Being Social in VR Meetings: A Landscape Analysis of Current Tools

Anya Osborne
University of California Santa Cruz
Santa Cruz, CA, USA
anyaosborne@ucsc.edu

Sabrina Fielder
University of California Santa Cruz
Santa Cruz, CA, USA
ssfielde@ucsc.edu

Joshua McVeigh-Schultz
San Francisco State University
San Francisco, CA, USA
jmcvs@sfsu.edu

Timothy Lang
San Francisco State University
San Francisco, CA, USA
tlang1@mail.sfsu.edu

Max Kreminski
University of California Santa Cruz
Santa Cruz, CA, USA
mkremins@ucsc.edu

George Butler
San Francisco State University
San Francisco, CA, USA
georgebutleriv@gmail.com

Jialang Victor Li
University of California Santa Cruz
Santa Cruz, CA, USA
jli394@ucsc.edu

Diana R. Sanchez
San Francisco State University
San Francisco, CA, USA
sanchezdianar@sfsu.edu

Katherine Isbister
University of California Santa Cruz
Santa Cruz, CA, USA
kisbiste@ucsc.edu

Figure 1: Social VR meeting sites – (1) Spatial, (2) Glue VR, (3) MeetinVR, (4) Mozilla Hubs, (5) VRChat, (6) AltspaceVR, (7) Rec Room (public press release kits).

ABSTRACT

In the 21st century workplace (especially in COVID times), much human social interaction occurs during virtual meetings. Unlike traditional screen-based remote meetings, VR meetings promise a more richly embodied form of communication. This paper maps the experiential terrain of seven commercial VR meeting applications, with a particular focus on the range of shared social experiences and collaborative abilities these applications may enable or constrain. We examine a range of applications including Spatial, Glue VR, MeetinVR, Mozilla Hubs, VRChat, AltspaceVR, and Rec Room. We analyze and map avatar system strategies, meeting environments and in-world cues, meeting invitation model, and different models of participation. In addition, we argue that commercial applications for meeting in VR that cater to workplace contexts might benefit from borrowing some of the strategies used in more leisure-focused environments for supporting social interaction.

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CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Collaborative and social computing systems and tools*; • **Hardware** → Emerging interfaces.

KEYWORDS

Virtual Reality, social VR, virtual meeting spaces, embodiment, social augmentation, communication affordances, VR meetings, emerging design practices

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1 INTRODUCTION

In the times of COVID-19 and the 21st-century workplace, much human social interaction occurs during meetings, especially virtual meetings. As Gudjohnsen predicted almost a decade ago, virtual teams have increasingly become the new norm as organizations are reducing costly office space in favor of virtual communication structures, thus de-emphasizing co-located spaces [33]. Amidst, these changes, the rise of XR (VR, augmented reality, and mixed reality) has brought with it a new set of interactional dynamics to explore in shaping social experience [43, 63, 81, 88, 100, 104]. Researchers have suggested that the goal of social VR mediums should not be to fully replicate reality, but rather to enable and extend existing communication channels of the physical world [51]. Unlike traditional screen-based remote meetings, social VR not only supports aspects of embodied awareness, including a heightened experience of social presence [4], but also enables new forms of social augmentation that exceed what is possible in face-to-face contexts. Research showed how the avatar-mediated collaboration conducted in multi-user VR environments provided an emerging creativity support tool [96], demonstrating improved behavioral, emotional, and social engagement, compared to the in-person pencil-and-paper approach [32, 101]. As part of our larger research agenda, we are interested in creating novel social affordances in social VR that can unleash new collective human capacities and establish new grounds for effective collaboration and social connection. As a foundation for this program of research, we set out to better understand the design opportunity space by examining the design choices in commercial VR meeting applications. How do existing VR meeting applications enable or constrain social interaction? What common gaps or shared blindspots exist?

We conducted a landscape analysis of meeting-focused social VR applications, with an emphasis on experiencing and better understanding design choices and how they impact the texture of the experience. Our research included two rounds of studies. The first round was preliminary research taking an autobiographical landscape analysis approach to seven commercially available VR meeting applications: Spatial, Glue VR, MeetinVR, Mozilla Hubs, VRChat, AltspaceVR, and Rec Room. This preliminary work gave us first-hand knowledge about this emerging area of design practice. Drawing on preliminary insights from this work, as well as others' previous research on social VR [24, 43, 50, 57, 60–64, 74, 76, 94, 98], we designed and performed a second study in which we more systematically examined these applications, also from a first-person perspective.

The results of our research are a set of mapped parameters of social VR applications in terms of design approaches to supporting meetings in VR, with a focus on the extent to which each may constrain or support communication in meetings. Understanding and articulating these common design patterns within the existing commercial social VR medium can help us see what emerging conventions are shaping "expectations and literacies of current users" [94, p. 1] and also, where there are gaps and opportunities, toward future design practices. This work foregrounds a timely opportunity for researchers to understand the relationship between the emerging design features and the kinds of social interaction they may support with virtual co-presence.

2 BACKGROUND AND RELATED WORK

There is a substantial body of work on organizational meetings and social VR research in HCI that has informed our approach to this landscape analysis of current tools in commercial social VR applications. Much of meeting science focuses on meetings in which talk is the action, where people make decisions, discuss problems, and generate solutions [68], where meetings are essentially viewed as a set of communication tools used by groups to accomplish common (organizational) goals [7, 48]. Despite the important role that communication plays in organizations, research suggests that meetings are widely regarded as a poor use of time [30], with empirical evidence showing the widespread inefficiency of workplace meetings [68]. Some estimates indicate that as many as half of all meetings are rated as 'poor' by attendees, where organizations spend approximately $213 billion on ineffective meetings per year [46]. Such negative dispositions toward meetings can negatively impact participants' perceptions of their work, well-being, and organizations' bottom line [1]. Compounding this challenge, remote meetings – which lack the rich nonverbal cues of face-to-face interaction — pose unique challenges for organizations [2, 53, 82]. Research on distributed meetings has documented numerous obstacles faced by participants in these meetings such as reduced trust and feelings of isolation [15, 42], reduced engagement due to multi-tasking [58], lack of cues causing difficulty in jumping into the conversation [41], and reduced awareness of other participants' presence and understanding [40, 102].

These challenges of remote meetings have been heightened during the pandemic, calling attention to technological alternatives. In the rise of COVID-19, the topic of "Zoom fatigue" became a focus of discussion in academic research and editorials [3, 18, 61, 70, 97], where authors identify it as an exhaustion not only because of reduced mobility and posture-related causes but also deriving from demands of attention management, nonverbal overload and confusing social cues. To overcome Zoom fatigue and mitigate related challenges, researchers have suggested VR meetings as an alternative [64, 97], which offer more richly embodied ways of connecting while conveying a sense of shared presence with others [92]. For example, Erikson proposed to utilize VR as an alternative to Zoom meetings for all meeting-based learning activities for their digital movie making course at the University of Gothenburg in Sweden [23]. McVeigh-Schultz and Isbister argue that VR and XR telepresence tools could replace a range of social interactions currently supported by video conferencing tools like Zoom, Google Meet, Skype, and Facetime, and facilitate broader societal changes by limiting the need for frequent travel and commuting [61, 64]. While contemporary social VR draws similarities from studies on traditional collaborative virtual environments (CVEs) [8, 9, 14, 43, 75, 91], recent research suggests that social VR supports a variety of nuanced activities, play, and entertainment that provide unique experiences compared to traditional virtual environments [57].

Recently, a number of enterprise-focused platforms that support in-headset VR meetings have emerged, such as Glue VR, MeetinVR,

and Spatial (which also supports AR headsets like Hololens 2 and Magic Leap One). In addition, there are quite a few consumer-facing commercial social VR applications that support remote meetings including Mozilla Hubs, AltspaceVR, Rec Room and VRChat. The success and popularity of these platforms within the past six years have led to an emerging research agenda in HCI. This research has utilized commercial social VR platforms to conduct academic and learning workshops (e.g., Mozilla Hubs [16, 21, 23, 98, 105]), as well as remote user studies and XR experimentation (e.g., VRChat [83, 84], AltspaceVR and Rec Room [78], Mozilla Hubs [79]). Mozilla Hubs is one of the most popular platforms for holding academic and learning activities due to the wide range of devices and VR hardware it is designed to support. Williamson et al. used a customized build of Mozilla Hubs to facilitate remote academic workshop activities that allowed them to log users' positions and orientations within these virtual environments, demonstrating how the scale of spaces affects group formation, shared attention and personal space [98]. In contrast to VR experiments that are often limited to using a small number of headsets for in-lab studies, Saffo et al. advocate for VRChat as a crowdsourcing platform for such experiments in allowing researchers to access a large pool of diverse VR users remotely without having to spend as many resources as in-lab experiments would otherwise require [84]. In addition, more work in HCI has emerged from using commercial social VR applications in conducting participatory and/or unobtrusive in world observations of VR users (e.g., AltspaceVR [57], Rec Room, VRChat [55]), mediating long-distance relationships (e.g., AltspaceVR, Rec Room, Facebook Spaces [106]), supporting collaboration activities among existing geographically dispersed social groups (e.g., Oculus Rooms, AltspaceVR, vTime [67], Spatial [74]).

As the adoption of commercially available social VR platforms in HCI practice increases, so has research work concerning various modalities of communication and interaction that social VR mediates [5, 45, 51, 54, 57, 73, 91, 94], including social interaction consequences [13, 56, 57], with some focusing specifically on avatars [27, 36, 38, 39, 49, 80, 89] and avatar systems [76]. Due to the novelty and a large number of platforms emerging in this medium, new research is devoted to categorizing and narrowing down the variety of design methods and strategies concerning social VR platforms [14, 43, 62]. The research that is closest to ours is that of Tanenbaum, who used the close reading digital media approach [11] to investigate an inventory of ten social VR platforms for expressive Nonverbal Communication (NVC) like movement and proxemic spacing, facial control, gesture and postures, and virtual environment specific NVC, identifying "gaps within the commercial design for expressive VR" [94]. While the results of their work have greatly informed the design of our landscape research, we analyze platforms' social affordances from the lens of meeting goals that can also be 'independently observable' [12, 94] regardless of the meeting context. McVeigh Schultz et al.'s analysis of commercial VR platforms was also an important influence on the present research framework [60, 61, 64, 65].

