Designing Immersive Multiplayer Location-Based Augmented Reality Games with Remotely Shared Spaces

Yasas Sri Wickramasinghe*, Stephan Lukosch and Heide Lukosch

HIT Lab NZ, University of Canterbury, Christchurch 8041, New Zealand

Abstract. Location-based augmented reality games (LBARGs) hold the potential to foster physical activity, enhance social engagement, and boost self-esteem. While LBARGs have shown success, they currently have limitations in terms of accommodating multiple players from remote locations in real time and how they interact with their physical surroundings. There is uncertainty on how to expand LBARGs to overcome these limitations. This exploratory study focuses on designing and evaluating immersive multiplayer LBARGs that enable remote player interactions within remote shared spaces through the game "ARrive." To better understand the experience and preferences of players, multiple prototypes are proposed to evaluate them through a user study. This helps to identify the impact of different game design elements and triangulate qualitative data with quantitative data. The proposed game design includes three different game modes, and data are expected to collect through questionnaires and semi-structured interviews to assess the level of spatial presence, AR immersion, and user experience of players. Moreover, these prototypes will help us understand the limitations of current LBARGs by pushing their boundaries and improving the way real-world environments are incorporated into gameplay. The outcomes of this study could contribute to a comprehensive understanding of real-time multiplayer LBARGs and inform the design of more engaging and healthier games for game developers.

Keywords: Augmented Reality, Location-Based Game, Multiplayer Games, Spatial Presence.

1 Introduction

The gaming industry has seen a significant surge in growth in recent years, with the global market estimated to be worth over $268 billion by 2025 [1]. This growth is influenced by various factors, including the development of cutting-edge technologies such as virtual and augmented reality [2]. Nevertheless, extensive engagement in conventional sedentary video games has been demonstrated to exert negative impacts on physical and psychological well-being, such as diminished physical fitness, poor self-esteem, and reduced social interactions due to prolonged gameplays being stationary [3]. However, on the other hand, active video games, particularly location-based games (LBGs) that incorporate augmented reality (AR), have been found to have the potential to promote physical activity, social engagement, and self-esteem [4,5,6].

This study explores the utilisation of synchronous multiplayer LBGs with AR to enhance player interactions within a remotely shared environment. Through research through design [7] approach, various prototypes were created to assess the impact of the overall gameplay experience. This paper describes these game designs in detail and the proposed evaluation methods but does not present the empirical data which are yet to be gathered. The objective of this research is to identify potential areas for improvement in future game designs by examining these factors through various game prototypes. Game designers could use these findings to create healthy, engaging game activities. Furthermore, these prototypes aim to examine the limitations of current LBGs [8] by broadening the scope of existing LBGs and enhancing the meaningful integration of physical environments in gameplay.

* Correspondence: Yasas Sri Wickramasinghe, HIT Lab NZ, University of Canterbury, Christchurch 8041, New Zealand, yasas.wickramasinghe@pg.canterbury.ac.nz

The following sections present the research gap identified through the literature review, the design of the game prototypes, and the experimental design to evaluate the gameplay experience.

2 Background on Location-Based Multiplayer Games

2.1 Location-Based Games

LBGs use the player's indoor or outdoor environment in the game through networked interfaces [9]. Therefore, LBGs promote novel ways of interacting with the physical world in play. Furthermore, LBGs create an interface between players and locations, leading to a hybrid intuitive gameplay space [10].

LBGs can have many forms, such as GPS coordinates-based, AR marker-based, or markerless approaches. In this study, the term "LBG" refers to any AR game that takes players' real-world location and physical-world interactions, such as movements, into the game using network interfaces.

LBGs are categorised into three main groups [11]: spatially discrete, spatially continuous, and mixed-formed LBGss, as shown in Figure 1.

