Contextual Group Walkthrough: Social VR Platform Comparison and Evaluation

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HCI-E MSc Final Project Report 2020
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ABSTRACT

As commercial virtual reality headsets become more commercially accessible, the social VR is increasingly popular in academia and in industry. For example, VRChat (one of the social VR platforms) is reported to have "over 25,000 community created worlds and growing" [55]. There is increasing research into ways to improve collaborative virtual environments, but relatively little into comparing the existing technology and the usability of design choices. This study aimed to compare the widely used and easily accessed commercial social VR platforms in Oculus Request (a commercial all-in-one headset), look at similarities and differences, and assess how usable they are 'in the wild'. This project adapted the refined cognitive walkthrough used in practice and observation to compare existing social VR platforms, including VRChat, Mozilla Hubs, AltSpace, RecRoom, BigScreen and Spatial. The study indicated the strength and potential of the cognitive walkthrough used in group evaluation of virtual environment (VE). Additionally, the design choices of social elements in these platforms are considered, and recommendations for further developments are provided.

Author Keywords

Virtual Reality; Social VR; Commercial platform; VR; Immersive Virtual Environments.

ACM Classification Keywords

H.5.m. *Information interfaces and presentation* (e.g., HCI): Multimedia Information Systems—Artificial, Augmented, and Virtual Realities

MSc Contribution Type

Empirical, Design, Interaction Techniques.

MSC HCI-E FINAL PROJECT REPORT

Project report submitted in part fulfilment of the requirements for the degree of Master of Science (Human-Computer Interaction with Ergonomics) in the Faculty of Brain Sciences, University College London, [2020].

1. INTRODUCTION

Many factors hinder people socialising or collaborating face-to-face, all of which can be overcome by technology to meet social demands. Such technologies include online collaboration tools and video conferencing platforms designed to serve remote workers to work effectively and efficiently. Collaborative Virtual Reality (CVE) is potentially the best choice for remote collaboration and relationship development [13,26] as it provides something very close to a real-world experience [27].

Virtual Reality (VR) is a computer-generated 3D environment which immerses people in the simulated real physical world or imagined world [1,9,43]. The feeling of 'being there' that it provides makes it quite different from other communication solutions [44,52] as it allows users to interact with objects and simulate multiple senses in a virtual environment. Although the virtual environment could be generated on the computer or the phone, the most prominent and immersive way is to display via a head-mounted display (HMD) [32]. The HMD is usually a helmet-like headset, which shows a stereo rendering of a virtual environment and obscures the real world [13], allowing the user to interact with whatever virtual environment is presented using a controller, a keyboard, or interactive gloves.

In the 1990s, the collaborative virtual environments (CVE) were mostly accessible in a lab context and virtual arcade machine commercially as a high cost entertainment facility; since 2016, several consumer-friendly virtual reality headsets have been introduced that are more accessible and user-friendly than ever before (e.g. Oculus Series, HTC headset, Samsung VR glasses). Oculus Quest is an all-in-one commercial headset developed by Facebook and released in 2019 [56,57]. As an off-the-shelf device, it is recognised for its price and convenience. The headset is composed of four cameras to track the environment, positional audio to render the surrounding sounds, and a microphone through which to communicate. The touch controllers transport hands and gestures into the virtual environments (VE) and provide realistic feedback. The system includes a built-in guardian system, which allows the user to define a safe space in which to play, and an application platform containing released VR applications [57].

With the prevalence and accessibility of commercial VR devices, Social VR is more prevalent than ever. Social VR is a platform which enables multiple players to communicate and interact with each other [35,43], examples of which are VR Chat, AltSpace and RecRoom. In order to evaluate and compare the design choices of social VR systems, a usability study can be utilised.

In previous studies, the feasibility of social VR systems has been proven. Research has found that the immersive platform could increase user concentration and help better understand spatial design with less cost and time in design review scenarios [37].

There are already some studies of social VR platforms, and any research regarding the commercial use of these platforms could help bridge the gap and provoke more interventions, both in academia and in industry. McVeigh-Schultz et al. [23,31] deployed design-oriented autobiographical landscape research to identify the issues in social VR, and then gathered the in-depth thinking of designers in various commercial social VR platforms (e.g. RecRoom, High Fidelity, VRChat) to identify a list of design topics for social VR designers. Blackwell et al. [13], interviewed 25 VR users about harassment, abuse and discomfort in social VR while Jonas et al. [14] reviewed and compared 29 applications and found more novel design choices worthy of considering in future design.

The following section will review the usability evaluation method used in the human-computer interaction (HCI) field and how studies adapted them into VE. Due to the specification of socialisation in virtual environments, the research emphasises the importance of social presence. To better understand the current social VR platforms, a self-walkthrough is conducted and the design choices from platforms are listed. Based on the differences and similarities, tasks are designed and analysed, underpinned by the theory of interaction cycles. Then contextual walkthroughs reveal how the real users feel and perform in these platforms and how the design choices affect their experiences.

In this study, we conducted a formative evaluation method within a comparative evaluation. When comparing the issues found within the various platforms, some common problems are listed, and better designs are recommended. There are also discussions regarding the various social mechanism issues.

2. LITERATURE REVIEW

Usability, as used in the HCI field, means “ease of use” [2], and usability evaluation has gained broad attention in the social VR design field and in collaborative virtual environments. In a virtual environment, usability can be seen as providing "a comfortable use of the system", which includes learnability and effectively with satisfaction. That is, in the virtual environment, the more successful people can reach their goals and complete their tasks, and the more satisfied they feel in interaction with others or objects, then the more usable the system is considered to be [28]. A social VR system is a multiple user VR system, which facilitates interaction between people inside virtual and social property.

A usability evaluation can help to identify design flaws in application concepts and improve understanding of users' mental models [42]. For the digital interventions (especially the software), there are a number of methods to evaluate usability, and those most commonly used are the survey/questionnaire, user testing, heuristic evaluations, interviews and think aloud [38]. However, the virtual environment differs from the traditional environment, and the devices used in VR could hinder some of these evaluation methods [7]. For example, the display used in VR makes it difficult to see both the real-world actions and those in the VE at the same time. Besides, the testing has more requirements for the network and environment to ensure safety and the participants' sense of presence. Moreover, the complexity of hardware and software increase the thresholds of participants' recruiting. On the contrary, integrated technology provides more opportunities to gather quantitative data. Schroeder et al. [42] pointed out that qualitative methods, like ethnographic analysis, are hard to generalise from the research to understand interactions in particular settings or environments. So, they identified two ways to analyse recording data: the frequency and patterns of the interaction categories and small fragments in detail, especially people's direction of focus.

The main difference between conventional Graphical User Interface (GUI) and virtual reality system is the fact that the latter supports 3D objects and interactions in the 3D virtual environments [28,46], which means the user in VR must operate differently than they would on a website or a mobile app. Therefore, the existing inspection approach used in a conventional evaluation may not be applicable. Sutcliffe and Kaur [46] noted that the heuristic evaluation cannot address issues of locating and manipulating objects in VE and cognitive walkthrough cannot find perceptual orientation and navigation issues. Additionally, the virtual presence, which is seen as a significant part of the virtual environment, is not involved in a traditional usability evaluation.

Many studies have examined the effectiveness of the conventional usability methods for VEs and then extended these methods. Interviews and questionnaires are flexible and good for getting subjective opinions and insights [7] as evaluators are allowed to ask broad, open questions rather than fixed sets of answers, though there are some sets of fixed questions developed by researchers which are usually based on theory or examined in practice. Using the fixed questionnaires can be both valuable and time-consuming in collaborative environments, a view for which some studies have provided support. For example, Witmer & Singer [53] developed the Presence Questionnaire (PQ) and the Immersive Tendencies Questionnaire (ITQ) to evaluate the presence and immersive qualities in VEs. However, the questionnaires and interviews are limited by the design of the questionnaires and the words used by the subjects; this means that people with strong preferences or knowledge could mislead the researchers, especially during immersion and presence evaluation.

The heuristic evaluation is a widely-used guideline for user interface (UI) design, offering an effective, inexpensive and straightforward approach to testing user interfaces [19,29,34]. Given that the virtual environment has some web-like interfaces as part of the menu, the conventional evaluation methods can also be effective. Paes & Irizarry [37] used the ten heuristics of Nielsen as a checklist for experts in an immersive design review system and successfully figured out a few issues of the virtual UI and also found five of the heuristic, which focus on the display features, are important for UI improvement in VE. Integrated the physical ergonomics and interface usability in VE, some researchers identified new heuristics for the VR system [33]. However, these did not cover all the potential usability issues in VR and need further examination.

Similarly, the cognitive walkthrough, which uses a task-based process simulation of users' detailed step through dialogue to check system's learnability and is always used for the first-time or infrequently user, adapted in some CVE evaluations [7,19,34]. Cognitive walkthrough is mainly worked as a question list to check by the indicator when participants are stepping through the tasks. The questions in the walkthrough are significant in practice. For the website design, Blackmon et al. [4] offered four questions during a cognitive walkthrough. In the VR field, Sutcliffe and Kaur [46] extended cognitive walkthrough to assess interfaces based on display in VR evaluation to desktop VR business park systems. In this approach, they defined three interaction cycle models for questions towards different scenarios: task action cycle, navigation cycle and system initiative cycle; each cycle contains a set of walkthrough questions. This method is good at identifying issues through individual evaluation (not groups) but needs heuristics to inspire solutions. Based on [46], Tromp et al. [49] conducted formative research on the COVEN London travel application, and in their cognitive walkthrough, they adapted a collaborative cycle to detect people's interactions. However, cognitive walkthrough in previous studies only conducted to their self-developed system by experts, not examined by other systems so far.

