deployed MOFA in various street locations, inviting passersby to play the game. We recorded these sessions and conducted interviews with both players and people who happened to observe the play. We also posted the gameplay video for collecting feedback from online forum.

This study contributes to the CSCW community by examining how emerging MRHMD technologies might reshape social interactions and collaborative play in public spaces. By exploring IMRSP in-the-wild contexts, we can better anticipate and address the potential social and technological implications of widespread MRHMD adoption. Our findings inform future research directions and design considerations for MRHMD applications in public spaces. In summary, our key contributions are:

- An overview of dynamics and phenomena related to IMRSP.
- Insights into the benefits and obstacles of this new form of play.
- An open-source research game probe (MOFA) for further exploration.
- A future research agenda and design implications derived from this exploratory work.

2 RELATED WORK

2.1 Technology-mediated Street Play

Street play has long been an integral part of urban culture, transforming streets into dynamic spaces where social interactions, creativity, and spontaneity flourish [91]. Traditional street play, characterized by informal, unstructured activities like hopscotch, tag, or ball games [97], utilizes public spaces in ways that challenge the boundaries of social and spatial order within urban environments [88]. Streets become arenas for social interaction, where norms are negotiated and social bonds are strengthened [95]. The spontaneous nature of street play fosters inclusivity and accessibility, enabling people of various ages and backgrounds to participate and interact. Urban play [13], playable city [70], pervasive play [1], alternate

[1] https://about.meta.com/realitylabs/orion/, visited on October 25, 2024
[2] https://nianticlabs.com/news/real-world-metaverse, visited on October 25, 2024
[3] http://www.apple.com/newsroom/2023/06/introducing-apple-vision-pro/, visited on October 25, 2024
[4] https://about.fb.com/news/2024/09/introducing-orion-our-first-true-augmented-reality-glasses/, visited on October 25, 2024
[5] https://www.forbes.com/sites/davidbirch/2024/10/16/mark-zuckerberg-and-why-smart-glasses-will-replace-mobile-phones, visited on October 25, 2024
[6] For one such video, see "Lightship x Snapdragon Spaces | Niantic" https://www.youtube.com/watch?v=sDNjVxX0LrE, visited on October 25, 2024
[7] "Niantic | Meet You Out There" https://www.youtube.com/watch?v=HljcLVXAxAU, visited on October 25, 2024

reality games [49], and pervasive games [61] have all contributed to redefining human-city interactions [51].

Technological advances in network coverage, power consumption, and device miniaturization have paved the way for new forms of outdoor interactive computing [4]. These breakthroughs have spawned diverse deployments and studies of technology use in public spaces. Examples include large interactive displays [11, 74], mobile-based mixed reality [26], location-based gaming (such as "Can You See Me Now?" [6], geocaching [73], and Pokémon GO [75]), and human-robot interactions on streets [76]. These technological interventions have transformed street play, introducing innovative forms of engagement that blend physical and digital realms seamlessly [17].

The street is a site of socially organized human actions. Studies of behavior in public spaces often draw from Erving Goffman's work, which identifies social behaviors and the management of impressions in everyday interactions [30, 31]. Ethnomethodological and conversation analytic studies have examined public settings, emphasizing that social order is fragile and easily disrupted [57]. These studies highlight how individuals utilize subtle bodily cues in street interactions to approach others, regardless of familiarity [18]. Furthermore, visual information plays a crucial role in how people navigate the street, coordinating movements and avoiding collisions [37]. Together, these insights illustrate the delicate nature of social interactions in urban environments and the embodied practices that facilitate social order amidst potential disruptions.

Informed by such studies, HCI has developed conceptual frameworks for thinking about design for interactions in public, including research in the wild [12], performance-led research approaches [7], and design considerations of bystanders and spectators in public interactions [82, 96]. These methodologies have been instrumental in understanding and shaping user experiences in outdoor settings.

2.2 Technology-supported Collocated Bodily Play

In recent years, HCI research has undergone a "somatic turn" [53]. This shift places the human body at the center of interactive technology design, moving beyond traditional user-centered approaches [20] to focus on the body as the primary site of interaction and experience [39]. Merleau-Ponty argues that the human body is fundamental to perception and action [58], with proprioception and kinesthesia serving as core movement-related senses [102]. Homewood et al. [38] outline three evolving conceptions of the body in HCI: the individual body (embodied interaction), multiple bodies (plurality of experiences), and more-than-human bodies (entangled assemblages). These concepts, particularly entangled assemblages [27], intercorporeality [59], and post-phenomenology [94], provide theoretical frameworks for exploring technology-supported collocated bodily play.

The conceptual frameworks of proxemics [15] and f-formations [5] significantly inform the practical exploration of collocated bodily play. They offer insights into how spatial and social arrangements enhance interaction within shared physical spaces. These principles are instrumental in designing collocated bodily experiences that are socially engaging and spatially harmonious. Research on collocated bodily play in exertion games [47] further underscores the importance of multiplayer experiences and social interaction in enhancing game adherence and enjoyment. Collocated bodily play design is rooted in social bodily play [67, 68], encompassing three key areas: bodily play [43, 46, 55, 56, 63, 66], movement-based design [29, 34, 62, 92, 93], and social exertion games [25, 54, 65, 69, 87]. This body of work collectively emphasizes the integration of physical activity, social interaction, and immersive digital content in creating engaging and harmonious social play experiences.

Unlike traditional pervasive games that rely on screen interactions—such as location-based multiplayer experiences like Pokémon Go [2, 75, 78, 98] or collocated handheld AR games [99, 100]—MRHMD wearers naturally use their bodies as controllers. This shift from screen-touching to movement-based collocated bodily play represents a significant change in technology-mediated gameplay. It highlights the need for designs that foster social inter-bodily engagement [64]. However, few works currently explore collocated bodily play using MRHMDs [3, 28, 52], with even fewer focusing on public spaces.

2.3 MR Head-Mounted Displays in the Public

The focus of MR research has increasingly shifted from single-user experiences to multi-user collaborations, particularly within the CSCW community. Billinghurst coined the term "Collaborative Mixed Reality" to describe this emerging field [9]. Collaborative MR can be broadly categorized into remote collaboration and face-to-face collocated collaboration.

Remote collaboration has been extensively studied [83]. These studies have demonstrated MR's potential to bridge physical distances and enhance communication in distributed teams. On the other hand, face-to-face collocated collaboration in MR [10] has been explored in two main areas: interactions between MRHMD wearers [72] and collaborative work involving both handheld devices and MRHMDs [101]. The latter has particularly focused on bystander inclusion, addressing the challenge of integrating non-HMD users into MR experiences [19, 105]. Research on collocated collaboration between HMD wearers has investigated shared workspace designs, collaborative problem-solving, and social dynamics in MR environments [85].

While extensive research has been conducted on collocated MR interactions [8, 16, 23, 32, 36, 52, 60, 79, 86, 90, 103], these studies have primarily been conducted in controlled lab settings. Notably, games like HADO [3] and Spatial Ops [28] have introduced the concept of collocated bodily play into immersive MR environments. However, these games often require specific setups or pre-defined environments, limiting their ability to support spontaneous play in public settings without extensive pre-configuration. Consequently, there are only a few collocated MRHMD games available for in-the-wild experiences.

In recent years, MRHMDs with passthrough functionality [44] have made significant strides. These devices, including video or optical see-through technologies like Apple Vision Pro, Magic Leap, Microsoft HoloLens, and Meta Orion, allow users to view their physical surroundings while interacting with virtual elements [80]. This advancement has sparked a notable shift in MRHMD usage, transitioning from private, controlled settings to more public, spontaneous environments. The rise in MRHMD usage in public settings raises social concerns for both users and non-users. Katins et al. developed the Mixed Reality Concerns (MRC) Questionnaire to assess these issues [48], including new challenges related to trust, security, safety, and privacy. In socially interactive environments—such as parks or public cafes—MRHMD acceptance tends to decline significantly [84]. This decline stems from two main factors:

First, MRHMDs can create an *imbalanced power dynamic* favoring users over non-users, impacting social experiences, privacy, and safety [14]. Previous AR glasses, like Google Glass, faced criticism for prioritizing user capabilities without considering these impacts. The term "Glasshole" emerged to describe the perspective of bystanders observing unsocial behavior by Google Glass wearers [24].