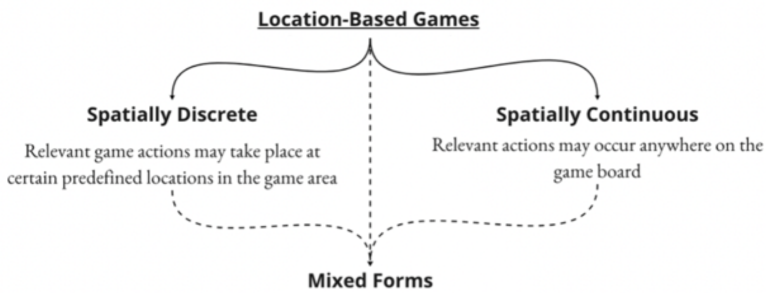

Fig. 1. Types of LBGs

Spatially discrete LBGs refer to a gaming experience where gameplay is tightly coupled to a specific, physically defined location. Players are required to be at a specific place to play this type of game. These games may employ GPS, mapping software, or AR features to create game experiences for players. Spatially discrete LBGs are popular due to their ability to consume virtual and real-world elements, creating a unique and engaging form of entertainment.

Unlike the spatially discrete, the spatially continuous LBGs allow players to navigate the real world while engaging in the game. However, due to the nature of this type of game, players may require some assistance to navigate through mini-maps or visual cues to navigate. Additionally, the game may change game elements and mechanics according to the present place of the player using GPS or AR features.

It is worth noting that it is possible to exist LBGs with features from both spatially discrete and continuous types, which can be identified as a mixed form. A game which requires its players to physically be present at a specific location only to initiate the game, and then, they are free to navigate around the physical space engaging with the game activities is an example of a mixed-form LBG.

According to the above classification, whatever the LBG type is, they are supposed to be based on a place of real-world location or virtual location in a meaningful way. Hence, the extent to which the features of a location within an LBG can impact the gameplay experience. For example, what if an LBG can use water from a nearby pond as a game artefact to extinguish a fire within the game? What if the LBG requires players to walk around the place and find wood and pass it to another player in AR as a game object to build a hut?

However, most LBGs are currently limited regarding the meaningful usage of their environment [12]. For example, they use the place as a medium to instantiate the game and to place AR content. But there is no effective use of the characteristics of the place within the game. This limitation is an opportunity to expand the boundaries of existing LBGs without limiting them to tabletop games or little spaces. Therefore, further studies are required to understand how to embed real-world location-based properties into LBGs in meaningful ways so players can enjoy an additional degree of freedom.

2.2 Location-Based Multiplayer Games

Multiplayer LBGs are certainly not new, and there has been massive growth in this field with popular games like Pokémon Go [13], Ingress [14], Geocaching [15], and board games like Tilt Five [16], and the upcoming version of the Catan game [17], in AR.

AR technology has taken the multiplayer LBG experience to a new dimension. It allows players to interact with virtual elements in real-life settings, creating an immersive and engaging experience. Studies have shown that AR game designs have the potential to promote collaborative social interactions [18]. Also, if the game has some level of uncertainty due to distributed gameplay, it has been discovered that this heterogeneity helps players to experience higher engagement with the game [19].

Another study [20] which used location-based AR in a Participatory Design (PD) approach to facilitate meaningful place-making for children, has presented some design recommendations for serious games to improve social interactions. According to those research findings, meaningful social interactions were observed when children worked together. Furthermore, that study encourages further research on location-based AR applications to accommodate more in-game interactions and collaborations.

However, it is imperative to acknowledge that LBARGs should not be restricted solely to co-located outdoor settings but may incorporate a combination of indoor and outdoor spaces. Despite the numerous benefits of LBARGs, this limitation persists in the game design-based research with regard to comprehending the impact on remote multiplayer games that bridge multiple gaming spaces. This limitation has also been identified in a recent study [21].

Moreover, it is crucial to understand how remotely located participants from distributed locations can contribute to LBGs, even though the researchers have already identified that LBGs help foster social interactions [20]. Therefore, when multiple people engage with an LBG, their social presence within the game needs to be studied further to understand whether it affects the gameplay experience and ultimately leads to more immersive real-time multiplayer LBGs.

Previous key findings are motivating to design highly engaging LBGs that make use of the real world. The traditional LBGs have sparked social interactions with each other, representing enjoyable, interactive gameplay experiences. Nevertheless, what if the LBGs could expand their scope further by utilising the characteristics of gameplay locations within the game and allowing distributed synchronous gameplay? This direction motivates us to explore LBGs, and further understand spatial presence, immersion, and how to use the attributes of a place in an LBG meaningfully.