The inspection method and group trials are the group evaluation methods used most frequently by researchers. Based on cognitive walkthrough, Pinelle and Gutwin [39] developed groupware walkthrough by analysing teamwork and using hierarchical task model to break tasks down. However, their questions regarding the tasks are focused mainly on effectiveness and satisfaction. On the other hand, some researchers suggest that the only way to get the true picture is to study the system in a real context [45]. In a group trial, pairs of subjects are asked to perform assigned tasks, the logs are recorded, and the collectors may observe their interactions. Greenhalgh et al. [12] have developed network traffic analysis, but this method only addresses the volume and type of interactions between users [42], and it is common to use hybrid methods to gain insights into the causal relationships between users.

Researchers have defined and fixed the usability issues of CVE. Geszten et al. [11], using Stanney's Framework, developed twelve usability factors and categorised them into three classes: VR environment, device interaction and task specific. From the overview of the literature, the most serious usability issues include (1) presence and copresence, (2) communication, (3) navigation and manipulation, (4) monitoring and (5) learnability.

In a realistic VR environment, people tend to behave like they do in real life [32]. The main characteristic of CVE is the presence and copresence it provides. Presence is the sense of being present in the virtual environment [16,43,44]. It is a vital aspect of the VR experience and is believed to be a powerful factor in the usability of VR [11,53]. Some researchers argue that presence is determined by technical factors such as image quality and latency, while others suggest it is a multi-sensory experience that could be affected by the avatar [16], interface [52] and physical interaction [35,36] in the virtual environment. Therefore, given that the VR system uses a multimodal interface, the sound, movement and feedback should all be considered in the design.

Copresence, or social presence, is the feeling of being with real people [10,48], which could be enhanced by observing others' activities, and communicating and interacting with others. It is related to ordinary social interactions between people. In traditional digital collaborative tools, there are seven activities that are required to support group work [45], which is similar to the activities in the collaborative virtual environment. Unlike media spaces, the embodiment or avatar can be seen as the representation of users and allows people to see each other and to be connected in a shared space [18]. Besides, some researchers believe that realistic interactions in CVE could increase the copresence [15,24].

Communication is a fundamental aspect of the social VR platform. According to research conducted on digital collaborative tools [45], people are unable to communicate with others outside the room and it is also difficult to determine who is listening. In addition, with the chat tool or whiteboard used to implement communication, users rarely make use of the tools or notice the messages [45]. In the VR environment, the same problems are described [11], as well as issues of the embodiment and feedback about users

[50,51]. In the early stages, the facial and gestural expressions were missing and users could not control their embodiment to appear normal [50]. Some studies [8,22] highlighted the issues of pointing and figure gestures in the virtual environment, as users could not point at the objects to which they were referring.

Navigation refers to the way in which users move around and arrive at a destination in the virtual environment, while manipulation refers to their interaction with virtual objects. These two components are key factors to enable users to interact with virtual environments. In previous studies [37,46,49], the computer keyboard and mouse were used to move and control actions in the virtual environment. In VR, it can be difficult for users to learn the mapping between the input devices and the actions. Though the controller and the haptic gloves have made the natural user interface (NUI) possible and increase user engagement, problems of navigation and manipulation still exist [22]. The HMD blocks out the physical environment, so users find it hard to use the input devices with good hand-eye coordination [40]. For example, in [21,37], researchers developed a desktop-based virtual environment where they defined navigation and manipulation problems. In their system, users need to use the mouse to click arrows on the screen in order to move. Subjects reported difficulties in spatial navigation, disorientation, preciseness and failure to understand the way the control buttons work, as well as, being unable to distinguish interaction objects in the environment and unable to position the cursor into the right place. Additionally, users sometimes experience unexpected sequences such as moving through walls or an overlay with others and were unable to control objects or menus [41,49]. Overall, delicate object manipulation [50] and navigation are clumsy and limited [42].

Monitoring represents the ability to see others and their activities and keep track of the history of the work or the environment [45,50]. Research has found users want to be able to focus not only on their own activities but also to monitor others' action [18]. If users are unable to see other collaborators and what are they doing, then there is no collaboration [10,47,49].

Learnability is another issue in virtual environments as it is a novel technology for most people. The virtual environment is 3D and involves more information and freedom for users [22], so, it is hard to learn how to act properly in the virtual environment [11].

Moreover, the use of immersive systems could potentially cause some health problems such as cybersickness and may carry safety risks as a result of long time use [42]. Due to the community property of social VR, some researchers emphasise the importance of social, moral and ethical norms to be coded into the future of VR system designs [5,36].

3. THE SOCIAL VR PLATFORMS

The nowadays social VR design is more complicated than in previous years, as are the evaluations. Each platform has a different interface and interaction to achieve the same task. There are many studies on understanding users and interviewing the designers [5,13,14,16,20,23,35,36,43], but there is a gap in evaluating the general social VR platforms in groups.

Since 2016, there have been a great many applications developed to provide social experiences to VR users. On Oculus, the following six are popular and accessible to everyone, and analysing their usability and design choices will help gain insights about the issues and developments of social interaction.

3.1 AltSpace VR

AltSpace released its initial version in May, 2015, and was acquired by Microsoft in October, 2017. It supports an eclectic combination [31] of social experiences for strangers and familiars to meet up and attend events. Users are allowed to join it via a VR headset and desktop applications. New visitors cannot customise their avatar, attend social events until they register.

3.2 RecRoom

RecRoom was released in June, 2016 and could be played on PlayStation, PC, Oculus Quest, Oculus Rift, HTC Vive and iOS. It emphasises playing games with friends or strangers. Users can manipulate a variety of objects and create 3D shapes using a tool called 'Maker Pen'. People's face-to-face interactions, like high fives and shaking hands, are supported in the public area. Moreover, in a public space called Rec Center, participants can be tied a wristband in order to enjoy the party.

3.3 VRChat

VRChat opened to Steam in February, 2017 and launched on Oculus Quest on May 20, 2019. VRChat is a multiplayer online virtual reality social platform where users create their own avatars and environments with a software development kit. Full-body avatars and body gestures are available on the platform. Due to the massive user base of the platform, they have a no-tolerance policy towards bullying and harassment, which is monitored.

3.4 BigScreen

The initial beta version of BigScreen, a virtual world where people hang out with friends and watch movies, was launched in March of 2016. Considering its primary aim is watching movies with friends, it offers interactive objects like popcorn, soda and tomatoes. Communication and avatar customisation is available in the platform, plus, users are able to share their screen in the virtual reality via BigScreen desktop installed on a computer.

3.5 Spatial

Spatial was first released in November 2017 and aimed for group meetings in AR/VR. People can get into a Spatial meeting on HoloLens, Quest, Magic Leap, or via the web app, spatial.io/app. For Oculus Quest, it is not accessible to everyone since people need to send a request to install. In this platform, a realistic 3D avatar is generated based on a selfie. Users with a headset are able to manipulate objects, add sticky notes and write by hand, while the website allows users to desktop and files.

3.6 Mozilla Hub

Mozilla Hub is a lightweight social webVR released on April 26, 2018. Group meeting and chat are both supported by the platform and, with VR headset, the 2D web is extended into a 3D environment. A robotic avatar and username are randomly generated when people join the room as there is no requirement to register. Users can share the screen and bring images and 3D models into the room.

4. METHODOLOGY

Cognitive walkthrough is a cost-effective and easy-to-implement method to identify potential issues in a system. In the traditional cognitive walkthrough, there are two main steps to conduct: define tasks and answer the walkthrough questions. For website design, Blackmon et al. [4] offered four questions during a cognitive walkthrough. In 2003, Tromp et al. [49] conducted a longitude study on CVE for four years and found that inspection provides a quick way to gain more insights for redesign and discussion in development phases. For group evaluation or multiuser platforms, some believe usability evaluation is more practical [45].

In this project, the method is derived from the study by Tromp et al. [49], and it contains three parts: task analysis, self-walkthrough and group trials. The interaction cycle [46] is the main theory to generate walkthrough questions for evaluation.

4.1 Design

The platforms all support meetups with friends and interactions with each other. The main scenario design to study is meeting friends on the platform and then communicating and interacting with each other before moving to another room. In order to understand and compare the design choices of different social VR platforms, a self-walkthrough is the preliminary work.

As some researchers suggest, the best way of evaluating the multi-user or collaborative virtual environment is to study them in a real context with real users [45]. Group trials will be run with tasks designed by the researcher to evaluate the usability of platforms and investigate the group actions.

4.2 Participants

Overall, 17 participants (8 males and 9 females, with an average age of 22.7) were recruited to take part in the study. Participants were assigned to groups of 2 or 3 according to their familiars. All the groups are based on the relationship of friends or a couple. None of them had prior VR experience and four of them are students at HCI. Some of them took part several times with different platforms, and all were incentivised with a £10 per hour payment for taking part.

4.3 Materials

A total of three Oculus Quests were used for the study with the latest version of the five applications installed (Mozilla Hub is a web-based platform able to build virtual environments on Oculus). The devices are delivered to participants before every trial.

The cognitive walkthrough questions, based on the interaction cycle [46], are used and refined in the self-walkthrough (see details in [49] or appendix 3 and the walkthrough questions section below).

4.4 Procedure

At first, the scenarios are identified and assessed to be supported by every platform. A task analysis is important to create before any walkthrough to act as an effective guide.

