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Improving VR Social Interactions with Architectural Spacing Strategies

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IMPROVING VR SOCIAL INTERACTIONS WITH ARCHITECTURAL SPACING STRATEGIES

A project report submitted in partial satisfaction of the
requirements for the degree of

MASTER OF SCIENCE
In
COMPUTATIONAL MEDIA
By
Bryan C. Chao
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The Thesis of Bryan Chao
is approved:

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Professor Angus Forbes, Chair

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Abstract

Improving VR Social Interactions with Architectural Spacing Strategies

by

Bryan C. Chao

Virtual Reality (VR)-based social platforms, such as VR Chat, heavily rely on third-party content creators that sometimes reference the VR-inefficient design approaches of real-life venues without fully considering VR-specific design modifications. This project proposes that additional architectural design and spacing modifications should be implemented in the development of Social Virtual Reality Environments (SVRE) to further facilitate and improve social interactions in VR-based social platforms. The findings from this study indicate that open-space hotspot (OSH)-based design implementations in SVREs can improve VR social interaction and user experience by facilitating open-spaced grouped formations (OSGF), which are essentially a type of user formation catalyst for VR social interactions.

This thesis is dedicated to my parents,
Thank you for always supporting me.

Acknowledgements

I want to acknowledge everyone who played a role in my academic accomplishments. First of all, my parents, who always supported me with love and encouragement.

Secondly, the faculty members that each played a role in the development of this thesis, Angus, Katherine, and Steve. Thank you all for your support.

Chapter 1

Introduction

Social VR refers to 3D virtual spaces where multiple users can interact with one another through VR head-mounted displays (HMDs). [18] As VR hardware developers such as Oculus, VIVE, and Steam continue to improve VR systems and lower the costs of obtaining one, the number of users and content developers in the Social VR space has never been higher. For the most part, the uploads of the developers consists of VR maps and avatars. While few of these designers are professionals, most of the content developers for Social VR platforms are hobbyists and intermediate designers. The reason for this is because social VR platforms, such as VR Chat (VRC), welcome developers of all skill levels to participate and upload content into their platforms. For instance, VRC makes available a free software development kit (SDK) that makes it much easier for novice designers to create and upload content. These SDKs augment content design software, such as Unity, to substantially facilitate the design and uploading process of social VR content. For instance, a designer simply needs to click a newly added “upload” button from the SDK, to submit and upload a complete design to the online VRC database via Unity.

While these social VR platforms have provided content developers with the appropriate tools to create and upload maps, there is very little guidance available on optimizing the designs of social virtual reality environments (SVREs) to promote improved social interactions. Furthermore, while there is an influx of new VR users and SVRE designers, empirical-based guidance and research relating to the design of SVREs is an underexplored area.

Two SVREs were created in this project for user testing. In the user study, the SVRE design component of space is examined through social interaction metrics such as peer proximity, sociometry, and qualitative observations. One SVRE represents a standard map layout that does not include additional spatial design motivations. The other SVRE implements open-space hotspots (OSH), which are designated open-spaced areas, free of collidables, in contrast to a collidable-dense remainder of the map. The results from this study indicate that (OSH)-based design implementations in SVREs can improve VR social interaction and user experience through facilitating open-spaced grouped formations (OSGF), which are essentially a type of user formation catalyst for VR social interactions.

1.1 SVRE Design & RL Architecture

Space is a substantial factor in shaping architectural outcomes. For instance, in real life (RL), implementing architectural designs with too little open space might entail a claustrophobic user experience. To an extent, the implications of modifying space in architecture also carry over into VR architecture and design. A room in VR that is too cluttered with little open space will also result in a claustrophobic user experience. However, while the more fundamental implications of space carry over into virtual reality environment (VRE) design, VR also has discrete implications of space unique to RL methodologies. For instance, in RL, all objects have physical properties. In VR, some objects might have VR-physics properties and colliders and while others might be fixed and permeable. Nevertheless, the unique properties of objects and space in VR bring a distinct set of implications from RL objects and space. As a result, VR architecture should incorporate additional VR-specific design considerations to optimize the VR user experience.

Often, social virtual reality environment (SVRE) designers tend to create and upload maps that imitate the layout of RL venues. While this design approach may promote user immersion and presence [23] by recreating a familiar RL scenario for the user, this approach does not facilitate improved VR social interactions with additional design implementations. While designers have access to a fair amount of reference material related to RL architecture design, SVRE-specific design-related references are limited. By testing and documenting SVRE related design strategies, more information on design methods becomes available to VE developers. As a result, these findings may help guide designers to implement more SVRE-specific design techniques into their uploads, improving social interactions and user experiences through improved VR maps.

1.2 Related Work

With VR becoming an increasingly used medium in multiple domains, there are plenty of new VR-related research areas, ranging from medical to entertainment categories. Regardless, the focus of this project, to examine VR-based social interactions through modified VE design implementations, is a relatively novel and underexplored research area. While studies have examined social interaction in VR, primarily when related to avatar design [16,20,21] this project has a more unique focus of map design.

As mentioned above, avatars have been a particular area of interest for social VR researchers. Studies have found that avatars that lack specific appearance features significantly reduces how other users might perceive one’s presence and physical performance [20]. Furthermore, studies have found that the anonymity aspect of virtual avatars has, to an extent, modified the amount of first-impression appearance bias that is tied to individuals in the online VR space [19]. VR-based semantics and non-verbal communication is also a recently trendy research area that examines how body language in VR adds depth and privacy to VR-based social interactions [2,16]. While avatar design might not relate directly to VR map design, it is vital to consider the social implications of avatars as a variable in conducting a social interaction-based user study of SVREs.

While desktop-based virtual environment (VE) design studies have been somewhat prevalent [17,21], immersive VRE design studies are also becoming an increasingly popular area of research [4,22]. Desktop-based VE studies have examined the implications of design implementations on social interaction to an extent [17], but VR studies have not yet covered this area sufficiently. Furthermore, the findings and concepts from the desktop-based VE studies do not accurately apply to VR environments due to the distinct user-immersive aspect of the VR platform. Lastly, of the archived VRE and social interaction studies, it is rare to find one that focuses solely on VR architectural design implications and VR social interactions. Nevertheless, this study aims to help expand SVRE research motivations and serve as a reference point for future SVRE designers.

In RL architecture and social interaction research, a study found that areas with fewer physical structures and barriers can facilitate social interactions [3]. In the study, two military barracks were constructed to house new military recruits. One barrack had the standard configuration where soldiers had their own cubicle living spaces. The other barrack had the same layout, but the walls inside were replaced with dotted lines on the ground. Their finding was that recruits could learn and retain more information about their peers in the barrack with fewer physical barriers than the recruits in the standard type of barrack could. The findings in this study inspired sociometry as a metric in SVRE map design and social interaction for this thesis.

