The House of the Impossible Gables: Player Engagement and Spatial Perception of Physically Impossible Spaces in Social VR

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Abstract. Social Virtual Reality (VR) provides an escape from the physical world, creating communities where visitors can imagine and play new roles. However, spaces in social VR platforms can have their own unique identities, shaping the interactions within them with virtual interactions that go beyond physical reality. To investigate the unique capabilities of the spatial part of the social VR experience to shape player perception and interaction, we designed "impossible spaces" in VRChat that defy spatial interaction expectations in physical reality, including "explosion" room, "teleportation" room, "furry" room, " levitation" room, "dark" room, "transparent" room. We qualitatively analyzed exploration patterns and interview data to identify exploration-oriented, task-oriented, and examining patterns of movement by players. We interpret how affordances like relocation and materiality can lead to diverse spatial judgments. The design of spaces that go beyond physical reality provides insight for the design of imagined scenarios and interactions in-game and exhibition environments.

Keywords: Impossible Spaces · Spatial Perception · Social VR · Virtual Reality

1 Introduction

Social Virtual Reality (VR) platforms, such as VRChat, transcend physical limitations and enable novel spatial dynamics that foster unique user interactions. Although many virtual environments still replicate physical constraints [23], even slight design modifications can spark distinctive relationships among players, objects, and surroundings [58][62][16]. By embracing "impossible" spaces that override real-world rules, social VR offers opportunities to investigate how users

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perceive, navigate, and connect within beyond-physical environments. Such environments are vital for nurturing place attachment, identity, and emergent interaction in VR [63]. While past studies have explored user behavior under reorientation [19], teleportation, and abnormal texture conditions [65], limited attention has been paid to how breaking physical constraints reshapes social interaction. Drawing on architectural form research [28] and virtual design principles [22], this study proposes six "impossible" rooms—'Explosion,' 'Teleportation,' 'Furry,' 'Levitation,' 'Dark,' and 'Transparent'—each challenging a conventional spatial feature through exploding elements, portals, textures, floating structures, brightness, or transparency. These alterations invite new modes of engagement [4]. We investigate how these elements affect player behavior through an object-finding and navigation task in which participants locate a specific object in each environment. This approach assesses how "impossible" virtual spaces influence player–environment interactions, and what unique affordances emerge. The study centers on the following research questions:

RQ1: *What kinds of spaces can we design in virtual environments that use rules distinct from those of physical reality?*

RQ2: *What types of unique interactions in social VR are fostered by these spaces, which operate beyond physical reality?*

This paper explores designing immersive VR spaces that encourage specific social interactions on platforms like VRChat. Our findings show that the movement patterns of the players vary depending on the quality of each "impossible" room. In more conventional spaces, participants tended toward task-oriented movement, focusing on goal completion, while rooms with complex visual affordances prompted exploration-driven behavior. In more challenging environments, participants performed examination-driven movements. Second, unique spatial features influenced how players perceived the environment. For example, a systematic search in the "Dark" room improved the accuracy of the players in describing objects, while reorientation in the "Teleportation" room caused perceptual distortions.

2 Background and Related Work

2.1 Interactions within Virtual Spaces

Virtual Reality (VR) revolutionizes digital interaction, offering immersive spaces where users engage with each other and the environment in novel ways [26]. Prior studies show that VR enhances cross-generational connections [55], stimulates creativity [23], and extends social interaction beyond physical limits [75]. Creative installations [20][6][34][1][2][38][33] further enrich experiences for players and heighten engagement with the environment [10]. However, much existing research focuses on realistic VR spaces—workplaces, fairs, or conferences [54]—largely overlooking how "impossible" architectural features expand the range of user behaviors. Such features spark curiosity and creative potential, especially when players import real-world habits and adapt them to new virtual rules. Accordingly, this study examines how “impossible” spatial qualities—categorized by space-time, anti-physics, and material abnormity—shape user interactions in VR.

2.2 Spaces in Virtual Environments and Their Influences

Prior work has investigated how rooms with changing scales [60], constant locomotion [8], reorientation [19], teleportation [9], or visual distortion [15] affect user navigation and behavior. Researchers often incorporate tasks that involve complex movement challenges [51][45][36] or object-finding in overlapped or reoriented “impossible” spaces [59][30], tracking how participants complete tasks and recall spatial layouts. In this work, we focus on two spatial properties—virtual relocation and visual unification—through object-finding tasks, then examine how players perceive and interpret location and size in these non-physical environments.