2.3 Spatial Presence in Location-Based Augmented Reality Games

According to multiple studies, spatial presence refers to the subjective sensation of being physically present in a mediated environment [22, 23]. Following the concepts of spatial presence, it has been discovered that the LBARGs have the potential to enhance player immersion and spatial presence [18]. Furthermore, multiplayer games in AR can increase spatial presence by allowing players to see and interact with virtual objects in the real world [18].

However, further study is required to fully comprehend the creation of immersive real-time multiplayer LBARGs that promote a higher degree of spatial presence. The following section outlines our suggested game design approach for the study of spatial presence in LBGs.

2.4 Immersion in Augmented Reality Location-Based Games

A widely accepted definition of immersion within the field of digital media is the state in which an individual experiences a raised sense of presence and engagement within a mediated environment, leading to a suspension of their disbelief and a perceived blurring of the boundaries between the virtual and physical realms [24]. This definition declares immersion as a multifaceted concept entangling cognitive, affective, and perceptual elements.

Another notable study defines immersion as a psychological state in which individuals are encircled and interact with an environment, allowing for continuous experiences [25]. The authors suggest that immersive virtual environments (VEs) have been achieved through wearable devices such as head-mounted displays (HMDs), which confine the user's view to the simulated environment. However, AR with handheld mobile phones may produce a different type of immersion, more closely associated with the context or content rather than display technology.

The combined subjective and behavioural methods used in another study [26] present that users' cognition dynamically influences and is influenced by immersion. These researchers argue that immersion and users are interactive and co-evolving; immersion influences users, and simultaneously, users build immersion. They consider these interactions as a constantly evolving element and bidirectional rather than being one-time or temporary. Previous researchers have also identified the need to explore different types of multiplayer LBG designs to understand how other participants from different locations can engage with a game [11]. However, as per our best knowledge, no study has identified how multiple players of a location-based augmented reality game (LBARG) experience spatial presence and immersion within the gameplay.

There are multiple definitions of immersion due to the continuous application of the concept in a wide range of research fields. Sometimes, it is visible that researchers use the term immersion interchangeably with other terms like engagement and presence [27]. According to Adam and Rollings [28], mental absorption in the narrative or the created world constitutes the phenomenon of immersion on a diegetic level, which they call "narrative immersion." This concept refers to the experience of being fully engrossed within a story, whereby the individual perceives the world and events of the narrative as real. When considering a truly immersive LBG experience, we believe that this way of looking at immersion is more relevant because the meaningful usage and interpretation of the characteristics of a place in an LBG play a significant role, as described in the following section.

Moreover, based on these previous studies [24, 25, 26, 28], we expect to evaluate the immersion of our proposed game designs and compare them with each other to determine which type of location-based interactions induce a higher degree of immersion and to identify possible recommendations for designing future LBARGs.

2.5 Place in a Location-Based Game

The location where an LBG takes place is essential to study further because it serves several important functions. Firstly, the location provides the context and sets the platform for the game, supporting the creation of a sense of place virtually and enhancing player immersion. Secondly, location can impact gameplay mechanics, such as providing opportunities for exploration, navigation, and problem-solving. Furthermore, location can also influence the social dynamics of the game, as players may interact with each other based on their physical proximity and the resources available in their respective locations.

Going one step further, the location-based aspect of these games has the potential to offer novel gameplay experiences through the use of real-world data. Some examples are using the weather conditions within the game to make the virtual gameplay more linked with the real-world. This location-based aspect not only adds to the authenticity of the game world but also may offer opportunities for increased player immersion and presence, as the game can be tailored to the player's physical location.

Researchers call the specific location relevant to an LBG a Point of Interest (PoI). Common examples of PoIs in an LBG can be a road, a pond, a statue or a building. By using PoIs, mobile applications have the capability to enhance physical locations with virtual content and interactive experiences, especially by linking game scenarios coupled with PoIs specific to real-world locations [29]. The quality of a PoI is influenced by the connection to the real-world, uniqueness and metadata available about the PoI and the placement of the PoI [29].

The attachment to a place in the physical world has been identified deeply in the field of psychology, and the concept of "place attachment" has been introduced. Place attachment is identified as the emotional connections individuals form with their places of dwelling [31]. Furthermore, previous studies have discovered that a consistent predictor of place attachment is the existence of strong social ties among people sharing a place [33, 34].