TABLE 1

Average Choices Given for Total Acquaintances Known and for Knowledge of Bunk Locations of Acquaintances as a Function of Open vs. Closed Cubicle Type Barracks

Day of Training	Barracks Type	Bunk Location Known	Bunk Location Unknown	Total Acquaintances
6	Open	18	12	30
	Closed	9	14	23
11	Open	15	11	26
	Closed	14	11	25
14	Open	23	13	36
	Closed	15	13	28
Total	Open	19	12	31
	Closed	13	12	25

Figure 1.1: Metrics from the Housing Architecture and Social Interaction study

1.3 Design Goal

Considering that VR architecture and social interaction is a relatively underexplored research topic and that the implications of space are a fundamental factor in any architectural design, this study aims to examine how space in SVRE design may impact VR social interactions.

In this project, two contrasting SVREs are designed to examine the social implications of space in SVRE design. The first environment, SVRE1, represents a standard design approach that VE designers incorporate in their uploads. This consists of referencing real-life (RL) venue designs with no additional VR-based design modifications. While these types of map designs can be aesthetically nostalgic and visually immersive for users, the design approach usually entails inadequate design features to facilitate improved user social interaction. For instance, a 1:1 copy of a nice RL diner in VR might visually seem just as pleasing as the real counterpart to some users. However, because the VR map does not incorporate VR-specific design components, such as usable furniture or open space to compensate for the clutter of collidable furniture, the areas on the map where users can socialize is limited, further reducing the social user experience aspect of the map.

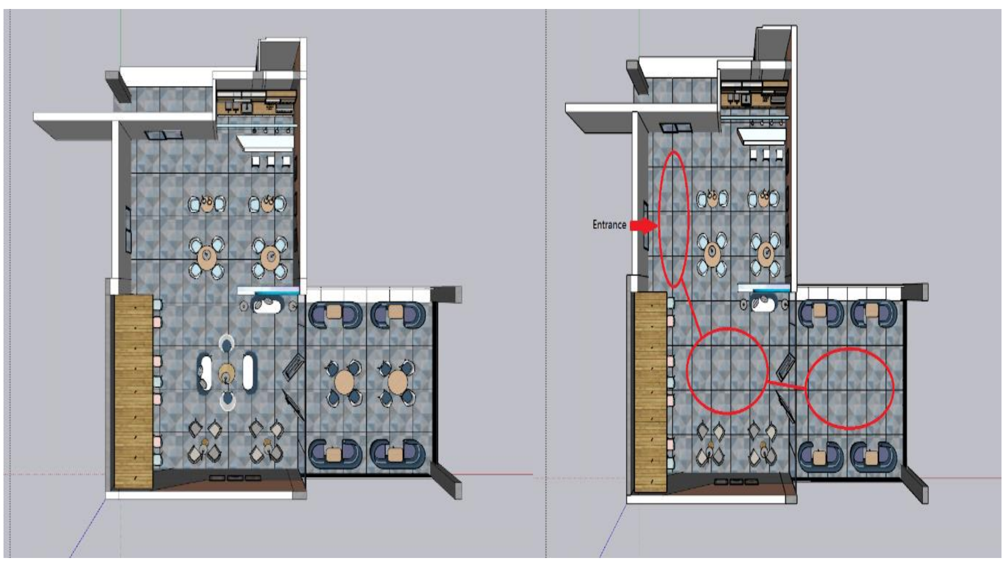

Figure 1.2: Sketch of comparison between SVREs with and without OSH.

The second environment, SVRE2, is a copy of SVRE1 that implements additional architectural design modifications of space to facilitate social interaction. Specifically, this includes modifying the position and number of collidable entities, such as furniture, to create open-space hotspot areas (OSH). These OSHs were initially hypothesized to attract users into closer social proximity of one another, increasing conversational frequency and improving social interactions. VR users find that it is generally undesirable to collide with entities such as furniture, as it can result in unideal situations such as avatar glitching, inconvenience, or a general feeling of claustrophobia. As a result, this project hypothesized that; in a cluttered room, VR users are inherently drawn away from collidable objects and towards open spaces. Hypothetically, this would suggest that OSHs can be implemented as an SVRE design technique to improve VR social interactions by facilitating increased frequency of conversation and multiuser interaction in a concentrated location on the map.

Figure 1.3: Sketch of users in-range for conversation w/o OSH

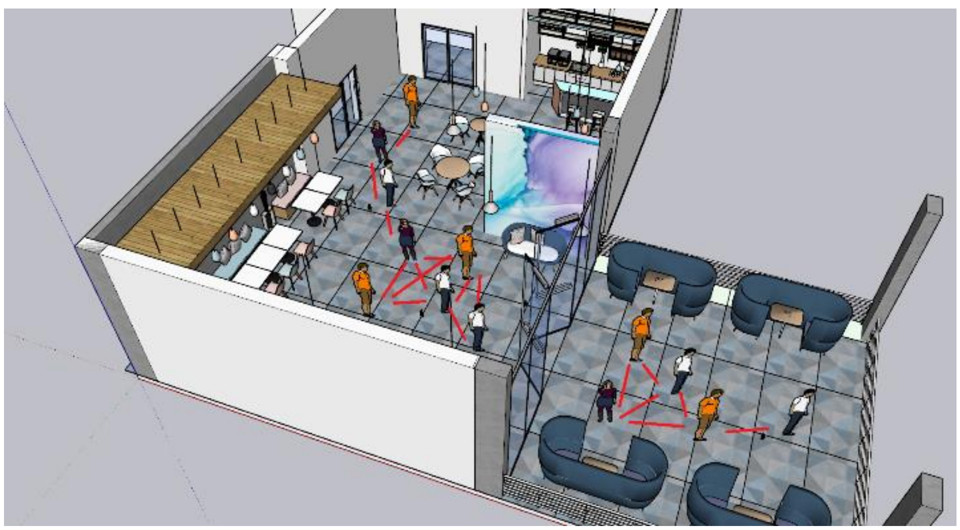

Figure 1.4: Sketch of users in-range for conversation w/ OSH

1.4 SVRE Platform

This study uses VR Chat (VRC) as a platform to conduct SVRE user testing. VRC is a VR-based social platform available free to download on Steam. Most PC-based VR systems, such as any HMD product from VIVE, Steam, or Oculus, are cross-play compatible in VRC. By providing software development kits (SDKs), the VRChat developers heavily rely on third-party content designers to upload VEs and avatars via Unity. As a result, there is a vast amount of community-built content accessible to the general VR public. This content includes avatars that range from favorite anime and video game characters to custom-built avatars. VEs, include anything from pleasant internet cafés and rooftop lounges to lively nightclubs or intense horror maps.