3 “Impossible” VR Spaces Design

We created six “impossible” VR spaces (Figure1) by modifying a “Baseline” room to test how unconventional architectural features affect user interactions. These designs draw on formal architectural principles [28], innovative virtual environments [22], and established classifications of spacetime (against spatial continuity), antiphysics (violating real-world laws) and materials [23]. Each “impossible” space alters one core element from the baseline environment, such as explosion elements, portals, textures, floating structures, lighting, or transparency, to reveal how defying physical norms reshapes user perception and engagement. The following paragraphs provide the designs and rationale behind, addressing RQ1.

The Baseline room is an art gallery with grid-based circulation (adapted from a Unity asset [12]) to ensure moderate spatial complexity [57]. It includes a mezzanine, partitions, paintings, and sculptures. Players also perform an object-finding task here to compare conventional versus “impossible” conditions.

Falling under “Space-Time,” the design for "Teleportation" adds four doors that teleport players back to random spots if they choose incorrectly. Borrowing from foldable-space concepts [21], the layout interrupts normal walking patterns, prompting users to closely re-examine their surroundings.

The "Explosion" room belongs to “Anti-Physics”, exploding architectural elements from the Baseline room, suspending them in midair. Though originally conceived as an animated effect, technical constraints in VRChat resulted in a static scene. Nonetheless, the anti-gravity setup encourages exploration and interaction with scattered objects.

Another “Anti-Physics” environment, this room divides the floor into floating platforms at different z-levels. Instead of stairs, players jump between segments to navigate vertical space, challenging everyday notions of gravity and circulation.

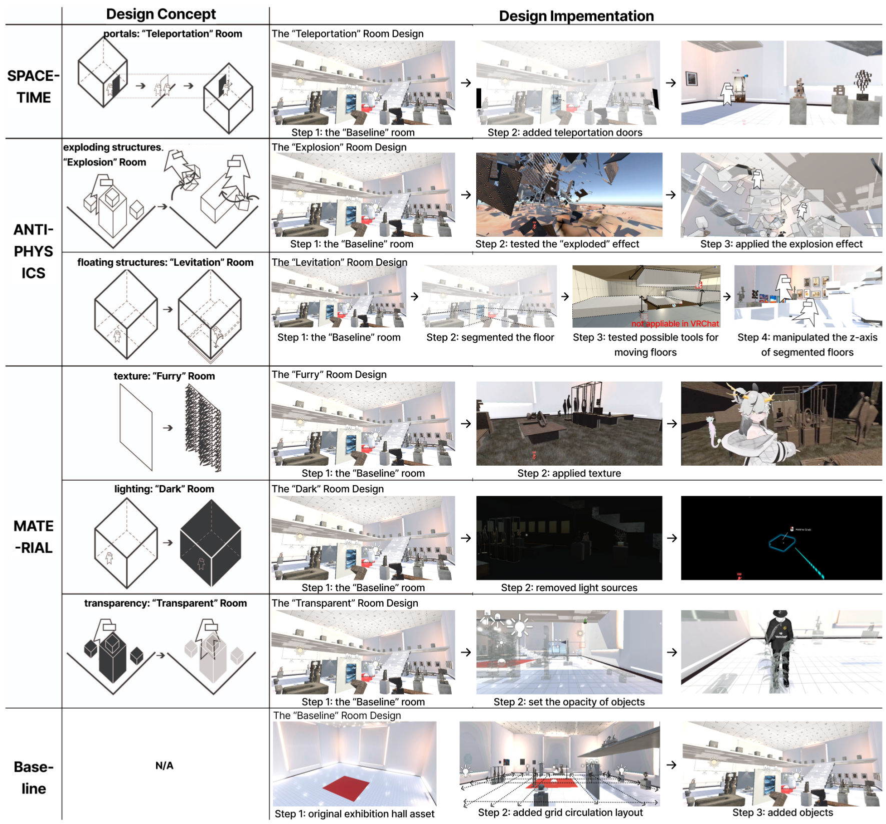


Fig. 1: "Impossible" Room Design Diagram and Implementation Process to illustrate design concepts, implementation strategies, and previews of the rooms

Under "Materials," the "Furry" room coats every surface in the gallery with fur. Using normal maps to create texture depth [23][24], the uniform "furry" layer blurs object–environment distinctions, making item detection more complex.