Second, MRHMDs inherently support *embodied interactions* [35], including mid-air gestures and full-body movements. While these provide intuitive and immersive ways for users to manipulate virtual objects and navigate mixed environments, they also introduce unusual behaviors that fall outside social norms. This deviation can create social awkwardness, as these unscripted actions break established social conventions [77].

A significant gap exists in the literature concerning collocated bodily play with MRHMDs in public spaces. At present, there's no structured understanding or empirical studies of IMRSP.

2.4 Research Gap: Immersive Mixed Reality Street Play

Our literature review revealed extensive empirical research on the social implications of smartphone-based street play (e.g., Pokémon Go [2] and Geocaching [73]), MRHMD concerns in public spaces [48], and collocated HMD-based bodily play in lab settings [104]. However, the intersection of these areas—immersive collocated bodily play with MRHMDs in public spaces—remains largely unexplored, despite being a long-standing vision in tech companies' promotional videos. This underexploration can be attributed to three main reasons:

2.4.1 Inaccessibility of affordable MRHMDs. As of 2024, full-color video or optical see-through MRHMDs—such as Vision Pro, HoloLens, and Meta's Orion—remain prohibitively expensive, with prices starting at $3,500 per device. This high cost poses a significant barrier to collocated multiplayer play, which requires multiple MRHMDs. Consequently, research in this area is typically confined to controlled lab settings, limiting the exploration of in-the-wild applications.

2.4.2 Limited technology for spontaneous multiplayer mixed reality collocation. Multiplayer mixed reality collocation requires low-latency spatial pose transmission—less than 20ms per frame—to prevent noticeable lag [89]. This necessitates either deploying a WiFi router in the wild or utilizing low-latency cellular networks like 5G, which aren't ubiquitous. Furthermore, routing data through remote servers between players often results in latency that exceeds user tolerance thresholds.

2.4.3 Social acceptance barriers and lack of established social norms. The current form factor of MRHMDs is far from resembling everyday glasses. Additionally, interaction behaviors such as mid-air gestures and full-body movements lack established social norms for use in public settings. This absence of social norms leads to social awkwardness and acceptance issues. Furthermore, commercial companies have little immediate market incentive to research this area.

3 DESIGN OF MULTIPLAYER OMNIPRESENT FIGHTING ARENA

To explore the social implications of immersive mixed reality street play—as envisioned in big tech companies' promotional videos—we employed a research-through-design approach. We created a game probe series called "Multiplayer Omnipresent Fighting Arena" (MOFA) and deployed these games in real-world scenarios. Using an in-the-wild research method, we observed the reactions of both players and passersby in public spaces. To gain a broader perspective on user reactions, we also released video recordings of the street play online. We then conducted desktop research, gathering and analyzing online reviews and comments to assess the sentiments expressed.

3.1 Design Considerations

To design gameplay probes that can actually run in the wild with current technology, we considered the following design factors to ensure the experiment's viability:

3.1.1 Easy to understand and learn. The game probe should be easily understood by city dwellers on the streets. Inspired by the *Harry Potter* fantasy, particularly wizard dueling, we adopted a 'magic' theme for the gameplay. This aligns well with the characteristics of augmented reality media—unseen energy invisible to muggles, who are unaware of magic. This theme draws from popular culture that has been deeply rooted in global consciousness for over three decades. It makes the rules and settings intuitively understandable for many without explanation in "in-the-wild" settings. Even when behaviors might seem unusual in public, they're explainable and comprehensible because people have been familiarized through Harry Potter movies—they recognize these wand dueling interactions. Players can instantly immerse themselves in imaginative wizard and witch roles.

3.1.2 Physical Props for Social Affordance. All gameplay for MRHMD wearers in MOFA incorporates a physical prop: a wand. We discovered that the wand provides an intuitive affordance for players to understand the hand-waving gesture used to cast spells. This proves effective for three main reasons: (1) It aligns with the stereotypical image of wizardry popularized by the Harry Potter series, enabling people to easily grasp the interaction without tutorials; (2) The physical shape and weight of the wand facilitate a natural "wave down" gesture, which is more intuitive than any bare-handed gesture for casting spells (which typically require tutorials). With wands, the interaction becomes second nature; (3) The wands help passersby readily comprehend the context of the games, even without seeing the augmented reality imaging overlay. Addressing the social acceptance concerns in Section 2.4.3, the wand serves as a strong social affordance for both players and passersby in public spaces.

3.1.3 Collocated Bodily Play without Physical Contact. As envisioned in promotional videos, MRHMD wearers engage in embodied

Figure 2: Gameplay design. From left to right: "The Training", a single-player probe; "The Duel", a competitive gameplay probe; "The Dragon", a collaboration and puppeteering gameplay probe.

interactions involving full-body movements, transcending traditional screen-touching gameplay. MOFA exemplifies collocated bodily play with MRHMDs, showcasing interactions ranging from single-player to multiplayer scenarios. The game deliberately avoids physical contact for two key reasons: (1) many existing mixed reality systems can’t detect physical contact between players, making tangible interactions like melee attacks impractical in game design; (2) to prioritize player safety, we designed the game with remote attacks only, eliminating the risk of direct physical contact between players. MOFA strategically incorporates a magic shield in front of players to indicate an attacking target, which allows opponents to aim at the shield, providing a clear target without risking physical harm. Unlike traditional fighting games where avatars show damage through fainting, blood spatter, or falling, MOFA uses shield breaks to provide feedback when an opponent successfully hits the target. This design ensures both safety and clear gameplay feedback.

3.1.4 Spontaneous Collocation. MOFA is designed for deployment anywhere, transforming any street into a game arena—hence its name, "omnipresent." It operates without Wi-Fi or cellular connections. Mixed reality collocation requires low-latency spatial pose transmission (under 20ms per frame) to prevent noticeable lag, necessitating a local server. To address the research gap in spontaneous collocation technology outlined in Section 2.4.2, we employed an open-source collocated network toolkit [40]. This toolkit utilizes MultipeerConnectivity[8]—the technology powering Apple’s AirDrop—to enable local networking. This innovation allows street play to begin anywhere, even in rural areas lacking cellular signals or Wi-Fi access. The technology also features a rapid QR scanning process for synchronizing coordinates across devices, eliminating the need to pre-scan the physical environment and enabling spontaneous player or spectator participation.

3.2 Gameplay Overview

MOFA includes three collocated bodily gameplay probes (see Fig. 2):

3.2.1 "The Training" - a single-player gameplay probe. "The Training" is a single-player dueling gameplay where players engage in magical battles with an AI-controlled cartoon character (see Fig. 2a). Inspired by Harry Potter’s training scenes[9], players take on the role of wizards, honing their wand skills to cast spells and attack virtual ghosts in Hogwarts. This game probe focuses on one spell-casting interaction: detecting "waving down" hand gestures with physical wands. It simulates single-player MRHMD gameplay in public spaces.

3.2.2 "The Duel" - a competitive gameplay probe. "The Duel" is a competitive gameplay mode pitting two players against each other in magical combat. It expands on "The Training" mechanics (see Fig. 2b), transitioning from player-versus-AI to player-versus-player. Drawing inspiration from Harry Potter’s classic Wizard Dueling[10], players use wands to cast spells and fight each other, incorporating dodgeball-like body movements to avoid attacks. This simulates future scenarios where MRHMD users might encounter each other on the street for impromptu duels.

3.2.3 "The Dragon" - a collaboration and puppeteering gameplay probe. "The Dragon," designed for three or more players and extending from "The Duel," introduces a new interaction paradigm (see Fig. 2c): puppeteering. In this mode, one handheld AR player—dubbed the "puppeteer"—controls a virtual dragon using their mobile phone, interacting with MRHMD users. Meanwhile, players equipped with MRHMDs become dragon-hunting warriors, casting spells to battle the dragon while using body movements to avoid attacks. This gameplay is inspired by Game of Thrones’ famous Dragon Hunting scenes[11]. It simulates a transitional future where MRHMD users coexist with handheld AR users, allowing for collaborative play between different device types when encountering each other on the street.