In the self-walkthrough stage, the researcher has to walk through all the functions the platforms provide and different designs for tasks and functions are defined. The walkthrough is interleaved with design choice analysis linked to interaction cycles. In this way, the walkthrough questions are refined and confirmed.

With the interaction cycle and walkthrough questions determined by a self-walkthrough, the group trials are conducted to gain more insights into the real context. In the group trials, participants are grouped and required to evaluate different platforms. Basically, the groups are requested to have group meetings and discuss their experiences with the tool in the social VR platform. A set of tasks act as the guide and the process will be recorded by Oculus.

To ensure a high quality of evaluation of different platforms, participants were arranged in groups to experience various platforms (Table 1). Initially, one person is asked to evaluate two platforms with the researcher involved. Groups of three participants are then required to walk through all the six platforms while the groups of two are assigned to evaluate one platform.

Platform	Group trial 1	Group trial 2	Group trial 3
VRChat	P1,R	P4,P5	P16,P17,R
RecRoom	P1,R	P6,P7	P16,P17,R
AltSpace	P2,R	P8,P9	P16,P17,R
BigScreen	P2,R	P10,P11	P16,P17,R
Spatial	P3,R	P12,P13	P16,P17,R
Mozilla	P3,R	P14,P15	P16,P17,R

Table 1. Arrangement of groups and platform distribution. Note: R refers to the researcher.

We first group one participant with the researcher to walkthrough all the tasks and check the validity of the questions. Then a group of two participants are recruited to work independently and the researcher stays in the same virtual environment to monitor and ask walkthrough questions. Prior to starting the formal group trials, a group of three participants was tested and this proved to be very disorderly since the researcher could only ask questions according to descriptions given by participants, and it was challenging to coordinate all the participants. Therefore, for the actual trails, the researcher acted as a real participant in the groups of three and asked questions when others implemented the tasks.

Before every trial, participants were required to take part in the Oculus tutorial, given that none of the participants had any experience of VR and they therefore needed to learn some of the basic operations. In every trial, they were required to complete the tutorial of the platform and complete the following tasks by themselves:

1) Find your offline or online friend in the platform and meet in a private/public room, make friends and interact with each other.
2) Talk about your experience and share related sources, using the objects in the room or in the system to express your emotions.
3) Move to another room together.

Participants are free to determine the order in which they complete the tasks and the approach they choose to take. The walkthrough questions were based on the sub-tasks chosen by the participant. If participants encounter problems, the researcher would ask questions to guide their actions.

The answers to each question and the first-person perspective recording are the primary sources of analysis, wherein usability problems were identified through negative responses from the participants.

4.5 Task Analysis

Task analysis is a detailed breakdown of user actions and cognitive processes. User task analysis can provide representative user scenarios by defining and ordering user task flows [7]. For the conventional digital collaborate tools, the mechanics of collaboration [45] defined seven activities:

1) Explicit communication
2) Implicit communication
3) Coordination of action
4) Planning
5) Monitoring
6) Assistance
7) Protection

Because virtual reality provides a realistic environment, human social needs in reality should be satisfied. For the real-life needs, people can communicate with facial expression and gestures, navigate to anywhere with other users, manipulate the objects and interact with anything. Otherwise, people are able to observe the actions of others.

In the collaborative virtual environment field, Tromp et al. [49] used a hierarchy task analysis to classified the tasks to four groups: navigate, find other users, find interactive objects and collaborate. However, these categories are now outdated as virtual reality provides a lot more functions. Therefore, breaking down the tasks based on the functions the systems provide is more applicable to this project.

Tasks and subtasks were subsequently identified, based on the functions evolved in social reality and those integrated mechanism of collaboration provided with each platform. Overall, the tasks can group into five types:

1. Identification, which is all the actions to identify a target, which could be a person or an object.
2. Communication, which includes verbal and non-verbal communication, and in this case, interpersonal interaction is covered.
3. Navigation means how people move in space or between the rooms, which includes movement of both individuals and groups. Group moving means moving as a group to the same place. Room transport refers to how people teleport to a new room.
4. Manipulation mainly relates to the interactive objects, such as creating, moving, passing and joint manipulating.
5. Coordination is the action to gather people, handle conflict, and plan the actions.

The platforms chosen were classified into two types. One is open-world for everyone (like VRChat, RecRoom, AltSpace and BigScreen), which allows people meet or play with friends but also encourage people to meet with strangers; the other is closed-world for people who already know each other (like Spatial and Mozilla), which aims to provide a space for people to discuss, collaborate or make presentations.

In order to make the platforms comparable, the tasks chosen had to be supported by all of them. Though they have different ways of functioning, they basically support all the requirements for social activities. Based on the previous work and the self-walkthrough, the tasks are listed in Table 2, where only the direct support function is marked. For some platforms, the function may not be available directly, but people could get the same result through other approaches. For example, group moving means to enter a new space as a group; in other words, all the users enter a space at the same time. In VRChat, people can create a portal which allows all the users transport simultaneously, but in RecRoom, this mechanism is missing, so users would enter the room and then invite others in instead.

	VRChat	RecRoom	AltSpace	BigScreen	Spatial	Mozilla
Identification						
Identify others	●	●	●	●	●	●
Identify speaker	●	●	●	●	●	●
Identify interactor	●	●	●	●	●	●
Communication						
Verbal communicate	●	●	●	●	●	●
Emotion express	●	●	●	○	○	●
Gesture communicate	●	●	●	●	●	●
Text communicate	○	●	●	○	○	●
Navigation						
Group gathering	●	●	●	●	●	●
Group moving	●	○	●	○	○	○
Room transport	●	●	●	●	●	○
Manipulation						
Creating objects	○	●	○	●	●	●
Moving objects	●	●	●	●	●	●
Passing objects	●	●	○	○	●	●
Coordination						
Mark friends	●	●	●	○	○	○
Room creating	●	●	●	○	●	●
Invite others	●	●	●	●	●	●
Public room meeting	●	●	●	●	○	○
Outer source sharing	○	○	○	●	●	○
System notification	●	●	●	○	○	○

Table 2. Tasks and enables of social VR platforms

4.6 Interaction Cycle Analysis

4.6.1 Interaction cycle

Interaction cycle is the general model of interaction to predict behaviours and requirements for successful interaction [21]. The cycles provide sets of fixed questions for inspecting the potential usability problems related to a particular action. Drawing on Tromp et al.'s work [49], the six interaction cycles they identified were initially used. The tasks analysed should be linked to one or more of the interaction cycles to help guide users through the inspection. A good understanding of cycles is significant when analysing the tasks.

- System initiative cycle is used when there are system prompts or events to take over the control from the user.
- Normal task cycle 2D is used when a user is interacting with 2D interfaces (e.g. the menu, or pop-up windows)
- Normal task cycle 3D is used when a user is interacting with a 3D object in order to achieve a goal.
- Goal-directed exploration cycle is using when a user is searching for a certain target in the environment.
- Exploratory browsing cycle is used when a user explores the system out of curiosity and seeking a greater understanding of the world.
- Collaboration cycle is used when a user is interacting with other users.

According to the different designs of tasks in the various platforms, different cycles should be linked. In self-walkthrough, the questions from six cycles are used and checked for their validity.

4.6.2 Task-based design choice analysis

Basically, the platforms adopted similar designs and the same interaction cycles could be linked. For the environment, the platforms all provide a private room for landing, while The VRChat, RecRoom, AltSpace and BigScreen have more public spaces for people meeting and playing together.

For identification tasks, the exploratory browsing cycle is the primary cycle used in subtasks since people need to look around. Almost all the platforms use a name tag and avatar to distinguish people visually; only AltSpace will show the name tag after user select other people. Therefore, when finding friends, goal-directed exploratory cycle with normal task cycle 2D should be added for additional interacting. Platforms use different icons to indicate the speaker, so exploratory browsing cycle and task cycle 2D are linked to icon indication.

For the interactive objects, platforms use highlights to indicate the interactive object when selected with a pointing ray. In RecRoom, the interactive objects are not indicated until people use a hand to select or pick it up. Therefore, the task action cycle 3D is used for this task in RecRoom.

Identification	Name tag	Speaking icon	Highlight object
VRChat	Y	A small icon next to name	When pointing
RecRoom	Y	Sound icon by mouth	After interacting
AltSpace	Pointing	Lips moving	When pointing
BigScreen	Y	A small icon on the head	When pointing
Spatial	Y	A small icon next to name	When pointing
Mozilla	Y	Head contraction	When pointing

Table 3. Design choices of identification

All the platforms support voice input all the time except for BigScreen, which requires users to press "B" on the controller to activate. This is understandable as BigScreen mainly provides a space for people to watch movies together and in that scenario, verbal communication could be annoying.

In order to express emotion in the platforms, users can select emojis provided in the shortcut menu, which links to task cycle 2D. Hands are visible in all the platforms, so hand movements and gestures can be used. For example, people could wave or point at something. In RecRoom, more interpersonal gestures with feedback are supported, like high fives and shaking hands, in which, the collaboration cycle can be used. In Table 3, we listed how they support verbal and non-verbal communication. For gesture type, we identified the basic function of tracking hands moving as a simple type which all the platforms support. Additionally, VRChat allows user to choose body language from menu and display as animations.