By eliminating all light sources, the "Dark" room also disrupts typical wayfinding. Players move carefully in near-total darkness, triggering object interactions only upon close proximity. This approach reveals how visual deprivation alters navigational strategies.

The "Transparent" room sets object transparency to zero, erasing traditional material boundaries and forcing players to rely on refraction and partial opacity to find a nearly invisible vase. This design further explores the relationship between visual feedback and user behavior.

3.1 Implementation of the "Impossible" Rooms

All rooms were developed using Unity [71] with the VRChat Software Development Kit (SDK) [72]. The "Baseline" Room was derived from a purchased exhibition hall asset [12] and modified by adding gallery-themed objects and a mezzanine level, to meet the requirements of the study.

4 Methods

This study is an object-finding task-driven study, aiming to understand how certain "impossible" spatial features (as shown in Section 3) can impact player-environment interactions and their perception of spatial information within the VRChat environment. To capture natural user behavior in virtual worlds [52], this study was conducted remotely, with all participants self-recording their first-person experiences under institutional ethical guidelines [56]. Approval was obtained from the institutional IRB.

4.1 Participants

Given the exploratory nature of this research, we recruited 12 VRChat players (3 females, 12 males) through popular social media platforms in China (WeChat, QQ, Xiaohongshu, and Weibo) and private VRChat player group chats on these platforms, to allow for in-depth behavioral and interview analyses while maintaining feasibility for remote VR testing. This size provided insight into varied exploration patterns. All participants were native Chinese speakers, aged 18 to 31, with an average age of 24 and diverse education levels as well as experience levels in VRChaat from Novice to Expert . Their VRChat experience included a broad range of familiarity with the platform from novice to expert. All participants owned a VR headset dedicated to VR activities.

4.2 "Impossible" Space Object-Finding Test Design

As shown in Figure 2, the process was as follows: (1) players were asked to join a group chat on QQ or WeChat (for convenience of communication) and complete a demographic survey. (2) Participants signed the consent forms which acknowledged the purpose of the study and asked for self-recording of the entire test process. We scheduled a time with the players individually and remotely to conduct the study within VRChat. Researchers explained the test procedure. (3) Then, the players used their accounts to log in, ensuring they were in a comfortable setting. Players went through the rooms in sequences of a random Latin square order [74]. (4) For each room, players followed a previously prepared document, which included a page with the room access link and the object to find, a page to mark the location and size of the found object, and a page instructing players to take a 5-minute break between rooms to minimize any influence from the previous room, for each room session. (5) After each break, participants continued this process until all rooms were visited and interacted with. (6) Players were compensated with 50 RMB upon successful completion of the experiment, aligning with ethical research practices.

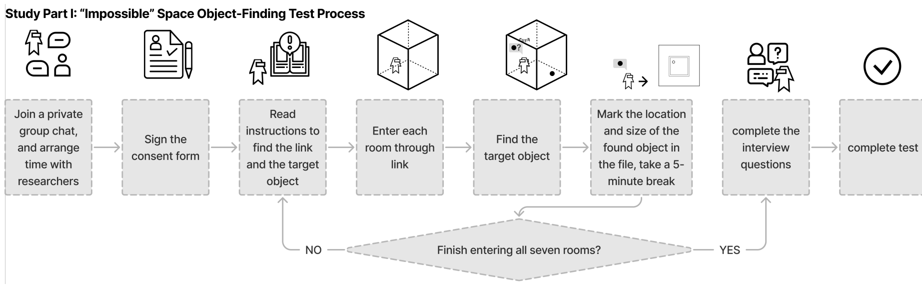


Fig. 2: Diagram of the study flow in the navigating and object-finding test.

Before the implementation of the official object-finding test with the recruited players, we conducted a pilot test among researchers. To ensure consistent difficulty across all rooms, we adjusted the level of difficulty of finding objects by modifying the location of objects based on the time spent in each room, so the difficulty level in each room would not affect players' behaviors and interactions. On average, researchers spent 2 minutes for each room during the final adjustment.