[8]https://developer.apple.com/documentation/multipeerconnectivity, visited on October 25, 2024

[9]https://harrypotter.fandom.com/wiki/Cast-a-Spell_training_room, visited on October 25, 2024

[10]https://harrypotter.fandom.com/wiki/Duelling, visited on October 25, 2024

[11]https://game-of-thrones-winter-is-coming-game.fandom.com/wiki/Dragon_Hunt, visited on October 25, 2024

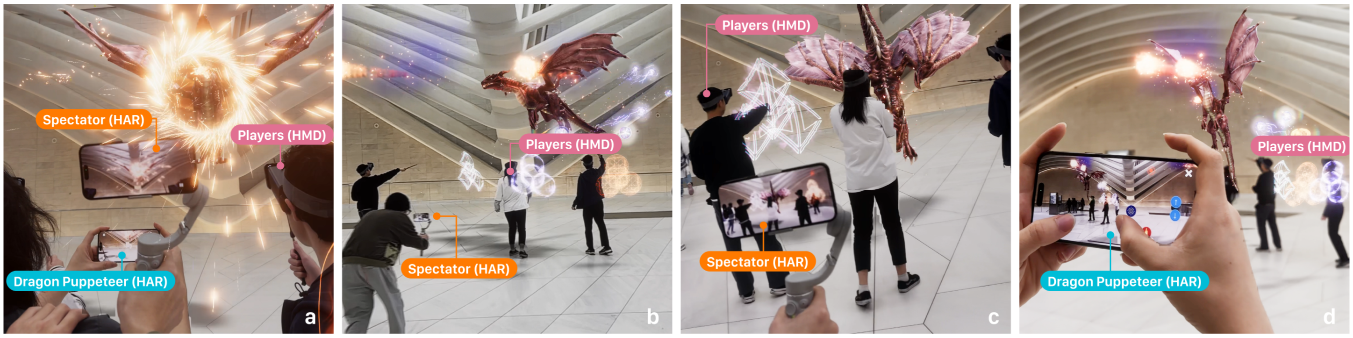

Figure 3: Tech demonstration of the in-the-wild study process. For example, in the game "The Dragon," a spectator view from a handheld AR device mounted on a camera stabilizer records all gameplay video from a third-person perspective, capturing both AR content and environmental audio. (a) One player takes the puppeteering role and uses a handheld AR device to control the dragon; (b) Other players fight against the dragon with HMD in immersive mixed reality, with spectators on the side; (c) A close-up shot of the spectator view; (d) A close-up shot of the puppeteering device, on which the player controls the dragon's movements through on-screen interactions. This device also serves as a spectator view for passersby.

3.3 System Implementation

To address the inaccessibility of expensive MRHMDs described in Section 2.4.1, we use HoloKit[12], an affordable ($129) smartphone-based open-source stereoscopic optical see-through mixed reality headset. This cost-effective solution enables multiplayer mixed reality experiences "in the wild," allowing a large number of passersby to try the gameplay.

We implemented the game probes using Unity (version 2022.3 LTS)[13] and the HoloKit SDK[14] based on ARKit[15]. We deployed the game as an iOS application on iPhone 12 or later models, which are inserted into the HoloKit. The headset displays stereoscopic renderings on the iPhone's screen, allowing users to see stereoscopic 3D images overlaid on reality when viewed through HoloKit.

We achieved interactions with augmented content through an Apple Watch. The watch's motion sensors capture wrist movements for spell casting, enabling remote attacking gameplay without physical contact between players. This approach cleverly sidesteps the physical contact issue by allowing players to cast magic spells for intangible interaction with opponents. MOFA's system features various spell classes, each with a basic attack spell and a utility spell. Players select one magic class per game round. While basic attack spells have minor variations in speed and size, utility spells differ significantly, adding depth to the gameplay.

We interconnect all collocated devices using the InstantCopresence toolkit [40]. This toolkit establishes spontaneous collocated mixed reality sessions for all players through QR code scanning of the host device. The network transmission of this toolkit wraps around MultipeerConnectivity—the technology powering Apple's AirDrop—to enable local low-latency networking. This innovation allows street play to begin anywhere, even in rural areas without cellular signals or Wi-Fi access. We've also implemented an auto-synchronization system for virtual objects. This system consistently syncs virtual object data across devices, ensuring all participants see the same virtual elements. Spectators can use mobile devices (like iPads) to view augmented content from a third-person perspective (see Fig. 3).

[12]https://holokit.io/products/holokit-x, visited on October 25, 2024
[13]https://unity.com/releases/2022-lts, visited on October 25, 2024
[14]https://github.com/holokit/holokit-unity-sdk, visited on October 25, 2024
[15]https://developer.apple.com/augmented-reality/arkit/, visited on October 25, 2024

4 METHOD

To comprehensively investigate the dynamics and societal acceptance of immersive mixed reality street play, we employed a mixed-methods approach. We collected data through onsite behavioral observations and interviews using the "research in-the-wild" method [7], and supplemented this with online reviews using desktop research techniques.

4.1 In-the-wild Observations and Interviews

During the past three years, the MOFA game probe has been demonstrated and played in pop-up shows by hundreds of users across 20 locations in North America, Asia, Europe, and Oceania. We conducted field studies where participants engaged with the game in real-world settings. Given the in-the-wild nature of the study, participants' play time and their degree of involvement varied. In this section, we detail five scenarios where participants volunteered for interviews, along with the observations and video recordings of player and spectator behaviors in those play sessions. The five scenarios include campuses, expos, urban parks, public buildings, and natural wildness (see Fig. 4).

4.1.1 Procedure. In each of these pop-up shows, two researchers initially conducted the game in a space of at least 3x3 meters in a public space, ensuring minimal disruption to pedestrian flow. Upon attracting passersby who stopped and started to observe, researchers offered them opportunities to try the game. Interested participants then consent to participate in the game and the data collection before using the headsets. Participants could play for their desired duration, typically completing two rounds, with the first round serving as a tutorial. During the game, researchers observed player behaviors and the sessions were video recorded. Where time and availability of the participants allowed, researchers invited them to join a semi-structured interview guided by the following

Figure 4: Five scenarios of volunteered participation and interviews. S1: campus; S2: expos; S3: urban parks; S4: public buildings; S5: natural wildness.

questions: The interviews were conducted either individually or in small groups of 2-3 players who had participated together. On average, each participant played the game for 4.08 minutes, and the interview lasted for 2.75 minutes.

4.1.2 Data Collection. For the in-the-wild observations and interviews, the following data were collected. *(1) Video recordings of spectator views.* For each session, a researcher holds an iPad with a spectator view, which shows the third-person perspective of player behaviors with augmented views of game content (see Fig. 3). In total, we collected 265 minutes of recordings of players' behavior data. *(2) Interview recordings with players and spectators.* We collected a total number of 88 minutes of video recording for the interview section.

4.1.3 Participants. Thirty-two players (P1-P32) volunteered to participate in the interview after their games. Along with this, 34 other players (P33-P65) were involved in the gameplay sessions but did not participate in the interviews, leading to a total number of 65 players contributing to the user behavior dataset (see Table 2). The video recordings showed a balanced gender distribution and a wide coverage of age groups and ethnicity. The campus scenarios predominantly involved undergraduate students, and most participants at the expo came from a tech-industry background. Participants from public spaces such as urban parks and public buildings had various backgrounds.

4.2 Desktop Research of Online Reviews

To understand broader societal perceptions, we analyzed online discussions featuring, referencing, or discussing our game. This approach provided perspectives from indirect observers. The analysis of online reviews helped us assess public receptivity, concerns, and attitudes towards Immersive Mixed Reality Street Play.

Online reviews were collected from discussion threads on a tech-enthusiast forum, totaling 14,919 words of comments. Game video links were provided in the initial post, ensuring all reviewers had seen the gameplay. After an initial review, 1,325 words of comments and discussions directly related to our game probes and research questions, focusing on social implications. We excluded discussions that are unrelated to mixed reality street play, such as general technology and economic topics. The relevant reviews ranged from 5 to 204 words in length and came from 31 unique users, labeled as L1-L31 (see Table 1).