Remotely located gameplays in LBGs require novel techniques for connecting places together, facilitating situational awareness, co-presence, and affordances for collaborative task performance. Therefore, this study aims to design multiple game designs connecting multiple players from remote locations in real time and understand which technique promotes a higher degree of spatial presence and immersion.

Doing so will strengthen social bonds connecting friends and families closer. Moreover, it has been discovered that LBGs help to make strong place attachments [34]. Strong people-place attachment may lead to positive attitudes and behaviours toward specific places and influences people to explore nature reducing the sedentary time.

However, a challenge in the development of multiplayer LBARG is the representation of the play environment and the effective sharing of this representation among players. This study endeavours to address this challenge by exploring and evaluating three different perspectives of place representation in the context of AR. The selection of these perspectives is guided by a review of relevant prior research in the field, drawing on established principles and empirical findings to inform the design of our study. Perspectives to be studied include the bird's eye view perspective, a room-scale perspective, and the use of portals to allow users entering or at least viewing a location.

Studies on remote multiplayer games have shown how a virtual environment is represented can significantly impact players' sense of spatial presence. For instance, a study found that AR tabletop views, which present virtual objects on a real-world surface, support collaborations between multiple users indoors and outdoors [35]. Presenting a bird's eye view perspective in location-based gaming can greatly facilitate the spatial understanding of crowd movements, and researchers argue that the perspective allows for a comprehensive and intuitive representation of the environment and enables users to effectively assist individuals on the ground level in navigating and comprehending their surroundings [35]. Therefore, this perspective influences us to investigate further how a bird's eye view or a top-down perspective affects an AR LBG.

Similarly, another study found that AR overlay views, which present virtual objects of the same size as the real environment, can enhance players' feeling of experiencing a more natural environment in AR [36]. Several studies [19, 37] denote that the ability to move through virtual environments and overall spatial awareness can be improved by incorporating virtual environments on a room-scale or real-world a like scale. Interestingly, another study [37] has looked into the effectiveness of using either table-scale or room-scale AR applications for learning. It was anticipated that the implementation of AR, allowing individuals to roam freely within large-scale virtual environments, would enhance the spatial aspects of the experience. However, the results failed to show a significant improvement in these metrics. Based on these findings, it can be assumed that the size of the AR content and environment can influence educational AR content and LBGs and alter the degree of spatial presence.

Portals are a relatively new, effective element to make game transitions seamless, and they have been helpful in achieving a higher presence within virtual reality game scene transitions [30]. This perspective, which allows players to see a remote environment from a real-world location through an AR window, was inspired by studies on mixed-reality games and teleportation mechanics. Research has shown that portals can create a sense of connection between real and virtual spaces and foster a higher presence during in-game transitions [30]. However, even though portals are studied in the virtual reality domain, we believe that introducing portals in AR, too, a like feature to provide a smooth interaction flow between distributed gameplay locations in AR, may depict some exciting influences on the gameplay experience.

2.6 Research Aim

Multiplayer LBGs that connect players through shared gameplay spaces need to study further to understand their impact on fostering spatial presence and immersion. Although studies have been carried out to understand engagement and meaningful social interactions in traditional LBGs, accommodating remote players in real-time and their interaction with spaces and each other is still unclear.

This study aims to investigate the fundamental research question of designing an LBARG that fosters the spatial presence of both remote and local players while simultaneously representing the spaces of remote players. Specifically, this study expects to delve further into the aforementioned research direction, with the goal of comprehending the mechanisms by which a player's space can be effectively represented to another player who is also remotely connected, all while inducing higher levels of immersion and spatial presence. Ultimately, this study intends to generate practical recommendations for game designers aimed at crafting multiplayer LBGs that encourage physical activity and social interaction, all based on the results of the study.

This study was inspired by previous studies [19, 30, 35, 37] that have explored the relationship between the representation of virtual environments and players' sense of spatial presence. Based on the findings from the literature review, this study includes three conditions for our game design to test our hypotheses. These distinct conditions vary based on their use of the place visualisation technique. The three visualisation techniques are AR miniature view, AR overlay view, and AR window view and based on these, we derived the below hypotheses.