4.3 Data Collection and Analysis

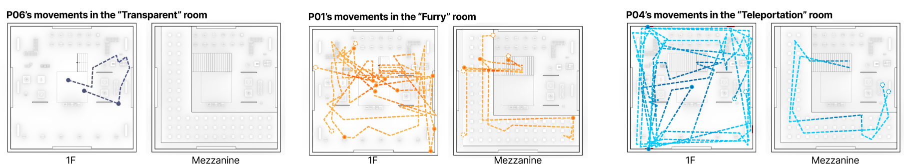
The collected data included self-recorded videos from each player and verbal interview feedback from the object-finding test. Due to the difficulty of analyzing the videos that were in the first person perspective or the usage of avatars, the researchers watched the videos and marked the trajectories of players' movements in each room (the example figure for the movement map is shown in Figure 3) while also recording each of the players' movements by marking the timestamp and content for each action. This study employed an in-the-wild qualitative research approach [61] [20] to explore similarities and differences in player interactions across the "impossible" rooms. We conducted a thematic analysis [5] for the analysis of the processed data from videos, the mapping data, and verbal feedback. The analysis resulted in three themes with three sub-themes for the object-finding test and three themes regarding the social event.

5 Results

5.1 Influence of "Impossible" Spatial Qualities on Player-Environment' Interactions

General Navigation Patterns Across the "Impossible" Spaces We mapped each participant's movements from their first-person video recordings, noting 2D trajectories (dashed lines) and "stops" (solid dots) where they paused for more than two seconds (Figure3). Three navigation patterns emerged:

1. **Task-Oriented Movement**: Predominant in the "Baseline," "Levitation," and "Transparent" rooms, where 11 players quickly located the target and exited (e.g., P6 in "Transparent," Figure3a).
2. **Exploration-Oriented Movement**: Common in the "Explosion" and "Furry" rooms, where many players continued exploring after finding the object (e.g., P1 in "Furry," Figure3b), drawn by novel visuals or tactile properties.
3. **Examination Movement**: Observed mostly in the "Teleportation" and "Dark" rooms. Participants carefully inspected the environment—checking doors systematically in "Teleportation" or methodically searching the unlit "Dark" room (e.g., P4 in Figure3c).



(a) Task-Driven Movement (Transparent)
(b) Exploration-Driven (Furry)
(c) Examination Movement (Teleportation)

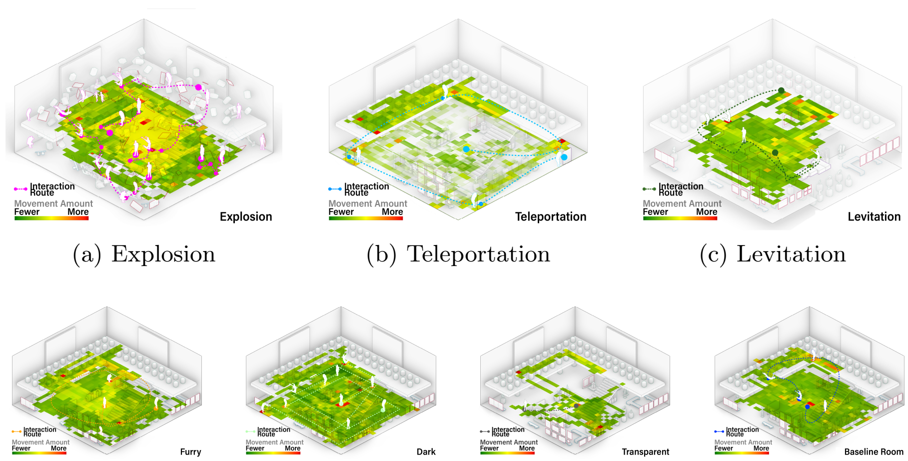
Fig. 3: Player movement trajectory examples.

Overall, visually complex environments or those with folded spaces prompted exploration and systematic examination, whereas more organized layouts led to task-driven movements. Additionally, limited visibility or reorienting spatial designs encouraged methodical exploration, while clear visual references facilitated quicker task completion.

