

Sharing Play Spaces: Design Lessons from Reddit Posts Showing Virtual Reality in the Home

Daniel Harley

daniel.harley@uwaterloo.ca

Stratford School of Interaction Design and Business

University of Waterloo

Waterloo, ON, Canada

Cayley MacArthur

cayley.macarthur@uwaterloo.ca

Stratford School of Interaction Design and Business

University of Waterloo

Waterloo, ON, Canada

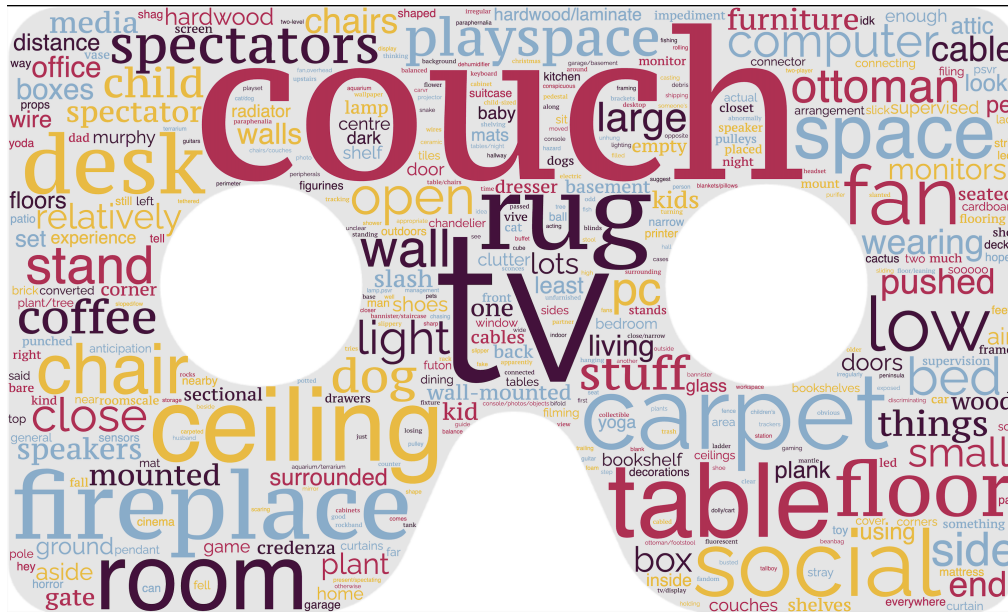


Figure 1: A word cloud visualizing words we used to tag the images of virtual reality play spaces gathered from Reddit.

ABSTRACT

With the increasing availability of consumer virtual reality (VR) devices for personal and recreational use, the domestic contexts of VR design are increasingly important. Given that much of the current interaction design research for VR is conducted in lab-based settings, there is a need for design considerations that engage with the complexities of these real-world spaces. We present an analysis of visual data (e.g., GIFs, videos, photographs) collected from a manual search of Reddit posts that show “play spaces” and other home-based contexts of VR. Our findings offer insight into the diverse and dynamic characteristics of VR spaces, with set-ups ranging from bedrooms to garages, and with the people, objects, impediments, and affordances of individual spaces demonstrating

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DIS '23, July 10–14, 2023, Pittsburgh, PA, USA
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ACM ISBN 978-1-4503-9893-0/23/07...\$15.00
<https://doi.org/10.1145/3563657.3596005>

a variety of ways that VR is used in the home. We conclude by discussing directions for future interaction design research that seeks to incorporate physical actions and environments while also engaging with the complex realities of domestic VR.

CCS CONCEPTS

- **Human-centered computing** → **Virtual reality**; *Interaction design*.

KEYWORDS

virtual reality, domestic, home, interaction design, social, play, visual analysis, Reddit

ACM Reference Format:

Daniel Harley and Cayley MacArthur. 2023. Sharing Play Spaces: Design Lessons from Reddit Posts Showing Virtual Reality in the Home. In *Designing Interactive Systems Conference (DIS '23)*, July 10–14, 2023, Pittsburgh, PA, USA. ACM, New York, NY, USA, 14 pages. <https://doi.org/10.1145/3563657.3596005>

1 INTRODUCTION

As virtual reality (VR) research in the HCI community continues to develop novel physical interactions that incorporate real-world objects and environments, the possible domestic contexts for these

interactions have received less attention. As O'Hagan et al. [33] write, many VR “systems are designed and tested entirely within the lab with little or no empirical evidence of the interaction being designed for actually occurring in the wild.” While the lab-based settings of much of the design research for VR will continue to be valuable to examine and propose novel physical, tangible, and embodied interactions, understanding how these experiences might extend to the home remains a challenge.

Meanwhile, consumer devices are increasingly capable of the kinds of tracking and representation explored in research settings, and VR devices are becoming more mainstream. The Meta Quest 2, a standalone headset that offers “room scale” experiences by tracking the headset and controllers, is said to be leading VR sales worldwide [41]. Although some research has begun to turn to domestic environments by analyzing VR fails [5], or bystander interactions [33], or proposing remote studies that leverage participants' own headsets [35], there are still many unknowns about the real-world spaces that people use for VR. For Dao et al. [5], the need to understand VR outside the lab presents opportunities for design that engages with the “messy, busy, and dynamic” contexts of VR in the home.

Recent work has only begun to reveal the complexities of these domestic spaces. For example, in their examination of the possibility of remote VR studies, Radiah et al. [35] note that 60% of their participants “seemed to operate within a space of up to 10m².” These were most often personal spaces like bedrooms, with participants reporting that using these spaces for VR required little to no effort for set-up. This amount of space would seem to be more than enough for room-scale VR (for example, Meta recommends 2m by 2m). However, current work has not yet examined what else might be in those rooms, and/or how the arrangements of these spaces might affect VR experiences. Differences in headsets require different set-ups: there are standalone headsets like the Quest 2 that do not require any additional hardware, meaning that they might be used in any room; other headsets like the HTC Vive and Rift require connections to powerful computers and external sensors with more elaborate set-ups; finally, the PSVR requires a connection to a PlayStation console, which is likely to be connected to a television. Differences as to where and how VR is used in the home stand to impact a range of interactions and experiences.

To better understand this research and design space, we present an analysis of visual data gathered from Reddit posts that show examples of domestic VR. While text-based analyses of Reddit posts are perhaps more common in HCI research to understand how communities engage with specific topics (e.g., [10, 11]), we propose that visual media (e.g., images, videos, GIFs) that people upload and share on VR subreddits offer insight into some of the everyday characteristics of VR use. Focusing specifically on the spaces that people use for VR (often called “play spaces”), our work strives to develop considerations for interaction design that responds to the unique attributes of domestic VR.