- H1. Game mode 1 (AR miniature view): Participants will elicit the lowest level of immersion and spatial presence in a top-down miniaturised view compared to other modes.
- H2. Game mode 2 (AR overlay view): Participants exhibit enhanced collaboration and coordination abilities while playing in this mode due to the local player being situated in a virtual space of real-world dimensions relative to the remote player due to the highest level of immersion compared to other game modes.
- H3. Game mode 3 (AR window view): The AR window view will elicit the highest spatial presence among participants compared to the other two modes, allowing players to pass objects between their physical and virtual environments.

Each modality of the game design is chosen carefully with the aim of getting a deeper understanding of how these visualisations affect the overall gameplay. Each of the game modes, gameplay scenario and also how we are planning to conduct the user study to assess the above hypothesises explained in detail in the next chapter.

3 Methodology

3.1 Study Design

This study follows the research through design (RtD) [7] approach as it will provide multiple game designs. Feedback from players will be gathered to understand how players immerse themselves in novel remote multiplayer LBG designs, as described in the following sections.

The user study is planned to conduct with test participants assigned within-subject form where each participant experiences all three game conditions, which would heavily reduce individual differences so that each participant may notice subtle differences in the spatial presence, immersion and user experience in each mode and provide more valid feedback. A within-subjects design may reduce the impact of extraneous variables such as gender, previous exposure to AR-related applications or age.

Adopting a "within-subjects" design presents the challenge of longer completion time for each participant, as they must experience the game and complete questionnaires for each condition. However, this challenge is being addressed by limiting the number of questionnaires and keeping them short. For instance, we will utilise the short version of the User Experience Questionnaire (UEQ-S) [43] consisting of only eight items instead of the longer 26-item UEQ. The following sections describe the game design, data collection and evaluation.

3.2 Experimental Game Design: ARrive

In order to elicit a thorough understanding of the influence of user experience and spatial presence, “ARrive” is designed including into three different game modes. These three game modes will be used to check the validity of the hypotheses through the analysis of the data collected from a user study, allowing for a comparative examination of each game design strategy.

The proposed game is designed as a mobile-first game and incorporates real-time networking capabilities for remote player connectivity. The game's development was executed using the Unity 3D game engine [38] due to its compatibility with the preferred AR development kit, Niantic Lightship ARDK [39]. This development kit was selected for its provision of essential features for LBARGs, such as real-time meshing, semantic segmentation, and a visual positioning system (VPS), which are crucial components in the design of the game. Furthermore, real-time sharing of updated AR content and environment is another vital game design requirement, and to fulfil that, we use the Normcore library [40].

The experimental game design facilitates two player roles as the "local player" (host), an individual participating in a game physically situated in the environment while being connected to another player remotely. Conversely, a "remote player" (peer) refers to a participant who is not situated in proximity to the other player but instead engages in the game from a remote location.

The game design requires the host and peer to exchange 3D scans of their respective physical locations to initiate a game session. Lidar scanning is our preferred method for capturing these 3D scans of their physical surroundings. In the context of this experimental game design, the host is placed in an outdoor environment while the peer is situated within an indoor space. This is illustrated in Figure 2, which depicts the distributed locations of both players and provides examples of 3D scans of their respective environments.

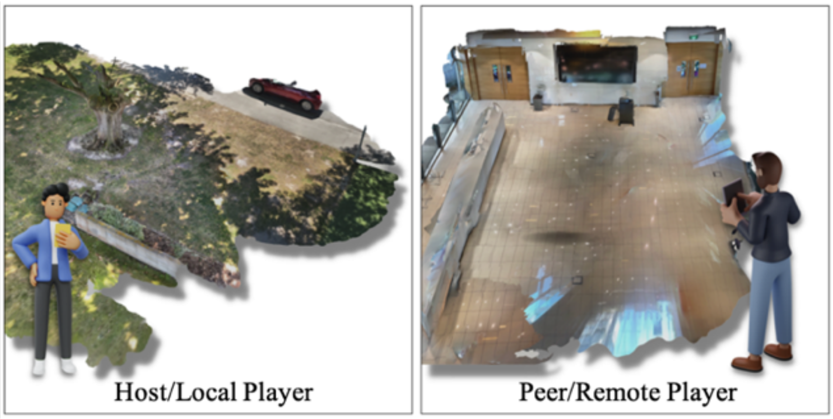

Fig. 2. Example scenario of host's and peer's location-sharing. From left to right: The host shares his outdoor surroundings as a 3D scanned model, and the peer shares his indoor surroundings as a 3D scanned model.