Communication	Voice trigger	Emotion express	Gesture type
VRChat	Auto	Emoji floating	Body language
RecRoom	Auto	Facial change	Interpersonal interaction
AltSpace	Auto	Emoji floating	Simple
BigScreen	Press B	N	Hand clapping
Spatial	Auto	N	Simple
Mozilla	Auto	Emoji floating	Simple

Table 4. Design choices of communication

All platforms, except BigScreen and Spatial, allow text communication between friends. Text communication involves three actions: send texts, receive texts and check text board. Sending text and checking text board are done via the menu and link to cycle 2D. The only difference between platforms is the way in which the receiver of a text is notified. There are two types; one a pop-up floating window with text; the other is to notify the receiver via a notification and require the user to check the menu. For the floating window and menu, cycle 2D is applicable. However, for system notification, a new set of questions should be used as there are no cycle matches.

In the six social VR platforms, teleportation is the main technique used to move the avatar and change the point of view. The mechanism of travelling to other environments or rooms is performed through the menu. For group gatherings, users are required to move to a certain place, for which a goal-directed exploration cycle is useful.

Room transport is a task to move to invited rooms to meet friends. For the platforms that support a friends list, receiving an invitation and accepting a request enable people to transport to the room, which is mainly a cycle 2D scenario. Those platforms without a friend mechanism, use a shared room code for which no available cycle is matched. In some platforms, people could also enter to the same public room by exploring the menu.

When it comes to a group moving to the same room, two of platforms (VRChat and AltSpace) enable users to create a portal for groups of people, but they adopt different techniques to actually enter the portal. VRChat allows users to move into the portal while AltSpace requires a click and a confirmation. Besides, AltSpace provide a function to teleport a user directly to the friends' place. However, the other platforms users could move to the room first and then invite others to come.

Navigation	Moving strategy	Room transport	Group moving
VRChat	Teleport	Invite	Portal/invite
RecRoom	Teleport/walk	Invite /friend go to/code	Invite
AltSpace	Teleport/walk	Invite/friend go to	Portal/invite
BigScreen	Teleport	Explore menu/room code	Invite/same room
Spatial	Teleport	Explore menu	Invite/same room
Mozilla	Teleport/walk	Room code	N

Table 4. Design choices of navigation

The virtual environment provides interaction objects for users and the actions to manipulate objects individually is supposed to use task cycle 3D, while the collaboration cycle ought to be used for multiple users manipulation.

Almost all the platforms use codes to invite offline friends to the room; for example, Mozilla uses numbers while BigScreen and RecRoom use a mixture of numbers and letters. Spatial provides an alternative design, which is to enter the email and the platform will send the invitation via email. When users are already friends in the platform, VRChat, RecRoom and AltSpace enable them to invite their online friend to the current room. Hence, the cycle 2D is used for the friend-based invitation whilst another set of questions should be designed for those platforms that share codes or links outside.

In order to create an open world, VRChat, AltSpace and RecRoom employ a friend mechanism, allowing users to search for friends, adding friends, and sending friends' invitation. These actions are to be done via the menu and should link to cycle 2D.

Coordination	Room invitation	Room creating	Friend search
VRChat	Friend-based	Private/public	Name
RecRoom	Friend-based/code	Private/public	Code
AltSpace	Friend-based	Private/public	Name
BigScreen	Code	Private	N
Spatial	Link	Private	Email
Mozilla	Code	Private	N

Table 5. Design choices of coordination

Overall, all the tasks are linked to the five interaction cycles and required two more sets of questions when walkthrough in the real context (Table 6).

4.6.3 Walkthrough questions

The task action and exploration models are used to exam the learnability of systems while the collaborative model is mainly used to check the copresence. The collaborative cycle is initially used to inspect the usability of desktop-based CVE. For the HMD VR system, most of the questions are still working. However, the question "Can the user easily switch views between the shared object, other locations and the other users" is not applicable since it is only used for computer-based VR.

The system initiative cycle is not applicable in those systems as it primarily used on desktop-based VR systems. In the HMD VR systems, a system notification is used to alert the user and inform the states of the room or any new messages. For notifications, a new set of questions, called system alert, was created:

- Can user receive feedback about system status/changes?
- Is the system notification visible?
- Can the user notice the system notification?
- Can user understand the system information?
- Can the user decide what action to do next?
- Can user keep informed about system status?

Considering the new scenarios in the HMD VR platform, a new cycle to discuss how users shift from reality with virtually need to be introduced. In this study, the following questions were used to examine its efficiency:

- Do you feel it is easy to switch between the actual and virtual world?
- Can you remember your goals?
- Is it flexible to manipulate?
- Will it store what you taped/manipulated?
- Is there any change you can observe?
- Will it take your many times?

In addition, in order to gain more insights about presence, copresence and health, more questions are used in the group trials:

- When you move your body, do you feel the avatar in the system act the same as you?
- Does the system follow real world conventions?
- Do you want/have to move physically when you want to move in the platform?
- Do you feel you are in the environment? What's the level of your immersion/feel presence? 0-5
- When you face some problems or glitches, do you know what to do?
- When you are talking, do you know others are listening?
- When trying to manipulate the same objects, do you know who is interacting with it?

- When do you feel uncomfortable most?

	VRChat	RecRoom	AltSpace	BigScreen	Spatial	Mozilla
Identify others	Explore	Explore	Goal +2D	Explore	Explore	Explore
Identify speaker	Explore+2D	Explore	Explore+2D	Explore+2D	Explore+2D	Explore
Identify interactor	Explore	3D	Explore	Explore	Explore	Explore
Emotion express	2D	2D	2D	--	--	2D
Gesture communicate	Collaboration/2D	Collaboration	Collaboration	Collaboration	Collaboration	Collaboration
Mark friends	2D+Switch	2D+Switch	2D+ Switch	--	--	--
Text communicate	System+2D	System+2D	2D	--	--	System
Group gathering	Goal	Goal	Goal	Goal	Goal	Goal
Group moving	Goal/2D	2D	Goal/2D	2D	2D	-
Room transport	2D	2D/Switch	2D	2D/Switch	2D/Switch	Switch
Creating objects	--	2D+3D	--	2D	2D	2D
Moving objects	3D	3D	3D	3D	3D	3D
Passing objects	Collaboration	Collaboration	Collaboration	Collaboration	Collaboration	Collaboration
Room creating	2D	2D	2D	2D	2D	-
Invite others	2D+System	2D/Switch	2D+System	Switch	2D+Switch	Switch
Public room meeting	2D+Goal	2D+Goal	2D+Goal	2D+Goal	--	-
External source sharing	-	-	-	Switch	Switch	-
System notification	System	System	System	-	-	-

Table 6. Cycles of tasks in social VR platforms (NB System refer to system alert; switch represent the shift from the virtual environment to reality)

5. RESULTS

Using the think-aloud protocol and inspection of walkthrough questions, platform usability issues were defined. Since we have three trials of each platform and five participants involved, the problems reported by more than two participants in different groups are identified as usability problems.

Comparing the usability problems of the six platforms, those problems reported in more than half of them are defined as common problems, while others specific in each platform are classified as particular problems. Finally, having compared the platforms, solutions for improving user experience are explained and recommended.

5.1 Common problems

Basically, all the usability problems in the platforms are not severe and affect little of the overall experience. Six problems were reported in all the platforms and came up in repeatedly. Some of them have no prescriptive solutions and raise interesting future research questions.

5.1.1 Communication coordination

There is no way to chat verbally across the rooms, which means people are unable to communicate before they enter the same room. In group trials, an extra instant communication tool is used for them to coordinate and keep track of each other.

When communicating in a room, it is difficult to tell whether the intended audience is listening across the platform. For the platforms supporting text communication, participants were concerned whether others read their messages, so, participants tended to use another communication tool to inform others and then ensure they have received the text.

For a large group (over 2 participants), people have difficulty in following threads. There is no indication to show ones speaking intentions, which led people to talk over each other, or unexpected silences.

Due to the multi-layer structure, the accuracy of pointing out objects is problematic. Spatial enables all the pointing rays with the username visible to everyone, whilst others do not. However, the pointing spot is too small to recognise and the angle from which a user is observing could cause a deviation.

5.1.2 Input device control and blindness

Though Oculus Quest is the main device used, the use of a controller provides for more natural input than the keyboard. The controller use is still a problem without good instructions, and the only option is to learn through using it. Basically, the index finger should be on the trigger button to select and the third finger is for the grab button, used to grab objects. The platforms endowed the other buttons with different functions. Almost all the participants feel confusion in using the controller, even when some platforms provide a tutorial. People cannot always conduct the right action for the first time, especially teleporting and interacting with objects. Most of the time, users tend to ask friends in the same room for assistance. However, with the verbal assistance and blindness of a real controller in their hands, people have difficulty finding the right button quickly.

5.1.3 Invisible menu in the environment

Most functions, except for object manipulation and movement, are hidden in the menu. However, the menu is not visible when people spawn into the environment, meaning that, users find it hard to orient to the necessary task actions. This was especially true when creating a new room (Mozilla was the exception) and participants spent much time exploring the right action and always asked for hints. For the invitation task, some of the participants would like to look around the room to seek cues. However, people were not able to get more information from the environment to assist them.

Besides, the menu in VR is private and customised to each user, and invisible and inoperable to other users. This increases the difficulty to communicate about the menu, for instance, choosing a new environment in which to play together.

5.1.4 Spatial navigation problem

Navigation is still a problem that still needs to be addressed in the platforms in which people are free to move about. Participants all faced the problem of themselves penetrating the environment.

When moving around the environment, users can experience some unexpected situations such as moving through walls and objects. In particularly, avatars could overlay or disappear coming close to others.