These online comments, unaffected by the researchers' presence or developers' interactions, offered unfiltered and naturalistic perspectives on the game and provided an additional layer of authentic feedback. The inclusion of online reviews complemented our research objective of understanding the holistic impact and acceptance of this novel gameplay format, incorporating both direct participant experiences and broader audience perspectives.

Table 1: Data collection for understanding player attitude, including onsite interviews ($N = 32$) and online reviews ($N = 31$).

Source	Participant ID	Number	Interview Recording Length / Text Length
In-the-wild Interviews			
S1. Campus	P1-P12	12	59 minutes
S2. Expo	P13-P21	9	7 minutes
S3. Urban Parks	P22-P25	4	8 minutes
S4. Public Buildings	P26-P29	4	6 minutes
S5. Natural wildness	P30-P32	3	8 minutes
(Subtotal)		(32)	(88 minutes)
Desktop Research of Online Reviews			
Tech-enthusiast forum	L1-L31	31	1325 words of reviews
Total		**63**	**88 minutes videos; 1325 words**

Table 2: Data collection for understanding player behaviors ($N = 65$).

Source	Participant ID	Number	Recording Length
In-the-wild Observations			
S1. Campus	P1-P12	12	43 minutes
	/	0	
S2. Expo	P13-P21	9	132 minutes
	P33-P48*	16	
S3. Urban Parks	P22-P25	4	30 minutes
	P49-P55*	7	
S4. Public Buildings	P26-P29	4	44 minutes
	P56-P65*	10	
S5. Natural Wildness	P30-P32	3	16 minutes
	/	0	
Total		**65**	**265 minutes**

**Participants who played the game but did not participate in the interview.*

4.3 Data Analysis

We conducted content analysis on the collected data. The video recordings were transcribed into texts for coding. We adopted an emergent coding technique, where we identify themes and patterns that arise naturally from the data rather than imposing predetermined codes. To begin with, three researchers familiarized themselves with the transcribed interview data and video recordings to gain a deep understanding of its content. Following this, one researcher completed the open coding on the data and the other two researchers reviewed the coded results, suggested edits, and reached an agreement on the coding results. Once initial codes were established, similar codes were grouped into broader themes. The researchers worked together to develop the themes and iteratively refined them to ensure that the themes accurately represent the core findings of the study. The themes were then validated by another researcher who was not involved in the coding process, cross-checking the themes against the data. All researchers agreed on the coding results and interpreted the findings based on the analysis, taking into account the occurrences of codes and themes as well as the contexts of the coded data. The results showed 121 unique codes that were organized into 4 themes: (1) social interactions, (2) social concerns, (3) gameplay experience, and (4) environment and location.

5 FINDINGS

In this section, we structure our findings around the four key themes that emerged from a comprehensive analysis of onsite interview transcripts, video recordings of user behaviors, and online review comments. These themes serve as the foundational framework for our discussion. To provide a more comprehensive and nuanced understanding, we integrate these thematic insights with additional data sources, including detailed behavior codings. In the following, the "(x/y)" notation indicates that x out of y total persons exhibited a specific behavior coding.

5.1 Social Interactions

5.1.1 Collaboration and competition (31/65, behavior). Mixed reality street play facilitates the establishment of social connections and fosters a positive community atmosphere through competition and collaboration. Street games enable direct, in-person interactions, allowing players to engage with one another in real-time.

Participants exhibited collaboration and competition activities in the game, both of which strengthened the bonds between players. Behaviors included teaching and explaining gameplay to other players, collaborating and encouraging teammates with words like *"come on"* and *"one more shot"*, warning teammates of the dragon's movements with *watch out*, celebrating after completing the game with phrases like *"Yes we did it!"*, congratulating and celebrating by *double high-fiving* or *bumping hands*, and claiming competition with words like *"I will beat you!"*.

In interviews and reviews, people expressed favor for multiplayer games, as competition and collaboration strengthen ties among players. Participants emphasized the excitement and competitive nature of multiplayer games, with one stating, *"If there are many people, and there is a certain sense of excitement and competition"* (P4). Further comments indicate people purely enjoy the time playing together with friends and family. Other mentioned *"Anyway, it's more interesting to have a relationship with many people* (P27), and "Probably the interesting part is not magic, but the person on the opposite side" (P10).

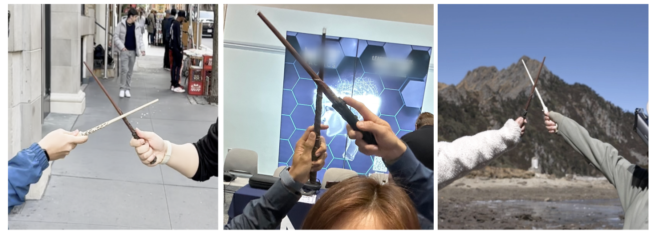

Figure 5: Clicking the wands before or after the play becomes popular among participants.

Figure 6: (a) Passersby being attracted by players' body movements, and then (b) approached the spectator view and took pictures.

5.1.2 Showmanship (25/65, behavior). The observable nature of the MR street play encourages showmanship among participants. The high-tech game provides adults with a unique opportunity to engage in non-daily behaviors in a public space, drawing attention from the audience and fostering a sense of excitement.

In many observable activities, the presence of the audience and the overall excitement of the experience can inspire participants to incorporate dramatic body movements and posts into their performance. This may not necessarily enhance their chances of winning but rather serve to entertain themselves and the audience and add to the overall spectacle. Some examples of these showmanship elements include:

- Jumping (3/65)
- Squatting while moving (3/65)
- Turning their back to the opponent (4/65)
- Spinning (2/65)
- Clicking the wands with teammates or opponents (13/65)

One particularly notable example is clicking wands together before the match. As this moment was captured in the tutorial video, this action quickly became a ritual for the game, with many players repeating the wand-clicking gesture before and after the game for photos or as a display of friendliness (P1-2, P11-12, P15-16, P30-32, P50-53) (see Fig. 5).

In some instances, the mere act of wearing the headset and wielding the wands was enough to inspire participants to engage in role-play and dramatic body movements, even before the researchers had officially started the MR session (P13, P14, P15, P59).

5.1.3 Spectating and self-recruiting (41/65, behavior). When played in public spaces, MR street play invokes the interest of passersby. MR street play is fully observable to the public, and passersby can show strong interest in the game.

People may stop to spectate for various reasons, including being attracted by the player's body movements, the spectators' view, or being attracted by other observing people (see Fig. 6). Observed behaviors include taking photos or videos of real people (12/65), taking photos or videos with the screen of the spectator view (7/65), cheering (25/65), sharing photos and videos with others or on social media (7/65), engaging in conversation with other spectators (34/65), and volunteering for the next game session (41/65).

Reviews highlight the importance of the spectator mode, with one reviewer noting, *"Spectator mode was also an incredible idea"* (L14). Participants also expressed increased curiosity and desire to join the game after seeing the spectator view, with comments like *"After I see the spectator view...I really want to join"* (P10) and *"This is sick I want to play too"* (P31).

The spectator view also adds a social and fun element to the game, as one participant mentioned, *"If they have the spectator view, the bystanders can also comment on the game when the two of us are dueling, this is more fun"* (P3). However, not having access to the MR view can be detrimental to the experience, *"If he can't see MR at all, he's actually an obstacle in my game for me"* (P9).

5.1.4 Joining Game with Hand-Held Device (8/65, behavior). The controller role on hand-held devices turns out to be more popular than the HMD player roles, despite many participants not having tried the game in HMD before. When the researchers showcased the dragon hunting game, all players and spectators eagerly volunteered to be the dragon controller, even if they had never used the HMD or played the wizard duel game yet. One participant stated *"Being the boss behind the scenes sounds totally sick"* and *"I wanna blast my friends with some fire!"* (P32). Another shared their surprise at the addition of the controller role, stating, *"Fight the Dragon gave me a new AR experience, because I used to think only of two-player battles, and I didn't expect that there would be a third machine to control the character"* (P18).