Drawing on visual ethnography for our study design and analysis, we performed a manual search of 9 subreddits and retrieved 83 visual depictions of VR play spaces. We argue that not only does this examination reveal additional considerations for conducting VR studies in domestic contexts, but it also raises important questions about how HCI researchers and designers might attend to the

complexities of these environments. We contribute insight into the real-world contexts of VR—including arrangements of furniture, possible impediments, and the many unpredictable characteristics of home environments—which in turn presents important opportunities for design research to accommodate home settings that are diverse and dynamic.

2 RELATED WORK

This section provides an overview of design research that is engaging the body and physical environments in VR, including tangible and haptic interactions, embodied action and movement, and other forms of physicality. Given that much of this work is conducted in lab-based settings, imagining how this research might be applied to domestic contexts begins to point towards a need for additional design considerations. The section concludes with research that is beginning to implicate the home more directly; ultimately, we suggest that understandings of the social and material dimensions of domestic spaces remains a gap in current research.

2.1 Extending the Physicality of the Virtual

2.1.1 Extending physical environments. In the years before and after the release of consumer VR, the HCI community has been pushing the boundaries of physical interactions in virtual worlds. Several projects have proposed that the physical environment can (or should) change to accommodate interactions in VR. In 2015, before the release of major consumer headsets like the Oculus Rift and the HTC Vive, Cheng et al. [4] proposed the labour of multiple “human actuators” to move physical props, walls, doors and other objects to provide people with the just-in-time realism of “feeling” the virtual world and the sensation that they were in a larger space. Subsequent work would propose robotics for similar applications, with swarm robots moving physical furniture to accommodate a virtual setting [45], or autonomous robotic walls for haptic interactions [50]. While these projects showed the possibility of extensions to the physical environment around the player, other projects would show extensions below and above the player. For example, Teng et al. [46] proposed the TilePop system consisting of pneumatically-actuated floor tiles that would raise based on the interactions in the virtual environment, and Han et al. [17] created a moveable structure rigged above the player's head that could provide effects like heat, wind, rain, and mist.

2.1.2 Interacting with physical objects. HCI researchers have also expanded physical interactions with tangible and haptic devices, as well as with perceptual illusions. Lopes et al. [23] used EMS to create the haptic sensation of holding, lifting, and touching virtual objects. Azmandian et al. [1] proposed a system for haptic retargeting in order to repurpose the same tangible props within a virtual environment. Cheng et al. [3] use a similar strategy for the “sparse haptic proxy,” a system that combined haptic retargeting and a wall that provided different forms of haptic feedback depending on the visuals. Other work has focused on the physical characteristics of tangible objects. Zenner and Krüger [51] presented a shape-changing device to simulate different weights with the same object. Harley et al. [18] explored a combination of passive and active haptics with a physical cube and a stuffed animal for storytelling in VR. Tangible design work has also turned to robotics.

Hoppe et al. [21] suggested that small flying drones could offer various forms of haptic feedback. Vonach et al. [48] use a robot arm for similar purposes, combined with an omni-directional treadmill for walking in VR.

2.1.3 Interacting with other people. A variety of research has also examined how multiple people can work or play together within co-located VR settings. Sra and Schmandt [43] presented the MetaSpace system to improve full-body tracking to enable multiuser VR interactions. Cheng et al. [2] showed two players acting as “actuators” for each other, playing different games but both physically interacting with a single prop that has different effects in the two virtual worlds. Work by Gugenheimer et al. [16] and Zhou et al. [52] present examples of asymmetric interaction, in this case referring to one player in VR and the other not, playing with each other in the same shared physical space.

2.1.4 Mixing realities. Exploratory design research proposing expanded forms of physical and embodied interactions have also imagined domestic contexts, anticipating both opportunities and challenges for novel interaction design in VR. Opportunities for at-home interactions are suggested by projects like Substitutional Reality [42] and Annexing Reality [20], which propose a pairing of virtual and physical objects, with physical objects in the space having virtual counterparts. Challenges are suggested by work that integrates a variety of sensory cues to help people avoid collisions. Hartmann et al. [19] visually blend the physical and virtual for this purpose, noting the possible danger when people have difficulty differentiating between physical and virtual worlds in mixed reality. Similarly, George et al. [13] use auditory and haptic signals to alert people to boundaries, and von Willich et al. [47] propose a system to dynamically integrate representations of passersby when they enter the play space.

2.2 Preliminary Understandings of Domestic VR Contexts

How any of the research described in the preceding section might be experienced in the wild or in at-home settings is largely unknown, yet there is some work that is beginning to assess some of the complexities of consumer VR in the home. For example, Dao et al. [5] present an analysis of YouTube videos depicting VR “fails” documenting a number of breakdowns that led to harm and/or damage to property, including people in VR falling over, hitting spectators or others in the room, or colliding with something in the real world. O’Hagan et al. [33] extend this work using surveys to examine the interactions in the room between people in VR and bystanders who are not in VR, which ultimately implicates the physical spaces that people use for VR.

Another relevant research area that has received increased interest (especially after COVID-19 lockdowns) has been the possibility of leveraging participants’ own VR headsets for remote studies [24, 25, 29, 36, 44]. This research suggests both benefits (e.g., opportunities for more diverse recruitment) and limitations (e.g., the need to adapt data capture tools originally created for lab use). However, efforts to leverage this research to understand how expanded forms of VR interactions might be applied in domestic contexts remain difficult: first, the research does not address the challenges of novel

interaction design; second, many of the characteristics of a possible participant’s home environment are not directly considered.

Given that the exploratory research described in section 2.1 was conducted in lab-based environments, one way to continue developing these expanded forms of VR interaction design is to test their use and applicability in “real world” settings, including the home. Overall, however, preliminary understandings of these domestic contexts raise questions about where and how consumer VR is used, suggesting an opportunity to provide insight into the specific characteristics of these domestic contexts.

3 METHODOLOGY

In section 2 we suggest that a next step for novel interaction design for VR is to engage with the specificity of at-home contexts. To contribute insight into this design space, we look to visual content shared on Reddit that shows real-world examples of domestic VR use. Although Reddit is primarily a text-based social media platform, the ability to post images and other visual material within specific (and often overlapping) VR communities (i.e., subreddits) offers a unique repository of visual material depicting examples of VR use, ranging from the mundane to the extraordinary. With posts roughly categorized within subreddits and (to varying degrees) moderated by these communities, the visual content includes images as well as embedded videos and GIFs that are in some cases also shared on other platforms like YouTube and/or TikTok. In this study we ask the following questions:

- **RQ 1:** Where and how does VR appear to be used in the home?
- **RQ 2:** What are the visible similarities and differences between the spaces used for VR?
- **RQ 3:** Based on the findings in RQ1 and RQ2, how might these characteristics affect novel interaction design research that incorporates physicality and physical environments in VR?