There are no facilities to record location, which means users have difficulty in re-entering the same location if they accidentally left, except for their home (the spawn room).

Unlike desktop-based virtual environments and desktop multiplayer games, the social VR platforms based on HMD do not provide a complete map of the environment. Obstacles like walls and objects in the environment impede users to locate friends and determine a direct pathway towards them. This drives people to spend more time changing their views and looking around.

5.1.5 Joint manipulation problems

All the platforms enable users to interact with some objects and a connection is built between the user's avatar and the relevant artefact. People can select and grab an object; then, more related actions are available and depend on the object. For example, in RecRoom, users can grab a bottle of water and pour it; in Spatial, users can zoom into a 3D model. Once secured, an article is labelled as temporarily in private hands, though there are no indications of this face to other users, which causes issues.

Lack of object identity

There are no facilities for identifying and locking shared objects or tools especially when the platforms uses a ray casting to control objects remotely. Sometimes, more than one user is able to select the same interactive object. However, people do not know who owns this object and who is interacting with it. For instance, Figure 1 is a third-person view of two participants interacting with an earth model. While it appears that the person on the right is in control, it's actually the person on the left.

Figure 1. Two people interacting with an earth model

On the other hand, users are free to select any objects in the environment and interact with them. For example, in Spatial, the objects created or uploaded by users are not privately owned. Some people did not realise that some objects are non-interactive until they have tried every method to interact with it. For example, in AltSpace, one of the participants tried to click the play button on the radio which is non-interactable.

Lack of mutual awareness

When people manipulate the objects, others' actions are visible for the user. However, two people are not allowed to manipulate the same object simultaneously. If two users are trying to select the same object, a conflict occurs, yet none of the platforms supports user awareness of they are not able to manipulate simultaneously. In Spatial, when asking participants to control the same object at the same time, they all thought they controlled the object but what they saw is only based on their own manipulation. In other platforms, participants had an illusion that the object was in their control.

5.1.6 Precise control and distance limitation

Choosing an object is complex in the virtual environment, although some platforms provide tools. Remote control is possible in the virtual world but is limited by distance. For example, people find it easy to grab the objects near to them but for objects even not beyond where pointing ray cast can reach, the manipulation is impossible and requires the user to move before manipulating. Given that the ray casting is an extended point, people find it hard to select objects precisely, especially for the objects close to each other. Figure 2 illustrates how the ray casting operates name tag. However, an object with the same distance is incompatible.

Figure 2. Ray casting in AltSpace

All the platforms provide a pen for users to write in the air. The layers and spatial attributes make it difficult to write in the same layer and keep it distinguishable for others. After writing, another problem is to erase it all because it is hard to select items precisely and the layers, in people's eyes differ from what is rendered in the computer, so some scribbles are hard to choose or to erase.

5.1.7 Bubble mechanism hinders close interactions

To avoid the overlapping of avatars, some platforms use a bubble mechanism to make the avatar transparent when in close proximity, though this also hinders interpersonal interactions.

In trials, most of the participants would like to pat someone's head, but the bubble hinders this by making the other avatar disappear. As can be seen in Figure 3, in RecRoom, when people shake hands, the other person will go invisible and it becomes hard to locate the hand.

Figure 3. Handshaking in RecRoom

Participants usually give up the task before the effects happen and just occasionally achieve it. The invisible people made them unconscious of the availability of interpersonal interactions.

5.1.8 Room coordination

Travel mechanism

In the six social VR platforms, the process of travelling to other environments or rooms is done via the menu.

Two of them (VRChat and AltSpace) enable a user to create a portal for groups of people, but they adopt different techniques to enter the portal; VRChat allows users to move into the portal while AltSpace requires a click and a confirmation. However, almost none of the participants used this function as they were not aware of how to activate it.

Mutual awareness is a deficit in portal use; when asked to use a portal to enter a room, participants are not always aware of who is moving with them or the location of their friends.

5.1.9 Health problem: cybersickness

Cybersickness is a side effect caused by the conflict between the feeling of movement in VE and being physically stationary in the real world, and often causes various symptoms like nausea, vomiting, eyestrain and disorientation [25].

Due to the limited point of view in virtual reality, people have to change views casually to locate targets. Unlike reality, virtual reality provides a new way to look around. All the platforms offer the ability to change views with the controller. However, users cannot control the speed of change, which can result in different levels of discomfort and dizziness.

5.2 Particular problems

Due to various design choices within the platforms, some particular usability problems that arise are unique to one platform.

5.2.1 RecRoom

RecRoom is a game centre for friends, offering various group games and interpersonal interaction. People can find their friends in a public place called the Rec Center, though the entertaining games can sometimes be a distraction and some participants forgot about the task of finding each other.

Emotion expression

People are able to express their emotions by choosing an emoji with the controller from a shortcut menu. Rec Room chose to display the emotion on the avatars' face, which is more like reality. However, users found it hard to get feedback on whether or not they were taking the correct action. In this case, participants tend to get confirmation from others or by looking in the mirror.

Inconsistency of manipulation

When manipulating objects, all participants reported difficulty to put things down as the system automatically applies a locking mechanism in gameplaying. People grab something and are then unable to drop it by releasing the grab button until they press the 'B' button on the controller. However, people would not know this and, in other environments, this is not the case.

5.2.2 AltSpace

AltSpace provides open events for everyone and enables massive meetups, depending heavily on the friend mechanism for coordination since adding friends is the precondition of all the tasks.

Avatar representation and identity

To assist users in recognising the person they encounter, all the platforms except AltSpace provide a name tag on the top of the avatar's head. In AltSpace, users need to point at the avatar, then the name with applicable actions will emerge. This design made things clear when there are many people in a room but made it difficult for people to find their friends. Some participants recognised the wrong person as their friend when they had a similar avatar appearance.

Emotion expression is displayed as a floating 2D emoji on avatar's head. Participants confirm their emotion effects through others responds and when others express emotions.

Delays and missing notifications

There is no system notification to tell the user the status of the room and about any newcomers. Adding friends is important in AltSpace since people can only invite their online friends to a room. However, it is hard for people to notice when there is a friend request as it has a long latency and an almost undetectable redpoint as an indication on the menu.

5.2.3 VRChat

VRChat is an open world and accessible from many devices. Users can customise their avatar and environment through the developing kit that the platform provides. However, because of the flexibility of the world, some rooms are of low fidelity and problematic.

Less presence of the avatar

The teleporting in VRChat uses a third-person view, which means the users can see their avatar walking in front of them and then the view changes. This design is easy for others to follow but weakens the sense of presence. Almost all the participants reported a feeling of controlling a figure in a game instead of their own embodiment.

Slight notification

The notification system in VRChat is relatively light as people found it hard to get attention and take the right actions. All the messages, including friend requests and invitations, are flashing icons on the left bottom of the view, prompting the user to open the menu and check, but most participants trying to click the icon instead of open the menu (Figure 4).

Figure 4 Notification icon in VRChat

Besides, even when opening the menu, the message noted as only a friend portrait at the top of the menu, which is still hard to notice.

Lack of feedback from the menu interface

According to group trials, it is hardest to create a room in VRChat since there are no cues to follow and no feedback to indicate the right action has been taken. In addition, the interface of room details makes users confused and it is difficult to decide what to do next.

5.2.4 BigScreen

BigScreen is a platform providing a virtual space for people to watch movies and TV together. Similar to AltSpace, there are no notification alerts regarding room status and the entry of a newcomer. Since watching movies requires focus, there should not be too much interference, so there are only a few social functions provided on the platform. The friend list and interpersonal interaction are unsupported.

Lack of private space to share movies

The platform aims to enable people to watch movies with others virtually. However, all the online movie sources provided are limited in their private room. People have to enter different public rooms to enjoy what they want with strangers. All the participants expressed a desire to watch online movies privately with friends as they experienced various unpleasant events in the public rooms.

Room coordination

BigScreen uses codes to identify the rooms, but the codes are random and consist of numbers and letters, which are hard to remember and share. Participants need to check several times to ensure they have the right code. People can also choose to watch the same TV in a room together, but they cannot be sure what they can enter to the right room before the programme starts.

5.2.5 Spatial

Spatial is a virtual conference tool for group meetings, which is ideal for design reviews and presentations.

Web media problem -- limited view and control

Spatial offers a web version of limited functions to log in, upload files and share the desktop with others. However, the web version is only a transfer implement since the view on the desktop is not under user control and depends on the speaker with HMD. Users without a headset are not able to manipulate or locate anything in the environment. Besides, for the HMD users, the web users only exist through voice or video in the environment and it is difficult to build a face-to-face setting for web users.

Invitation transferring

Spatial uses email to send invitations which is a good practice to bridge the virtual world and reality. However, people always got lost after they open the invitation link in the email. For the first-time user, the link leads them to register, then they need to login to the website, and then pair their device. The two problems that arose was an inability to distinguish the link attributes before sharing and a lack of understanding of the teams concept.

Presentation difficulty

In the virtual environment of Spatial, there is a fixed board for sharing documents, which is presented as a wall for the environment. However, when people face the board and talk about the documents there, it is impossible for them to notice what others are doing and their status because of the limited view and their focused attention on the board.

5.2.6 MozillaHub

As a web-based social VR platform, mobility is the biggest advantage but there is also a high risk of encountering glitches. For example, if using a pen in the environment to draw something in the air, people found it hard to write in an exact place in the air as it writes on the ground instead.