5.1.5 Appreciation of AR over VR (8/63). People expressed a strong preference for augmented reality (AR) experiences over virtual reality (VR) when engaging with the MR street play MOFA, both on-site and online. The ability to interact with friends and other facilities in the real world, rather than fully immersing in a virtual environment, was a key factor in their enjoyment and interest in the game. As one participant stated, *"I am way more interested in a digital world being overlaid on the real world - augmenting rather than escaping"* (L22). Other participants highlighted the limitations of VR, mentioning, *"You can't even pick up a beer while playing VR"*; *"You can't see around you in Quest unless you tap on the side to see it to the past as through me personally, I like to be immersed in the game while also being able to see what's around"* (P19).

5.2 Social Concerns

5.2.1 Social awkwardness and perceived impropriety (13/63). 13 reviewers, all from the online data collection, expressed feelings of awkwardness as their main impression of the game, with some feeling offended by the prospect of engaging in immersive MR street play. The reviewers questioned the social acceptance level of wearing the device in public, particularly regarding the potential impact on non-participants:

> *"I'm not sure if I'd like to walk around the streets wearing them though - would be incredibly annoying to other people."* (L1)
>
> *"Disregard for culture and obvious social media reactions."* (L19)

One reviewer expressed empathy for passersby who might be unintentionally captured in the middle of others' game space, noting that they *"don't look too pleased"* (L26). The impropriety of engaging the game in certain contexts was also highlighted, with one reviewer commenting, *"It seems pretty impolite to be LARPing in a busy train station"* (L10).

The rest comments expressed more straight-forward emotions towards this phenomenon as *"playing complete idiots in public places"* (L2), or *"dork"* or *"dorky"* to using HMD on streets (4/63), and refer the MR street players as *"being a nuisance to everyone"* (L27).

The aesthetics and form factor of the MR devices were also a point of concern, with one reviewer comparing the experience to strapping *"a heavy awkward thing to the front of my face"* (L5).

These responses reflect explicit social disapproval of public immersive MR games. It underscores the challenges of overcoming social awkwardness and perceived impropriety. Addressing these concerns will be crucial in fostering widespread adoption and acceptance of this emerging form of entertainment in public spaces.

Regarding the on-site participants, only 1 participant showed slight hesitation and discomfort when first introduced to the headset in public, who later accepted it and tried the game (P20). Other on-site participants didn't express feelings of awkwardness or initiate this topic in interviews until the researchers asked about their feelings of social awkwardness in the interview.

5.2.2 Establishing social norms. While some users expressed concerns about the social awkwardness and perceived impropriety of using MR technology in public spaces, others held a more optimistic view. They believed that the adoption of new technologies has historically led to changes in social norms, and MR street play is likely to follow a similar path (7/63).

Several users drew comparisons to the normalization of other technologies and behaviors that were once considered socially unacceptable or embarrassing. One participant noted that talking with headphones is now socially acceptable, despite the initial awkwardness of *"talking to the air"* (P20). Another user pointed out that glasses, umbrellas, and bikes were all "embarrassing at first until it becomes normalized" (L23). Some participants expressed confidence that technological evolution would lead to reduced headset sizes, drawing parallels to the historical miniaturization of mobile phones from their initial *"brick-like"* dimensions to current compact forms that have gained widespread social acceptance (L22).

The widespread adoption of Pokémon Go was also cited as an example of how a seemingly *"dorky"* behavior can become socially acceptable when enough people engage in it. Users agreed that people would wear headsets outside if the experience is compelling enough, just as there was *"a plague of arms-length phone-holders in every park for a year"* during the height of Pokémon Go's popularity (L25). The social acceptability of the behavior was further reinforced when enjoyed in the company of others, as one user noted, *"If you and a friend are doing this together, you're no longer a dork"* (L31). These comments suggest that there are people believing that as

MR technology becomes more compelling and widely adopted, the social norms surrounding its use in public spaces are likely to evolve.

However, some others pointed out that the social norm surrounding MR technology in public settings has yet to be established (4/63). One user highlighted the difference between the social acceptability of looking at a phone and engaging in MR street play, stating, *"Waving a stick around and shouting fireball while wearing a goofy headset is, at present, still unacceptable"* (L8). Others suggested that the widespread adoption would require the integration of a popular AR game like Pokémon GO (L11).

The form factor of the device was identified as a crucial factor in determining the social acceptability of MR street play. As one user pointed out, *"This is not the form factor that will change the paradigm. The smartphone was...Whoever gets the AR glasses that look like glasses out first wins the game"* (L14). Another user doubted the establishment of a new social norm surrounding MR in the reply as *"This will only happen if the devices start to become indistinguishable from a normal pair of glasses"* (L12).

5.2.3 Gradients of Social Awkwardness.

Our findings revealed a clear hierarchy in social acceptance levels, where multiplayer scenarios demonstrated lower levels of social awkwardness compared to single-player experiences. Furthermore, active players consistently reported less social discomfort than bystanders.

First, players in multiplayer games are less likely to feel awkward compared to single-player experiences. They feel more comfortable when the MR world is shared with another person, knowing they are not alone in MR while being observable to passersby. From the passersby's perspective, watching the players' interactive body movements gives them hints about the content of the MR game. An online reviewer commented, *"If you and a friend are doing this together, you're no longer a dork. You're going your own way"* (L31). When questioned about awkward levels in public settings, all onsite participants reported lower awkward feelings during paired games than single-player games. *"2 people playing the game out there is fully acceptable"* (P1-12). One of them stated,

> *"It's no longer embarrassing if it takes two doing embarrassing things together."* (P12)

Secondly, participants are also less likely to feel embarrassed than spectators or passersby. When participants recalled their feelings before they tried the game, they described as bystanders they would feel confused and anxious as not knowing what was actually happening in the MR experience. In contrast, after the game, even if playing in single-player mode and behaving abnormally, many claimed they did not feel embarrassed but were eager to explain the content and gameplay to others. As one participant put it, *"It's not embarrassing to play, once you start it's someone else's concern to be embarrassed"* (P6).

However, opinions vary on whether playing with strangers is more awkward than playing alone in public spaces. The spectator view can help alleviate awkwardness but does not fully change people's willingness. More introverted individuals tend to stick to close friends, while some extroverted people prefer playing with others over playing alone in public.

5.2.4 Safety and security concern (7/63).

Many people also expressed practical concerns about the potential safety issues that immersive MR street play can result in. There is a common concern about tread accidents due to the players being too immersed in the MR game and ignoring the context in reality (5/63). One person commented online about the MOFA videos: *"I do worry that one of my kids is going to get trampled by an adult who can't see because he's too busy slaying a dragon."* (15)

The other major concern is about the HMD device being stolen (2/63). People worried that putting an iPhone in the headset would bring a *"significant risk of phone theft in major cities"* (L25).

5.2.5 Divergence of Online and Onsite Review.

The rate of negative reviews online is considerably greater than that of onsite reviews. Online reviews demonstrate a notable imbalance, with a positive-to-negative feedback ratio of 19:20, with some posting both interests and concerns. In contrast, on-site feedbacks reflect a much higher ratio of 70:12 in favor of positive comments.

Moreover, the content of negative feedback also differs in the 2 data collections. On-site negative comments are often about specific technical limitations, including the field of view limitations and anchoring issues (10/32), as described in the Gameplay Experience section. These critiques are typically framed in a manner that suggests a desire for improvement, with a more subdued and neutral tone. Most on-site participants (31/32) didn't express concerns about social acceptance until the researchers prompted them on this topic.

In contrast, online feedback is significantly more critical and confrontational. Online reviewers frequently raise pointed questions challenging the social acceptance of the game (13/31), potential safety risks associated with gameplay (3/31), MR headset form factors (3/31), and even the overall entertainment value of the content (2/31).

5.3 Gameplay Experience

Onsite participants unanimously liked the game experience, which was described as *"fun"*, *"amazing"*, *"incredible"*, and *"magical"* (31/63). They particularly liked that the game was intuitive to understand and operate and that they could play and communicate with other players. However, some players also expressed frustration due to technological limitations.

