



Designing Shared VR Tools for Spatial Scientific Sensemaking About Wildfire Evacuation

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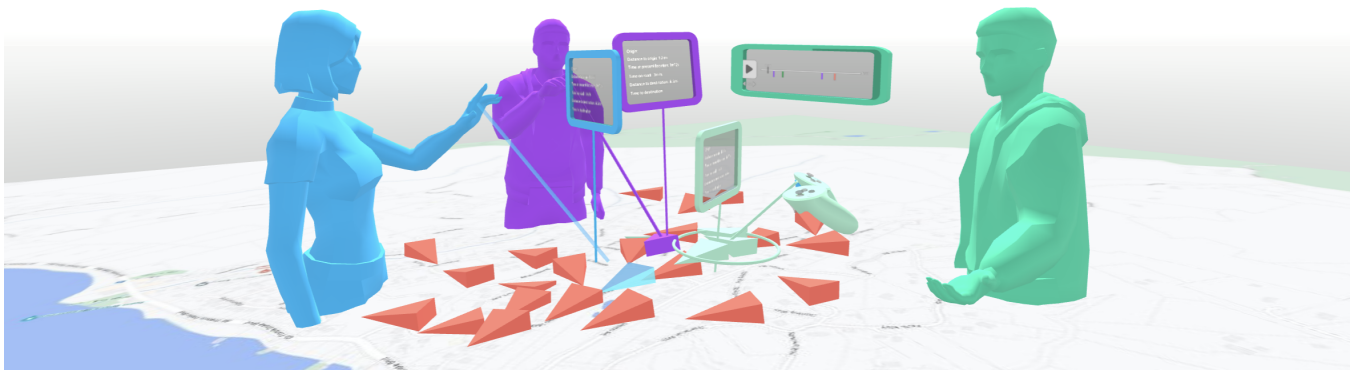


Figure 1: In this mockup, three civil engineering researchers use virtual reality interfaces to analyze bottlenecks in a traffic simulation of a wildfire evacuation.

ABSTRACT

We posit that scientists who work with spatial data could benefit from shared VR tools that allow them to do immersive sensemaking together to generate new insights and approaches to their work. We engaged with researchers studying wildfire evacuation who currently use 2D spatial simulations to develop prototypes of shared VR interface features to allow them to explore and discuss their data. We present results of preliminary interviews, our design process and mocked-up features (callouts, shared time scrubbing, 3D marquee selection, photospheres, and metaboard), and follow-up feedback from the scientists about these features. Scientists found these features useful, in particular callouts due to ability to indicate objects of interest and examine relevant metadata and offered suggestions for extending and developing the features in future prototyping work.

CCS CONCEPTS

• **Human-centered computing** → **Interaction design process and methods**; *HCI design and evaluation methods*; **Collaborative and social computing systems and tools**;

KEYWORDS

Social VR, Scientific Sensemaking, Wildfire Resilience

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1 INTRODUCTION

Increasingly, scientists are working with spatialized datasets both in person and across networked teams during their research process. Virtual reality (VR) offers an opportunity to bring such datasets into a shared environment where the information can be examined, discussed, and can lead to new insights and innovation. The unique affordances of VR can allow for a 'beyond real' approach to exploring data, allowing scientists to manipulate and examine spatial

information at multiple scales, over time, and in novel ways. In our project, we seek to develop interaction concepts and prototypes that build upon the work practices of scientists to develop tools that can enhance their work practices toward advancing their research and collaborations.

We interviewed researchers at the Soga Research Group, whose civil engineering research involves sensemaking around spatial datasets for a variety of topics such as the following:

- **Wildfire evacuation planning** - collaborating with fire-fighters and emergency agencies to create better evacuation plans and roadway improvements to make communities resilient to wildfires.
- **Computational geomechanics** - applying mathematical models to historical data of dam failures and landslides to understand if these can be applied to future projects and communicate risks to communities.
- **Net-zero infrastructure planning** - renovating utility systems to transfer consumption and production of energy between buildings to achieve net-zero resource consumption.

Due to the availability and fidelity of the data, we have begun this work with a collaboration with the team of scientists focused on wildfire evacuation. This team creates 'digital twins' of traffic and other data in order to engage in discussion with community stakeholders and local authorities to plan for future wildfire events more effectively.