To answer these questions, our methodology draws on visual ethnography [34], which examines and incorporates visual data to better understand everyday contexts “from inside” as a reflexive and experiential process. As Pink [34] describes, it is an approach that can leverage a variety of visual evidence, which then functions not only as “a mode of narration or story telling about everyday activity, but also as a mode of revealing the analytical interests, intent and argument of the researchers.” Within visual ethnography, visual data like photographs and videos are understood to offer more than simple documentation of a scene or an event. The data provides visible evidence of social, cultural, and material realities that might be taken for granted, or (in some cases) seen as mundane and unexceptional parts of everyday life.

This focus on the communicative potential of visual material informed both our manual approach to data collection on Reddit as well as our analysis of the data. For data collection, rather than an extractive approach that might separate all visual material within a specific timeframe, a manual approach offered an opportunity to use some of the platform’s affordances in the data collection procedure: scrolling, searching, and using the subreddit’s sorting functions. Not only are scraping tools that extract particular forms of visual data against Reddit’s terms of use, but a manual approach

Selection	Select subreddits (highest volume, VR-related subreddits)	Gives us: r/Quest2, r/OculusQuest, r/virtualreality, r/oculus, r/vive, r/steamVR
Filtering	Use post flair, if applicable ("photo/image/video") and/or Scroll back 6 months	Gives us: First round of posts for initial tagging
Initial tagging, iterate on Selection & Filtering	Selection: Add subreddits frequently cross-posted Filtering: Search "playspace" and "play space"	Gives us: Additional 3 subreddits r/psvr, r/valveindex, r/VRtoER (total n = 9 subreddits)
Collecting and tagging data with new Selection and Filtering criteria		Gives us: n = 117 posts
Filtering for eligibility	Included: 83 posts Excluded: 34 (e.g., duplicates, not enough information shown about the room/only depicts one object)	
Tagging and indexing	Tag/index items and characteristics of the space depicted in each of the 83 included posts	
Categorizing	Develop guiding questions to categorize spaces shown in posts (results reflected in Table 2)	

Table 1: A summary of our procedure, which is described in detail in Section 3.1.

offered specific benefits. As our interest was in the spaces that people use for VR, seeing the posts that we selected in the larger context of the platform helped us to familiarize ourselves with the visual material, ultimately leading us to include GIFs and videos in addition to images (which had been our original plan), and would help us identify additional subreddits and keywords. Our approach to data collection received clearance from our university's Research Ethics Board, and involved removing any personally identifiable information from the posts during data collection. As a further step towards removing any possible identifiers, we chose to convert any images included in this paper into line drawings.

As for analysis, visual ethnography stresses that the findings are an interpretive reflection on situated practices and 'ways of knowing'. This is especially relevant in the case of the data we collected: the people who use VR and post images of their homes on Reddit are not necessarily representative of broader populations. However, this sample offers an entry point for more complex ethnographic studies that strive to bridge speculative design work and the ways that people bring VR into their homes.

3.1 Procedure

We began our investigation of Reddit sources by starting with six subreddits that represented the most popular groups at the time (in terms of total subscribers membership) pertaining to the topic of virtual reality. These were: r/Quest2, r/OculusQuest, r/virtualreality, r/oculus, r/vive, r/steamVR. Following our methodological interest in using Reddit's affordances to collect data, we determined an initial procedure through which we selected and saved visual content: 1) begin with subreddit's default sorting (*Hot* is the default, with other options being *New* and *Top*); 2) when possible, sort posts by photo/video (Reddit calls sorting categories *flairs*); and 3) scroll through the posts until either the subreddit ends, the platform prohibits further scrolling, or posts are at least 6 months old.

We then iterated on the procedure based on preliminary observations of our initial tagging, and, in some cases, a lack of data. For example, r/vive returned no relevant images of homes after scrolling to posts that were six months old. However, working through the subreddits in this way revealed two relevant additions for a second round of data collection: first, images of rooms where people use VR would sometimes be referred to as a "play space" (even though Meta and HTC Vive sometimes call this a "play area"), and second, some

relevant content was cross-posted in other subreddits, including r/psvr, r/valveindex, as well as a subreddit called r/VRtoER, which focuses on injuries and damage caused by VR use. We included these additional subreddits and added another step to our procedure: use the search term "play space" and/or "playspace" in cases where the previous steps failed to yield results to supplement the initial pass (this resulted in the inclusion of posts older than six months). This resulted in 117 posts that we used for further analysis. Rather than attempt to capture every post with possible relevancy, we relied on the principle of saturation, determining our stopping point when our initial tagging of data collected in the second round did not offer any new higher level categories for analysis.

3.1.1 Tagging, indexing, and categorizing data. Two researchers participated in tagging, indexing, and developing categories [37] for the data. Posts were removed if they were duplicated in another subreddit or if not enough information was visible to be able to discern what room or part of the home the source showed (e.g., 16 images from r/VRtoER showed a close-up of something that was ostensibly broken while playing VR, like a TV or a light fixture, without showing the rest of the room—these were removed). These exclusions resulted in removing 34 images across the data set, with the remaining 83 used for closer analysis. At this stage, we determined that some surface level differences were not directly relevant to our overarching research question. We therefore did not explicitly consider such factors as the date of the post, or how many times it has been up-voted, or attempt to draw out distinctions between posts that included photographs compared to those that included videos. These latter cases simply offered more visual information for tagging and indexing. Moreover, while an analysis of the text of the posts might have helped to determine possible intentions, reflections, or how people used Reddit for community or advice, this too was outside the scope of the current research questions.

For each successive stage of data collection, we began by tagging the sources to document what was visibly depicted. We then discussed the tags to begin to identify larger categories to help classify and analyze the content. Figure 1 presents a tag cloud generated using the resulting tags, offering a quick visualization for the purpose of impression formation [38]. The top ten tags were: TV, couch, ceiling, table, carpet, rug, fan, fireplace, social, and chair. Looking for similarities and differences across our tags served as an initial point of discussion. TVs and couches were the most common, and began to suggest not only what room might be most common