Patterns of Interacting with Each "Impossible" Room Figure 4 presents heatmaps of player movements. Central "impossible" features often drew participants' attention, while certain designs (e.g., portals) prompted methodical inspection. Notable findings include:

1. **"Explosion"**: Players spent around 4 minutes, frequently jumping between levels and objects before or after finishing the task (Figure5a).
2. **"Teleportation"**: Participants averaged around 7minutes, examining doors and teleporting carefully (Figure5b). Approaches varied from one-by-one testing to meticulous scrutiny.
3. **"Furry"**: Most displayed quick, task-driven behavior, though a few spent up to 11minutes exploring the furry textures (Figure5c).
4. **"Levitation"**: Primarily task-focused, but the floating platforms took around 1minute on average—slightly longer than baseline—to navigate vertically (Figure5d).

5. **“Dark”**: Low visibility led to slow, systematic searching and thorough environment checks (Figure5e).
6. **“Transparent”**: Despite full transparency, objects were quickly found (around 30seconds) due to rendering cues (Figure5f).



(a) Explosion (b) Teleportation (c) Levitation

(d) Furry (e) Dark (f) Transparent (g) Baseline

Fig. 4: Player movement trajectory heatmaps in each room:

5.2 Influence of Spatial Qualities on Players’ Perception

Spatial Information of Location The results to show how players perceive the spatial information by examining the distance discrepancies between the object location and the players-mapped location are shown in Figure 6a. Particularly, in the “Teleportation” room where the average and the range of the discrepancies are the largest, teleporting doors reoriented participants, creating significant discrepancies between perceived and actual target-object locations. Participants struggled with distance estimation due to frequent reorientations. The “Explosion,” “Furry,” and “Transparent” rooms also showed large deviations in perceived versus actual object locations. In the “Explosion” room, fragmented objects and chaotic layout obstructed visibility, leading to confusion. In the “Furry” room, uniform textures made differentiating object profiles challenging, while in “Transparent,” invisible boundaries impaired participants’ depth perception. By contrast, the “Levitation” and “Dark” rooms yielded smaller location deviations. Players navigated more cautiously in these environments, improving memory and accuracy regarding object locations.

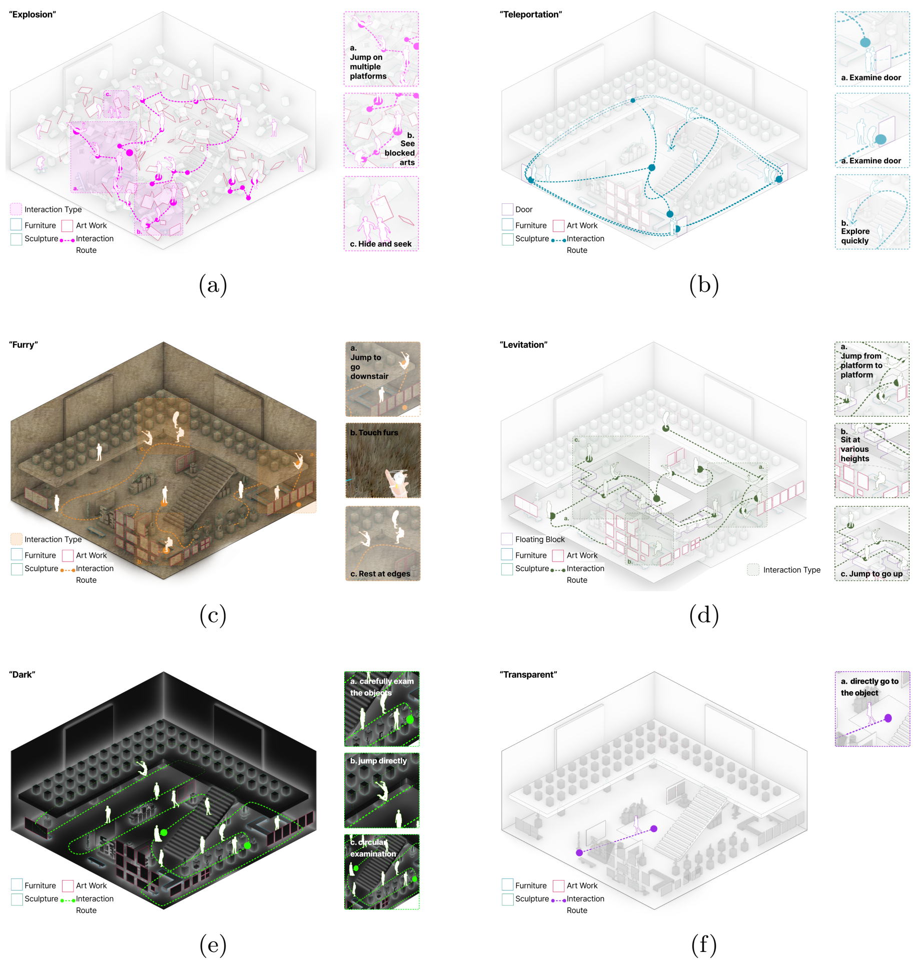
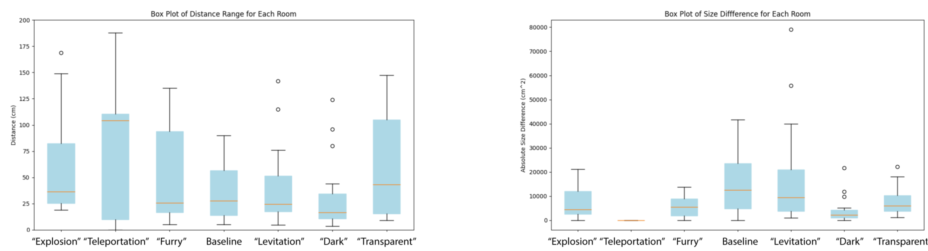