Despite the variety of scholarly work on social VR, there is limited systematic research that focuses on investigating existing design affordances pertinent to meetings. For example, Lee et al. investigated user perceptions of Mozilla Hubs as a medium for business meetings, revealing some key challenges among business professionals in utilizing this platform for meeting tasks in screen(web) based mode (rather than in-headset) [50]. And more recently, Williamson et al. examined social interaction in Mozilla Hubs with a focus on spatial dynamics (digital proxemics) [99], and Olaosebikan et al. investigated affordances for creative collaboration among the remote team of corals scientists in Spatial [74]. These studies suggest that the nuanced interplay of existing design affordances in social VR meeting applications may affect group formation [99], participants' perceptions [74], and consequently shape social practices in VR meetings [63, 76]. The research described in this paper takes a design-focused approach, looking to understand the impact of various design affordances of social VR meeting sites toward grounding our own future design innovations. For our purposes, we approach VR meeting applications as a subset of commercial social VR, which we define here as "social VR with people you already know for the purpose of goal-oriented social interaction." The research reported in this paper focused in particular on questions about extant design techniques for supporting social connection and engagement in meetings, e.g.: How do existing VR meeting applications enable or constrain social interaction? How do these tools relate to one another (clusters of commonality or areas of divergence)? What gaps or blindspots exist that the research community can identify and call attention to?

3 METHODS AND MATERIALS

Our approach integrated methods of experiential close reading [11] and autobiographical/autoethnographic design research [19, 37, 62, 71]. Autobiographical landscape research is a method for exploring design choices that includes documentation of self-usage [35, 65]. In our landscape research, the goal was to understand how existing applications enable or constrain social interaction in group meetings in VR and to understand design choices within commercial VR applications through an experiential lens. In examining each of the social VR meeting applications in turn, we attended to the following:

- Our own experiences (sensations, emotions, actions, intentions, desires, etc.)
- Specific mechanics/affordances/constraints of in-context use.
- Particular features included and excluded.
- Frustrations/confusions, pain points shared by the group.

Throughout, we attended to the full arc of experience, including sign-up, login, onboarding, and interacting with others in the context of a real meeting. This approach was intended to provide us (and those who read our paper) with first-hand, granular insights about design [71] presented by a systematic set of comparisons of our own meetings experiences in VR. Readers may think of it as Tanenbaum et al.'s 'inventory' [93] discussed earlier, but rather, focused on tools for social interaction in the context of meetings. Similarly, this method is highly accessible to designers and researchers in studying product design. This style of investigation can also be seen as a hermeneutic-like mode of inquiry which "produces knowledge about how the [artifact] created its meanings, thus contributing to the development of craft and design knowledge" [93, p. 60]. While we cannot attest to having experienced all possible tools and features for social interaction, the subject of this research is a

representative sample of the current design space for VR meetings, toward future Research through Design [29] innovation that our research team targets. Our criteria for identifying suitable commercial social VR platforms for this research included the following:

1. Does the platform provide support for meetings with people who already are connected or know each other?
2. Is it available in VR and can be accessed using either Oculus Rift, Oculus Quest, HTC Vive, or Valve Index?
3. Does the platform support cross-platform participation? (i.e., Do VR headset users appear collocated in the same virtual space with desktop users?)

We then assessed seven commercial social VR applications: Spatial, Glue VR, MeetinVR, Mozilla Hubs, VRChat, AtlspaceVR, and Rec Room (see overview of each application in Appendix A.1). To investigate how existing commercial social VR applications enable or constrain social interaction in group meetings, we carried out two rounds of study. First, we conducted preliminary work to help sketch out the contours of the design space of remote meetings in VR and establish thematic categories for our subsequent analysis of observations. Second, we used the preliminary findings from the first investigation, combining them with prior scholarly work on commercial social VR applications [43, 50, 57, 60–63, 76, 76, 94, 98] to design and conduct the second round of study using a more systematic approach to data collection and analysis, tailoring it down to a particular meeting experience and 'aspects of actual use' in a professional research setting [72]. The details of each are presented in the following sections.

3.1 Participants

In taking an autobiographical/autoethnographic [19, 37, 62, 71] approach, our goal was to evaluate the design space based on our own experiences of using the commercial social VR applications to conduct meetings. Our group of 9 participants were members of our research team already focused on conducting social VR research. The team consisted of 6 graduate students and 3 professors with backgrounds in design research, game design, game development, cognitive science, and social VR design. Though we were studying ourselves, we still obtained human subjects' consent for our planned process. To 'recruit' participants, we announced the launch of landscape research at one of our weekly research meetings on Zoom. Individuals who verbally agreed to participate in the study were sent a follow-up email with a consent form and a link to a pre-study survey with demographic questions and prior experience of using social VR apps (Fig. 2). Participants had each been using social VR apps for a minimum of 6 months, with 60% using for over 2 years. 70% reported using social VR apps to meet with colleagues weekly, while 20% reported at least once a month. Of the applications we were interested in for this research, the most visited amongst participants was Mozilla Hubs, with 60% of its users in our study visiting weekly.

3.2 Round One: Preliminary Work

In the first round of study, we examined seven social and meeting VR platforms: Spatial, Glue VR, MeetinVR, Mozilla Hubs, VRChat, AltspaceVR, and Rec Room. We visited each social VR meeting environment in a team of 6-9 researchers at a time, collecting data over the course of 4 months (October 2020 – January 2021), taking notes, screenshots, and screen recordings to document our observations and experience for analysis. While in each VR environment, our research team participated in a free-form semi-structured discussion, addressing initial perceptions of the tools, features, and environmental settings–in essence making the topic of our meeting the space itself. We also tested various environmental and social affordances, prioritizing meeting spaces and examining core functions available in those spaces, to develop an initial understanding of "the activities and behavior of potential users" (p. 5 in [19]). Data collection notes were kept using Google Suite and Miro. For each application, we clustered key observation notes pertinent to communication affordances using an affinity diagram in Miro and compiled them into the list of categories in Table 1.

As a result of the preliminary work, we acquired a great deal of rich first-hand knowledge about this emerging area of design practice, forming insights about what each social VR platform has to offer to support meetings. The preliminary findings in Table 1 served as an initial analytical framework for key provisional factors that support social interaction in VR meetings. These factors formed the topic areas of the group interviews, online surveys, and observations we conducted in the second round of the study.

One broad provisional factor for categorization was whether the application seemed to be targeted at business or leisure meetings. This served as an important lens for us in understanding the characteristics of each environment and the tools it brought to bear to support meetings. Specifically, we observed that Spatial, Glue VR, and MeetinVR seemed to be primarily designed for holding business meetings, while VRChat and Rec Room seemed designed to afford leisure and play. AltspaceVR and Mozilla Hubs had design characteristics that seemed to afford both types of gathering contexts. To make our assessment of where a particular app should be categorized, we relied on the applications' web marketing approach, and prior research on commercial social VR [43, 50, 57, 60–64, 74, 76, 94, 98], in addition to our own observations. It is important to note that this categorization was preliminary. We did not thoroughly test all conditions and features of all applications, as we were taking an exploratory approach to understanding the design space. (Due to space constraints, other key factors touched on in Table 1 are presented in Section 4 in the context of results from Round Two.)

In the process of the preliminary round of research, we realized that a great deal of time was spent on getting all participants ready (downloading updates, making sure invitation links worked, etc.). At times, once within the VR environment, participants would wander the space, drifting away from the perspective of engaging in meetings. As we prepared for the second round of study, we worked to better lay the groundwork for the sessions with participants so that everyone was ready to join the applications quickly, and we set a more formal agenda for the explorations themselves to focus more carefully and deliberately on meeting support in particular. In the following sections, we present methods and analysis from the second round of research.

3.3 Round Two: Study Design and Procedure

To deepen our understanding of key factors surfaced as the result of the preliminary work (see Table 1), we conducted the second

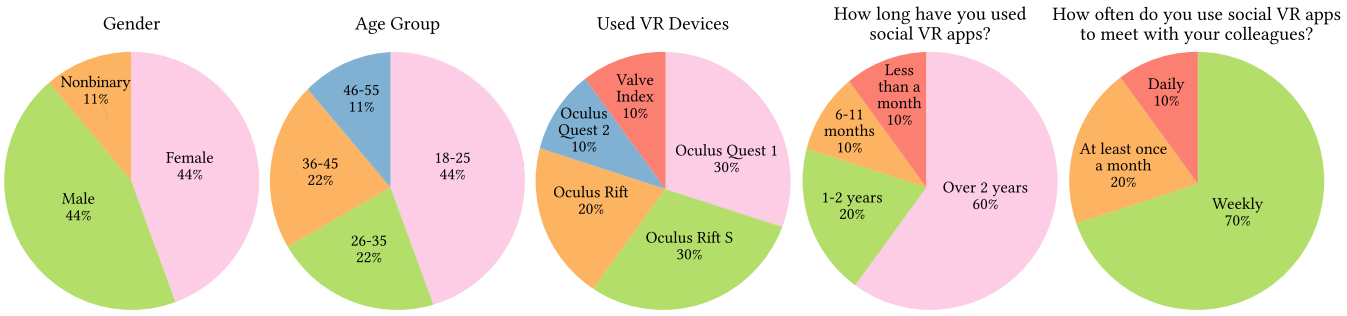

Figure 2: Participants' demographics, used VR devices, and prior experience of using social VR applications for both personal and research needs. Results illustrate subjects' responses to five questions in the survey (*N*=9).

round of research, focusing on how various tools and features worked in practice during real research meetings among our team of collaborators. We aimed at investigating which tools we as meeting attendees chose to use during our presentations, what features we found the most helpful in supporting our meeting experience, and what we thought could be improved. To address these questions, we held regular remote research meetings in social VR applications each week as a potential substitute for our typical Zoom calls, to see how far social VR can push beyond Zoom. For data collection, we used group interviews during the meeting sessions in VR, post-study online surveys aimed at reflecting on the meeting experience in VR, and an observation protocol to analyze our interactions in the social VR meeting environments.