5.3.1 Fantasy world overlaid on the real world (23/63).

Participants onsite think this MR street play provided them with a unique opportunity to immerse themselves in a magical fantasy world that seemingly came to life in reality. Players expressed a strong sense of being transported into the realm of their dreams and fantasies, where they could embody the roles of powerful wizards and engage in long-awaited duels. One player exclaimed, *"I have been waiting for this duel all my life!"* (P13) Another participant expressed her excitement:

> *"You have fulfilled my wildest fantasies. This is why I'm here."* (P14)

The game evokes a strong emotional connection to fantasy lovers and their childhood dreams. A participant commented: *"I feel like a wizard. I think my letter from Hogwarts is finally gonna come in the mail after all these years."* (P25) Referencing the Harry Potter series, their words showcased how this game tapped into the collective imagination and allowed players to embody the roles of their favorite fictional characters. These reviews show that the seamless integration of immersive MR technology and fun gameplay contributed to a deep sense of immersion, making the fantasy feel tangible and real for the players.

5.3.2 Wand as a meditator for intuitive interaction and narrative immersion (33/65, behavior). Onsite participants praised the intuitive and smooth interaction facilitated by the combination of the wand and Apple Watch in this game. Unlike traditional handheld controllers, this design allowed for natural and immersive casting of spells in the real world. Participants quickly grasped the gameplay mechanics. In the on-site study, 24/65 participants were observed to immediately understand how to cast spells after the game started, either by listening to oral instructions or observing other players. Another 31/65 participants learned the mechanics within 30 seconds with guidance from organizers and fellow or previous players. As one remarked, *"It's so easy to use (the wand) too, very comfortable and functional"* (P15). Another participant noted, *"The strange rhythm of beating is actually quite strong"* (P6).

The wand also served as a crucial element in the narrative design, providing a compelling explanation for the asymmetrical perspectives between players and passersby. By assuming the role of wizards and perceiving passersby as Muggles, players could engage in the MR experience smoothly. The physical presence of the wand helped bystanders understand the ongoing MR experience, even without an MR view. *"It's just making so much sense when you see people waving a wand. Much better than randomly stubbing your hands."* (P4)

The significance of the wand was further highlighted during a demo where it was taken away from a player's hand in the later stage of the game. The player immediately struggled to perform as she had been doing just 5 seconds earlier, expressing her confusion and requesting the wand back:

> *"Now I forgot how to move… Can you give me back the wand?"* (P8).

This incident demonstrated how the presence of a prop can support players' understanding and engagement, and maintain the narrative immersion.

5.3.3 Exercise and work-out (14/63). The game led to a notable increase in physical activity and exercise among players. Many participants (26/65, behavior) were observed breathing heavily after playing, indicating significant physical exertion. The level of physical activity varied depending on the game mode, with the single-player game resulting with minimal movement, the duel game encouraging more movement and dodging with the opponent, and the dragon game resulting in the most physical activity, with players running to chase the dragon or avoid fireball attacks.

Participants appreciated the physical demands of the game, with some expressing surprise at the level of exertion required (*"This is such a workout!"*) (P16,17). Another compared it to playing a *"fierce badminton game"* (P9), suggesting that MOFA could serve as an engaging alternative to traditional forms of exercise. The physical nature of the gameplay was also seen as a distinguishing factor compared to traditional PC games, as noted: *"The main difference from PC games is its physical exertion."* (P7)

5.3.4 Frustration caused by technological inadequacies (12/63). Despite the overall positive gameplay experience, some participants expressed dissatisfaction with certain technological aspects of the MR street play MOFA. One of the main concerns was the form factor and weight of the devices used. One commented, *"This is not the form factor that will change the paradigm (for MR)"* (L2). Another person who is interested in the game expresses concern about the device *"But iPhones are really heavy"* (L29).

Participants also complained about the lack of body movement input and prompt feedback. *"It didn't look like I sent it out with my own hands. the angle of my hand, the angle of my body, and the angle of my head will not affect the result"* (P7). Similarly, another participant stated, *"I have no way of judging how precise I am going to be, it's hard to go"* (P8).

Another issue raised was the precision of the anchoring system. *"Sometimes the shield is here and there"* (P3). Some other participants found the connecting technology and user flow to be cumbersome. *"I think the connecting could be a bit easier"* (P18).

In terms of MR imaging, the transparency of the optical see-through AR became a point of criticism, with one participant stating, *"It (AR part) is a little too transparent."* (P26, P27). The limited field of view was also a concern, *"It can only show a part of the dragon, and I feel that it's trapped in the screen"* (P11).

5.4 Environment and Location

The environment provides context for gameplay, influencing the gameplay excitement, actual play movement, and social acceptance extent.

5.4.1 Landscape acts as a vital backdrop. The surrounding environment setting can be seen as the backdrop of the game map and plays a crucial role in players' emotional envokes. A proper backdrop of landscape allows players to fully engage with the game's mission and narrative in a meaningful way. Environments that fit the game content can enhance the game experience. In S5, researchers organized to demonstrate and play MOFA the Dragon on a snow mountain. The environment and natural scenery gave the participants a feeling of awe and epic. The small group of players and spectators started to call the players *"heroes"* and *"heroine"* in the process. After the test, one of the heroine"* posted on her social media an image of her playing the game together with the text:*"Today I feel like I am in a dream."* (P30)

On the other hand, the same game experience can be diminished in environments that do not align with the thematic elements of the game, for instance, attempting to play the dragon hunting game in a small, low-ceiling interior setting may feel less immersive and impactful.

5.4.2 Real world acts as the digital game terrain. The design of mixed reality (MR) environments is not solely confined to the digital realm; the physical environment serves as a "game terrain" that influences players' behaviors in games. In "The Duel", participants frequently navigate around pillars or tables for cover and shielding (P3, P4, P11, P12), as shown in Fig. 7. The MOFA games currently

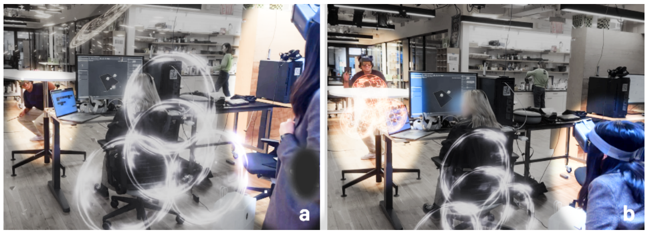

Figure 7: Players instinctively used the physical table as coverage, moving from (a) a standing position to (b) a squatting position, despite it being unable to block digital attacks.

do not integrate occlusion function in gameplay, meaning that obstacles in the physical world do not impede attacks; moreover, the shield and spells visually also are not affected by the occlusion in players' views. Despite of that, players still inherently engage in these strategies, as their vision tracks opponents' movements rather than merely relying on MR content. Participants also expressed expectations of future gameplays reacting to the physical environment, like spells bouncing off walls and grounds, or *"imagine a Charizard (Pokemon GO dragon) standing on top of my local mall"* (L22), considering *"The connectivity to the building and the space will be the strong point of the game"* (P12).

5.4.3 Context Decides Social Acceptance. The spatial context, including the environment and location, plays a crucial role in determining social acceptance and adherence to social norms when it comes to immersive MR street play. People perceive that open spaces, such as parks, are more suitable for engaging, while crowded and busy spaces or potentially unsafe situations, like sidewalks, are considered inappropriate. One online reviewer expressed a strong objection to the video depicting people playing the MOFA games: *"The park, yes, that works but a busy street, are they just out of touch with reality?"* (L13)

Reviewers who favor the game envisioned the success of the game should be tied with open areas in urban parks rather than crowded areas: *"This is doing all the right things and I think I'll get one (the game), though I think their videos are doing a disservice showing people playing in crowded areas. Show people playing in parks surrounded by people bored on picnic blankets...in Dolores Park when the weather turns nice in April."* (L16)

Certain venues also provide social acceptance to the immersive MR street play, as one commented *"If Pokemon GO had this during its hay-day the dork factor would have been socially acceptable"* (L15).

6 DISCUSSION

6.1 Immersive MR Street Play in Public

While visions of a future where MRHMDs transform public street play have been widely portrayed in media—from movies and animations to product videos, game trailers, and commercials—most of us have yet to experience such a reality firsthand. These portrayals often present an idealized version of how immersive mixed reality street play might seamlessly blend into our daily interactions in public spaces. There is significant research within Human-Computer Interaction on interactive systems in public, covering areas such as large interactive displays in public spaces [11], urban environments [74], mobile-based mixed reality [26], location-based gaming [75], and human-robot interaction on the street [76]. These studies offer valuable conceptual frameworks and terminology relevant to our research. Although some MR researchers have studied mixed reality and location-based augmented reality (AR) in public, our investigation of Immersive Mixed Reality Street Play (IMRSP) provides an early glimpse into what this future might look like, specifically through the lens of MR street play in real-world settings.