Fig. 5: (a) The "Explosion" room's chaos encourages players to explore fragmented objects. (b) In "Teleportation," participants systematically check each potential exit. (c) In the "Furry" room, players are less universally drawn to the material "impossibility," though some enjoy interacting with the fur. (d) In the "Levitation" room, floating floors extend playtime but do not strongly encourage additional exploration. (e) The "Dark" room prompts cautious navigation and thorough searching. (f) In the "Transparent" room, unintended reflections allowed players to rapidly locate the object.

Spatial Information of Size The results to show how players perceive the spatial information by analyzing player-marked versus actual object sizes are shown in Figure 6b. In the "Teleportation" room, size estimations were more accurate, likely because portals maintained uniform dimensions within VRChat. Conversely, the "Baseline" and "Levitation" rooms exhibited larger deviations



(a) (b)

Fig. 6: Spatial perception impacted by "impossible" features: (a) Position-deviation box plot comparing marked versus actual object locations; (b) Size-deviation box plot comparing marked versus actual object sizes.

in size perception. Extreme values were found in the "Dark" and "Transparent" rooms, indicating variability in players' adaptation to extreme uniformity (complete darkness or transparency).

6 Discussion

In addressing RQ 1, Section 3 illustrates the possibilities of "impossible" space designs in VRChat. Concerning RQ 2, our study shows that "impossible" features influence how players interact with virtual environments, as evidenced by the identification of three distinct navigation patterns and unique interaction modes observed during the object-finding tasks.

6.1 Influence of "Impossible" Spatial Design on Interaction

Participants' navigation was notably shaped by visual factors, including texture manipulation in "Furry" and lighting constraints in "Dark." These features increased exploration times and produced dispersed, boundary-free movement. Unified materials blurred object–background distinctions, complicating object detection. By contrast, suboptimal rendering in "Transparent" deviated from expectations, suggesting future enhancements through haptic rendering [3]. Balanced visual cues are essential for reliable spatial perception [53], a consideration especially relevant for physical applications such as dance [13][39][40][37][80]. Object placement also significantly influenced user actions. In "Explosion," visually complex scenes [7,64] prompted dispersed exploration, indicating that players enjoyed surveying all corners. "Teleportation," meanwhile, relied on constant spatial redirection [9], causing disorientation, reduced presence, and heightened VR sickness risks [11]; players responded by carefully testing each exit. Designs like "Levitation" embrace anti-physical movement [29], and redirected jumping [27] enhances realism and user comfort.

6.2 Spatial Perception Influenced by "Impossible" Features

For location discrepancies, the teleportation feature created the largest gap between perceived and actual object locations, as repeated reorientation hampered distance judgments. Conversely, it yielded the smallest size deviations because VRChat's uniform portals provided consistent size references. Rooms like "Explosion," "Furry," and "Transparent" exacerbated spatial confusion. Designers might mitigate this by adding landmarks [18]. In "Furry" and "Transparent," uniform textures and invisibility made object detection difficult [47]. "Levitation" and "Dark" saw fewer discrepancies as participants moved more cautiously. However, floating platforms and minimal light sometimes introduced outliers, reflecting variations in user adaptation to extreme conditions. "Baseline" and "Levitation" produced larger errors in estimating object dimensions, likely due to fewer realistic spatial cues on the second level. Without clear references (e.g., sculptures), objects' actual sizes proved harder to discern [53].