In this second round of study, we did not examine MeetinVR, because of prohibitive costs (the company wanted several hundred dollars from us for a monthly membership even for a single research use). Most of the other selected social VR applications like Spatial, Mozilla Hubs, VRChat, and AltspaceVR were available for free download and usage. The developers of Glue VR were very interested in our research project and allowed us to renew our admin account with them after the end of the demo trial we used in the first investigation. We modeled this study based on other's previous research on commercial social VR applications [43, 50, 57, 60–64, 74, 76, 94, 98] and the preliminary findings of available communication affordances we acquired from the first round of study presented in Table 1. The second study included four phases: preparation, orientation, meeting, and post-study phases. Data collection was completed within 5 weeks (from May to July of 2021). The details of each phase are presented below.

3.3.1 Preparation Phase. Prior to each meeting session in the social VR app, we appointed a research moderator to work on the preparation phase. Their role was to host a meeting, set up a meeting environment and send participants instructions via email on how to join and navigate each environment. This was an important step in the study procedure that helped us avoid potential technical issues and saved us a lot of time at the beginning of each meeting session in social VR. The selection criterion for the environment's settings within the VR platform was whether the environments could facilitate a meeting of our group size and include useful tools to support a meeting (see screenshots of selected environments in Fig. 3). Our rationale behind selecting multiple settings in Glue VR and VRChat was to test the 'travel as a group' feature found in the preliminary work (see "Congregating Together in a New Space" cluster in Table 1). Although this feature was also found in AltspaceVR and Rec Room, we chose to use one meeting environment in each of them to avoid traveling as a group into public worlds and maintain other users' privacy in accordance with the IRB protocol for this research. In addition, we placed the study instructions in the form of either presentation slides or text on walls in the selected 3D meeting environments.

3.3.2 Orientation Phase. We would first convene and check in on Zoom with a research moderator at a predetermined time and agree as a group to then meet up in the VR environment. We joined using either a desktop (28%) or a VR headset (72%, see "Used VR Devices" in Fig. 2), with at least one researcher joining from a desktop to take video recordings of each session for later analysis. Upon getting everyone on board in an environment, a research moderator would start off with a brief introduction of research goals and study instructions using the in-world presentation slides (5 mins). We then invited our team to participate in a group interview to discuss what we noticed or found interesting about this environment (10-15 mins). Group interviews took an open-ended format, with participants responding to questions without a prescribed turn order. Interview questions were designed based on the list of communication affordances presented in Table 1 and addressed the following set of topics:

1. Initial perceptions of each environment, including environmental setting and avatar embodiment (e.g., What do you like/dislike about this environment?; What do you think of the avatars?)
2. Congregating together in a new space (e.g., Can we travel together into a new space?)
3. Orientation to others in VR (e.g., What do you think about the orientation to others in this environment?)

3.3.3 Meeting Phase. Upon the completion of group interviews, our research team remained in the same meeting environment in VR to present research updates to the group. The exceptions were Glue VR and VRChat, where we presented in multiple environments within each platform, a planned part of the self-study that allowed us to see various private environments within these platforms. Research updates consisted of each researcher giving an informal

Table 1: Topography of communication affordances among social VR meeting spaces. Cells marked with "●" stand for available tools observed by participants (*N*=9), whereas "○" for unavailable tools.

Communication Affordances:		Spatial	Glue VR	MeetinVR	Mozilla Hubs	VRChat	AltspaceVR	Rec Room
Targeted at:	- Business	●	●	●	●	○	●	○
	- Leisure	○	○	○	○	●	●	●
Screen (Desktop) Mode:	- Web and Desktop	●	●	●	●	●	●	●
	- Mobile	●	●	●	●	○	○	●
	- Console	○	○	○	○	○	○	●
Avatar Embodiment in Desktop Mode:	- No Avatar	●	○	○	○	○	○	○
	- Without hands	●	●	●	●	○	○	○
	- With hands	○	○	○	○	●	●	●
Avatar Social Mechanics - Communication Cues:	- Emojis	○	○	●	●	●	●	●
	- Gestures	○	○	○	○	●	●	●
	- Avatar Gaze	○	●	○	○	○	○	○
	- Body Expression	○	○	○	○	●	○	●
Invitation Model:	- Admin Invite	●	●	●	○	○	●	○
	- Friend Model	○	○	○	○	●	○	●
	- Share Link	○	○	○	●	○	●	●
Ability to Create a Meeting Space:	- Yes	○	○	○	●	●	●	●
	- No	●	●	●	○	○	○	○
Congregating Together in a New Space:	- Email Link	●	○	○	●	○	○	○
	- Verbal Agreement	○	●	●	○	○	○	○
	- Travel as a Group	○	●	○	○	●	●	●
Orientation to Others in VR - Rotation Degree:	- Freely	○	○	●	○	○	○	○
	- 60°	●	○	○	○	○	○	○
	- 45°	○	●	○	●	●	○	●
	- 22.5°	○	○	○	○	○	●	○
Environmental Settings and Cues:	- Skeuomorphic	●	●	●	○	○	○	○
	- Experimental	○	○	○	●	●	●	●
	- Meeting Prefabs	○	○	○	●	●	●	●
Note-taking Ability:	- Snapshots	○	●	●	●	○	●	○
	- Sticky-notes	●	●	●	○	○	○	○
	-Other	○	●	○	●	●	○	●
Shared Tools:	- Whiteboards	●	●	●	●	●	●	●
	- Markers and Pens	●	●	●	●	●	○	●
	- Sticky Notes	●	●	●	●	○	○	●
	- 3D Drawing Tools	○	●	○	●	●	○	●
	- Files Sharing	○	●	●	●	○	●	○
	- 3D Objects' Import	○	○	○	●	●	○	●
	- Desktop Screencast	●	●	○	●	●	●	●

verbal presentation of weekly progress on their research. Updates were given to the group on a voluntary basis taking from 5 to 10 minutes per presentation. To investigate the usage of the discovered set of communication affordances, presenters were encouraged to utilize any note-taking or shared tools to support their presentation. Spectators were welcome to use avatar social mechanics (i.e., emojis, gestures, gaze, avatar body expressions) to communicate their reactions to presenters and other listeners. At least one researcher at a time was presenting using in-world tools like screen share or file share, while 7 to 8 others were spectators (Table 2). The meeting phase was video- and audio-recorded for further analysis.

3.3.4 Post-study Phase. Shortly after each meeting session in a social VR environment, we sent participants an email to complete an online questionnaire to reflect on their meeting experience. The post-study survey was hosted on Qualtrics and included both close- and open-ended questions designed to address the following set of topics (primarily drawn from the preliminary results presented in Table 1):

1. Our perceptions of the general purpose of the social VR application (e.g., How would you describe what seems to be the general purpose of this social VR application for most of its users, including yourself?)
2. Application's invitation model (e.g., What did you do to join the meeting environment?; "How challenging was it for you to join the meeting space?)
3. Application's environmental model (e.g., How would you describe the environment(s) our team has visited?)

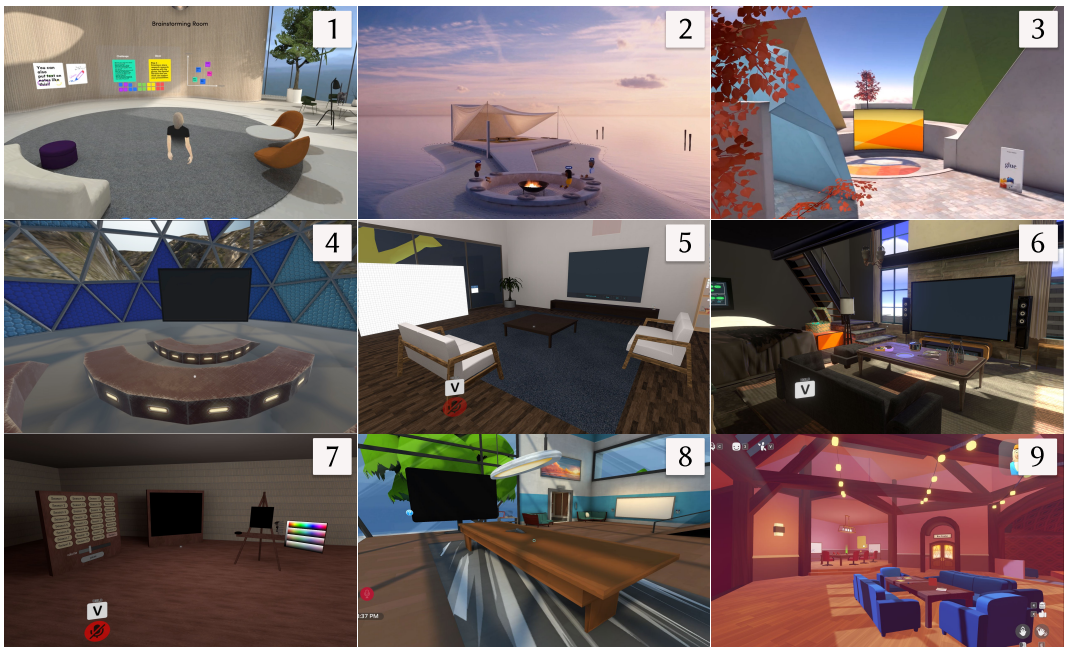

Figure 3: Selected environment settings in social VR applications. (1) Brainstorming Room in Spatial; (2) Island Space in Glue VR; (3) Garden Space in Glue VR; (4) Quintessential Colorful Commons in Mozilla Hubs; (5) "Just Paint and Chill" (creator yoshio_will) in VRChat; (6) "Iwsd Room" (creator chiugame) in VRChat; (7) "The Joy of Painting" (creator Kenoli) in VRChat; (8) Board Room Meeting in AltspaceVR; (9) Lounge room in Rec Room.

Table 2: Participants' roles distribution in each VR meeting site.