Figure 1.5: A group of VRC users posing for a photo in a VR nightclub.

Chapter 2

Social Virtual Reality Environment (SVRE) Design

2.1 Theme

Using Unity integrated with VRChat's SDK, two SVREs were designed for this study. Since SVRE2 is a modified version of SVRE1, the two environments share many fundamental design traits. Both maps share the same venue style and selection of props but are different in layout. SVRE2 implements one primary additional design modification, which is the incorporation of open-space hotspots. A hotspot is considered a designated area of the map free of collidable entities in contrast to the entity and collidable dense, rest of the map. The three main design aspects of both maps are the theme, props, and layout. These aspects were carefully considered in the design process to create the most suitable user testing SVREs for this project.

After exploring several options, the coffee shop theme was ultimately selected for the SVREs venue for three reasons. The first reason was that the coffee shop theme is intended to put more atmospheric context into the user study and make users feel more comfortable with the activity. Coffee shops are generally recognized as an ideal place people like to have brief social meetings. Considering this sentiment about coffee shops, it seemed suitable to pick it for the social interaction-based user study.

The second reason for choosing the coffee shop theme relates to being able to create fixed boundaries in the map without breaking the immersive experience for the users. To elaborate, the area of the map that participants can access during the study is a controlled variable. Altering this variable would affect results and variables such as user proximity and conversational initiation frequency. As a result, this user-accessible area of the map needs to be enforced with the same fixed-sized boundary in both SVREs during the study. Because of the indoor and small venue aspects of a coffee shop, these boundaries can simply be enforced by the walls of the shop. On the other hand, outdoor or larger venues might require invisible walls or other immersion breaking boundary implementations. Nevertheless, sustaining user immersion is an essential component of maintaining the VR experience. By bypassing the issue of immersion-breaking boundary implementations, this coffee shop theme for the SVREs enforces the accessible area control variable and maintains an immersive environment for the user.

Lastly, the generic layout of coffee shop venues generally includes coffee tables and chairs throughout the venue, which fits the collidable objects requirement for this project. Since SVRE2 is meant to implement open space hotspots in contrast to

SVRE1's layout, the tables and chairs of a coffee shop were a suitable source of collidables for implementing these changes.

2.2 Collidables

The implementation of props in the SVREs essentially relied on four main factors; selection, modification, colliders, and layout. Most of the 3D prop models and textures were based on purchased pre-modeled object packs. In selecting which props would be used, entities that supported a coffee shop atmosphere were prioritized, while entities that might have been too flashy or distracting were disregarded. By filtering out distracting or interactive props, the study controls the variable of props that can affect VR social interaction results. For instance, in SVREs, users can be drawn towards interactive elements such as mirrors or grabbable objects, altering proximity values and other results. In VRC, it is common to see users gather in front of a large mirror element to have conversations. It has also been observed that some users, especially when entering a map for the first time, will be drawn towards interactive entities such as grabbable food and drinks, beer pong, bouncing balls, etc. Interactive entities are known to facilitate social interactions in VR, which emphasizes the importance of controlling this variable by not including them in the study.

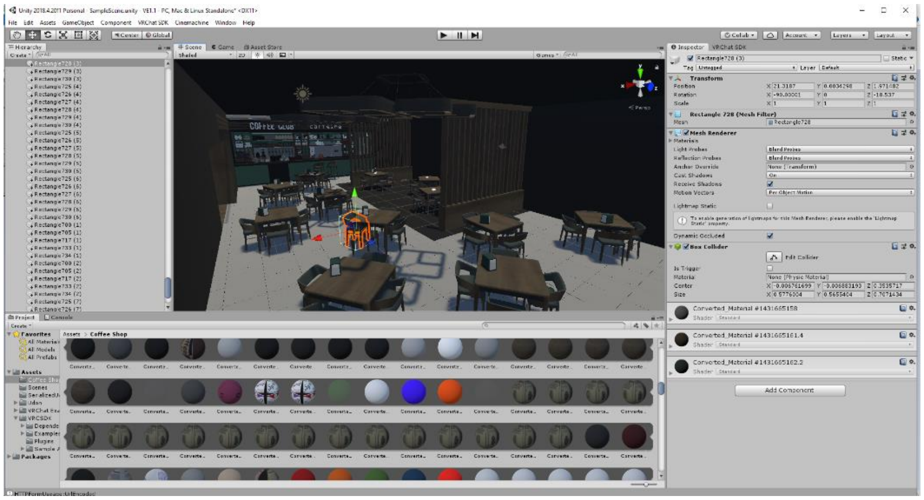

Figure 2.1: Placement and Collider Mapping of objects in Unity

After selecting the appropriate SVRE props, the props were modified before being implemented into the map. These design modifications included rescaling, recoloring, and repositioning the props to fit the coffee shop aesthetic and be optimized for VR experience. For instance, the scaling ratio of furniture size to user avatar size was adjusted so that props were proportional to the average user's height in VR. This ensures that the SVRE does not have distracting elements like overly small chairs or excessively large coffee cups. In another example, the shading and color palette of some furniture was changed to improve aesthetics. After undergoing these modifications, the props are ready to be implemented into the next step of SVRE development.

Physics colliders are then mapped onto each prop so that each prop has its own spatial barrier. These colliders consist primarily of box colliders and cylindrical colliders, which are essentially boundary markers derived from cubical and cylindrical shapes. The mapping of each collider is adjusted until they are consistent with the shape and size of the props. This means that colliders only occur where there is visually an object; in other words, there are no objects that users can walk through and that there are no invisible colliders in the map where there is no object. After this step, all objects will essentially take up space in VR, and depending on the size of the prop, users may have to jump over or walk around the object to get past it. These collidable entities are a central component of this study, which aims to examine how solid VR objects (collidables), which are configured in a specific layout, may affect social interactions in VR.

2.3 Architecture & Layout

This brings us to the final aspect of SVRE development: the architecture and layout of the SVREs. The first architectural component is the scaling of the walls. Depending on how many participants are expected to partake in the study, the walls can be stretched or shrunk in Unity. This allows the venue and user-accessible area to be adjusted accordingly. In this study, which had 8 participants, the venue was scaled down to be approximately 1000 square feet. Since both SVRE1 and SVRE2 had the same number of participants, the wall and venue scaling were the same for both. In future iterations of this user study, which may have additional architectural implementations or participants, the scene can be scaled to the appropriate size and reused.