No room backup

The room used to meet up in the Mozilla Hub is disposable since people cannot enter the same room the next time. If the room owner encounters glitches or has to quit for some reason, the room becomes inaccessible to everyone.

Less presence in the environment with the avatar

The faulty environment and the robotic avatar decrease the feeling of ‘being there’ with real people. In this environment, people are less enthusiastic about exploring and playing.

In addition, there are random usernames and avatars in the platform, since people are allowed to use it without registering, and this makes it more difficult to identify friends.

5.3 Design choices considerations

When designing a social VR platform, some recommended design choices and solutions have been distilled from the comparison of these six commercial social VR platforms. Ideas for future research are also offered.

Overall, here are the designs all the platforms chose and this study recommends considering.

1. Verbal communication is essential in social activities. People depend more on the source of voice (e.g. timbre and location) in a room that is open to people they already know. Surround sound, to indicate the distance and direction of the voice, is recommended. For public spaces, a voice icon is advocated to identify the speaker.
2. The name tag and representative avatars are effective in identifying others. A photo-generated avatar is only accepted in business scenarios where users are familiar with the others; in a more open world, such avatars could create social awkwardness.
3. Others’ actions, as well as interacting with the menu, should be visible and recognisable to everyone. For example, RecRoom and VRChat use a lightened screen to represent the menu, which could reveal the action while protecting the privacy of users.
4. The better platforms imitate the known world and familiar social contexts and metaphors to shape user expectations and reducing the learning cost. For example, attributing the real physical characteristic to objects in virtual environment could enhance presence.
5. Split the functions of the menu and create simple shortcut actions or sub-menus to achieve the same task. For instance, all the platforms which offer emotions use a shortcut menu to activate the emotion function.
6. Provide instant feedback either on screen or on the hand. When people interact with the 3D objects in the environment, real feedback is expected. The flexibility of the metaphor of 3D objects could be problematic. The more real the object is, the more expectations people will have. People naturally use grab and throw actions with every object in the environment, which make it hard to notice all that is really possible.

Additionally, after comparing usability evaluation, there are some better designs in practice.

1. Provide spatial cues when people need. Due to the blindness of the physical controller, more spatial cues should be used to assist the user. For instance, VRChat provides a virtual controller with notes to remind the user what to do.
2. Create more feedback to indicate object interaction. Appropriate haptic feedback with voice is expected when manipulating something in hand. The time and frequency of feedback should consider since some participants reflect unknown vibrate feedback in VRChat.
3. Teleporting is the basic moving approach in virtual reality. However, for others in the space, it is weird to notice someone disappear suddenly. Consider a route indicator to assist with locating others. For instance, there are two ways the existing platforms use, displaying the teleporting destination to others and showing the process of walking to a destination.
4. An effective notification system should be developed. Basically, there are three types of information: system

notification about the room status and online friends, text message from friends and room invitations from friends. They have different levels of priority and alerts.

5. Portal is a solution to achieve group moving. The scenarios of using portal should be considered as sometimes it is not appropriate.
6. Eyes gaze of an avatar could create an illusion of focus. All the platforms assume that what the avatar is looking at is the same as the user, but there is less clarity around who is listening. One participant in AltSpace, in answer to the question 'do you know others are listening to you?' replied to the affirmative, saying that he sees the eyes of others moving and always look at him. These were, in fact, fake gazes which actually provides an illusion to the user.

Some problems with regard to social activities have already raised, like avatar representation, user embodiments and collaboration. This study calls attention to design considerations on task flow of communication, manipulation and monitoring. However, there are some detailed design topic areas solely discussed in previous studies that need further improvement as there is yet no proven effective solution.

1. Most of the platforms are trying to make VE more like in the real world, whether through the manipulation of objects or the avatar's actions. However, virtual reality should do more than is possible in reality, such as enabling visualisation of ideas and concepts.
2. The virtual environment to enable clearer, easier and more accurate pointing. For example, in a live presentation, the person might use a laser pointer to indicate and emphasise very precisely to others. However, in reality, pointing ray casting is always private and invisible to others. In Spatial, the ray cast is visible to everyone, but it is not obvious. Will there be a better solution to attract people's attention and not cause a cluttered environment?
3. Some platforms offer a shared board for people to write on, but it differs from the real world because the field of view is limited in virtual reality and it is hard to write on the board. People cannot write words or interact easily when they are talking to others, and better method is required.
4. The menu is the key to all functions, yet the menus are not always easy to use and navigate through. A shared menu should be considered to work as an assistant.
5. Motion sickness was always reported when people changed views, so, a more effective way should be considered. It is worth noting that a restriction in the field of view somehow mitigates the cybersickness.

Finally, some technical improvements that could improve the user experience in social VR.

- Lighter HMD to mitigate user fatigue
- Higher refresh rate and less latency when sharing a desktop in VE
- Higher fidelity environment representations and closer to reality

6. DISCUSSION

In this study, we adopted a contextualised walkthrough method to examine the usability of a series of social tasks. The subjects studied are the existing commercial social VR platforms on Oculus Quest. Through comparing the performance of six platforms concerning the basic social tasks that were defined, a number of design usability problems were identified and recommendations were made.

Some findings are similar to conventional collaborative tools, especially communication functions. Steve et al.[45] inspected a teamwork tool called Teamwave Workplace and found the same communication problems as were identified in this study. The difficulty to know the status of the audience and communicate outside the room usually happens when people cannot see each other directly. It is worth noting that the Teamwave Workplace investigation took place in 2002 and currently, there are more technology could be used to optimize. On the contrary, social VR figured the monitoring problem in digital collaborative tools, which is to determine what others are doing and who is using a tool.

Furthermore, compared to problems identified in previous studies, some have been solved in the current technology, some still remain. The social VR concept, extended by a collaborative virtual environment (CVE), started from the early 1990s and, at first, focused on two people collaborating in virtual environments. In the early stage, technology only created simple scenarios and tackled some basic technique issues. For instance, the field of view (FoV) of VR devices is limited and people have to consider peripheral awareness. This problem is not significant today as the Oculus gives an FoV of 110 degrees; this compares favourably to the healthy human eyes which have a horizontal FoV of about 135 degrees and a vertical FOV of over 180 degrees. The usability issues about moving to the desired destination and inability to manipulate objects have been improved.

Overall, our study is preliminary research focused on the social tasks between people in virtual reality and is the first to use the inspection method among real-contextual situations to compare social VR platforms.

6.1 Mechanism to bridge the reality and virtual

McVeigh-Schultz et al. [30] divide the social VR platforms into two types: open-world environments and closed environments which can only be accessed by invitation. However, all the platforms are able to support people who already know each other. That means, the needs to bridge VR and the outside world is significant to all the social VR platforms, especially how to transfer real-world friends into a virtual world.

As we observed, all the platforms studied involved the input or output of some information from the virtual environment.

There are two scenarios related to this mechanism. One is entering a code and sending it to friends who are not yet in the platform yet. For the real-life tools, people tend to copy and paste to a switched application. In Oculus, they already developed a platform communication tool based on Oculus Friends. However, the difficulty is how to support copy and paste in VE as there are no existing solutions for switching between the apps in VR.

Spatial provides an attempt to solve this problem by sending emails by the platform. However, entering the right email address is still a painful experience. So, a website to access the platform is provided that allows users to send invitations. Nonetheless, this solution is also painful for the receiver who has to log on to the website and then link to the headset. There is definitely a need for a more seamless integration between the apps and instant massaging would be a better choice.

Another scenario is to share a desktop or some external source in the platform. Only two platforms support this function, BigScreen and Spatial. However, controlling the computer screen with a headset is difficult. There is already a solution called 'virtual desktop' to enable people to use the controller in VR to manipulate their computer.

Finally, all the processes involved actions of taking off the headset and putting it back on again, which interrupts any activity flow. A new mechanism is required to bridge between the real world and the virtual world.

6.2 Social mechanisms

Virtual reality has been recognised as an effective tool to maintain interpersonal relationships between people, especially who separated by geographic distance [32]. McVeigh-Schultz et al. [25] noted the importance of environments in managing users' expectations, and they also emphasised the use of social catalysts. In our study, we would like to note the importance of mutual task flows as a social mechanism to improve the usability of platforms.

Friend mechanism

In order to create an open world, VRChat, AltSpace and RecRoom all provide a friend mechanism, allowing users to add friends, send friend invitations and text messages. AltSpace provides more details about the location of online friends and the ability to teleport to a friend's space.

The basic function of adding a friend requires a comprehensive friend task flow to include finding a friend on the platform, sending a friend request and being accepted by the friend. There are already four choices of finding friends on the platforms:

1) Using friends' code to search. This is the most popular choice and is a similar process to that used on online social platforms except that others cannot verify the word typed in as they are unable to observe another's' view in virtual reality.
2) Using friends' username to search. This is harder than a username as the codes are usually meaningless and too long for people to remember.
3) Adding through face-to-face, which requires people to meet in the same room on the VR platform and identify each other, which is impossible for the first-time user and needs more coordination outside the platform.
4) Importing friends from other platforms like Oculus friend or Facebook friend which is easier but is restricted to the existing group of friends.

Clearly, a more usable method should be designed in VR, such as innovative use of a QR code for adding friends.

Invitations and texting involve another basic function on the platform, namely notifications. In our result, we found that RecRoom has a more user-friendly notification system than any of the others. In RecRoom, all status information is presented in front of the user while other messages from friends require the user to check on their 'watch' (a metaphor for menu) with visual guidance. However, people sometimes accidentally activate the menu by lift their hands and easy to mistouch other functions.