Participant's Role:	Spatial	Glue VR	Mozilla Hubs	VRChat	AltspaceVR	Rec Room
Presenter	1	3	0	2	0	2
Spectator	4	7	3	4	4	1
Both Presenter & Spectator	0	1	1	1	2	2
Total N of Participants	5	9	4	7	6	5

4. Our reflections on the meeting experience (e.g., What was it like to present (spectate) presentations?)
5. Use of shared tools (e.g., What shared tools have been used to support the presentation during the meeting?)
6. Our evaluations of the range of avatar choices, styles and non-verbal expressions (e.g., How expressive was your avatar? Please rate from 1 to 5 the range of avatar's non-verbal expressions.)

3.4 Analysis Methods

To analyze collected data, we applied two methods: (1) Qualitative analysis of responses to open-ended questions in group interviews and the post-study survey (see examples of questions in Sections 3.3.2 and 3.3.4); (2) Qualitative analysis of recorded videos using an observation protocol. The observation protocol was filled out separately by two researchers who reviewed video recordings of the meeting sessions in VR. The length of each video recording varied from 45 mins to 1.5 hours. Group interviews with meeting participants were manually transcribed, documenting the most relevant quotes in the observation protocol (also designed in Qualtrics for internal use). During the review process, each researcher took a series of screenshots to support their observation notes and/or insights. Screenshots from videos were then itemized based on the related observation notes/insights and shared with the group of other researchers for further discussion and analysis. Our research team included a broad set of expertise suited to assessing social and meeting VR environments, including backgrounds in design research, game design, game development, cognitive science, and social VR design.

The design of the observation protocol addressed two sets of recorded data — (1) answers to interview questions during the orientation phase, and (2) the details of each meeting session including how participants congregated in the space, what tools we used in the space, what avatar social mechanics were expressed during the meeting, as well as other observation notes. We then generated two data reports using Qualtrics' built-in system for data analysis, one from the completed observation protocols, and the other from

the responses in the post-study survey. Each report consisted of tables with the calculated count of selected choices to close-ended questions visually supported by graphs and raw text-based data sets of reported observation notes and answers to open-ended questions (we used percentages due to the uneven number of participants in each VR meeting site for better comparison as shown earlier in Table 2). Responses to open-ended questions were analyzed using the text iQ feature in Qualtrics that allowed us to assign topics, calculate the percentage distribution among all received responses, and generate reports. Data reports were then sorted by applying a combination of two filters: social VR application title, and general purpose of social VR app (i.e., business/ leisure/both). This helped us make initial assumptions about potential inter-dependencies between different factors that can support or hinder social interaction in VR meetings.

To finalize the analysis of compiled reports with applied filters, we organized the resulting data according to major topic areas pertinent to communication affordances by adding secondary annotations for observation notes, interview transcriptions, and survey responses, using an iterative, bottom-up approach to generate final topics. We grouped these responses into four topics: *Avatar System Strategy*, *Meeting Invitation Model*, *Meeting Environments and In-world Cues*, and *Asymmetric Participation*. We used interpretive techniques of close analysis [11, 93], and took cues from Saldaña's approach to qualitative coding [85] combined with preliminary areas of focus from literature review and prior work on social VR [43, 50, 57, 60–64, 74, 76, 94, 98] to arrive at these categories. In the following section we present findings from the second round of study and compare them with the topography of communication affordances in meetings we found in the preliminary work (see Table 1).

4 FINDINGS

The categorization of the applications in terms of business or leisure focus was similar to our preliminary phase categorizations for most social VR applications, such as Spatial, VRChat, AltspaceVR, Rec Room (see survey results in Fig. 4). The exceptions were Glue VR and Mozilla Hubs. In the preliminary work, we posited that Glue VR and Mozilla Hubs were targeted at business meetings. For Glue VR most of us (56%) indicated that it was targeted at both business and leisure. We think this was due to different styles of environmental settings participants experienced during the second round of meeting sessions in Glue VR: the "Garden Space" seemed more formal and business-like, whereas "Island Space" was more informal and beach-like, and could potentially be used as an ice-breaking setting in meetings. As P1 noted, "*There was a beach scene* [Island Space] *and an office scene* [Garden Space]." In the case of Mozilla Hubs, we believe the rankings were due to our extensive knowledge of the platform affordances acquired through using this platform for building prototypes for social augmentation as part of our research. In this regard, P2 said: "*I think Mozilla Hubs can be used for both – to hang out with people you already know without having a specific meeting agenda, and also for running business meetings*"; P4 thought of Hubs as a platform for "*making custom meeting environments for business and maybe more formal friend hangouts*." These findings corroborate our earlier observations that Spatial seemed to be primarily designed for holding business meetings, while VRChat and Rec Room seem designed to support leisure and play activities. Social VR applications that seemed to support elements of both leisure and business activities included Mozilla Hubs (100%), Glue VR (56%), and AltspaceVR (83%).

Individual arguments for making these choices varied, pointing out to different features we thought were important in identifying the right category. These features included environmental settings, avatar styles, shared tools, and built-in invitation models observed in visited social VR applications. Below are the examples of arguments our research group used in relation to each topic:

1. Shared Tools: "(Glue VR) *Lots of presentation affordances – screens for projecting slides, laser pointers, etc.*" [P3]; "*The functions within the app* (Spatial) *were very business-like. Screen sharing, web browsing pop up in the VR environment* (…)" [P1]
2. Invitation Model: "*Also, it* (Glue VR) *assumes you're a member of a predefined/fixed team rather than having open-ended join/invite affordances*" [P3]; "*It's* (Mozilla Hubs) *linking structure makes it easily accessible to the web, and this ease of access makes it amenable to a wide range of meeting contexts (both professional and hanging out with friends)*" [P2]
3. Environmental Settings: "*They* (AltspaceVR) *advertise public events in their menus, have a mix of playful and more work-oriented meeting spaces, and don't strongly assume that all users belong to a single team/ company/ organization*" [P4]
4. Avatar styles: "*Avatars* (in VRChat) *are much more playful*" [P1]; "(…) *the VR avatar created from the user's camera* (in Spatial) *to create a realistic personal avatar*" [P1]

Based on the meeting purpose categorization and descriptive analysis of data collected throughout two rounds of study, in the following sections we share details about key design areas of interest – *Avatar System Strategy*, *Meeting Invitation Model*, *Meeting Environments & In-world Cues*, and *Asymmetric Participation*, noting overarching themes, commonalities, and constraints across the applications.

4.1 Avatar Systems Strategy

Drawing from previous research on avatars in commercial social VR, we analyzed collected responses about avatars from a systemic standpoint [76]. Factors included variations in avatar choices (i.e., humanoid or non-humanoid), avatar aesthetics customization (i.e., stylized or realistic), social mechanics (i.e., emojis and other non-verbal expressions), and embodied locomotion (i.e., orientation to others in VR).

We found that seemingly business-focused apps like Spatial, MeetinVR, and Glue VR generally showed narrower variation in avatar choices that included mostly humanoid, realistic-looking avatars, with no affordances for customization (see the detailed distribution of responses for each topic in Appendix A.2). The avatars in Spatial, for example, were generated based on capturing a user's image or a photo they upload to the platform (see Fig. 5). However, there was a large disparity between the appearance of the avatar in the virtual world and its movement, referred to as the uncanny valley in existing research on avatars [49, 86, 103]. Our general impressions of avatars in Spatial were described as follows:

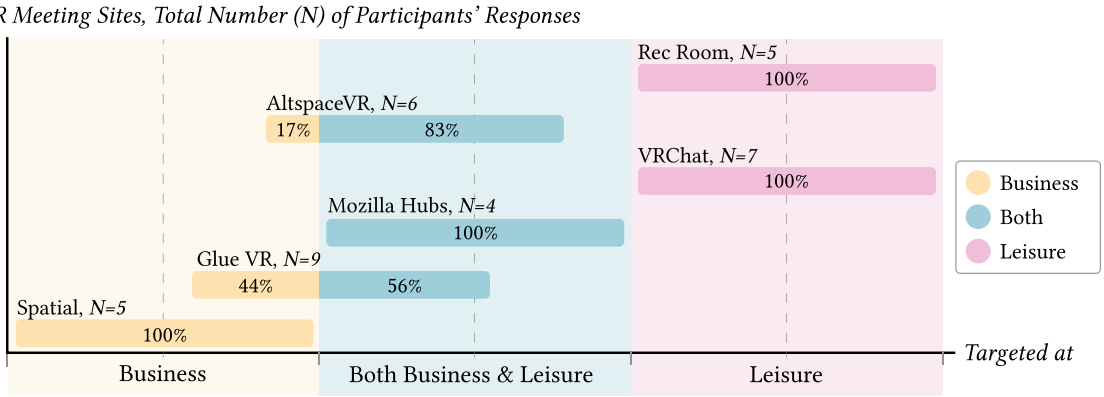

Figure 4: General purpose of each social VR meeting site perceived by participants after each meeting session. This graph demonstrates the distribution of subjects' responses to a close-ended question in the post-study survey.

Figure 5: Examples of avatars among examined social VR applications. 1 – Photo-generated avatars in Spatial; 2 – Default avatars in MeetinVR; 3 – Public avatars participants used in VRChat; 4 – Customized avatars participants used in Rec Room; 5 – Participants' avatars in Glue VR; 8 – Participants' customized avatars in AltspaceVR (screen-captures from video recordings).

"*I didn't like how people's avatar wasn't properly rendered. The weird bug that people had two or more avatars in the environment also made it creepy*" [P1], "*The avatars were very uncanny valley which was uncomfortable*" [P3].

Results of group interviews attended to mixed feelings about default avatar choices in Glue VR. P4 said: "*I like the aesthetic style of a character customization, the level of abstraction for avatars feels comfortable to me*", whereas P1 noted: "(…) *I can't make my avatar look like me – picking a realistic-human avatar that's closer to me than the others but still pretty dissimilar to my actual appearance feels very uncanny valley.*" In contrast to business applications, leisure-focused ones such as Rec Room and VRChat provided more latitude and attention toward avatars and identity play. VRChat in particular offered a wide range of full-body avatars of different shapes and styles. We also believed such variation can impact social dynamics in group meetings in interesting new ways as opposed to real life-like avatars — a direction we explore in future work.