In this paper, we present a cycle of design work that includes initial needfinding interviews with the team, the creation of feature mockups based on these interviews, and follow up interviews with the team members after they have experienced the use of these mockups.

Key contributions of this work are initial interaction paradigms for supporting shared scientific sensemaking in VR, which we intend to extend in future work.

2 RELATED WORK

VR has unique affordances for making sense of challenging multi-dimensional or spatial data [12]. This is often leveraged for complex visualization applications, represented in the literature in diverse cases such as exploring genomic data [7], annotating a great quantity of documents [9], and navigating a spatiotemporal dataset of geolocated tweets [14].

While using virtual reality for spatialized data sensemaking is an active area of research, many of these tools are built for a single user. Social VR applications are multi-user applications that facilitate virtual presence, often allowing for custom 3D environments, real-time voice communication, and avatar embodiment—such embodied interactions have benefits for working in spatial environments that contain visualizations [3]. Research has demonstrated the powerful impact that physical co-presence can offer teams [16, 17]. Social extended reality (XR) applications can afford some of the richness of co-located collaboration through embodied cues such as shared orientation to others (and to the environment) through gaze, proximity, and gestures [1, 11]. Furthermore, social VR researchers have explored the creation of tools that permit inter-locutors to transcend the affordances of typical in-person meetings [8, 13].

Through interviewing coral reef scientists about experiences using tools in a social VR environment, Olaosebikan et al. show that VR provides unique affordances for group cognition and collaboration, however, future tools must address specific needs for controlling a virtual environment and integrating with scientific data [15]. Ubiq is a recent extendable open source research tool designed to test novel social VR experiences [4], providing many features available in commercial VR software such as avatar embodiment and real-time voice chat. By extending Ubiq, researchers could create multi-user VR environments for the testing of novel scientific tool designs. The work presented here could be extended and adapted for a platform like Ubiq.

3 NEEDFINDING

The first phase of this participatory design project was needfinding, where we explored opportunities for shared VR tools that could contribute to scientific sensemaking. We interviewed a researcher at the Soga Research Group who plans evacuation communication strategies and optimizes traffic infrastructure through creating and analyzing simulations. They work with diverse stakeholders such as expert professionals in fire, traffic, and emergency agencies who have local knowledge to calibrate the models. In this way, their team are practitioners as well as researchers. They explained that this type of simulation is also useful for other environmental dangers like hurricanes.

Interview questions were carefully chosen so we could surface possibilities for interface features of multi-user VR environments. Towards this end, we wanted to understand their spatial datasets, communication needs, and current challenges with existing workflows to identify opportunities for improvement. Interviews lasted about one hour, and the interviewee provided access to sample datasets and views into their existing tools after the interview.

We identified the following user needs:

- **Navigate between multiple types of spatial data** - Discussions are informed by multiple types of data that often have a geospatial attribute. Traffic simulations are composed of simulated vehicles, termed *agents*, road data that includes metadata, and map overlays. Wildfire spread and risks are informed by maps of vegetation type, street view images, and weather conditions.
- **Navigate various geographic scales** - Users shift between examinations of small road junctures to identify traffic bottlenecks to large scale map views to see overall evacuation patterns.
- **Navigate various timesteps and durations of a simulation** - During discussion, stakeholders navigate between moments in the simulation to compare and contrast bottlenecks and traffic phenomena that occur at different times e.g. earlier and later in the evacuation. Discussants would benefit from seeing the simulation occur at different speeds and at different timescales such as in the range of minutes or in the range of hours.
- **Identify and annotate spatialized data** - Users must indicate phenomena on a map to call attention or use annotations to describe an idea. For example, when examining a

traffic simulation, discussants identify and annotate traffic bottlenecks.

- **Domain experts individually examine details on objects before offering objects for discussion** - Domain expert judgements can be informed by metadata that is not readily available in views of the simulation. However, such information is not always worth presenting to a larger group. There is a need for users to individually investigate details before calling group attention.
- **Overcome challenges in realism for stakeholder communication** - Often stakeholders come from diverse backgrounds, and a technical engineering simulation may not aesthetically communicate the severity of a situation. The interviewee pointed to realism and immersion as opportunities for virtual reality to aid evacuation planning work by increasing communication efficacy for both between domain experts and to others.