In a game session, players are encountered flying enemies that pose a threat to their survival. Players are equipped with the capability to throw water balls to counteract these enemies. However, first, each player has to craft water balls before throwing those toward enemies to destroy. For crafting water balls, players must collaborate with each other. The player designated as the host is responsible for exploring the physical environment to gather necessary resources such as wood, grass, and clouds, which are incorporated into the game mechanics. The collected resources are then transferred to the other player via AR, which can be achieved through an AR window, overlay space, or miniature mode. An illustration of this game scenario is presented in detail in Figure 3.

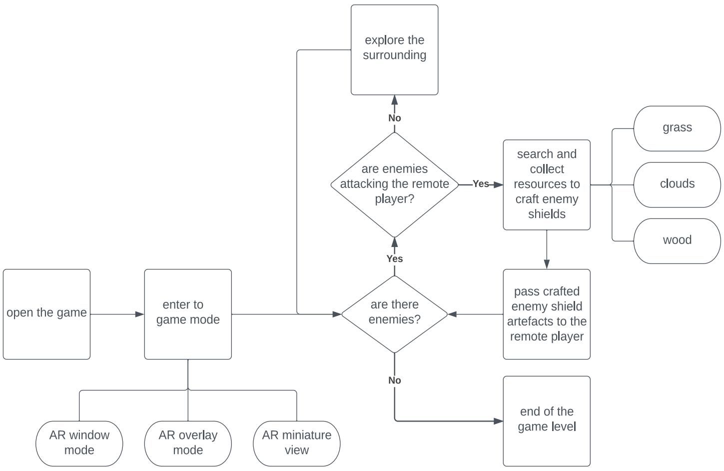

Fig. 3. Flow diagram of the game scenario

This game design allows for the integration of real-world elements into the gameplay by exploring the local environment to find resources. This further gives meaning to the game-based interaction across multiple locations by allowing each location to contribute to the game's progress. In multiplayer scenarios, if one player lacks certain resources, they can obtain them from their peers, who have collected them from their own physical environments. This feature induces collaboration and encourages players to work together to achieve their objectives. Figure 4 presents screenshots of occasions where the host is requested to collect some resources by scanning real-world physical properties to help the peer under attack.

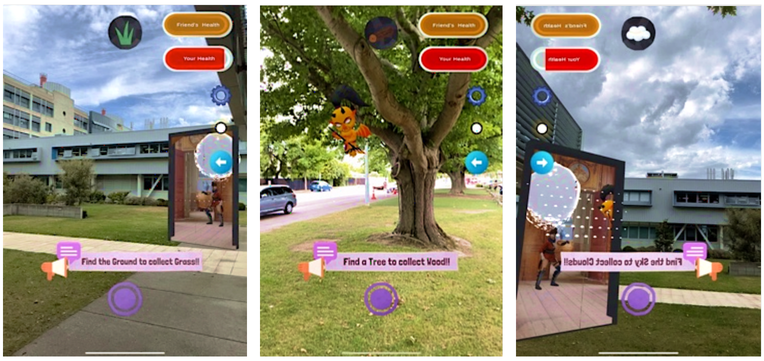

Fig. 4. Screenshots of the resource collection phase. From left to right: The host is requested to find grass, wood, and clouds.

For this game design, three game modes are introduced, as shown in Figure 5.

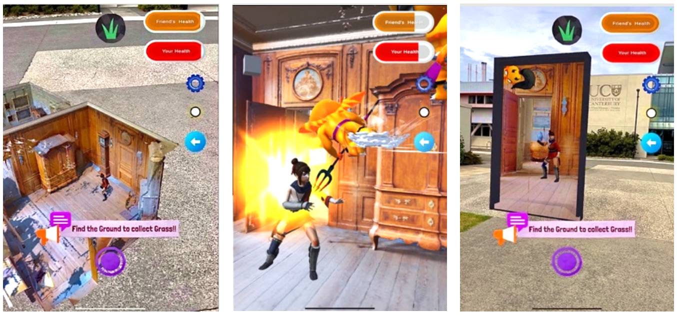

Fig. 5. From left to right: AR miniature mode, AR overlay mode, and AR window mode.