Based on the analysis of recorded videos, the range of avatar social mechanics we used during our meeting sessions in VR included emojis, gestures, avatar gaze, avatar body expressions, and other expressions. We found that avatars were the most expressive in meetings in AltspaceVR (8 observations), followed by VRChat and Rec Room (6 observations). The least expressive avatars were found in Spatial, with a total of 2 noted observations for avatar gestures. Among other observed social mechanics, we noted eyebrow-raising in Glue VR, emoting and wearing a hat in AltspaceVR, and computer-generated randomized facial expressions of avatars in Rec Room (see Fig. 6). Most social VR applications, except Spatial and Glue VR, included features for non-verbal communication, such as emojis. Emojis in VR offers an alternative channel for users to communicate emotional affect or pathic meaning [61, 63, 76], and gestural communication play a key role in creative collaboration [69]. Yet, the accessibility and navigation to these features in

Figure 6: Examples of observed social mechanics during our meeting sessions in VR. 1 – Eyebrow rising in Glue VR, 2 – Wearing a hat in AltspaceVR (participant took a virtual selfie of their avatar with a hat acquired from a shared in-world widget), 3 – Randomized facial expressions of avatars in Rec Room (one avatar is smiling, and the other looks upset, regardless of the social context), 4 – Emoting in AltspaceVR accessed through an individual menu.

social VR seemed rather unintuitive in the meeting contexts, especially for non-experienced VR users. Similar results were observed in Tanenbaum et al.'s research, where they noted that controls for facial expression were often hidden within multiple layers of menus, reinforcing assumptions from (screen-based) virtual world paradigms [94].

Avatar gaze and viseme (visual components of facial expressions) mechanics were particularly interesting in Glue VR. During the orientation phase of the second round of study, P1 said: "*The first thing I noticed is that P2 was giving me a dirty look* [laughing]. *There is an interesting dynamic for the avatar's facial expressions like eye lines and eyebrows. Eyebrows are moving in interesting ways. I'm getting some mixed signals based on facial expressions.*" In Glue VR, the avatar's mouth moved during a speech, and its gaze appeared to be focused on the speaker, or someone else's avatar if their voice was louder within the conversational zone of a respective user, regardless of the person's actual gaze status (which could not be detected by the headsets we were using).

Orientation to others was another important factor of embodied locomotion we examined during our meeting sessions in VR. The analysis of preliminary findings (see "Orientation to Others" in Table 1) combined with the results of group interviews and observations in the second round of study showed that the predominant default setting for orienting to others in VR meeting environments was 45° across most commercial social VR applications (Spatial, Glue VR, AltspaceVR and Rec Room). In VRChat and Rec Room the degree of orientation to others (i.e., turning to face them) is adjustable, which we found particularly helpful in meeting contexts. For example, in Rec Room, 90° was a default setting that could be adjusted to 45° or to even a smoother rotation. Unavailability of this feature in Glue VR we perceived as a disadvantage, especially when some of us had ourf in-world tablets opened while taking notes. At the group interview, P2 noted: "*The social proxemics of the tablet affect how I orient myself towards other people, this is an extra step to do to move the tablet and inability to see who is standing behind the tablet.*"

4.2 Meeting Invitation Model

Unlike open-world environments such as AltspaceVR, Rec Room and VRChat, where anyone can visit common spaces (as well as create their own private spaces), four of the applications that we examined—Spatial, MeetinVR, Glue VR, and Mozilla Hubs—were focused exclusively on supporting people who were already connected in some way to one another. We found three major models for inviting people into social VR meetings - admin invite (one person is an account holder who sends invites to teammates), friend model (people become friends in the application to meet one another), share link (one shares a web link often coupled with an invite code to bring others into the meeting). In Figure 7, we present the distribution of our responses as to how we entered the shared space. According to these responses, with most business-focused social VR platforms we entered used an admin invite, whereas with leisure platforms in 75% of cases we joined using a friend invite. Platforms we have categorized as supporting both business and leisure meetings combined elements of admin and shared link models, as experienced by 71% and 50% of us respectively.

We found that applications that included the admin invite model like Spatial, Glue VR, AltspaceVR, and Rec Room enabled a meeting host (admin) to generate a shared link and/or invite code for others to join the meeting environment in social VR (see Fig. 7). The design of such an invitation structure is sequential and resembles the traditional hierarchical approach to holding meetings. In this regard, an admin or a host has default controls over the course of a meeting such as the ability to mute/unmute participants (Spatial), remove participants (Spatial, AltspaceVR, Glue VR), amplify someone's voice (AltspaceVR), and modify the meeting environment (AltspaceVR and Rec Room), unless the admin role is also granted to participants. While the design intent behind admin controls may be to preserve the group's safety measures in social VR environments, leisure-focused applications like VRChat and Rec Room seemed to have a more democratic approach to this challenge. For example, to remove someone from a public environment in Rec Room and VRChat, participants can use anonymous voting feedback [10] – a similar approach is presented in prior work on conversation contribution and is also used in social and competitive games [17, 20, 26]. Unlike in most examined applications, where an admin invite was coupled with the shared link model, Mozilla Hubs was a unique example that used a shared link approach only to bring meeting participants on board.

To reflect on our impressions of onboarding experience in each social VR application, we used a close-ended question in the survey (see Table 3) about how satisfied each of us was with this experience, followed by an open-ended opportunity to comment on that experience. Mozilla Hubs' shared link invitation model seemed the most satisfying to all compared to other platforms. P1 wrote:

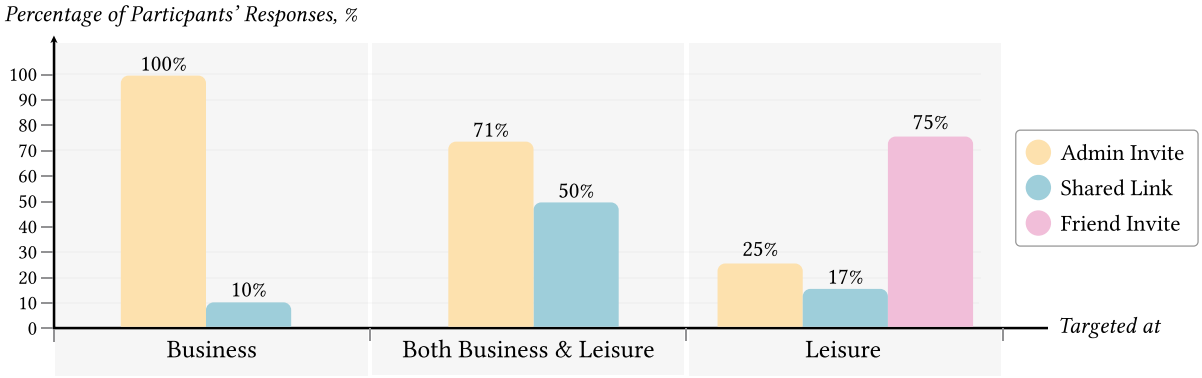

Figure 7: Meeting invitation methods (*N*=9), clustered by Business, Leisure, and Both categories. This graph illustrates the distribution of our responses to a multi-choice question in the post-study survey.

"*Mozilla Hubs was the easiest* (…), *you just share a link and that gets everyone on board pretty easily.*" The runners-up were Glue VR (67%) and VRChat (71%). It's important to note that in the second round of research our meeting group was revisiting the applications and most participants already had their accounts set up – something we will discuss in research limitations. In referring to Glue VR's onboarding, P2 said: "*I had already done it before, and it was pretty straightforward.*" In the case of VRChat, P3 wrote: "*It seemed pretty easy to join the environment via a friend invite.*" Regardless of the fact that most of us had already used the applications, 40% of people in our group rated Spatial's onboarding experience as the least satisfying – mostly due to a series of technical issues for VR headset users and multiplication of avatars for desktop users (see image 1 in Fig. 9). In regard to Rec Room, the majority of us (60%) associated difficulties with joining the meeting environment with navigating the platform's menu: "*It was harder to join with a code* (…) *because the option was a bit buried beneath menus*" [P3], "*The Rec Room menu is really difficult to navigate, it's too easy to accidentally click on things*" [P2], "*I had trouble finding where to put the room code*" [P5].

We explored affordances for traveling into different in-world environments together at the same time, as part of the "Congregating Together in a New Space" cluster presented earlier in Table 1 of the preliminary work. We found that business-targeted platforms like Spatial, MeetinVR, and Glue VR included these affordances, but they were offered to users in individual user interfaces, rather than visually prompting everyone in the group about starting such transitions. In contrast, leisure-focused platforms like AltspaceVR, VRChat, and Rec Room provided embodied visual cues for traveling together into a new space. In testing this feature during the second round of research, we found that AltspaceVR and VRChat, for example, provided users with affordances to drop a portal into the space and everyone who entered it could transfer into the new environment as a group (see Fig. 8). Our research team seemed to appreciate this feature in AltspaceVR in particular by saying the following: "(…) *people had a lot of fun with dropping portals into the environment, it is one of the unique features that I haven't seen in other apps*" [P1]. We also believed that these examples of facilitating group movement based on embodied visual cues seemed to have a greater impact on social presence and positive group dynamics than the strategies promoted via individual user interfaces.

4.3 Meeting Environments and In-world Cues

Depending on the purpose, each meeting requires a suitable space or environment — whether a space for presentations, workshops, or social gatherings. As noted in previous research on social VR [63], the aesthetics and design of environments indicate the kinds of social encounters users are likely to have. In each application, we examined environment settings designed for meetings (the screenshots of selected environments are provided in Fig. 3) and the kinds of interactions they support or constrain. More specifically, as shown earlier in Table 1, we highlighted the following communication affordances: the ability to create a meeting space, environmental cues (i.e., skeuomorphic pre-built environments, experimental, and prefabs-based user-editable), shared tools (i.e., whiteboards, markers, pens, etc.), and note-taking ability (i.e., snapshots, sticky-notes).