4 DESIGN

In order to explore solutions to the needs described above, we engaged in iterative bodystorming sessions using an off-the-shelf VR design tool called ShapesXR, which allows for ready creation of shared prototyped spaces and interactions. ShapesXR environments allow for the import of custom images and 3D models, allowing us to integrate stand-ins for simulation dataset elements, while containing features such as real-time voice communication, avatar embodiment, and locomotion which allow the emulation of bespoke multi-user environments. As a base for interface design, we placed a map of an area of interest for the wildfire evacuation planners around table height. On this map, we placed pointed objects along roadways to depict agents in traffic bottlenecks, and stock models of people in group formations to depict users.

We present the design of five interface features:

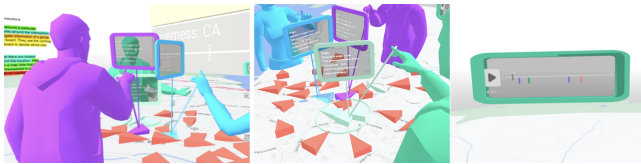


Figure 2: *Left:* Researchers use callouts to examine metadata and indicate parts of a traffic bottleneck. *Middle:* A researcher uses 3D marquee selection to examine a group of agents. *Right:* Object representing the interface for shared time scrubbing.

- **Callouts** - With callouts, a user can point to object in the environment that contains two dimensional metadata such as text attributes or images. At this point, the card is only viewable by the user that pointed to the related object, permitting the user to examine the metadata without changing the environment for others. If the user would like to call attention to the object or its corresponding metadata, the user can activate the callout and bring the card into view

for all users. This interface facilitates the individual exploration of metadata while providing a mechanism to indicate a phenomena during discussion.

- **Shared Time Scrubbing** - Shared time scrubbing is an interface feature that facilitates time controls commonly used for video playback for a simulation such as play/pause, and dragging a cursor on a timeline to select a moment. The timeline also features colored lines which indicate moments of interest— these colored lines are added to a moment when a user activates a callout. During tests of the tool in ShapesXR, we found that users may try to operate time controls at the same time. To avoiding colliding actions among users when changing the time of a simulation, we designed two ways of placing the shared time scrubbing controls. One way is to place the controls on an object that users must hand to each other in order to pass authority, similar to the negotiation of a television remote. Another way is to place the time controls on an object at the side of the simulation so that users can locomote away from central phenomena to change the time parameters.
- **3D Marquee Selection** 3D marquee selection describes a method by which a user can select multiple interactable elements within an environment, such as agents or roadways. When the user performs this selection, a callout appears with aggregate information calculated from the metadata from each individual element. For example, if a user selects a group of agents that have slowed in a bottleneck, and each agent contains metadata for speed, the 3D marquee selection would afford the user a way to see the average speed.

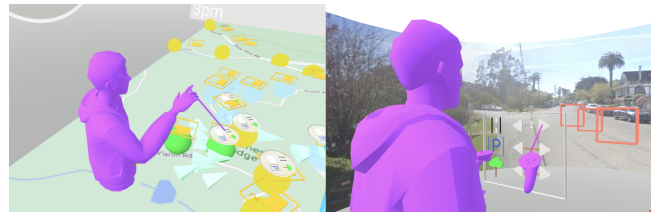


Figure 3: By using photospheres, users can switch between map views (*left*) and immersive real-world images (*right*) to annotate hazards.

- **Entering Photospheres** Users can select a sphere from a map view to enter an immersive environment, a photosphere, generated from stitched Google Street View images. This 360 degree image provides an opportunity to see hazards that may not be informing the simulation such as parked vehicles, combustible vegetation, and roadway obstacles. Within photospheres, users can annotate such hazards, and when users return to a map view, they can see representations of these annotations as icons on the surface of the photosphere.
- **Metaboard** - A metaboard (composed of the terms metadata and whiteboard), in Figure 4, is a vertical board at the side of the environment that is positioned so that users can see displayed information from many viewpoints. When users activate a callout or engage with a photosphere, they can promote this information to be included on a metaboard



Figure 4: User promotes information on a callout (left) to the metaboard (right) for group discussion.

card. Later in the discussion, or when another group joins the environment, cards on the metaboard can be used to orient to the moment in time and location of the phenomena. Since cards are placed next to each other, the metaboard also facilitates the comparison of phenomena.