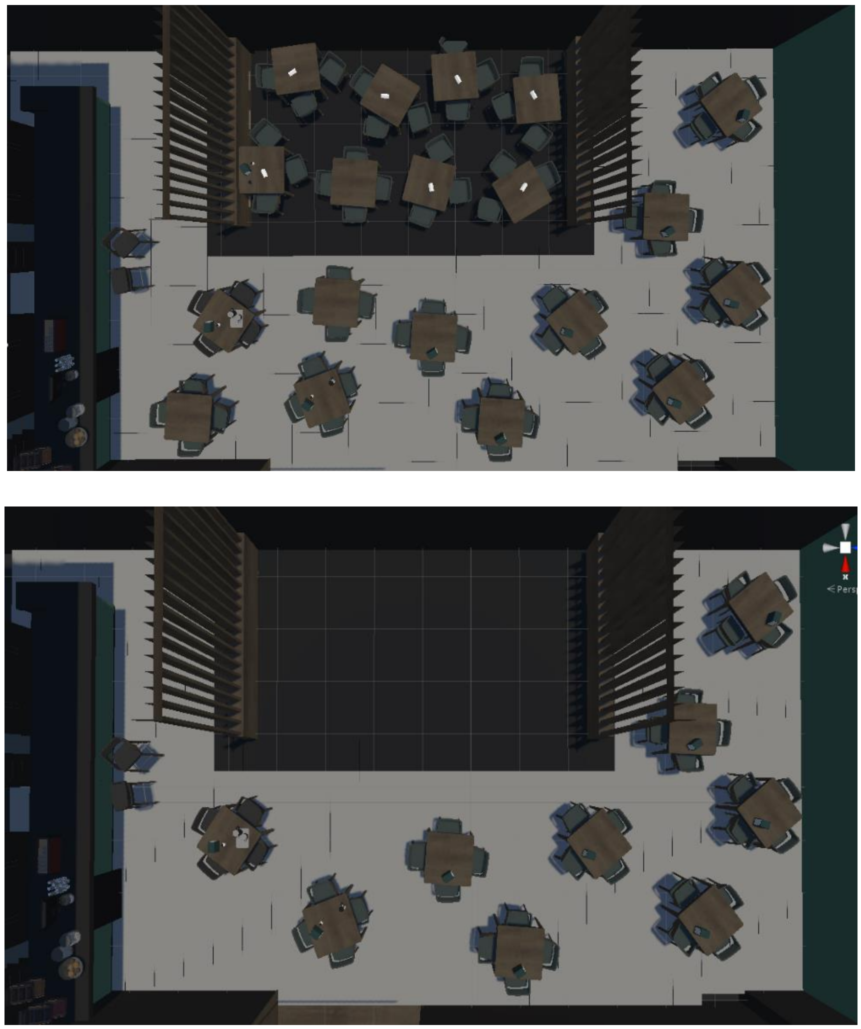

Figure 2.2: SVRE1 layout (Top) & SVRE2 Layout (Bottom)

The other main architectural component relates to the placement of collidables in VR space. This is where the design of SVRE2 is distinct from SVRE1. Both SVREs have three areas of the layout: the barista area, outer area, and inner area. The barista area takes place on the western edge of the map and consists of all the elements that a barista would need to serve coffee to customers. This includes beans, taps, bar stools, and other objects. The barista area is primarily for aesthetic and atmospheric supporting reasons. As a result, the barista area has the same layout in both SVREs.

The outer area takes up the majority of the map and consists of numerous coffee tables and chairs. Unlike the barista area, this area has a distinct layout in SVRE2 than in SVRE1 and is intended to influence user proximity and social interactions. In SVRE1, the tables and chairs are relatively equidistant from one another. Additionally, the objects are distributed throughout the map so that there are minimal open space areas. In SVRE2, the tables and chairs are fewer, and the common area is less condensed overall. Additionally, the furniture is not always equidistant since there are designated areas where more space is provided between tables to form more extensive walkways and open space. The implementations of these larger walkways were hypothesized to accentuate open channels in the map and connect a path between hotspot areas.

The inner area takes place in the furthest most center of the room and, like the outer area, also consists of coffee tables and chairs. In SVRE1, the inner area is the most collidable condensed part of the map. Props in this area are so close to each other that there is virtually no area without a collider above the ground. If participants chose to be in this area of the map, they would be either be standing on a table or a chair, which is not entirely uncommon in some circumstances in VR. In SVRE2, the inner area has no collidables. The layout of this inner area has been transformed to be a designated open space hotspot area. Incorporating these various levels of collidable dense areas in both SVREs allows the study to contrast and examine how such collidable-based architectural decisions influence user social interactions.

Chapter 3

Methods

3.1 Study Design

The main goal of this study is to examine how the implementation of collidables in VR may affect VR social interactions and indicate if there are any architectural patterns in this area that can improve the social VR experience. In other words, this study aims to test out the concept of open space hotspots in SVREs and determine its effectiveness as an SVRE design technique to improve VR social interactions. The approach of this study is to monitor the three main metrics of proximity, sociometry, and interview in an SVRE based user testing. The initial hypothesis of this study was that open-space hotspots would improve SVRE social interactions through facilitating group conversation and bringing users into a closer level of proximity to one another.

3.2 Participants

Participants are recruited through two main approaches. The first is through Discord channels that are related to VR Chat. The second approach is by recruiting users verbally from public instances in VR Chat. For this study, eight participants were selected to participate in the user testing of a 1000 sq. ft. venue. Each participant accesses the user testing instance through their own head-mounted display system (HMD) from home. Participants were free to use their own avatars under reasonable moderation. This moderation suggested users pick an avatar that fits the VR Chat rules, is humanoid, is not overly gigantic or miniature, and does not have excessively flashy and distracting special effects. To control the variable of participants consciously making decisions based on design intentions, only after the user interview process was it revealed to them that the study was related to collidables in VR architecture. All participants gave verbal consent to partake in this user study after understanding the user tasks. This user study was certified as exempt from IRB oversight by the UCSC Office of Research Compliance Administration (ORCA).

3.3 User Tasks

Each user testing phase lasts 5 minutes for each SVRE. Before the activity begins, participants are told to think of an alias and fictional fun fact about themselves. Furthermore, all participants are spread out from each other and stand next to the venue's walls before the testing commences. This is to prevent two or more participants from starting the testing phase in close enough proximity to one another, which may allow them to begin a conversation immediately. Additionally, starting participants off alongside the wall will encourage participants to move to new parts of the map to find conversations rather than remain centered in the map the whole time. Controlling this variable of where participants will be as the testing phase begins allows for results that will be more indicative of the architectural influence.