6.3 Design Implications

Our results show that "impossible" spaces can enhance user engagement and immersion by offering novel interactions beyond those found in physical environments:

- Incorporate elements like teleportation or furry materials to promote particular user behaviors like exploration, examination, and goal-oriented tasks.
- Strategically position objects to guide user behavior, improving overall user engagement by encouraging ongoing exploration.
- Recognize that visual complexity and material characteristics that influence user navigation and perception. Designers may modify these aspects according to valence and arousal[46] to either challenge or facilitate movement.
- Provide clear spatial references to minimize discrepancies between perceived and actual object dimensions and distances, to ensure higher usability and accessibility in virtual spaces.
- Create interactions that integrate with narrative aspects of the design to [41][43][69] [69][66][67][68]optimize spatial effects for a particular narrative purpose.

6.4 Limitations and Future Work

This study examines only six "impossible" rooms, constrained by VRChat's developmental environment. While VRChat's openness and accessibility facilitated public participation, platform-specific limitations may have restricted our design scope. Future research could incorporate additional platforms (e.g., Minecraft VR, Meta Horizon Worlds) to explore and compare more "impossible" designs. Despite pilot tests aimed at balancing task times, the final participants who were unfamiliar with these "impossible" environments, produced uncontrollable variability in duration. Future studies should recruit randomly selected pilot participants to optimize design parameters and ensure more consistent room-to-room comparisons. Our research, largely observational and qualitative, suggests broad design implications but lacks controlled, quantitative measures of engagement. Future studies should include experiments and user surveys to systematically evaluate the effects of "impossible" spaces on interaction and perception. Furthermore, future works can also employ computational metrics to fine-tune spatial layouts, for creating a quantifiable baseline to compare user exploration and engagement in physically impossible spaces and refine how complexity affects navigation, collaboration, and immersion in social VR. Additionally, most participants were experienced gamers familiar with VR, possibly affecting how they navigated these environments. Future work should sample users of varying experience levels to discern whether results hold across broader demographics. Finally, We acknowledge that our sample of 12 participants (predominantly male Chinese VRChat users aged 18 to 31) limits the generalizability of our findings. As an initial exploratory study, our focus was on understanding core interactions within a specific context. Future work can expand the demographic scope. In summary, future research should employ empirical studies with validated surveys to measure immersion and presence, enabling deeper insights into how "impossible" spatial features shape virtual experiences. Broader demographic participation will also elucidate cross-cultural differences, further refining our understanding of "impossible" spaces in social VR. Given the rise of generative tools for procedural generation in VR[46], we also surmise that GenAI workflows for teams and group collaboration[25][78][77][44][48][31][32] may be applied to physical design workflows[17][76][35][50][49][73], digital game environments[83][82][81][42][70], social apps that rely on spatial design[79], and novel spatialized musical experiences[14] for affecting the perception of users in customized environments.

7 Conclusion

Social VR applications provide players with virtual social spaces that transcend the boundaries of real-life interactions. This study explores the concept of "impossible" spaces within the context of an object-finding test, to understand the design and impacts of these impossible rooms on player behaviors, perceptions, and interactions. These anti-physic "impossible" features, such as explosion, teleportation, and abnormal textures like the "Furry" room, were shown to influence how players navigated and engaged with the environment. Three primary navigation patterns—task-oriented, exploration-oriented, and examination movements—were identified during object-finding tasks, highlighting how the spatial qualities of each room shape player interaction and perception. Spatial perception was notably affected by complex visual elements or uniform materiality, as seen in the "Explosion" and "Furry" rooms. The "Teleportation" room, with its reorientation mechanics, introduced challenges in spatial judgments, particularly in maintaining accurate distance perception. By exploring player navigation and interaction strategies, we uncovered insights into how "impossible" spatial designs can enhance user engagement in social VR. This study provides insights into the unique behavioral patterns exhibited by VRChat players, offering insights into how interactions may occur in virtual "impossible" environments.

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