To understand how these interface features would be used in conjunction, we created two related user scenarios. In the first user scenario, two graduate student researchers and a community stakeholder examine and discuss a traffic simulation around two particular intersections, using the interface features to facilitate discussion and promote key pieces of information to a metaboard for future discussion. In the second user scenario, two experienced researchers, a postdoctoral scholar and a professor, use the cards on the metaboard to navigate between moments of interest in the previous discussion and understand patterns. This pair of user scenarios were intended to encompass the various audiences and dialogue between sensemaking sessions. To iterate on these designs, we presented these user scenarios in "Stages" of ShapesXR, step-by-step scenes that depict parts of the user scenarios, to two civil engineering researchers who provided feedback.

5 PRELIMINARY EVALUATION

In order to aggregate feedback on the efficacy and potential use of these interface designs for real-world applications, we conducted a pilot study where the two researchers who work on civil engineering simulations for wildfire evacuation planning were asked to evaluate the five interface designs yielded by the design process.

5.1 Procedure

The evaluation procedure occurred in three parts. In the first part of the procedure, participants tested mockups of each interface in a 3D environment using ShapesXR while being recorded by an experimenter from within virtual reality. Participants were asked to think-aloud and voice their impressions as they used each tool. In the second part of the procedure, participants verbally answered questions about their overall experience and were asked to compare the potential of the interface designs with the following questions:

- What would be the most impactful?
- What would be the least impactful?
- Did this inspire further ideas for features you would like to have in a VR environment?

Then, for each interface feature we administered a NASA-TLX usability survey which aims to assess aspects of cognitive load and performance for tasks within a system [5]. In the final part of the

procedure, participants provided written feedback with a Qualtrics form for each interface feature, responding to the following queries:

- Any additional impressions about the interface?
- How could such a tool be used?
- How could such a tool influence discussion?
- How could a tool be improved?

For each participant, the total evaluation duration lasted approximately one hour.

5.2 Results and Discussion

Overall, participants reacted positively to the simulated experience, with general agreement about utility despite some distinctions about why some features were preferred over others. For example, when discussing the callout, one participant highlighted the utility of examining metadata on an object, and the other participant described the convenience of a callout for sharing information with others.

When discussing the utility of the shared time scrubbing, participants noted the need for precision, as discussions revolve around critical moments that cause bottlenecks. Therefore, when designing time controls for a simulation, designers should consider ways discussants can refer and navigate between specific moments.

During discussion of the photosphere, participants discussed multiple ways that this immersive view could aid discussion. When looking at a traffic bottleneck, users entering a nearby photosphere could help facilitate planning of infrastructure improvements. When examining a photosphere, discussants may identify real world features that the traffic simulation must incorporate. The source image of photospheres was critiqued— since these images were culled from Google Maps, the images might contain hazards such as parked cars that may not be present during a real wildfire scenario, as people may be evacuating the area.

When asked to identify which interface feature would be the least impactful, both users agreed that the metaboard would be the least impactful (though clarified that it would still be impactful overall). The justification for its lower ranking was that the information contained on the metaboard was already represented in other interface features. However, while showing the designs to participants in ShapesXR during the preliminary evaluation, it was difficult to act out the use of the metaboard without multiple simultaneous participants, underscoring the need for testing these interfaces with larger groups. Discussion of the metaboard led us to consider circumstances that were not encompassed by the user scenarios. When a participant noted the size of the metaboard, they imagined the environment supporting large teams of stakeholders, not just two or three people, which may align better with the reality of current evacuation planning meetings. In this way, participants still pointed to the need for some mode of amplifying selected metadata details for a wider audience.

Possible contributions of our work include expanding the design focus of existing work from simple user tasks of viewing, interacting, and sharing [1], to incorporating aspects of annotating (callouts), "diving in" to immersive details together (through photospheres), ways to share with others and communicate saliency through scale and position (for example through use of metaboards),

and finally adding the importance of time as an important dimension to support through scientific social sensemaking (for example, through the timescrubbing mechanic).