With participants already briefed on their task and in position ready to go, the host of the study will begin the 5-minute stopwatch and signal the participants to begin. At this time, users seek out to meet their peers and learn as many aliases and fun facts as they can. Participants are motivated to meet as many people as possible within the given timeframe because they know that they will be asked to record and submit as many details as possible about their peers afterward. During the 5 minutes, the participants move around the map freely, whether that requires jumping over props or walking around them. After 5 minutes have passed, the host signals the participants to stop their task. The participants then take off their HMD and record their results in a document provided by the study. After a brief intermission, the same process is repeated with the same participants in SVRE 2.

3.3 Measures

3.31 Proximity

Studies have indicated that distance between participants is a factor of social interaction quality [19]. Considering this, the first metric of the study tracks the user-to-user proximity and how it changes based on the environment. Proximity findings include measurements in two areas. One measurement is the distance, in ft., between participants and their nearest peer, at certain time intervals. The other measurement is the number of peers within a certain level of proximity from the participant at certain time intervals. This proximity value is based on the proxemic frame of reference from the Hall [8] paper, which indicates that a proximity of under 4 ft. is considered a personal level of closeness. When compared to the socially consultative proximity level of under 9ft., which the Proxemics study [8] claims is the minimum social recognition distance, the personal level of proximity may entail a more intimate or focused interaction.

While VR user-to-user proximity values might entail slightly different implications than in real life (RL), studies have shown that there are many similarities for the most part [22,25]. For instance, a study on VR proxemics [14] found that users had a similar psychological and electrodermal response to approaching entities in their proximity as they would in RL. Considering these similarities, the proxemic frame of reference from the Hall paper [8], which was initially meant for RL circumstances, may also be a suitable means to gauge VR-based user proximity implications.

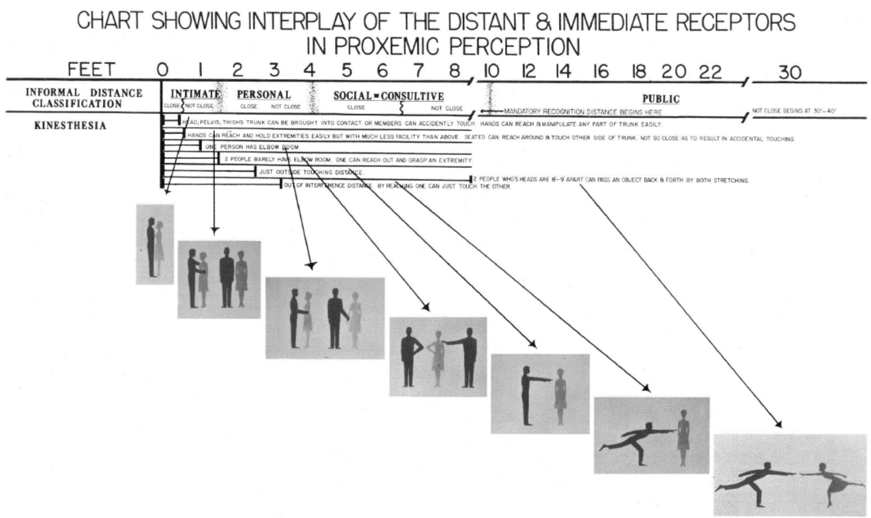

Figure 3.1: Proxemic frame of Reference from the paper, Proxemics [8]

The user testing instance is video recorded by a virtual video camera that captures the scene from a birds-eye perspective. Using this footage, the proximity values can then be calculated using the floor tiles as a size reference. Each floor tile in the SVRE is deliberately made to be 2ft by 2ft. Together, these tiles give off a grid-like appearance to the SVRE floor from the top-down perspective. This allows for more accurate distance measurements. These measurements are logged for each participant on the frame of each 30-second interval of the 5-minute video recording.

Nevertheless, the proximity values from this metric can later be examined collectively with the results of other metrics to infer further conclusions.

3.32 Sociometry

Sociometry is defined as the quantitative study and measurement of relationships within a group of people, according to the Britannica encyclopedia. Inspired by the approach to measuring social interaction-based implications in the "Housing Architecture and Social Interaction" study [3], this project also uses the metric of sociometry. The number of aliases and fun facts that participants could obtain and remember in each SVRE was recorded. From comparing these quantitative results, several things can be interpreted. For instance, hypothetically, a higher number of peer details remembered in one SVRE vs. the other might indicate improved social interaction conditions or the additional occurrence of more frequent group conversations.

3.33 Written Interview

After participants tested both SVREs, they were provided with a Word document that asked them to describe some thoughts. Questions include asking the participant to explain why one SVRE might be preferred when meeting new people.

The written interview is valuable in how it gives the user a chance to describe their user experience with words. This qualitative feedback can then be considered alongside the quantitative findings to draw stronger inferences from the data. All in all, the qualitative aspect of the written interview metric gives clearer insight into certain VR architecture social interaction-related concepts.

Chapter 4

Results

4.1 Quantitative Metrics

4.11 Sociometry

Sociometry results were recorded to help determine to what extent the VR architectural modifications affected VR social interactions. This metric ultimately tested how much detail, in the form of aliases and fun facts, participants could learn and remember about the peers. If a participant remembered a name correctly but the associated fun fact incorrectly, a point would be counted towards retaining the name but not the fun fact. Points were only given to correct details if the participants associated the proper alias with it.

In the standard layout map, SVRE1, users learned and remembered an average of 5.14 of their peers' names and 4.57 correct fun facts. On the other hand, participants in SVRE2 could remember approximately 5.25 names and 5.13 peer details. These numbers indicate that, on average, participants could learn and remember slightly more aliases and details than they could in the SVRE1 map configuration. However, SVRE2 had a strong outlier in the dataset of participant scores. One of the participants scored a 2 on both the name and detail categories in SVRE2. This deviates from the median score, of 5.5, for both categories by 64%. All other scores remain within a 21% range of the median score. The percentage deviation from the median was calculated with the below formula.