Subreddit name	r/VRtoER	r/Quest2	r/OculusQuest	r/virtualreality	r/oculus	r/vive	r/steamVR	r/PSVR	r/ValveIndex	Sum
Total posts	33	5	7	4	6	11	2	3	12	83
Room type										
livingroom	26	3	4	3	1	5	0	2	2	46
bedroom	2	0	0	0	3	2	0	1	3	11
basement	3	1	1	1	0	0	0	0	2	8
other	3	1	1	1	0	0	0	0	2	8
office	1	0	0	0	0	2	0	0	3	6
garage	0	1	0	0	1	1	0	0	0	3
Characteristics (yes/no)										
Impediment(s) present	33	5	7	4	5	11	2	3	11	81
Social space	26	2	0	2	1	2	0	0	1	34
Dynamic space	12	1	1	0	1	1	0	0	2	18
Dedicated arrangement	0	0	0	1	3	2	0	0	5	11
Seated experience	0	0	0	3	1	1	0	0	1	6
Modifications to the space										
No visible changes	28	5	2	3	1	5	0	2	0	46
Temporary	4	0	5	0	2	4	2	1	8	26
Permanent	1	0	0	0	3	2	0	0	4	10
Headset type										
Quest2	24	5	1	3	1	1	0	0	0	35
Valve Index	0	0	0	0	0	0	0	0	12	12
Vive	2	0	0	0	0	10	0	3	0	12
Unclear/unknown	3	0	2	0	1	0	2	0	0	8
Quest 1	0	0	4	1	0	0	0	0	0	5
PSVR	4	0	0	0	0	0	0	0	0	4
CV1	0	0	0	0	2	0	0	0	0	2
RiftS	0	0	0	0	2	0	0	0	0	2

Table 2: The key categories and subreddits for our data collection, including rooms used for VR, relevant characteristics of the space, types of modification to the space, and types of headsets.

but also what else was in that room: often a table or other furniture; sometimes a fireplace, and often some evidence of a social environment. Ceiling and fan were both common words because they offered combinations — e.g., a ceiling fan and low ceiling were separate tags, but both pointed to a possible impediment above the player. Similarly, carpet and rug showed common surfaces that players would stand on. Ultimately these tags offered a chance to draw attention to the spaces around the player to begin to develop higher level categories.

To answer RQ1 and RQ2, we then iteratively developed a series of questions to begin indexing and categorizing the data: 1) What is the type of room (e.g., bedroom, office, living room, etc.)? 2) Are there visible impediments (i.e., is there something within or near the play area that could be a danger to a player)? 3) What are the types of impediments (i.e., is it furniture, objects on the ground, something associated with infrastructure like walls or light fixtures, or a combination thereof)? 4) Is it a social activity (i.e., does the source visibly show others in the space at the same time as the person using VR)? 5) Is there evidence that the space is dynamic (e.g., direct evidence of people or pets moving into or around the play area)? 6) Is the set-up a dedicated space (i.e., is the room used *only* for VR)? 7) Is it a seated experience (vs. standing, or movement-based)? 8) Is there visible evidence that something has been modified or changed to create a play area (e.g., visual evidence of furniture pushed aside)? 9) If there have been modifications, what is the relative level of effort or permanence (i.e., are the changes temporary like a coffee table pushed aside, or more fixed, like cables tethered to the ceiling)? 10) If a headset is depicted (and identifiable),

which headset is it? The results of this process of categorization are shown in Table 2, which shows how our answers to the questions were counted across each of the subreddits.

4 FINDINGS

In this section, we report on the findings of our tagging and categorizing to answer RQ1, which asks where and how VR is used in the home. Table 2 shows how many posts were collected and sorted across the subreddit data, with r/VRtoER offering the most (33/83) and r/steamvr offering the least (2/83). Although we were initially concerned that the data from r/VRtoER might skew our results towards particular set-ups and environments, there were no observable differences in the spaces themselves compared to the rest of the data set. While the type of headset was not always easily identifiable (or in some cases not visible in the image), the most popular in our data set appeared to be the Quest 2 (35/83). The most popular space overall for VR was living rooms (46/83), and more than a third of the spaces (34/83) included visible evidence of social activity. Although these visible examples of social activity were not exclusive to living room spaces, spectators often sat and watched from couches or sofas.

4.1 Impediments

While r/VRtoER solicits posts that show evidence of property damage or injury, the vast majority of posts across all subreddits (81/83) showed possible impediments, meaning that if the set-up was a contributing factor, similar damage or injury would be possible in

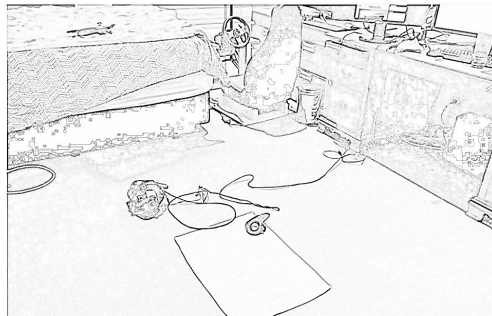


(a) An example of a living room presented as a VR space.



(b) An example of a person playing VR in their living room.

Figure 2: Two images showing living rooms presented as VR spaces.



(a) An example of a bedroom with a play area defined by a towel on the ground.



(b) An example of a Murphy bed against the wall to make space for VR.

Figure 3: Two images showing bedrooms as VR spaces.

almost all cases. Moreover, there was no specific type or combination of impediments that we could definitively identify as resulting in danger; instead, impediments ranged from nearby furniture to objects on the ground, to infrastructural characteristics like walls, or built-in shelving, or light fixtures. 23/83 of the spaces showed all three types of impediments (with 9 of those cases in r/VRtoER). Given that 12/18 of the posts that we categorized as dynamic came from r/VRtoER, there may be something particularly dangerous in those cases. Differences in headsets and/or in-game affordances may help to predict degrees of difficulty navigating impediments. For example, the Quest 2 is designed to provide standing experiences, meaning that in almost all of the instances where that headset was shown, people were navigating some kind of impediment while moving. Only 6/83 showed seated experiences, though these also all had some visible impediment (e.g., a nearby table).

4.2 Set-ups

Although living rooms were often used as play spaces (46/83), there was usually very little visible set-up or modification to these spaces beyond moving a coffee table or creating space in front of a TV (e.g., Figure 2a, Figure 2b). While our tagging process can only capture rough approximations of the level of effort that people used to set

up their play space, we found that more than half of cases (46/83) showed no visible evidence of modifying the space to make it more conducive to VR. 26 posts showed temporary modifications (e.g., moving a chair out of the way in Figure 3a to create space between a desk and the end of a bed), while 10 posts showed evidence of more permanent modification (e.g., the Vive Base Stations screwed into the wall in Figure 3b). We only categorized two rooms as having no impediments, both of which were also classified as among the 11 dedicated spaces. Both of these rooms were relatively large (one appeared to be a large bedroom, the other a living room, which was the only living room categorized as a dedicated space) and completely empty. In both cases there was enough room to create a large virtual boundary while staying safely away from the walls; the bedroom included soft play mats on the ground, while the living room had hardwood floors. While the remaining spaces classified as dedicated had possible impediments, a common feature in dedicated spaces appeared to be an effort to distance and/or close off the space from other parts of the home. None of the dedicated spaces had visible evidence of in-person social activity.