In the preliminary work, we found that most business-targeted social VR apps did not allow users to create a custom meeting space. Instead, they included pre-built environments imitating real-life business settings, such as conference rooms, scrum boards, tables with chairs and projectors, etc. In contrast, open-world social VR applications designed for leisure and play activities like Rec Room and VRChat allowed users to create their own custom environments. To test this feature in the second round of study, we asked our research group to categorize the types of environments we visited in each social VR world as either "*Skeuomorphic*" (pre-built environment that imitates real-life business settings), "*Experimental*" (very divergent, highly creative, and user-editable), or "*Prefabs-based*" (pre-built meeting environment template that allowed users to customize it using built-in prefabs).

All categorized Spatial as "skeuomorphic" which confirmed our initial assumptions about environmental cues in business-targeted platforms (image 1 in Fig. 9, Table 4). Interestingly, Glue VR had wider design variation in terms of architecture and layout. Along with conference-like rooms, categorized by 67% of participants as "skeuomorphic" (image 2 in Fig.9, Table 4), Glue VR included open-world spaces like an island surrounded by the ocean that users could wade into together. Due to the combination of both real-life

Table 3: General impressions of the Onboarding experience.

Scale for onboarding:	Spatial	Glue VR	Mozilla Hubs	VRChat	AltspaceVR	Rec Room
Unsatisfied	40%	0	0	29%	17%	0
Neutral	20%	33%	0	0	17%	60%
Satisfied	40%	67%	100%	71%	67%	40%
Total N of Participants	5	9	4	7	6	5

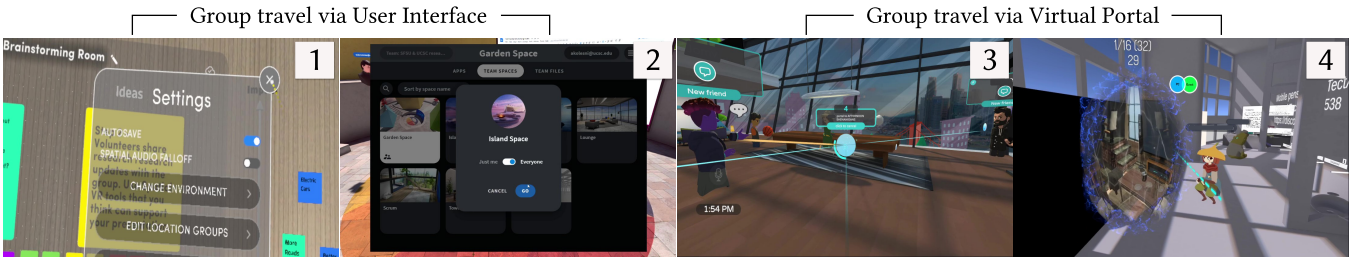

Figure 8: Examples of group travel facilitated through user interface vs. embodies visual cues. 1 - Change of environment in Spatial, 2 - Team travel to Island Space in Glue VR, 3 - Travel portal in AltspaceVR, 4 - Portal in VRChat.

Figure 9: Examples of Skeuomorphic, Prefabs-based, and Experimental environments. 1 – Brainstorm Room in Spatial, 2 – Garden Space in Glue VR, 3 – Lounge Room in Spatial, 4 – Quintessential Colorful Commons in Mozilla Hubs, 5 – "The Joy of Painting" (creator Kenoli) in VRChat, 6 – Island Space in Glue VR (screen-captures from video recordings).

and open-world meeting settings offered in Glue VR, 33% of us categorized its meeting environments as "experimental" (image 6 in Fig. 9, Table 4). Unlike in other examined apps, the design of environments in Glue VR was more nuanced, as noted by a couple of researchers at the group interview: "*I like the lighting and that the trees are moving a little bit. I like the details about the ambiance, so it feels less like a corporate hell*" [P4], "(…) *I really like the ambient water sounds, the lighting – all these little details make you feel very present, it feels like being disembodied or like you are in cyberspace*" [P2].

Environmental settings in Mozilla Hubs and AltspaceVR were categorized as "prefabs-based" by 75% and 67% of us respectively (Table 4), whereby we were offered more agency in shaping aesthetics and social expectations of custom worlds. Similarly, all thought of Rec Room as "prefabs-based" where users could use existing world templates and prefabs, providing room for creativity and user-editable content. To one of us, for example, Rec Room's environmental cues were "*very interactive, lots of things to play with, things you cannot do in real world.*" Rec Room's event space consisted of multiple rooms, each with slightly different settings – one

Table 4: Types of environmental cues participants selected in the post-study survey.

Environmental Cues:	Spatial	Glue VR	Mozilla Hubs	VRChat	AltspaceVR	Rec Room
Skeuomorphic	100%	67%	25%	0	33%	0
Experimental	0	33%	0	100%	0	0
Prefabs-based	0	0	75%	0	67%	100%
Total N of Participants	5	9	4	7	6	5

designed for business meetings, where we gathered around the table (image 3 in Fig. 9), and others were more lounge-like areas with couches and chairs (image 9 in Fig. 3). A few of us found that some of these rooms had limitations. For instance, meeting attendees could not teleport onto a stage located in one of the rooms. We believed this had something to do with a room setting that only an event host had access to. Due to the user-driven content generation of VRChat, all in our group thought of the meeting environments we visited as very divergent from one another, highly creative, and experimental (image 5 in Fig. 9). From conference rooms that included beds for avatars to sleep, to stage rooms with a backstage for presenters, and in-world cues with control panels for lighting, music, and other sound effects like "crowd applause" and "bravo."

An example of an in-world cue that particularly stood out across all of the social VR meeting sites was the social augmentation of users' interactions with an avatar's wristwatch in Rec Room. To access options in the menu, VR users looked at their wristwatches, and desktop users pressed <TAB> on their keyboards. The in-world tablet would then appear to the user, as well as seen by other users (image 1 in Fig. 10). This example served as an important visual cue to other meeting attendees signaling about your present focus of attention. In contrast to Rec Room, other applications did not support this feature, which we believe was a design gap, potentially misleading other participants in understanding non-verbal cues occurring during social interactions in meetings. For example, in image 2 of Figure 10, a participant is using an avatar's hand gestures to navigate the menu in Glue VR. Without a visual cue, someone in the audience could misinterpret the participant's behavior and think they are pointing at something specific in the environment instead. In this regard, P1 noted at the group interview: "*Lack of shared awareness of personal interfaces makes it really challenging to orient yourself and interact with others, it makes social proxemics difficult.*"

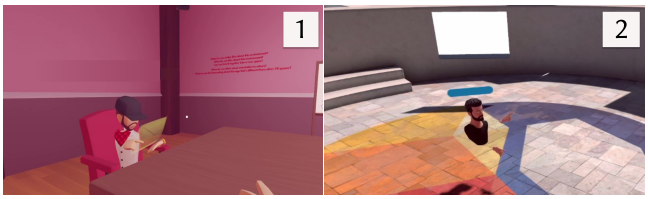

Figure 10: Example of an in-world cue for interacting with the menu in 1 – Rec Room vs. no visual cue in 2 – Glue VR.

Prior research showed that collaborative manipulation of objects in VR environments is more efficient than single-user manipulation [25]. We examined the range of tools our meeting participants used in the meeting environments that could be shared with the group to support social interaction (see survey results in Appendix A.3). We found a total of 9 tools that included pens and markers, whiteboards, file sharing, desktop screen sharing, importing 3D objects into the environment, laser pointing tools, sticky notes, tools for taking snapshots and selfies, web browsing in VR, and other tools (e.g., the 'maker pen' in Rec Room). Among the prefabs-based custom event spaces, AltspaceVR showed the lowest quantity of shared tools participants used during the meeting, such as pens and markers (50%), whiteboards (33%), and importing a 3D object into an environment like a hat widget for avatars (33%). The latter was also available in Rec Room in the form of the 'maker pen' tool (60%) that allowed us to modify environments right in the world without taking our headsets off. However, in both Rec Room and AltspaceVR, the tool to spawn a 3D object into the virtual world was restricted to meeting attendees unless a host enabled other attendees to use it as well. To conduct a presentation, AltspaceVR required users to have Microsoft-specific software installed on their computers, which was perceived as a major disadvantage of this otherwise promising platform for holding meetings. In this regard, P1 wrote: "*As a presenter, I had trouble with setting up the world panel to display my slides. It required me to upload my slides as images, host them on the external server, and then copy-paste the images' URLs for each slide in a multi-media console.*"

Skeuomorphic and business-targeted social VR platforms (such as Glue VR and Spatial) provided us with the broadest range of shared tools compared to experimental leisure-focused environments like VRChat (see Appendix A.3). Desktop screen-share was the most popular tool our participants used upon its availability across all platforms, including Spatial (100%), Mozilla Hubs (100%), and Glue VR (89%). It allows any user to import a 3D object (such as Google Drive notes) into the environment to share with others during a meeting. The ability to import a 3D object into the space so that it is shared with the group to manipulate it creates a great opportunity for participants' engagement in training and workshops that video conferencing software does not allow. In reflecting on the meeting experience in Mozilla Hubs, P4 wrote: "*As a spectator, it was very helpful to see the working notes of presenters and make edits to the document so that everyone in the team could see it.*"

Note-taking tools used by participants in our group varied — from sticky notes and snapshots to other tools like web browsing and drawing pens (see Appendix A.3). We found that business-focused platforms and prefabs-based custom event spaces like Spatial, Glue VR, AltspaceVR and Mozilla Hubs included more affordances for note-taking compared to leisure-targeted applications like VRChat. Sticky notes were used the most in Spatial (100%), and Rec Room (80%). The Web-browsing tool was used in Mozilla Hubs

by 50% of us for note-taking. Features noted in Glue VR were a speech-to-text feature that provided users with an opportunity to create notes via speech recognition and personal tablet clock to keep track of timing during presentations.