(Median 5.5 – Deviation **3.5** = Outlier Score 2.0)

(Deviation 3.5 / Median 5.5 = **64%** Deviation)

Furthermore, the sigma value of both SVRE2 datasets were calculated with the below formula for standard deviation. These calculations showed that the standard deviation for names learned in SVRE2 was 1.67 and that the standard deviation for details remembered was 1.73. While no other results deviated 5% beyond one standard deviation from the mean, the outlier deviated 95% beyond the mean. The participant that scored this outlier would later mention in the written interview that they consistently have more trouble than others in certain memory-based tasks. They described that they were confused by trying to forget the aliases and details from the previous SVRE1 user test to learn new names in the SVRE2 section of the study. Because the participant did not indicate they had difficulties memorizing details in SVRE1 and their scores did not indicate otherwise, the participant's scores from SVRE1 were still included in the SVRE1 average scores.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

Figure 4.1: Standard Deviation Formula

On the other hand, considering that the outlier in SVRE2 was nearly two standard deviations away from the mean data point, it seemed reasonable to examine the dataset without the outlier score. In this case, participants in SVRE2 would have an average of 5.71 names and 5.57 details learned and remembered about their peers. This would indicate an 11.1% increase in names learned and a 22% increase in details remembered in SVRE2 compared to SVRE1.

Alias: $$11.1\%\ Increase = 100 \times \frac{(5.71 - 5.14)}{5.14}$$

Detail: $$21.9\%\ Increase = 100 \times \frac{(5.57 - 4.57)}{4.57}$$

Figure 4.2: SVRE Percentage Increase

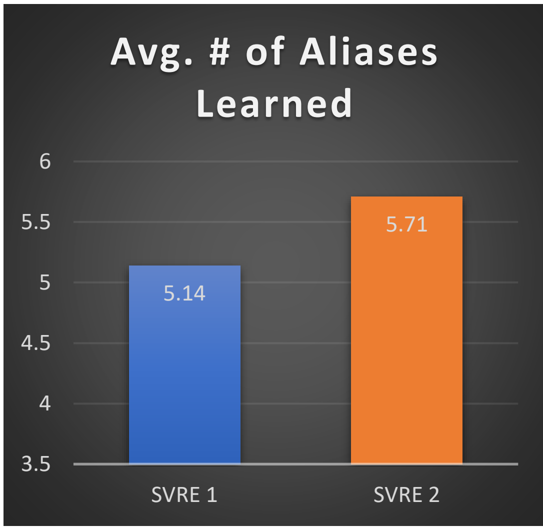

Figure 4.3: Avg. # Aliases Learned

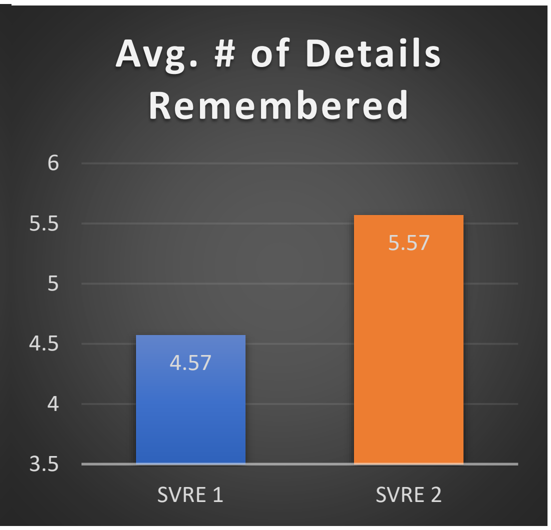

Figure 4.4: Avg. # Details Remembered

4.12 Proximity

Proximity results were recorded to examine how participants moved around the SVREs, in relation to one another. This metric includes two measures; how close in proximity participants are to their nearest peer and how many peers are within a certain proximity of a participant at a given time. Figure 4.5 shows the average distance participants are from their nearest peer throughout the 5-minute study of each SVRE.

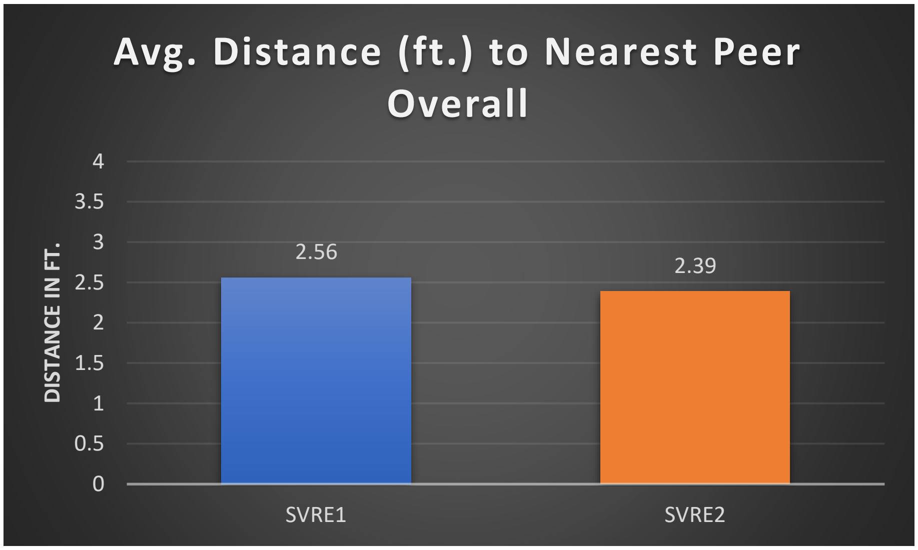

Figure 4.5: Avg. distance to nearest peer overall

The project's initial hypothesis was that overall user-to-user proximity values in SVRE2 would be lower than in SVRE1 because the open space hotspots that were implemented in SVRE2 would draw users closer together. While the results indicate that the overall proximity values in SVRE2 were indeed lower, it was only by a slight amount. Solely based on these numbers, it might be difficult to infer firm conclusions. However, in examining how the user-to-user proximity values changed over time, rather than as an overall value, more information about participants' dynamic movements based on SVRE architecture is revealed.