4.3 Dynamic data

The iterative process that we used to come to a consensus when categorizing the data revealed important analytical challenges. The visual data, whether still images or short videos, only provides a snapshot of a lived environment, and the categories we developed often imposed an artificial permanence to the moment that was captured. For example, to classify an image as dynamic meant that we saw visual evidence that something or someone was entering the play space, which in turn would require the person wearing a headset to be aware of that possibility. Common examples were young children and pets. This narrow definition meant that the dynamic environments we identified (18/83) were primarily a reflection of play spaces that were or could be unexpectedly interrupted, though generally speaking that is also possible in cases with spectators, which was more common overall (34/83).

Similarly, our narrow definition of a dedicated space (one in which the primary purpose appeared to be for VR alone) meant that there were very few dedicated spaces (only 11/83). Although many of the rooms in our data may be the only space that person or family used for VR, we determined that it was an important distinction to separate attempts to transform the space into something more conducive to VR. Such caveats could be applied to each of our categories. For example, without deeper ethnographic engagement, the snapshot that the data provides also meant that identifying rooms into five main types (bedroom, office, garage, living room, basement) could flatten what would otherwise be important distinctions between how those rooms are used and referred to within their original context. As we suggest in section 6, such uncertainties point to opportunities for further ethnographic work.

5 VISUAL ANALYSIS

In this section, we turn to a qualitative visual analysis of a subset of the data to answer RQ2, which seeks to better understand similarities and differences across spaces used for VR. Our goal in selecting the images in this subset is to begin to show some of the range of play spaces within our data, which in turn can be used to help develop future ethnographic or design-based work. By pairing descriptive text with the photographs, we acknowledge the different ‘views’ these formats provide of multimodal environments [7], with the text alternating between description and interpretation of how the environment is, or may be, impacted by VR use. Analyzing this visual material is important for the additional detail and contextual information it provides: our categorizing and tagging only provides a surface-level analysis of what is shown in the data, with a need for further ethnographic analysis to examine how these spaces are configured and used. As we will describe, images that are assigned similar tags can show rooms that require different design considerations.

The six images selected for this analysis include two depicting active movement and nearby impediments (Figure 4a, Figure 4b), two images offering examples of dynamic characteristics in the space (Figure 5a, Figure 5b), and two images showing examples of modifications to the space (Figure 6a, Figure 6b). We begin with descriptions that serve to annotate characteristics in the selected images, followed by analysis that draws out findings across this subset.

5.1 Movement in small spaces

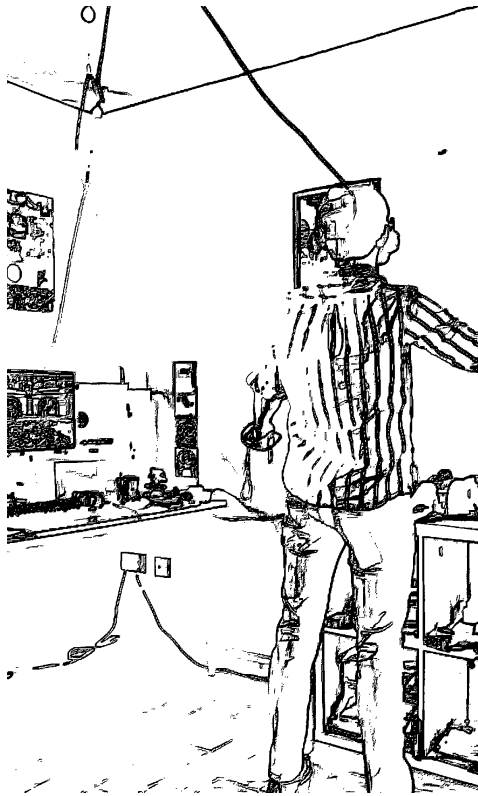
Figure 4a is a screenshot showing a player stretching out their arms within a relatively small room. To their left is a desk with a PC, which powers the headset, and a monitor. On top of the desk is a variety of gaming paraphernalia. Wires from the PC to the headset are anchored to the ceiling. Directly in front of the player is a cabinet; there are objects both inside and on top of the cabinet. The headset is an HTC Vive, meaning that this is a tracked, “room scale” experience. The game can be seen on the monitor screen; it is a fighting game that requires a swinging motion with the arms. With this degree of expected movement, the cabinet and the desk are both possible impediments that the player would have to avoid. The short video ends with the player accidentally hitting the cabinet with their hand.

Figure 4b is a screenshot showing a player punching while playing a VR boxing game. The headset is a Quest 2, meaning that it offers untethered tracking for this room scale experience. Behind the player is a couch, and what appears to be a dog bed with a blanket on top of it. The containers by the wall to the right of the player are what look like two glass terrariums, stacked on top of one another. The video shows that in front of the player is a large television casting the experience in real time, with at least two spectators (one filming, one standing nearby) watching. Above the player and not visible in the screenshot is a ceiling fan, which is turned on. Reaching up would be a possible danger, as would any additional movement forward, backward, or to the sides. There does not appear to be any effort to clear a play space.

5.2 Dynamic environments

Figure 5a is one of a series of photographs posted under a single thread. It shows an adult and a child both wearing Quest 2 headsets in what appears to be simultaneous play. The child stands directly in front of an ottoman, while the adult stands a few steps in front of a couch. The adult wears shoes, but the child does not; not visible in the line drawn version of the image are a pair of sandals by the couch. The blur of the ceiling fan above the adult shows that it is on, and would be an impediment if the adult raised their hands above their head. It is a social experience in the sense that there are two simultaneous players, but other than a possible photographer, there are no visible spectators. The room is relatively large, with ample space for VR, but there does not appear to be any effort to clear a play space. The proximity of the two players could pose a danger. The series of images shows different arm positions, and also suggests that the two players are within reach of one another.

Figure 5b is one of a series of photographs under a single thread, showing a player and their dog, with the dog resting its head on the player’s feet. The headset is a Quest 1, and the room appears to be used mostly for storage, with a fridge and cupboards in the background to the player’s left. The nearest visible impediment (other than the dog) is a chair a few feet in front of the player. With entryways on the left and right-hand side of the image, there is a possibility of other people passing through the space, but otherwise there is no space set aside for spectators, and the room does not appear to have been cleared or modified specifically for VR.



(a) An example of a smaller play space with nearby desk and computer.



(b) An example of playing a VR game in a living room.

Figure 4: Two images depicting active movement and nearby impediments.