In addition to the range of shared tools designed to support meetings, spatialized audio and the quality of text rendering in screen-shared objects were the other two factors participants said as significant to our meeting experience. The design of spatialized audio in Glue VR was particularly interesting. When we traveled as a group into the Island Space (see image 6 in Fig. 9), we found an underwater condition in the environment that could be achieved by wading the avatar's head into the water. As P1 noted: "(…) *The Island environment was really cool though, being able to talk underwater and not hear people talking under water is very interesting!*." However, this experience was available for VR headset users only; some of us who joined from a desktop could not wade into the water to join others, which points to the question of asymmetric participation we discuss in the next section.

4.4 Asymmetric Participation

Most social VR environments allow participants without headsets to join from other devices. Such asymmetric participation, sometimes referred to presence disparity [95] and asymmetric interaction systems [44] among distributed users, was another factor we considered in our research, specifically desktop mode affordances, and avatar embodiment in screen (desktop) mode. Drawing from the preliminary findings (Table 1), followed by the analysis of video recordings captured in the second round of study, we found that all examined social VR platforms provided telepresence options via web or desktop (note: in VRChat it was available for PC users only). Affordances for using the web/desktop mode varied across all platforms. In Spatial, for example, desktop users could not move notes on the whiteboard, nor manipulate objects in the environment, compared to VR users. In Glue VR, the position of participants' avatars among desktop users appeared slightly elevated above avatars of VR users (image 6 in Fig. 9) without the ability to adjust it. This, in turn, restricted users' affordances in terms of accessing certain features in meeting environments, like wading into the water in the Island space and the ability to orient themselves towards other VR users vertically. A similar situation was observed in Mozilla Hubs meetings, although desktop users could adjust their vertical orientation to others by looking down and moving forward in a fly mode.

We also noted that some VRChat users spontaneously specified the platform they were using by indicating it in their name tag, such as VR or PC. This allowed other participants to better understand the potential constraints and opportunities within a hybrid presence group for social engagement activities, including the selection of environments for accommodating both PC and Quest users. In contrast to PC users, Quest users in VRChat could not view the slides presented in the environments via the built-in media player. Instead, they followed presentations based on participants' avatars' verbal cues. Rec Room seemed to perform better than other applications in supporting hybrid presence as no participation asymmetries were registered during the second round of study.

Considering avatar embodiment in screen mode, we wanted to understand whether avatar bodies looked different among screen (desktop) mode meeting attendees and those attending using VR. Prior research showed that full-body avatars increase social presence more than partial ones [36, 89, 103]. We observed full-body avatars in VRChat and AltspaceVR, and partial-body avatars – in Spatial, Glue VR, Mozilla Hubs, and Rec Room. Avatar body completeness remained the same across all platforms, regardless of devices participants used to enter the meeting spaces. The exception, however, was avatar's hands. In Glue VR and Mozilla Hubs, desktop users appeared in the environments as avatars without hands. Full avatar embodiments in screen mode were observed in most applications including Spatial, VRChat, AltspaceVR and Rec Room. In Rec Room, VRChat and AltspaceVR, avatars included hand movements registered during hand gestures and other interactions with objects in the space (i.e., holding or moving objects) that were piloted by the user using typical computer control schemes (e.g., menus, pointer).

5 LIMITATIONS

As noted earlier, we took an exploratory approach to understanding the design space, and therefore did not thoroughly test all conditions and features of all applications. For example, testing the telepresence affordances via mobile and console devices were outside of our scope, as were any other additional features one could potentially identify unless they were otherwise included in the list of our preliminary findings we presented in Table 1 (they served as foundation for the phase two research). Business applications were more recently created than the leisure applications (as described in Appendix A.1), and thus had a smaller user base and less robust features. Finally, usage habits (business vs. leisure) may of course change over time, depending upon platform strategies and markets.

When conducting meeting sessions in social VR environments, the particular meeting spaces we visited of course impacted our perceptions. In addition, our impressions of onboarding experience in the second round of study were likely impacted by the prior use of the applications, as we were revisiting the meeting sites, and most members of our group already had their accounts set up. The categorization of Mozilla Hubs' meeting purpose was also affected by participants' extensive knowledge of the platform's affordances because we were also building prototypes for social augmentation at the same time in Spoke, an online 3D scene editor developed by the Mozilla Mixed Reality team to create custom environments for Hubs.

6 REFLECTIONS AND OPPORTUNITIES FOR THE DESIGN OF MEETING EXPERIENCES IN SOCIAL VR

Our landscape investigations of these VR meeting spaces revealed some repeating design patterns. Current business-leaning enterprise serving platforms that support in-headset VR meetings (e.g., Glue VR, MeetinVR, and Spatial) tended to delimit avatar choices, replicate familiar productivity spaces, and provide productivity-focused tools, whereas consumer-facing applications focused both on leisure/play activities and meetings (e.g., Rec Room,

AltspaceVR, Mozilla Hubs and VRChat) provided many divergent approaches to supporting connection and communication.

6.1 Latitude for Play

In contrast to business apps, more generally consumer-facing applications that support remote meetings and leisure activities (e.g., Rec Room and VRChat) provided more latitude and attention toward avatars and identity play. As prior research on avatars in remote organizational meetings showed [87], in situations when the primary goal is to get work done, playful avatars may provide a means for creating a more engaging meeting experience. In addition, a recent study on user-avatar relationships in virtual meetings showed that comic-like avatar representations are significantly related to the perception of the avatar as a friend across all meeting contexts, including collaborative work [77]. Similarly, we believe such open-ended variation in avatar creation can impact social dynamics and social presence in group meetings in interesting new ways, as opposed to realistic avatars, in part due to the uncanny valley effects realistic avatars have been shown to produce [49, 86, 103], but also because participants may appreciate opportunities for more nuanced and even playful self-presentation. Future research aimed at exploring participants' avatar preferences for different meeting scenarios in social VR could help more thoroughly explore the nuances of avatar design and its relationship to meeting support, leading to further design innovation and iteration.

6.2 Affinity Signaling

Commercial social VR currently affords diverse communication modes for expressivity and sociality in meeting contexts. While avatars in social VR systems do not yet have as wide a range of expressivity as humans have in the physical world [28, 66], in today's commercial social VR medium, this has improved to some degree. Designers have managed to balance the degree of an avatar's expressivity and the constraints related to cross-platform compatibility aspects between the web and VR [76], especially with the adoption of lip-syncing technology for avatars' facial expressions we observed in Glue VR. While most leisure-focused social VR platforms seemed to provide embodied affordances for emoting, gesturing and affinity signaling, little is known about how these designs can best support the communication goals of meetings and there are significant opportunities for design innovation in this area. For example, are traditional 2D emoticons that float upwards and then disappear (Fig. 6) indeed the best way for collections of users to communicate affect? Commercial explorations of these sorts of design opportunities are only scratching the surface. Design questions remain about how such social signals should be represented in the VR environment to best help participants make sense of social dynamics over time (e.g., shared avatar attributes to signal groupness found in Rec Room). Our research team sees this as a fruitful space for future design exploration as well as empirical research.

6.3 Dynamics for Spaces and Interaction

Current meeting environments in the examined social VR apps vary widely in terms of aesthetics and architecture, including the variation in affordances, fidelity, scale, and accessibility. While all virtual environments in commercial social VR apps create social meeting spaces, they "result in dramatically different experiences" and sometimes lead to unexpected group behaviors [98]. Unlike in most business-targeted apps, the design of environments in Glue VR was more nuanced and had a wider variety of architecture and layouts. Along with conference-like rooms, it included open-world spaces like an island surrounded by the ocean. Much like Williamson et al. talked about how the floor pattern in Mozilla Hubs influenced the positioning of participants during a workshop [98], we observed how the layout of the Island Space in Glue VR impacted the spatial dynamics of social interaction, such as proxemics [6, 31, 34] and F-formation [47, 59, 90]. Its layout design somewhat playfully 'invited' participants to wade into the ocean together to have a meeting and triggered backstage communication exchanges about participants' in-the-moment experiences of being under the water. We believe similar processes of discovery could uncover new social affordances in workplace VR meetings that expand our understanding of communication beyond what is possible in physical space. We see this opportunity not just as a form of playfulness of expression but as a shift toward in-world cues and tools that enable us to be together better.

6.4 Who Is Invited and How?

Novel meeting experiences always face onboarding challenges. These challenges vary depending on multiple factors, such as the context of a meeting event (i.e., private or public event), the type of invitation model each platform supports, participants' prior VR experience as well as their knowledge of each other prior to the event (i.e., participants who already know each other tend to help others with their onboarding during the event). Several enterprise serving platforms (e.g., Spatial, MeetinVR, Glue VR) used an administrator-style hierarchical model for controlling who could be in the environment together. Open-world apps (e.g., Rec Room and VRChat) offered more creative options for self-expression but could make it harder to initially convene and coordinate closed meetings. These applications did make it easier for people to travel fluidly from place to place. Mozilla Hubs is a unique outlier that supports both openness and ease of convening/coordinating, reinforced by a shared link invitation model.

6.5 Meeting Tools

Enterprise serving platforms (e.g., Glue VR, MeetinVR, and Spatial) provided a wide range of productivity-focused tools that resemble familiar workplace environments through skeuomorphic design. The implicit assumption, however, that VR meetings should be modeled on "real life" is reinforced by features like virtual whiteboards, sticky notes, projection spaces, and meeting rooms that resemble familiar workplace environments. While such familiar features may be necessary to ease people into a new meeting experience, questions remain about when to rely on skeuomorphic analogues from the physical world to scaffold experience. Alternatively, in what contexts it is worth departing from familiar analogues and instead activate new practices of communication and coordination in meetings. An example of such potential new practice is presented in prior work that utilizes a shared VR visualization tool in the Mozilla Hubs environment that supports conversation balance in

groups [52]. Here, we argue that the drive to make VR meetings "more realistic" reflects a gap in understanding how productive defamiliarizing social interaction in VR may become as we learn to adapt to and take full advantage of the affordances of this medium. Applications that were more leisure or play focused (e.g., Rec Room) tended to push the boundaries of this affordance more and may serve as an important resource for design innovation for meeting VR applications in the future.

6.6 "I Can't See Your Menu!"