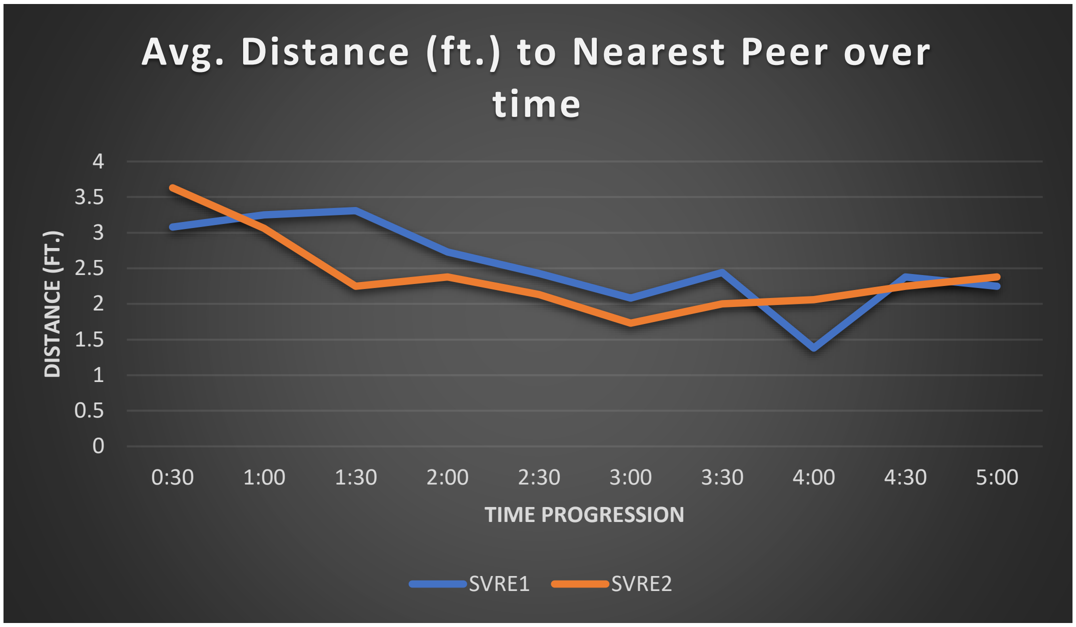

Figure 4.6: Avg. Distance to nearest peer over time

The above figure illustrates the average distance between participants and their closest peer in proximity. To find this value, the distance between each individual participant and their nearest peer were collectively averaged for each SVRE. Figure 4.7 illustrates that within the first 1:30 of the user study, the average user distance rapidly dipped in SVRE2 compared to in SVRE1. The video recording of the instance reveals that this is because early on in the SVRE2 study, all participants began to consolidate in the designated hotspot location in the inner area of the layout. As a result of participants grouping up in closer proximity, the average distance that participants were from their closest peer was also reduced. One potential reason for this is that participants have to get closer to one another to hear each other more clearly over the conversations of their nearby peers. Additionally, in a higher concentrated area of participants, participants are more likely to be closer to another peer than in less concentrated areas due to the increased number of surrounding peers.

On the other hand, during the first 1:30 of the SVRE1 study, participants were on average more spread out from their closest peer. The video recording of the instance showed three smaller groups of two or three forming around the map with participants slightly further apart from one another than in SVRE2. While it took longer than it did in SVRE2, participants in SVRE1 would eventually consolidate into one area on the map. Figure 4.7 illustrates how this occurred in SVRE1 approximately one minute after it occurred in SVRE2.

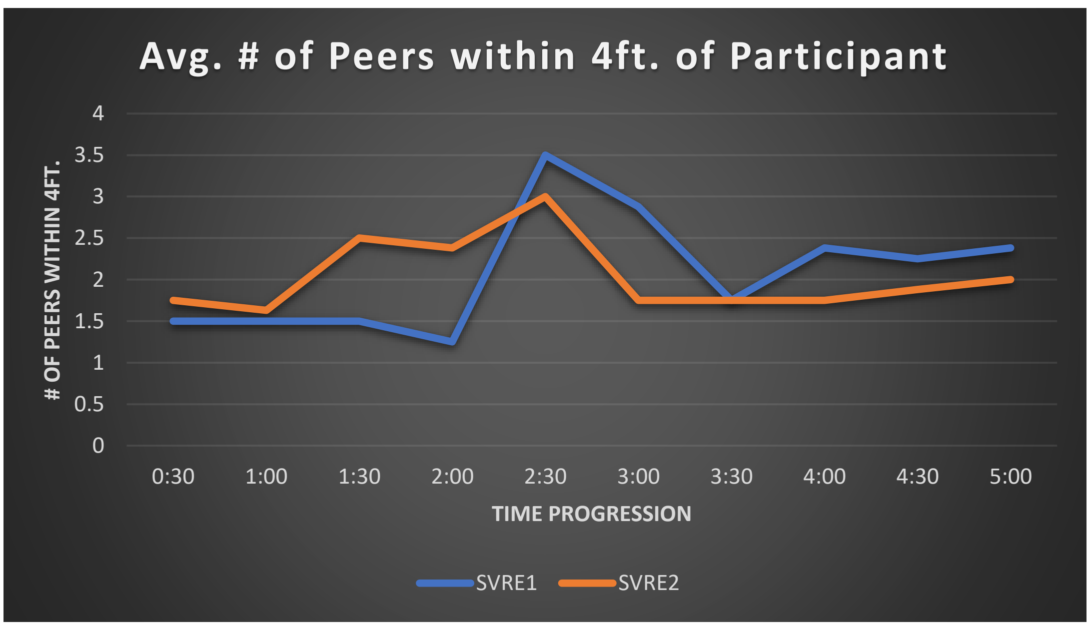

Figure 4.7: Avg. # Peers within 4ft of Participant

For the rest of the user testing duration, both SVREs indicate a similar trend: a progressive decrease in user-to-user distance followed by a rise in the distance apart. Additionally, the proximity measure in figure 4.7, which shows the number of peers in proximity over time, illustrates a similar pattern with a rise in the number of nearby peers followed by a decline. The video recordings of the instance showed that this was due to the formation of group conversation followed by participants splitting off into smaller, more focused groups near the main group.

4.2 Qualitative Findings

4.21 Interview

At the end of the user testing for both SVRE1 and SVRE2, participants were asked to answer three SVRE-related questions. At the time of answering these questions, participants were not yet briefed on the design intentions of the SVREs. Below are the questions that the participants received, followed by a summary of their responses.

Question 1: If you wanted to meet new people in VRC, which of the two environments would you choose? Why?

Of the eight responses, one participant responded that they thought both maps were the same, two participants misinterpreted the question and listed maps unrelated to the study, and five responded SVRE2. In the five responses that indicated SVRE2 as the preferred environment, all five answers explained that it was due to having more open space. Participants described that SVRE2 was less crowded and that it was easier to join conversations when there was more open space.

Question 2: What is your opinion on the moved furniture in map #2 VS map #1 in terms of your ability to learn more/less aliases?

All but one participant had positive responses to the furniture modifications in SVRE2. Seven participants mentioned that it was easier to talk to one another with more open space available. Participants mentioned how less cluttered areas made it easier for them to see and talk to people, unlike in the crowded scenario of SVRE1. On the other hand, one participant described how it was easier for them to join conversations in SVRE1, where furniture and people were more crowded. They mentioned it was more difficult for them to join conversations in SVRE2.

What do you think is a design feature that we could add into the map to make it better for meeting new people?