Invitation mechanism

Inviting others into the room is difficult in the virtual environment, especially when the person to be invited is outside the platform because then they have to receive the invitation in the physical world and be able to transform to the virtual world.

In the platforms studied, there are three ways to navigate people into the same room: 1) share code or link; 2) send an invitation directly to online friends in the platform and 3) ask friends to use the 'go-to' function. The results show that sending invitations to online friends is the quickest of these three methods, though the ability to add friends to each other and an instant alert would be useful additional functions.

Emotion and gesture expressions

Non-verbal communication like emotion and gesture is significant in social life [32,54]. Regardless of the avatar's type (animated or robotic) to represent the user, users still express their demands to seek for affective supports. In our study, the truth is when all the platform supports simple gestures like pointing, thumbs-up and hand waving, in the virtual environment, people have less expectation about interpersonal interactions.

Because of the technology limitation, whole-body tracking and facial tracking is not available. In these platforms, users need to choose the emotion listed in the menu which can then be displayed in one of two ways; through facial expressions offered in RecRoom and through 2D emoji pictures in the other platforms. However, the way to choose emotion is hidden and not natural. Sometimes, the platform would use inauthentic facial expression (like RecRoom) and eyes moving (like eye gaze in AltSpace), which could cause misunderstanding.

Besides, RecRoom enables more interaction like high five and handshake. However, all the interactions are hidden and need to exploration, but when participants were asked to try it, they reported surprised. McVeigh-Schultz et al. [25] noted those emotions and interactions as social catalysts and we believe that better, more nuanced expressions in VR could enhance engagement and level up the user experience.

Nevertheless, we believe that a more seamless way to express emotions and gestures should be developed. For example, instant digital communication tools like WhatsApp or text enable people to use emoji to express their emotion in a visual and entertainment form, but whether this 2D solution is viable in a 3D virtual world is open for discussion. In current studies, head tracking, gesture tracking and face tracking is possible to apply but hard to difficult to make them ubiquitous due to the high cost. As the technology develops, devices are increasingly able to track more hand gestures; for instance, accurate hand shapes and simple gestures are now available in Oculus Request. Some facial expressions could be recognised with eye-tracking cameras [17] while more complex facial tracking needs more technique supports and can't be commonly available in a few years.

Joint manipulation

Actual joint manipulation is not available in existing platforms but should be in future. The ray casting is the common target pointing technique to help select things [3]. On current social platforms, the ray casting is only visible to the user whilst in Spatial, it is visible to everyone. In our result, we verified the usability of the visible ray casting. We believe that if supporting remote control to the objects, who is interacting should be recognisable.

Social protection and policy

It is important to ensure that users have sufficient personal space in social VR platforms, ideally following real-world conventions. The bubble is the way almost all the platforms chose to retain a suitable distance between avatars, to prevent them being overlapped by other users, and to stop more than one avatar from occupying the same place. It is questionable, though, if the disappear mechanism necessary since it impedes some close interpersonal interactions. Therefore, a more flexible social distance protection policy should be considered as people apply different social norms to various relationships.

All the applications support blocking, muting and reporting to avoid offence and prevent harassment. In the public space in VR, harassment is serious and easy to do as people are pseudonymised. For example, in RecRoom, putting a bin on the head of another user is a common source of entertainment, though this is best done between people who know each other; such actions would be seen as violent in public. Furthermore, uncomfortable experiences are reported when users meet strangers in a public place. For example, a group of participants reported an unpleasant experience in seeing someone bully another person. As suggested by Blackwell [6], online harassment is subjective, an individual-based governing and reporting policy should be created and implemented.

6.4 Inspection evaluation

Cognitive walkthrough is used by experts to assess usability problems and is supplemented by heuristic evaluation for the purpose of design inspiration. Some researchers believe that a groupware tools evaluation can only be carried out in a real context. So, in some cases, a group of experts could take part in the inspection. However, in order to assess learnability and avoid expert bias for a new technology like Virtual Reality, interview and experiments with questionnaire are a common choice. As a result, there is less work regarding users' task flow.

In this study, we aim to check the usability, especially the learnability of existing social VR platforms. A task analysis based on interaction cycle theory is used and checked by an expert, and then a real user walkthrough is used. The gap between expert and user is thereby filled in order to avoid expert's bias and gain some design inspiration by comparing different platforms.

6.4.1 Challenges

Since the cognitive walkthrough is initially conducted by experts, the questions are technical and need a transfer. To the end, control was passed to users by asking them what do you want to do next and then asking them the follow-up questions related to the action they will take.

Then, using the think-loud protocol, the participant has to talk to the researcher and the partner, which sometimes cause conflict and disorder. Instead of asking questions in reality, we conduct a new approach that is the researcher play as an observer in the virtual room that participants in and asking questions at a suitable time.

6.4.2 Limitations

In this project, we only focused on the social behaviour of familiar people in the social VR platforms. The sample size of participants was limited and the participants were all young who had never experience VR before. Most of them just participated once.

It is worth noting that all the participants were required to take part in the tutorial provided by the platform. In the investigation, when participants have difficulty to find their target or determine their next task, the researcher offered some hints and instructs.

Additionally, throughout our projects, the platforms released several new versions to iterate. Some problems reported may be fixed or changed.

Finally, the task analysis and the link of the cycles are based on a self-walkthrough, meaning that some subjective evaluations are included.

7. CONCLUSION

The aim of the study was to compare social VR experience on different platforms and identify usability problems. A self-walkthrough was used to analyse the tasks and cycles before the participants were required to complete the social tasks with friends. With the group walkthrough in a real context, the expert's bias has been avoided. For the general social VR platforms, the cognitive walkthrough based on the interaction cycle is proved to be practical.

The inspection results gathered various usability problems in social VR platforms like communication coordination, spatial navigation, joint manipulation and some technique shortcomings. We demonstrated the social mechanism problems and the needs to bridge the virtual world and the real world, as well as the significance of considering relationship in communication, navigation and protection.

Overall, as a preliminary study, we conducted a contextual inspection method in user groups to compare different platforms and provided evidence of current usability problems in social VR platforms.

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to Professor Anthony Steed; thank you for your continued support and patient guidance throughout the project, and thank you for providing the devices and trust to me. An extended thank, too, to all the participants who took part in this study. At last, thank my friends who supported me and helped me test the trials before recruiting.

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APPENDIX 1: INFORMATION SHEET

Participant Information Sheet

UCL Research Ethics Committee Approval ID Number: 4547/012

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

Title of Study:
Social Virtual Reality Platform Evaluation Experiments
Department:
Computer Science
Name and Contact Details of the Researcher(s):
Qiaoxi Liu, qiaoxi.liu@ucl.ac.uk
Name and Contact Details of the Principal Researcher:
Anthony Steed, a.steed@ucl.ac.uk

1. **Invitation Paragraph**
   You are being invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. If there is anything that is not clear or if you would like more information please ask the experimenter. Thank you for reading this.

2. **What is the project's purpose?**
   The purpose of the study is to investigate the user experience of current commercial social virtual reality systems.

3. **Why have I been chosen?**
   We require that participants are able to see, hear and walk unaided for the duration of the study, that users do not consume alcohol within 6 hours of the start of the experiment and that users are not sensitive to photosensitive epilepsy.

4. **Do I have to take part?**
   It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. You can withdraw at any time without giving a reason and without it affecting any benefits that you are entitled to. if you decide to withdraw you will be asked what you wish to happen to the data you have provided up that point.

5. **What will happen to me if I take part?**
   You will be asked to use assigned social VR platform in Oculus. You will then complete a task in a virtual reality system potentially with another participant. The task will involve social tasks like finding friends and communication. You will answer a set of post-experiment questions and undertake a short interview. Finally, you be paid £10 per hour in cash. The whole experiment should take approximately 60 minutes.

6. **Will I be recorded and how will the recorded media be used?**
   Data such as actions in virtual reality environment may be recorded. Audio of a short debriefing interview may be recorded. This will be transcribed and immediately destroyed. It will not be possible to identify

participants through this data. Data recorded during the experiment may be used for analysis, demonstration and further research.

7. What are the possible disadvantages and risks of taking part?

Users of virtual reality sometimes experience some degree of nausea. If at any time you wish to stop taking part in the study for this or any reason, please tell the researcher who will immediately end the experiment. As a safety precaution, we advise any participant not to operate heavy machinery (including driving) for two hours after the study.

Some users report 'flashbacks' and other side effects of using virtual reality equipment. Research suggests using virtual reality may cause short-term disturbances in vision.

Virtual reality can be a trigger for photosensitive epilepsy. You will be asked to confirm that you do not have photosensitive epilepsy.

8. **What are the possible benefits of taking part?**

You will be paid £10 per hour for your participation. You will get to experience a novel virtual reality experience. Additionally, it is hoped that this work will improve understanding of how users interact with virtual reality and the usability of existing social VR platforms. The ultimate goal is to make virtual reality more successful as a technology.

9. What if something goes wrong?

Should you wish to raise a complaint, please contact principal researcher Anthony Steed using the contact details above. If your complaint is not handled to your satisfaction, you can contact the Chair of the UCL Research Ethics Committee at ethics@ucl.ac.uk.

10. **Will my taking part in this project be kept confidential?**

All the information that we collect about you during the course of the research will be kept strictly confidential. You will not be able to be identified in any ensuing reports or publications.