5.3 Modifying spaces for VR

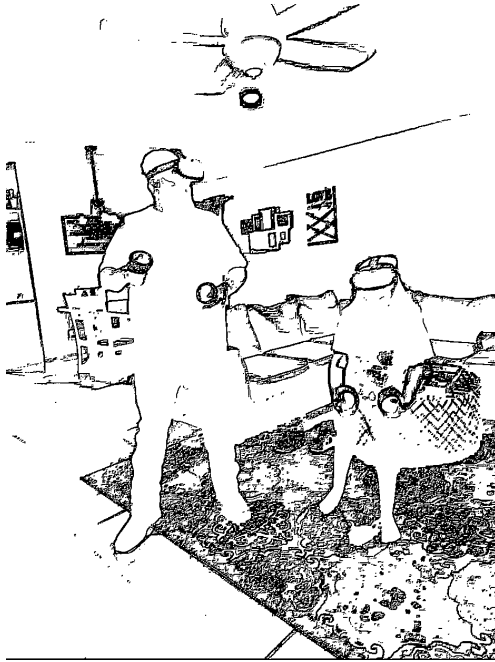
Figure 6a shows a living room with a clear attempt to move objects and furniture out of the way to create a play space, represented here by a relatively bare carpeted area in the centre of the image. In the back corner of the room to the right of glass doors is an ottoman in front of a glass aquarium. Next to this is a TV and fireplace, with the hearth of the fireplace covered in towels or blankets, perhaps to protect the player from hard edges. On the right-hand and left-hand sides of the image are couches, which are mostly out of frame. In this arrangement, the player would be just below a ceiling fan.

Figure 6b is one of a set of two images showing a “dedicated” VR space. The room is a garage. Foam mats have been placed on the majority of the ground shown in the image. A Quest 2 headset is on the ground in the middle of the image. Along the back wall is a variety of storage and objects, including chairs, a fan, tools, weights, a vacuum and other items. To the left of the image is a couch, with the alternate image in the set (not included here) showing that the couch is almost directly in front of a TV and a computer monitor. Also shown in the alternate image is a fridge and additional storage shelving, which would be located just out of frame in the lower left-hand side of this image.

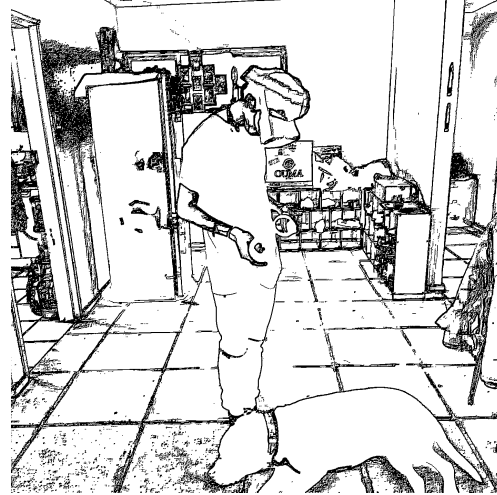
5.4 Drawing connections across spaces

Interpreting this subset of visual material alongside our quantitative data begins to reveal important details and a level of complexity that might otherwise be overlooked. Analyzing these images in pairs and/or across this subset helps to show what the higher-level categories cannot capture.

5.4.1 Revealing differences. The first finding of our visual analysis is that there are crucial differences in spaces that might fall under the same categories. For example, Figure 4b and Figure 5a had nearly identical tags: both are examples of living rooms, both have nearby furniture and ceiling fans that could become a danger if the players moved more freely. Both are also social experiences, though one is with another player and the other is with spectators. The higher-level categories, however, do not show what these players would need to do to make their VR spaces safer for the movement that their play requires, or the number, range, and variety of visible objects within the play spaces. There are also important differences in the size of these spaces, not only the size of the room but also the size of the space that is available given the current arrangement of furniture, objects, and bodies within that space. Yet, noting these



(a) An adult and child both playing VR in the same space.

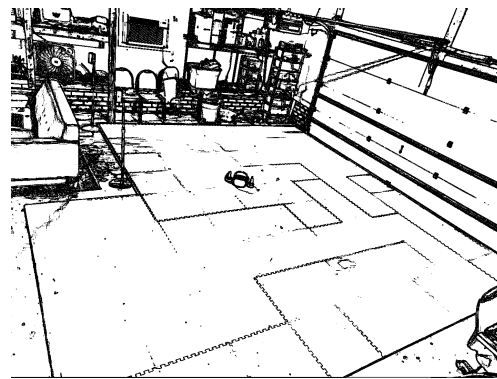


(b) An example of a dog entering, and staying within, the play space.

Figure 5: Two images offering examples of dynamic characteristics.



(a) A living room with temporary modifications to create a play space.



(b) A garage that has been transformed into a dedicated VR space.

Figure 6: Two images offering examples of modifications to the space.

differences does not negate the need to also recognize the similarities between these spaces: Figure 4b and Figure 5a show that living rooms, however different they might be, are also opportunities for spectatorship. Some of our other living room examples showed that spaces of common gathering in the household might leverage the room's current set up, with the orientation of the couch often pointing towards a TV screen casting the player's view of the VR game.

5.4.2 Revealing similarities. Just as comparisons of images within similar categories can reveal important differences, comparing images across different categories can reveal important similarities. In Figure 4a and Figure 6b, while a clear distinction is the easily noticeable differences in available space to manoeuvre, both images show steps that the players have taken towards a more permanent VR set up. In Figure 4a, although we do not classify it as a “dedicated” VR space, because the room clearly serves at least one other function, this is likely the primary room where this player uses VR, and there is a semi-permanence to this set-up as suggested by the wires tethered to the ceiling. Using VR elsewhere in the home would require relocating the PC, the wiring, and the tracking sensors for the headset. By contrast we classify Figure 6b as “dedicated” because the primary purpose of the room has changed: although the garage is still partly used for storage, using it entirely for storage or for cars would mean changing the primary purpose of the room again. The more dedicated the space, the less its original purpose is visible, with most explicit example of a “dedicated” space being an empty room. The function of the room has changed entirely. While the space in Figure 6b is bigger than some of our other examples of dedicated spaces, what is relevant in these cases from a design perspective is how much of the original purpose remains, and what (if anything) is included in these set-ups. In Figure 6b, the fridge, storage, and assortment of objects, suggest some of the original purpose of the garage. The soft play mats suggest a consideration to create a tactile sense of the boundaries of the play space, with the mats extending beyond what is likely necessary. Although a TV (not shown in the image chosen here) offers the possibility to cast the player's view of VR, people sitting on the couch would have their back to the player, suggesting that although the player's virtual movement is intended to be watched, their physical movement is not.

5.4.3 Revealing unknowns. While all our images show examples of people attempting to take advantage of some amount of open space for VR, comparisons across the images also help to reveal many unknowns about the justifications, expectations, and effects of these room choices for VR. In Figure 5b, for example, the space appears to be immediately available, while in Figure 6a, the space shows clear evidence of attempting to make it more open. Moving furniture out of the way temporarily makes it a VR space, but it is not a permanent change, raising questions about how often the player does this, and what it means for others who use the space. Moreover, looking at Figure 5b and Figure 6a side by side helps to raise questions about how the dominant use of the space might impact its use for VR. For example, although Figure 5b has fewer outward indications of how that space might be used in everyday life (marked “other” in our initial indexing), the open doorways might suggest that other people could enter and exit the space at

any time, and the dog provides visible evidence that the space is dynamic, meaning that the player has to be aware of something entering their play space unexpectedly. Importantly, although both cases show examples of how players might temporarily reorient or repurpose the original and/or dominant use of a space, images like these provide a reminder that the visual data can only offer a partial perspective of the physical, structural, and social characteristics of the home.