One participant responded by suggesting even more open space. The other seven participants suggested interactive objects. Specific examples they listed include mirrors, game tables, and grabbable objects. While interactive objects might be something to implement in future iterations of this study, they were excluded in the SVRE design process of this study to help isolate the implications of architecture and open space on social interactions.

Chapter 5

Discussion

The user study results were relatively consistent with the study's initial hypothesis from section 3: open-space hotspots would improve SVRE social interactions by facilitating group conversation and bringing users into a more optimal level of social proximity. In hindsight, this hypothesis was relatively accurate but was missing sufficient detailed elaboration. The user study findings indicated that there were additional aspects of improved social interaction due to the open-space hotspot implementation in SVRE2 that the hypothesis did not predict. These aspects include participant ability to see and interact with more people, be more expressive with body language, and have more freedom to move around and approach conversations at their own pace. On the other hand, results also indicated that closer user-to-user proximity might improve social interaction quality, but only to an extent. Under certain circumstances, users too close in proximity may find conversation difficult, as indicated by participant feedback and proximity measures. Nevertheless, the data from the findings can give a much clearer idea of how VR social interactions are influenced by architectural design modifications to space in SVREs.

Results indicated that participants in SVRE2 had an improved ability to learn the aliases and details of their peers than in SVRE1. Specifically, this was an improvement of 11.1% in their ability to learn aliases and 21.9% to learn peer details. The only variable manipulated in the SVRE2 user test, versus in the SVRE1 user test, was the design implementations of open-space hotspots (OSH). Considering the above statistics and isolated variable, it could be inferred that the design implementations SVRE2 might have been a critical factor in this outcome. Furthermore, it is reasonable to suggest that when conversations are more productive, in that participants learn the names and details about their peers more efficiently, social interaction is improved.

In the written interview component of the user study, participants expressed a user sentiment about the SVREs that was consistent with the quantitative findings above. Participants mentioned that the implementation of a centralized open-space area in the map provided them with a designated space to consolidate and socialize conveniently. They described that unlike in SVRE1, SVRE2 was much less cramped, which allowed them to have conversations more comfortably and enabled them to see and interact with more peers. Overall, the written interview responses strongly indicate that participants prefer to socialize in an open-space hotspot integrated environment, such as SVRE2, over SVRE1.

Regarding the proximity metric, results may have revealed why the design implementations in SVRE2 led to higher detail retention scores and more positive user feedback. According to figure 4.7, the formation of all participants gathering together to have a group-oriented conversation is indicated in both SVREs by the sudden upwards spike in the number of peers in proximity (Y-axis). This metric suggests that participants have transitioned from multiple smaller spread-out groups into one large social group, hence the increased average number of peers in the participants' proximity. These larger group formations in SVRE designs will be referred to as open-space group formations (OSGF). It was observed in the user feedback and instance recording results that when OSGF forms, it becomes easier for participants to initiate conversation or join in on an ongoing conversation. As a result, the occurrence of OSGF is a relevant component of improved VR social interactions.

Figure 4.7 shows that in SVRE2, the main OSGF occurs one minute before it does in SVRE1. This one-minute difference in group formations is likely to be a significant factor in why peer detail-retention scores were higher in SVRE2 and why participants reported a better social experience in SVRE2. In both SVREs, the sudden increase of peers in proximity, which indicates the occurrence of an OSGF, is followed by a gradual decline in peers in proximity. It was observed that the gradual decrease of peers in proximity was a result of participants breaking off into smaller groups near the OSGF. In these smaller groups, participants seemed to be in more focused conversations than in the initial larger group conversation. Furthermore, since these smaller groups were tethered to the initial OSGF, in that they maintained close proximity to the center of the group formation, participants found that it was easier to join in on other nearby smaller conversations and meet new people. As a result, the

OSGF serves to be a type of designated central social hub area from which numerous smaller, more intimate group conversations can form around. In other words, OSGFs are a type of VR social interaction facilitator that provides participants with proximity and access to numerous nearby peers to socialize with while also setting up the social framework for smaller, more focused group conversations. Considering how OSGFs facilitate VR social interaction in this sense, it can be inferred that; the sooner a group of participants in an SVRE can reach an OSGF, the more time there is for participants to maintain the optimal formation for quality social interaction. Nevertheless, successfully implementing spatial design features, such as OSHs, may expedite the occurrence of OSGF in SVREs and improve the overall user social experience.

Chapter 6

Conclusion

The results from this study indicate that open-space hotspot (OSH)-based design implementations in SVREs can improve VR social interaction and user experience. Specifically, this is achieved by creating an environment that facilitates the occurrence of open-space group formations (OSGF), which are essentially a type of user formation catalyst for VR social interactions. The design approach of creating an OSH-based SVRE generally consists of designating an open-spaced area, free of collidables, in contrast to a collidable-dense remainder of the map. OSHs are an efficient means of improving VR social interactions because they are relatively simple to implement in the map design process while still facilitating an optimal social interaction formation through OSGFs.

OSGFs occur when numerous users consolidate in proximity to an open-spaced area of an SVRE. In turn, this designates the area as a centralized hub from which users are more inclined to join in, reach out to one another, and socialize, as indicated by participant feedback and quantitative measures in the results section. Furthermore, a range of simultaneously occurring conversations around the OSGF occurs, which affords users various avenues for more in-depth and focused discussion. Nevertheless, OSGFs provide users a type of social formation structure that facilitates and improves SVRE social interactions.

While group formations can occur in SVRE open spaces that are not deliberate OSH implementations, the proximity measures in the study indicated that OSGFs manifest more quickly and effectively, in terms of facilitating social interaction, in designated OSH designs. This was exemplified in how the metrics from OSH-integrated SVRE2 indicated the expedited occurrence of an OSGF 1-minute prior to than it did in SVRE1. Furthermore, participants described that the OSH of SVRE2, compared to the spot where participants gathered in SVRE1, afforded them more space and thus the ability to see and interact with more peers.

This study indicates that the implementation of architectural spacing strategies in SVREs can be utilized to improve VR social interaction. SVRE2 showed that the inclusion of OSH afforded participants a more optimal setting to socialize. However, while results from this project were consistent and indicative of social interaction facilitation in VR, the user study hosted a relatively small group of participants. Future work should scale up the SVRE venue size and increase the number of participants to verify the trends found in this study. With a larger dataset of participants, the social implications of OSHs in SVREs can be further validated. Additional variables that can be examined in future iterations of this study include the incorporation of interactive elements in OSHs and the implementation of numerous smaller OSH. Exploring these variables would further expand the understanding of

OSH implications on VR social interaction. Ultimately, more research in SVRE-based OSHs may help guide an advanced method of SVRE design that extensively improves social VR interactions and experiences.

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