1. The AR miniature mode presents the game environment on a surface from a tabletop perspective, providing players with a more holistic experience. In this mode, players' movements and AR objects are updated in real-time and maintain the high-level spatial representation of the peer's entire space.
2. The AR overlay mode superimposes the AR environment over the physical environment, allowing players to perceive both virtual and real elements simultaneously. In this mode, the host can experience the peer's space in its true-to-life size and aspect, including the peer's avatar representation. In addition, both players can interact with virtual game objects within the AR space as well as observe real-time updates on each player's movements.
3. The AR window mode shares the 3D scan of the peer's environment through an AR window, enabling the host to interact with the peer in real-time. For instance, the host can share virtual objects from his space with the peer, which will be reflected in real-time through the AR window to the peer.

Additionally, during the game's development, we recognised two categories of game components: screen space elements are fixed on the display screen and don't interact with the physical world. These elements, such as the health bars of each player, game menu icons, and informational pop-up messages, are deemed screen space components due to the requirement for immediate accessibility and ease of use. On the other hand, world space elements interact with the real world and are part of the game scenario. In this regard, all AR game objects, and shared spaces were designated as world space elements to create a seamless blend of virtual and physical components, resulting in a heightened sense of spatial presence for the user.

3.3 Participants and Data Collection Methods

The user study envisions user testing with approximately 30 participants. This sample will include individuals who have and have not previously played LBARGs. We expect to keep each user study session approximately 45 minutes, including time to fill out questionnaires. The questionnaires are based on the Spatial Presence Experience Scale (SPES) [41], the Augmented Reality Immersion (ARI) Questionnaire [42], and the short version of the User Experience Questionnaire (UEQ-S) [43].

The UEQ-S instrument will be employed in this study to assess the user experience and test the first hypothesis (H1), which posits that the AR miniature view would result in lower immersion and spatial presence levels compared to other modes. The UEQ-S questionnaire comprises only eight items, including dimensions such as "obstructive or supportive" and "boring or exciting." This instrument is chosen over UEQ due to its simplicity, making participants complete the evaluation without feeling overwhelmed.

The ARI questionnaire consists of 21 questions categorised under six factors: interest, focus of attention, flow and more. Participants rate their agreement with each statement on a seven-point Likert scale. An example item from the ARI questionnaire is: "I was more focused on the activity rather than on any external distraction." This questionnaire will be used to evaluate the level of AR immersion experienced by the participants, particularly in testing the second hypothesis (H2), which stated that the AR overlay view would elicit the highest level of AR immersion due to the local player being situated in a virtual space of real-world dimensions relative to the remote player.

The SPES will be selected to evaluate the level of spatial presence elicited by the AR game modes, particularly in testing the third hypothesis (H3), which stated that the AR window view would elicit the highest spatial presence among participants compared to the other two modes. This questionnaire consists of eight items that assess the degree of spatial awareness. Participants rate their agreement with each statement on a 5-point Likert scale. An example item from the SPES is: "I felt like I was really there in the environment of the presentation."

During the reflection phase, the players can report on their game experience, explain why they liked or disliked game elements, and express ideas for further improvements. The collected data will be further analysed to evaluate each game mode's degree of spatial presence and immersion and use elicitation techniques to propose design guidelines for designing future remote multiplayer LBARGs.

4 Conclusions and Further Work

The game design presented in this study highlights the potential of multiplayer LBARGs to deliver elevated levels of spatial presence and immersive user experience to all remotely connected players promoting physical activity and social engagement. The implementation of the three game modes provides the opportunity to assess the most impactful approach for the gameplay scenario. Furthermore, resource sharing may yield higher collaboration between players as an innovative game element enhancing the gameplay experience. The design recommendations derived from this study may guide future game developers in creating healthier and more engaging LBARGs. Future research can build upon the insights gained in this study to further research design meaningful game interactions for multiplayer LBARGs. Overall, this study sheds light on the promising future of LBARGs and their potential to promote healthy and socially engaging gameplay.

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