6 DISCUSSION AND FUTURE WORK

Based on our review of prior research, we noted that the possible at-home contexts for novel physical interactions in VR are under-examined in the HCI community. While there will continue to be a need for lab-based work, we draw on our findings in RQ1 and RQ2 to begin to answer RQ3, which asks what implications these findings might have on future design research that strives to bring novel interactions into the home. As we suggest in 2.2, there is a need to better understand the specific contexts of VR use in the home. We therefore group our considerations into two overlapping areas to help build on and extend prior work. In the first, we articulate general considerations and opportunities, providing insight for interaction design research that strives to navigate the unpredictability of domestic VR spaces. In the second, we discuss possible implications of these physical and material contexts, contributing to broader design research that strives to examine and/or leverage domestic VR. Before we discuss these implications, however, we note some important limitations of our study.

6.0.1 Limitations. As Pink [34] suggests, an analysis of visual data collected online is a useful stage of inquiry for visual ethnography, helping to develop themes and questions for future work. However, we can make no claim about the demographics of the people represented in the visual data we collected, or the generalizability of our findings. Some people posting to Reddit may be “power users” whose actions do not represent broader VR use. In addition to unknowns about who is posting on the VR subreddits, there are also unknowns about the intentions and expectations associated with those posts. In some cases, people might post images of tidy VR rooms suggesting an idealized set-up that might change the following day. In others, people might post short videos of people falling down or punching walls, which may be posted for their perceived entertainment or shock value; the latter is particularly the case in r/VRtoER. While we do not expect that our sample represents wider usage, there is nevertheless something to be learned about any environment that people choose for VR. For example, because we do not assume that people sharing accidents knew that those accidents would happen, the rooms still provide insight into some of the social and physical conditions of VR use. Further, as we note in section 3, our data collection procedure was not intended to comprehensively capture all visual material on the specific subreddits. Instead, our data collection, categorizations, and findings are based on an interpretive, qualitative approach to visual information, suggesting opportunities for future ethnographic work that might incorporate additional forms of data collection (e.g., interviews and site-specific observations, etc.) and other strategies for analysis. The discussion we offer is an effort to initiate conversations about

how the HCI community might address some of the overlapping implications of this study.

6.1 Designing with the unpredictability of domestic VR spaces

6.1.1 Consider a spectrum of impediments. In the vast majority of cases (81/83), there were visible impediments in the rooms that people chose for VR. While it is difficult to assess the actual size of the rooms, or the boundary system that people used, the impediments ranged from those that were visibly within reach, or those that would have restricted movement to a much smaller area of the room. While the physical and material differences between types of rooms stand to have an impact, our visual analysis showed that high-level categories for rooms do not necessarily help in identifying impediments. Impediments were common to every type of room in our data set. Moreover, instances that visibly showed an effort to remove or move furniture or objects did not guarantee a safe play space. A coffee table or an ottoman moved out of the centre of the room to make space for VR might position the player directly below a light fixture or ceiling fan. These findings suggest that when designing physical interactions that require movement and gesture-based interactions, rather than expect perfect and unobstructed environments, designers should anticipate the possibility that players may be unable to make their spaces safe, especially because of the varying degrees of effort required to make a given space more conducive to VR.

The variety of possible impediments within these environments also suggests an additional layer to the asymmetric qualities of current interaction: with their view of the physical environment obstructed by VR, players have little else to rely on to alert them to possible impediments. Because bystanders must also judge when and how they might interrupt the person using a VR headset [12, 32], there are opportunities to consider the ways that dynamic systems might allow for customizable social cues based on need. More immediately, as O'Hagan et al. [33] note, bystanders are in a position of power, with some evidence that while some will use that power to benefit the person in VR, others might abuse that power. These latter cases were evident in r/VRtoER, especially in examples showing what appeared to be a novice VR user walking a virtual plank (or, in some cases, a narrow board on the ground) only to be pushed by a spectator. Though we do not expect these instances to be the norm, future work might continue examining the ways that designers can help to scaffold and facilitate safe interactions in VR.

6.1.2 Leverage affordances of spaces. Understanding where the headset is used has a number of design implications, but predicting what rooms people choose for their play space is not straightforward. Differences in headsets or in the ways that VR devices track physical space do not necessarily dictate where they will be used in the home. For example, headsets that require tethered cables for additional computing power like the HTC Vive and Valve Index were used in multiple settings. Similarly, we did not see any clear predictor for the location where Meta's Quest 1 or Quest 2 might be used, though it was most often in living rooms. One possible exception is the PSVR, which has cables connected to a console that are connected to a TV: in our sample these cases were almost always in the living room. Rather than attempt to predict what

room the headset will be used in the home, our data suggests that a more relevant indication might be whether the player's view is (or could be) cast on a nearby television, which in our sample was most commonly in the living room. One design implication of this is that a living room (or family room) with a television is not, strictly speaking, a space that will be used exclusively for VR. Another implication is that any possible modifications to that space to make it more conducive to VR are expected to be temporary.

When a given space is used for VR, prior work suggests there is an opportunity to leverage the possible social characteristics of that space [5, 33]. Based on our sample, the primary form of this social activity is spectatorship, with one person wearing a headset and others positioned around that player on couches or chairs. In at least one case, the data showed that an additional role for the spectators is to help guide the person in the headset, catching them before they run into nearby impediments [32]. While supporting this chaperone-style role is in itself a design opportunity, these arrangements also provide some support for VR applications exploring asymmetric forms of play, with one player in VR and the other player(s) not wearing a headset [22, 39]. Although our data cannot capture other forms of in-person social interaction, these would be relevant here too, like the explicit or implicit rules that people might put into place between a VR and non-VR user [33].

6.1.3 Expect change within environments. While our analysis of the spaces in the visual material relied on what was visible within the snapshot provided, designers could begin to anticipate the dynamic qualities of spaces. For example, while 34/83 instances visibly showed something or someone entering the play area, the physical affordances of the room suggested the possibility of dynamic cases in many other instances. This not only includes evidence of social activity, but could include spaces with open doorways, or open-concept interiors. The exceptions might be the few instances that we classified as dedicated spaces (11/83), that, in their transformation of spaces into VR rooms seemed to also close the room off. In these cases, there were often no doors left open for possible interruptions. The interpretation of 'dedicated' spaces that we propose emphasizes the dominant purpose of the room, both to analyze how these households are changing to accommodate VR, and to better interpret how such spaces are envisioned by players. Given that single-purpose spaces appear to be less common, a more reasonable design assumption is that any space may have dynamic or unexpected characteristics. If spaces are dynamic, design might dynamically respond to differing needs and possible use cases.