Our findings highlight an emerging type of streetscape where interactions between players, passersby, and the urban environment converge into a new form of public spectacle (Finding 5.1.3). MR street play moves beyond private or controlled environments, where MRHMDs have primarily been used, into the open and unpredictable dynamics of the street. Studies that consider the street as a site of socially organized human action [76] emphasize that streets are not neutral spaces; rather, they are inhabited, vibrant areas where daily life unfolds. MR street play weaves into these social and cultural dynamics—not merely overlaying digital elements onto the physical world but reshaping the social landscape by creating shared, performative experiences.

Our research underscores the importance of recognizing how MR street play both impacts and is influenced by the rhythms and practices of everyday urban spaces. We argue that MR street play should not be viewed merely as a technological novelty or an isolated form of entertainment but as an active component of the social life of public spaces. The street—with its passersby, organic flow of movement, and evolving social dynamics—becomes a stage for MR street play, where players, bystanders, and passersby engage in new types of public interaction.

By conducting our study in real-world street environments, we gained insights into our research question:

> What are the implications if IMRSP becomes a prevalent form of play in public spaces in an MRHMD-dominated future?

These insights serve as a foundation for further discussion on what might happen if this form of play becomes a common part of urban life. What new forms of social norms, public behavior, or spatial use might emerge as this technology becomes more integrated into street life? Our research begins to address these questions through the specific lens of IMRSP, but the broader implications of this shift warrant further exploration, particularly regarding how we design both the technology and the public spaces that will accommodate this new form of play.

6.2 New Social Dynamics in Public Spaces

Our findings suggest that the introduction of MRHMDs for street play will reshape social dynamics in public spaces by fostering new interactions among players, bystanders, and passersby. This resonates with previous research highlighting how traditional street play transforms urban spaces into dynamic arenas for social interaction, creativity, and spontaneity [88, 91]. In our study, MR street play served as a catalyst for spontaneous social engagement. Players reported developing strong connections with fellow participants, driven by the need for teamwork, shared challenges, and physical coordination within the urban environment (Finding 5.1.1).

These social interactions often extended beyond the immediate group of players, as passersby transformed into spectators or, at times, active participants in the experience. This phenomenon reflects the self-recruiting nature of MR street play, where traditional social boundaries blur and strangers are drawn into the game through the shared act of play (Finding 5.1.1). This creates a new urban social fabric where play becomes a form of public performance, inviting bystanders into the spectacle by their proximity to the players (Finding 5.1.3). This aligns with prior HCI research on designing for public interactions, emphasizing the importance of considering the experiences of both participants and spectators [82, 96]. By engaging passersby, MR street play extends the dynamics of street play into the realm of performance-led interactions [7].

As MR street play becomes more widespread, MR technology transcends its role as a mere tool for play, becoming a technological mediator that actively shapes both the players' and bystanders' relationships with the environment. From the players' perspective, MR street play transforms public spaces into interactive stages, altering how they perceive and move within these settings. This transformation aligns with the concept of embodied interaction, where technology becomes integrated into users' physical experiences [21]. For bystanders, witnessing MR street play may prompt a re-evaluation of the familiar street environment, as it now incorporates unexpected, digitally mediated activities. This reconfiguration of public spaces echoes De Souza e Silva's notion of hybrid spaces, where physical and digital environments merge to create new forms of social interaction [17].

However, this new social dynamic also introduces potential tensions. While some bystanders might be entertained and intrigued by the play, others could experience discomfort or confusion, particularly if they do not fully understand the interactions unfolding around them (Finding 5.2.3). This reflects Goffman's observations on the presentation of self and the management of impressions in public spaces [30, 31]. The introduction of MR street play can disrupt established social norms and expectations, potentially challenging the fragile social order that governs behavior in public settings [57]. Thus, the social acceptance of MR street play may depend on whether the technology can mediate interactions in ways that align with the broader social and cultural expectations of public space. As the boundaries between players, spectators, and passersby blur, society may need to develop new behavioral norms and expectations to address both the inclusive and disruptive potential of MR street play in shared spaces.

6.3 Shifts in Public Behavior and Norms

As MR technologies become more integrated into public spaces, we anticipate shifts in public behavior and the development of new social norms, similar to how smartphones have transformed social interactions over the past decade. Descriptions of behavior in public spaces often draw from Goffman's work, which identifies phenomena like "civil inattention" as a means of maintaining social order in public settings [30]. However, MR street play may reconfigure bystanders' expectations of public spaces, challenging Goffman's notion of civil inattention. As MR play unfolds, it disrupts conventional social norms by transforming the street into a stage, inviting, and at times demanding, attention. This mirrors observations from studies on large interactive displays in public spaces, which have altered social interactions and challenged established behaviors [11, 74].

This shift points to a broader change in public behavior centered around performance and showmanship. Our findings suggest that MR street play encourages players to engage in creative, performative behaviors that entertain both themselves and bystanders (Finding 5.1.2). The MRHMD becomes an embodied mediator that alters players' sense of presence, encouraging expressive and performative actions as they respond to both digital and physical cues. This aligns with Dourish's concept of embodied interaction, where technology shapes our engagement with the world through physical actions [22]. The performative aspect of MR street play reflects the principles of performance-led research approaches, which explore how technology can create new forms of public performance and interaction [7]. This could give rise to a new form of public entertainment, where MR users actively seek out public spaces as stages for their virtual performances. However, it may also necessitate the development of new social norms and rules around how and when it is appropriate to engage in such behaviors, particularly in settings where they might disrupt the natural flow of everyday life.

Another key finding from our research is that some participants felt awkward or embarrassed when engaging in MR street play, especially in single-player scenarios (Finding 5.2.3). In contrast, multiplayer interactions seemed to mitigate these feelings, as shared experiences provided a buffer against social discomfort. This distinction indicates that public behavior in MR environments may be heavily influenced by the presence or absence of shared experiences. This observation aligns with Reeves et al.'s discussion [82] on designing public interactions, where shared activities can reduce individual self-consciousness and enhance social acceptance. As MR becomes more normalized, we expect an increasing emphasis on group interactions and collaborative experiences in public settings. Activities involving multiple participants may become more socially acceptable, while solitary MR use in public spaces, especially when involving non-normative behaviors, could continue to provoke discomfort, particularly if the technology is not widely understood or accepted.

6.4 Transformations in Spatial Use and Urban Design

The integration of MR into urban spaces is likely to transform social interactions and how we perceive and utilize public spaces. Our research highlights the role of the physical environment as a vital backdrop for MR street play, with players reporting that open, contextually appropriate spaces (such as parks or pedestrian plazas) significantly enhanced their experience (Finding 5.4.1). These findings align with Stevens' concept of the ludic city, where urban spaces are seen as playgrounds that encourage playfulness and social interaction [88]. Such spaces allowed for freer movement and greater social comfort, while more confined or inappropriate settings led to increased concerns over safety and social acceptance

(Finding 5.2.4). MR transforms spatial use by acting as a technological mediator that reshapes the way users experience and interact with public spaces.

As MR technologies become more prevalent, urban planners and designers may neped to rethink the design of public spaces to accommodate new forms of mixed-reality interaction. This aligns with De Souza e Silva's concept of hybrid spaces, where mobile technologies merge physical and digital environments, redefining mobility and spatial use in urban settings [17]. This technological mediation may also impact how non-users perceive and interact with these spaces. Open, flexible areas that support physical movement and encourage social engagement will likely become essential in an MR-integrated future. For instance, there may be a need for dedicated MR zones or "playgrounds" within urban environments where people can safely and comfortably engage in MR activities without the risk of disrupting others or feeling socially exposed.