All applications included issues such as individual menus which were invisible to others — reproducing assumptions about device ownership from the digital realm that made sharing and social learning difficult. In other contexts, interface features were embedded into the world itself (e.g.: pens, whiteboards, a shared projector screen button in Glue VR). However, the idea that menus and interfaces should be shared social resources seemed underexplored in all enterprise serving platforms [74]. In particular, this oversight was observed in MeetinVR, Glue VR and Spatial, where the change of environment interface was represented by an individual menu and did not provide any cues for others about transitioning into a different setting as a group. We believe that the *socially translucent* examples [22] of facilitating group movement we observed in leisure apps (e.g., travel portal in AltspaceVR) have a greater impact on social presence, group formation, and collective decision-making than the strategies promoted via individual user interfaces.

6.7 Joining With or Without a Headset

Asymmetric participation [44] resulting from presence disparity [95] had varying impacts on avatar capabilities and a shared sense of presence among participants. Some applications gave users who joined from a screen(web) mode a virtual body (Glue VR, MeetinVR, Mozilla Hubs, AltspaceVR, etc.); others put screen-based users on an in-world screen that was not part of the social arrangement of bodies (Spatial). Sometimes screen-based participants had hands, other times not. Designers seemed to be mixing real-world assumptions (everyone has a body) and screen-based conventions (people not in VR have menus but no hands). Conveying mixed participation constraints and providing for shared social presence is a continuing area for focus and evolving standards.

6.8 General Reflections and Future Directions

The highly creative individual expression in the leisure-focused apps was inspiring to us in thinking about the potential for supporting shared meeting spaces more broadly — why not break away from whiteboards and screens to more creative and flexible support for social sense-making? Attempting to translate real-world metaphors into a VR setting may hinder team processes, not only because of the platform's limited social affordances [63, 76] but also because of the lower fidelity of social and environmental cues [99]. Challenging traditional/skeuomorphic design expectations of a work setting and self-presentation in social VR has the potential to facilitate greater social cohesion and creativity in informal situations. This is one direction that our current Research-through-Design prototyping efforts are taking. Although social VR cannot completely substitute for physical meetings, virtual and hybrid teams are finding new ways of technology-mediated communication, attending to novel possibilities for creative expression and collaboration. Overall, our landscape investigation revealed a wide-open terrain with some convergent tendencies, but also many divergent approaches to supporting connection and communication using social VR, providing plenty of room for future insights and innovations.

7 CONCLUSION

With this research, we set out to better understand the current landscape of social VR application design as it supports meetings toward identifying patterns and gaps that could inform future design efforts. We have mapped the experiential terrain of seven commercial VR meeting applications in a two-phase landscape analysis, using an autobiographical/autoethnographic style approach [35, 65]. We examined and analyzed avatar system strategies, meeting environments and in-world cues, meeting invitation models, and different models of participation, among other factors. Results can be of use to researchers and practitioners interested in innovating the design space of social VR to better support meetings, an important growth area in a world in which virtual meetings will likely continue to be a primary mode of engagement.

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A RESEARCH MATERIALS

A.1 Social VR Meeting Sites

Below we provide a brief overview of each social VR meeting we examined in this research.

A.1.1 Spatial. It is an VR/AR startup founded in 2016 and released in early September of 2020 for Oculus Quest (image 1 in Figure 1). It is designed for immersive presentations, team planning, hangouts, product reviews, and brainstorms. For VR and AR users, it creates realistic 3D avatars from a 2D selfie. When in a meeting, users can organize 3D videos, documents, models, and images. Additionally, they can write notes, share their desktop screens via the web app, and upload presentations.

A.1.2 Glue VR. It is a Helsinki-based virtual collaboration platform designed for teams' remote meetings. It was founded in 2017 and released the newest Glue 2.0 update as a standalone application in December of 2020. Glue has integrated AI-powered animation technology for customizable avatars to enhance facial animation and lip-syncing technology. The Glue VR (image 2 in Figure 1) meeting spaces can be used for project scrums, product marketing showcases, workshops and virtual training simulations. It includes a file-sharing system, and virtual touch interfaces that allow users to write notes, create whiteboards and make annotations in 3D.

A.1.3 MeetinVR. It is a Copenhagen-based start-up founded in 2016 and designed to use the 360-degree immersion of VR for business meetings events (image 3 in Figure 1). Initially, it was created to address "Zoom fatigue" and maintain high team spirit targeting small group meetings of 8 to 33 people. It was released in the Oculus Store in March of 2021. MeetinVR users can draw sketches in 3D space, screencast presentations, create sticky notes, and instantly change the background landscapes to places like the Dubai skyline, a penthouse in Miami or a luxury home.

A.1.4 Mozilla Hubs. It is a social VR chatroom, which is also an open-source project for webVR (image 4 in Figure 1). The project was created largely by a team of former developers of AltspaceVR and released by Mozilla in April of 2018. It is designed for every headset and browser. In Hubs, users can create a room with a single click and share it with a URL. Meeting spaces include an office environment, a medieval castle area, and other custom environments users can create through a browser interface. Ensuring users' privacy is a guiding design principle of their work, they do not collect data from their users and draw design insights from internal testing and engagement with users through community events, and forums [63, 76].

A.1.5 VRChat. It was first released as a standalone social VR application in 2014, compatible with Oculus DK1 and then opened to Steam in February of 2017 (image 5 in Figure 1). Known for its "wild west" character, VRChat is a unique home for a wide range of creative expression, ranging from avatars to user-generated custom worlds, thus contributing to inventing new social rituals [63, 76] and popularity among YouTubers and Twitch streamers. The VRChat development kit allows users to create or import various characters and world models from different franchises. Users are classified into various "trust levels", depending on factors like their use of the platform. Users with higher "trust levels" can upload their own content using the VRChat SDK.

A.1.6 AltspaceVR. It was founded in 2013 and released in May of 2015. It was acquired by Microsoft in October of 2017 and is now part of the Mixed Reality division in the Cloud and AI group (image 6 in Figure 1). It emphasizes a combination of experiences, including live virtual events, where individuals can talk, present, conduct art

Table 5: Distribution of participants' responses about the range of avatar choices across examined social VR meeting sites (Q: "How would you rate the range of avatar choices? Please select a number from 1 to 5, where 1 is limited or no avatar selection and 5 – wide selection of avatars").

Targeted at:	**1**	**2**	**3**	**4**	**5**	*Total N of Responses*
Business	10%	40%	30%	10%	10%	10
Leisure	0	8%	25%	8%	58%	12
Both Business & Leisure	0	29%	21%	50%	0	14

Table 6: Distribution of participants' responses regarding the range of avatar styles across examined social VR meeting sites (Q: "Please rate from 1 to 5 the range of avatar styles and looks, where 1 is skeuomorphic/low variation (i.e., photo-realistic humanoid only) and 5 – stylized / high variation (i.e., both humanoid and non-humanoid avatars)").

Targeted at:	**1**	**2**	**3**	**4**	**5**	*Total N of Responses*
Business	10%	60%	0	30%	0	10
Leisure	0	8%	25%	8%	58%	12
Both Business & Leisure	0	36%	29%	21%	14%	14

performances, collaborate, and congregate together in both small and large groups with the capacity to host thousands of people co-present in a single space. In 2018, AltspaceVR released custom building kits to create shareable words and new virtual hangouts. Upon activating the World Beta feature, users can customize environments using built-in assets from the library of shapes, structures, and ready-to-use plug-ins.

A.1.7 Rec Room. This application, formerly known as Against Gravity, was released in June of 2016. It emphasizes playing games such as 3D shares, co-op adventures, paintball, laser tag, bowling, Among Us, and others. Rec Room (image 7 in Figure 1) is designed to allow users to both build and play games together with friends. After Rec Room launched the ability for players to create and share their own rooms, the creativity and collaboration projects have greatly increased, bringing more popularity to the platform. In Rec Room, users can create their own meeting spaces using a 'maker pen' that allows them to generate 3D objects and set up interactions via node-based visual programming language directly in the game world.

A.2 Range of Avatar Choices, Styles and Social Mechanics

Here we show the distribution of participants' responses regarding three examined factors: a range of avatar choices (Table 5), styles (Table 6), and social mechanics (Table 7). The responses are grouped based on the prior categorization of systems as business-focused, leisure-focused, or both (see Fig. 4).

A.3 Range of Meeting Tools in Examined Social VR Applications

Table 8 demonstrates the range of tools participants used in meeting environments that could be shared with their group to support social interaction.

Table 7: Distribution of participants' responses regarding avatar's expressivity across examined social VR meeting sites (Q: "How expressive your avatar was? Please rate from 1 to 5 the range of avatar's non-verbal expressions, where 1 is low variation (i.e., limited non-verbal expressiveness) and 5 – high variation (i.e., emojis, expressive body movements like dancing and facial expressions)").

Targeted at:	**1**	**2**	**3**	**4**	**5**	*Total N of Responses*
Business	20%	40%	30%	10%	0	10
Leisure	17%	25%	0	33%	25%	12
Both Business & Leisure	21%	36%	14%	29%	0	14

Table 8: Tools participants used in examined social VR meeting sites. Results are based on participants' responses to a multi-choice question in the post-study survey (the percentage is calculated from a total *N* of meeting attendees in each application).

Types of Tools Used:	Spatial	Glue VR	Mozilla Hubs	VRChat	AltspaceVR	Rec Room
Pens and markers	80%	78%	50%	86%	50%	80%
Whiteboards	60%	89%	25%	71%	33%	100%
File sharing	60%	22%	50%	0	0	0
Desktop screen-share	100%	89%	100%	0	0	0
3D object import	20%	0	50%	0	33%	20%
Laser pointer	0	22%	0	0	0	0
Sticky notes	100%	22%	25%	0	17%	80%
Snapshots & selfies	0	33%	25%	0	17%	20%
Web browsing in VR	20%	33%	50%	0	0	0
Other (e.g., maker pen)	0	0	0	0	0	60%
Total N of tools used	22	35	15	11	9	11
Total N of participants	5	9	4	7	6	5