As Dao et al. [5] suggest, current 'guardian' systems that offer a just-in-time virtual boundary offload the "burden of spatial positioning on the player." In response, they propose systems that provide players with the ability to create more complex virtual boundaries, or design that provides interactions that integrate or incorporate the space 'outside' the virtual boundary. Although there is a growing body of research demonstrating additional notifications or technological affordances across a variety of scenarios [13, 15, 19, 26, 27, 31, 47], as we have suggested for other forms of interaction design for VR, these solutions require more testing in home environments. Our findings show some of the flexibility that is necessary for this design work, contributing insight into challenges that current exploratory work may face if deployed in

the wild. For example, the material and social realities present in the visual data suggest several additional layers to the burden placed on players, whether based on the availability of a given space within a household or on the varying degrees of effort or ability required to modify that space. As designers examine perceptions and responses to notification-based systems [30], or the ways that VR and non-VR users set boundaries within the same space [49], our findings are a reminder of the need for design to accommodate spaces that might change before, during, and/or after the player puts on a headset.

6.2 Bringing physical interaction design to domestic VR

6.2.1 VR in the home always mixes realities. With a possible turn towards a more explicit and/or active incorporation of the player and the environment in VR design, there may be an opportunity to examine assumptions of what this means for notions of immersion. For headsets like the HTC Vive and the Meta Quest 2, the “boundary” that the player draws is ostensibly a line between the physical and virtual reality, as if to mark the separation between the two worlds. Whatever illusion this boundary design may create, the fact that our visual data only shows physical realities offers an important reminder: while much of the design research in our related work section already blurs the lines between virtual and mixed reality, our findings suggest that it may be expedient to view VR in the home as mixed reality with different degrees of physical engagement. The physicality of the player and their environment is always present; the degree to which those forms of physicality are considered by the designer is another matter.

If design research strives to help accommodate and understand the unpredictability of domestic spaces, a complementary approach may be to develop strategies to improve the ways that the physicality of the player and their environment are integrated into the experience. Current research shows possible beginnings, including design that leverages the physical reality of real-world objects and spaces in virtual worlds [20, 42]. However, applying these forms of mixed reality into the home suggest a need to consider how mixed reality design will change based on the social, material, ethical, and functional considerations within a given space. The same can be said about other environments that VR design research will seek to understand, including those for offices, health contexts, or educational settings. Each of these would benefit from an examination of how these spaces mix various realities and social dynamics, and each also raises questions about differences between public and private spaces, as well as differences between shared, collaborative, or personal spaces. While this paper provides early ethnographic data for one of these contexts, there will be much more to learn from future ethnographic studies that extend these questions into other contexts-of-use.

6.2.2 Consider the implications of increased tracking. As we described, designing with a direct consideration for the physicality of domestic VR could offer strategies for addressing the many possible impediments we see in our data. These strategies could prioritize player safety and their personal awareness of their environments, and the many notification-based systems cited in the previous subsection point to a desire to create technological solutions. In this view, the most likely impediments are the ones that are not tracked

and appropriately represented in the environment. Continuing this line of thinking would require that designers improve how the VR headset uses external cameras and other sensors to capture, catalogue, and interpret physical space. If the Meta Quest 2—the most popular consumer headset—represents a significant direction for future VR production, consumer VR production has already been moving in this direction. However, a design strategy in which increased player safety requires increased data collection is problematic given the corporate control of the resulting data when using consumer devices [8, 9, 40]. For design researchers, this leads to open questions about how we might responsibly create safer interactions for VR in the home while balancing the technology and the oversight of the corporations that manufacture and distribute the hardware and software. Moreover, if an increasing standardization of interaction paradigms for VR is led by corporations with the expectation of increased data collection, there are opportunities for academic design researchers who push the boundaries of physical interactions to help develop considerations for the responsible use of the data that is generated by those interactions.

6.2.3 Foreground a diversity of spaces and a diversity of bodies. Our visual analysis also draws attention to the variety of and complexity of living arrangements within similar higher-level categories. Our sample suggests that the amount of available space within bedrooms or living rooms depends on a variety of factors, and as we have suggested, current attempts to clear space may not be sufficient for design that actively engages physical bodies and environments. Designing with attention to the differences in domestic contexts can contribute to current efforts to run VR studies in participants’ homes (e.g., [35]), which cautions researchers that home set ups might be smaller than expected, and provides important ethical considerations related to participant safety, ranging from health to privacy, especially when the participant is not as supervised as in lab settings. Our findings provide additional context for these recommendations, which are particularly relevant given the kind of design research we discuss in the related works section. More broadly, increased attention to the physicality of VR must also respond to the need for improved accessibility and considerations for diverse bodies (e.g., [14]), as well as participant safety and privacy within tracked environments.

Finally, there is also an opportunity to consider other work in HCI to incorporate complementary genres of research [6] with overlapping considerations. For example, in an article about smart homes, Mennicken et al. [28] write, “designers and researchers face the challenge of developing solutions that will suit and benefit such diverse households and be flexible enough to deal with constantly changing needs.” From a design perspective, our findings suggest that VR technologies add additional challenges in such environments, with an ongoing need to develop approaches that accommodate and explicitly examine the contexts of VR use in the home. Future work might expand our considerations by developing appropriate guidelines, ideation techniques, and design prompts for specific moments during the design process, striving to make VR design more flexible to address the needs of diverse households.

7 CONCLUSION

As physical interactions that incorporate real world objects and environments extend across consumer VR and design research, there is a need to engage with the realities of domestic spaces more explicitly. Our visual analysis of Reddit posts contributes important considerations for design researchers. For example, the frequent presence of possible impediments could motivate alternate strategies in current work striving to incorporate physical objects, furniture, and infrastructural features into the virtual world. Similarly, these findings add urgency to work striving to develop improved boundary or management systems that responsively adapt to each new environment. Differences across rooms and how they are used signal opportunities to consider how social and physical interactions may differ depending on nuanced contextual factors, including where, why, and how people choose their set up. These considerations also raise important challenges, including questions about the role that design researchers will play if increased tracking and representation in domestic contexts facilitates increased corporate data collection. Ultimately, we suggest that the play spaces that people share online are only a sample of the diverse domestic environments of VR, requiring further research to examine how and when VR enters real world spaces.

ACKNOWLEDGMENTS

We would like to thank Garret Tracey and Derrick Wang for their assistance in the initial phases of this work. This research was funded, in part, by the Social Sciences and Humanities Research Council of Canada.

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