Data such as actions in virtual reality environment may be recorded and stored with a unique participant number. It will not be possible to identify participants through this data. However, to facilitate removal of your data from the project should you wish to withdraw, a record matching your name and participant number will be made on a piece of paper separate from all other data collection means and kept in a locked cabinet. The record will be destroyed by shredding the relevant paper seven days after the completion of the data collection. Once the record is shredded, the data will be anonymous.

11. Limits to confidentiality

Please note that assurances on confidentiality will be strictly adhered to unless evidence of wrongdoing or potential harm is uncovered. In such cases the University may be obliged to contact relevant statutory bodies/agencies.

12. **Use of Deception**

Research designs often require that the full intent of the study not be explained prior to participation. Although we have described the general nature of the tasks that you will be asked to perform, the full intent of the study will not be explained to you until after the completion of the study, at which point you may withdraw your data if you wish.

13. **What will happen to the results of the research project?**
    The results of the research project are mainly used for the MSc dissertation and probably publish the results of the research as part of a research paper in relevant journals or conferences. The data collected during the project might be used for additional or subsequent research. Should you wish to obtain a copy of the published results, please contact the researchers using the contact details above. Any published results will be available as open access in the UCL library. You will not be personally identified in any report or publication, and it will not be possible to personally identify participants from any data presented.

    Anonymised data may be stored for subsequent research.

14. **Data Protection Privacy Notice**

    Notice:
    The data controller for this project will be University College London (UCL). The UCL Data Protection Office provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk. UCL's Data Protection Officer is Lee Shailer and he can also be contacted at data-protection@ucl.ac.uk.

    Your personal data will be processed for the purposes outlined in this notice. The legal basis that would be used to process your personal data will be the provision of your consent. You can provide your consent for the use of your personal data in this project by completing the consent form that has been provided to you.

    Your personal data will be processed so long as it is required for the research project. If we are able to anonymise or pseudonymise the personal data you provide we will undertake this, and will endeavour to minimise the processing of personal data wherever possible.

    If you are concerned about how your personal data is being processed, please contact UCL in the first instance at data-protection@ucl.ac.uk. If you remain unsatisfied, you may wish to contact the Information Commissioner's Office (ICO). Contact details, and details of data subject rights, are available on the ICO website at: https://ico.org.uk/for-organisations/data-protection-reform/overview-of-the-gdpr/individuals-rights/

15. **Who is organising and funding the research?**
    The research is funded by the University College London Interaction Centre (UCLIC).

16. **Contact for further information**
    Researcher:
    Qiaoxi Liu
    Address: A209.3 New Hall, 465 Caledonian Road, London, N79GU
    Phone: 07421823217

    Supervisor:
    Anthony Steed
    Office: 66-72 Gower Street, room 4.13, WC1E 6AA.
    Phone: +44 (0)20 3108 7112

Should you wish to take part, you will be given a copy of this information sheet and a signed copy of your consent form to keep. Thank you for reading this information sheet and for considering taking part in this research study.

APPEDIX 2: CONSENT FORM

PARTICIPANT CONSENT FORM

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study:

Social Virtual Reality Platform Evaluation Experiments

Department:

Computer Science

Name and Contact Details of the Researcher(s):

Qiaoxi Liu, qiaoxi.liu@ucl.ac.uk

Name and Contact Details of the Principal Researcher:

Anthony Steed, a.steed@ucl.ac.uk

Name and Contact Details of the UCL Data Protection Officer:

Lee Shailer, data-protection@ucl.ac.uk

This study has been approved by the UCL Research Ethics Committee: Project ID number:
4547/012

Thank you for considering taking part in this research. The person organising the research must explain the project to you before you agree to take part. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study. I understand that it will be assumed that unticked/initialled boxes means that I DO NOT consent to that part of the study. I understand that by not giving consent for any one element that I may be deemed ineligible for the study.

		Tick Box
1.	I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of me. I have also had the opportunity to ask questions which have been answered to my satisfaction.	
2.	I understand that I will be able to withdraw my data up to seven days after study end.	
3.	I consent to the processing of my personal demographics information for the purposes explained to me. I understand that such information will be handled in accordance with all applicable data protection legislation.	
4.	I understand that all personal information will remain confidential and that all efforts will be made to ensure I cannot be identified except as required by law. I understand that my data gathered in this study will be stored anonymously and securely. It will not be possible to identify me in any publications.	
5.	I understand that my information may be subject to review by responsible individuals from the University for monitoring and audit purposes.	
6.	I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason. I understand that if I decide to withdraw, any personal data I have provided up to that point will be deleted unless I agree otherwise.	

7.	I understand the potential risks of participating and the support that will be available to me should I become distressed during the course of the research.	
8.	I understand the direct/indirect benefits of participating.	
9.	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher(s) undertaking this study.	
10.	I understand that I will not benefit financially from this study or from any possible outcome it may result in in the future.	
11.	I understand that I will be compensated for the portion of time spent in the study, and that I will still be entitled to this if I choose to withdraw.	
12.	I agree that my anonymised research data may be used by others for future research. No one will be able to identify you when this data is shared.	
13.	I understand that the information I have submitted will be published as a report and I wish to receive a copy of it. Yes/No	
14.	I consent to a debriefing interview being audio recorded and understand that the recordings will be destroyed immediately following transcription.	
15.	I hereby confirm that I understand the inclusion criteria as detailed in the Information Sheet and explained to me by the researcher.	
16.	I hereby confirm that: (a) I understand the exclusion criteria as detailed in the Information Sheet and explained to me by the researcher; and (b) I do not fall under the exclusion criteria.	
17.	I agree that my GP may be contacted if any unexpected results are found in relation to my health.	
18.	I have informed the researcher of any other research in which I am currently involved or have been involved in during the past 12 months.	
19.	I am aware of who I should contact if I wish to lodge a complaint.	
20.	I voluntarily agree to take part in this study.	
21.	I would be happy for the data I provide to be archived. I understand that other authenticated researchers will have access to my anonymised data.	

If you would like your contact details to be retained so that you can be contacted in the future by UCL researchers who would like to invite you to participate in follow up studies to this project, or in future studies of a similar nature, please tick the appropriate box below.

	Yes, I would be happy to be contacted in this way	
	No, I would not like to be contacted	

______________________ ______________ ________________

Name of participant Date Signature

______________________ ______________ ________________

Researcher Date Signature

APPENDIX 3: QUESTION LISTS OF INTERACTION CYCELS

Goal-directed exploration	Exploratory browsing	System initiative model	Normal task action 3D	Normal task action 2D	Collaboration
Do you know where to start looking?	The user determines a pathway for movement	Is it clear to the user that the system has taken control?	Can the user form or remember the task goal?	Will the user be trying to produce whatever effect the action has?	Can the user locate the other user?
Can the user determine a pathway towards the target?	The user executes movement and navigation actions	Can the user resume control at any point and is the appropriate action clear?	Can the user specify an intention of what to do?	Will users be able to notice that the correct action is available?	Can the user recognize the identity of the other user, tell the other users apart?
Can the user execute movement and navigation actions?	The user recognizes objects in the environment	Are the effects of system actions visible and recognizable?	Are the objects or part of the environment necessary to carry out the task-action (users new intentions) visible?	Once a user finds the correct action at the interface, will they know that it is the right one for the effect they are trying to produce?	Is there an indication of mutual awareness?
Can the user recognize the search target?	The user interprets identify, role and behaviors of objects	Are the system actions interpretable?	Can the objects necessary for the task action be located?	After the action is taken, will users understand the feedback they get?	Are the actions of the other user visible and recognizable?
Can the user approach and orient themselves to carry out the necessary action?	The user remembers important objects or locations	Is the end of the system action clear?	Can the user approach and orient themseleves to the objects so the necessary action can be carried out?	Is there an obvious next action to perform for the user, now what this task has ended?	Can the user act on a shared object while keeping the other users in view?
Can the user decide what action to take and how?	The user forms a mental map of the explored environment	Is there an obvious next action to perform for the user, now that this task has ended?	Can the user decide what action to take and how?		Can the user easily switch views between the shared object, other locations/object of interest and the other users (sweep from one to the other)?
Can the user carry out the manipulation easily?			Can the user carry out the manipulation easily?		Can the user get an overview of the total shared space and all other users in it?
Is the consequence of action visible?			Is the consequence of action visible?		Can the user tell when there are interruptions in the attention of the other users to the CVE?
Can the user interpret the change?			Can the user interpret the change?		
Can the user decide what to do next?			Is it made clear to user what the next correct/needed action could be?		
			Is there an obvious next action to perform for the user, now that this task has ended?		

APPENDIX 4: SCREENSHOTS OF PLATFORMS

Figure 1. People in VRChat

Figure 2. Meeting in AltSpace

Figure 3. Checking menu in RecRoom

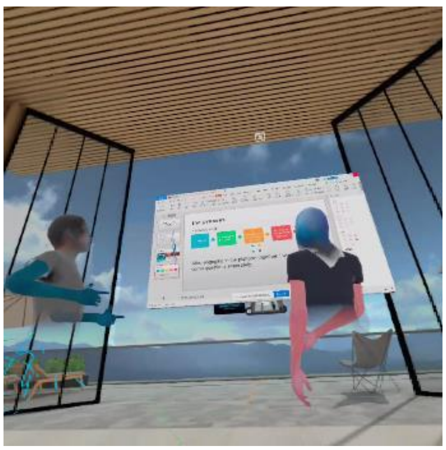

Figure 4. Presentation in Spatial

Figure 5. Private room in BigScreen

Figure 6. Meeting in Mozailla Hub