Intentionality also plays a significant role in how public spaces are used for MR play. Our findings show that players exhibited varying levels of intention when performing in public, with some more willing to engage in visible, active behaviors, while others preferred more subtle or private interactions. This reflects observations by De Stefani and Mondada, who describe how people use subtle, embodied methods to navigate social interactions on the street [18]. These differences emphasize the need for urban spaces that can support a diversity of MR interactions, accommodating both those who enjoy public performance and those who prefer more subdued, context-aware engagement. It also underscores Goffman's insights into how individuals manage their self-presentation in public settings [31].

Beyond physical layout, there will be technological requirements to ensure seamless MR experiences. Reliable connectivity, minimal technical failures, and real-time spatial data are essential for creating environments where MR can flourish without disrupting the established rhythms of urban life. Prior research highlights the importance of context-awareness and robustness in AR systems deployed in public settings [33]. Thus, MR in public spaces demands a nuanced approach that considers both technological support and the lived, embodied experience of these spaces, blending physical design with mediated interactions to shape future urban landscapes.

6.5 Design Implications for IMRSP

6.5.1 Design for Contextual Appropriateness. Our findings suggest that MR street play fosters collocated interactions and public performance, which implies that MR design should enhance the social aspect of play. Designing MR applications with features that facilitate teamwork, shared challenges, and visible achievements can encourage group engagement and reduce the potential for social discomfort, particularly in settings with bystanders. Moreover, allowing for adaptive performative levels in embodied interaction, might encourage users to transition between subtle and more performative engagements depending on their comfort levels and social settings. Given that MR street play often turns the public space into a stage, designing for spectator experience, or public display and audience engagement can enhance the shared experience for both players and bystanders.

6.5.2 Harmonizing with Social Norms with Explainable Social Affordance. As MR street play disrupts conventional social norms, it creates a disconnect between players' social and virtual identities, potentially causing social awkwardness. There's a need to design MR street play that promotes social etiquette and manages instances of "civil inattention" [30] in public settings. This can be achieved by incorporating narrative elements, role design, and physical props that signal ongoing MR activities to bystanders, thus reducing confusion and promoting mutual awareness. For example, in our MOFA game, we emphasized the use of physical props, such as wands, to rationalize players' behavior. Given the narrative roles of wizards and witches, these props bridge the gap by offering a tangible connection to the player's in-game persona, enhancing player immersion while alleviating bystanders' concerns. These social affordances also help lower the learning curve for players. Furthermore, incorporating additional elements like music, costumes, and visual cues can enrich the gaming experience and enable clearer communication of player behaviors to the public. Furthermore, designers can help users navigate social boundaries by providing guidelines on appropriate behaviors within different social and cultural contexts. This might include features that notify users when they enter culturally sensitive areas or crowded spaces where MR play could potentially cause social friction.

6.5.3 Guiding Users to Appropriate Locations. Respecting the importance of contextual flexibility and spatial appropriateness in urban design, MR street play should guide users to open, adaptable spaces. Parks, pedestrian zones, and urban plazas are ideal environments for such activities, offering ample room for movement while minimizing the potential for physical or social collisions. Urban spaces can benefit from design features that subtly guide MR use. For example, visual markers or delineated zones can indicate areas where MR activities are encouraged, allowing participants and bystanders to understand the social expectations within these spaces.

6.6 Limitations and Future Work

Limited Game Probe. The MR street play experiences in our study were based on a limited game probe—MOFA, which comprises three games: The Training, The Duel, and The Dragon, all set within a thematic context of magic. While this theme provided a shared framework for players to engage and understand gameplay mechanics quickly, it may not fully capture the diverse range of potential MR street play scenarios. Future studies could expand beyond a single thematic area and consider games with different themes, interaction styles, and levels of physical engagement to better understand the full spectrum of MR street play possibilities and their effects on social dynamics.

Limited Physical Interaction. Due to the game design and safety considerations, all three games in MOFA have no physical contact, which limited our exploration of potential physical interaction dynamics in MR street play. Physical contact could introduce richer, more complex social interactions that might enhance or complicate MR experiences in public. Future studies might explore MR street play scenarios that permit safe, controlled physical interactions to better understand how touch and close proximity impact social bonding, comfort, and behavioral dynamics in public MR environments.

Limited Environmental Interaction. The environmental interaction in our study was limited, as the MOFA games were designed primarily to encourage social interaction among players rather than interaction with the surrounding physical environment. While players could move freely within certain spaces, the games did not incorporate elements of the physical environment, such as urban infrastructure, landmarks, or other spatial features, which could enhance immersion and contextual relevance. Future studies could explore MR street play designs that integrate environmental interactions—such as using real-world objects as interactive components or adapting gameplay based on specific environmental characteristics.

For future research on IMRSP, we propose the following agenda:

Explore the design space for IMRSP. As this field remains largely uncharted, we encourage researchers to investigate its various aspects and potential. This includes exploring different game mechanics, interaction modalities, and social dynamics that are unique to IMRSP.

Develop ethical, health, and safety guidelines for IMRSP. These guidelines should address issues such as player privacy, physical safety in public spaces, and potential psychological impacts of immersive experiences in urban environments.

Develop protocols for inviting bystanders to join IMRSP. What permissions are necessary? How can we protect privacy? Which invitation methods are most effective? This research could involve testing various invitation strategies and analyzing their effectiveness and social acceptability.

Facilitate intent inclusivity in public spaces for spectatorship. As described in [41], this includes understanding the Intent Differentiation of HMD wearers and non-HMD wearers. For HMD wearers, this may include unconcerned players, privacy-conscious players, acceptable non-sharers, eager sharers, and casual inviters. For non-HMD wearers, this may include enthusiastic recruiters, indifferent passersby, tolerant observers, disturbed onlookers, curious spectators, included spectators, and those ready to join with handheld AR or head-mounted displays. Studying these different intents could lead to more inclusive and socially aware IMRSP experiences.

Identify effective social affordances that communicate social norms in IMRSP. Beyond wands, this could involve designing and testing various physical props, visual cues, or auditory signals that help convey players' actions and intentions to bystanders.

Explore the relationship between Live Action Role Play (LARP) and IMRSP. How can mixed reality enhance LARP [45] experiences? This research could involve adapting existing LARP scenarios to IMRSP contexts and analyzing the benefits and challenges of this integration.

Investigate ways to incorporate more environmental interactions, such as with buildings, streets, and landscapes. This could include developing techniques for real-time environment mapping and creating dynamic game elements that respond to the urban landscape.

Theoretical exploration of IMRSP's relationship to Ludology, Urban Games, Playful City, Urbanism, Persuasive Games, Mixed Reality Games, and Exertion Games. For future research on IMRSP, we suggest a theoretical exploration of its relationships with various fields. This includes investigating how IMRSP fits within existing game theories and urban play concepts, examining its potential to transform urban spaces into interactive playgrounds, exploring its use for social change or education in urban environments, and analyzing its intersection with immersive technologies and physical activity-based gaming.

7 CONCLUSION

Will immersive MR street play become a prevalent form of play in the future, as promoted in visionary videos from big tech companies? Through empirical studies based on our open-source exploratory game probe series MOFA, we glimpse the future of IMRSP, providing an initial understanding of the social implications of this novel form of play in this under-explored area.

> *"A dream you dream alone is only a dream. A dream you dream together is reality."* — Yoko Ono

We found that IMRSP is a novel urban activity that's highly socially engaging, allowing players to immerse themselves in a collocated private social reality. It involves full-body movements and creates unprecedented social and immersive experiences mediated by virtual digital elements, augmented with visuals and audio—surpassing traditional sports or urban games. However, the inherent power imbalance of MRHMDs, where passersby cannot see what the wearer sees, creates awkwardness and social acceptance issues. While spectating experiences can mitigate these issues, they raise additional privacy concerns, particularly regarding who can join game sessions. Moreover, regardless of the MRHMD form factor—headset or smart glasses—IMRSP interaction goes beyond button-pressing or small gestures, involving large body movements. This exacerbates the awkwardness and acceptance problems and even raises safety concerns.

We concluded that despite its novelty, the widespread acceptance of IMRSP in public spaces may take longer than anticipated. While some argue that, like smartphones, it will eventually change social norms, the extensive body movements required by IMRSP present a significant hurdle. Perhaps, like other sports, we'll eventually see dedicated playgrounds for IMRSP, similar to baseball or basketball fields, rather than it being played everywhere in the streets as promoted in those visionary videos.

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