In the future, these interface features should be tested with a greater quantity of evaluators, both simultaneously in one session to see if these interfaces can facilitate discussion among large groups, and among disparate groups to provide perspective on the efficacy of these designs. Since many scientific domains involve group sensemaking of complex 3D datasets, these interfaces could be refined through feedback from scientists working in other domains. This could also help us to evaluate how these design patterns could be applied to a broader array of scientific sensemaking circumstances.

As participants noted, interface features such as 3D marquee selection should be tested with real simulation data, in order to properly understand the efficacy. In a custom environment that contains simulation datasets, there is also an opportunity to introduce custom telemetry systems to help validate designs using quantitative methods. By measuring concurrent body positions and orientations, we could measure proxemics (the dynamics of how people to arrange themselves in group formations during conversations) as these positions may be an indicator of communication efficacy [6, 18]. While we collected NASA-TLX data, only having two sets of this quantitative information is inconclusive. Furthermore, we acknowledge that further research must incorporate design approaches and evaluative methods to address cybersickness and accessibility concerns [2, 10], perhaps including the examination of alternative ways of access by 2D means.

6 CONCLUSION

This paper has presented research conducted with wildfire evacuation researchers, aimed at facilitating their sensemaking process, with a set of mockups of social VR features that enabled them to explore their data together while immersed in a shared space. We demonstrated the promise of these features, in particular, callouts, which facilitate both individual exploration and group communication, and photospheres, which facilitate navigation between real-world immersive images to traffic simulations that occur on a map. Future work will include building follow-on interactive prototypes of the features that were best received, enabling extended interaction sessions with the scientists to further ascertain the potential value of these features. Our results may be of use to others in the CHI community focused on developing shared VR tools for exploring spatial data.

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REFERENCES

- [1] Mark Billingham, Maxime Cordeil, Anastasia Bezerianos, and Todd Margolis. 2018. Collaborative Immersive Analytics. In *Immersive Analytics*, Kim Marriott, Falk Schreiber, Tim Dwyer, Karsten Klein, Nathalie Henry Riche, Takayuki Itoh, Wolfgang Stuerzlinger, and Bruce H. Thomas (Eds.). Springer International Publishing, Cham, 221–257. https://doi.org/10.1007/978-3-030-01388-2_8
- [2] Simon Davis, Keith Nesbitt, and Eugene Nalivaiko. 2014. A Systematic Review of Cybersickness. In *Proceedings of the 2014 Conference on Interactive Entertainment (IE2014)*. Association for Computing Machinery, New York, NY, USA, 1–9. <https://doi.org/10.1145/2677758.2677780>
- [3] Barrett Ens, Maxime Cordeil, Chris North, Tim Dwyer, Lonni Besançon, Arnaud Prouzeau, Jiazhou Liu, Andrew Cunningham, Adam Drogemuller, Kadek Ananta Satriadi, and Bruce H Thomas. 2022. Immersive Analytics 2.0: Spatial and Embodied Sensemaking. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. ACM, New Orleans LA USA, 1–7. <https://doi.org/10.1145/3491101.3503726>
- [4] Sebastian J Friston, Ben J Congdon, David Swapp, Lisa Izzouzi, Klara Brandstätter, Daniel Archer, Otto Olkkonen, Felix Johannes Thiel, and Anthony Steed. 2021. Ubiq: A System to Build Flexible Social Virtual Reality Experiences. In *Proceedings of the 27th ACM Symposium on Virtual Reality Software and Technology (VRST '21)*. Association for Computing Machinery, New York, NY, USA, 1–11. <https://doi.org/10.1145/3489849.3489871>
- [5] Sandra G. Hart and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Advances in Psychology*, Peter A. Hancock and Najmedin Meshkati (Eds.). Human Mental Workload, Vol. 52. North-Holland, 139–183. [https://doi.org/10.1016/S0166-4115\(08\)62386-9](https://doi.org/10.1016/S0166-4115(08)62386-9)
- [6] Adam Kendon. 1990. *Conducting Interaction: Patterns of Behavior in Focused Encounters*. CUP Archive.
- [7] Maxim Kuznetsov, Aviv Elor, Sri Kurniawan, Colleen Bosworth, Yohei Rosen, Nicholas Heyer, Mircea Teodorescu, Benedict Paten, and David Haussler. 2021. The Immersive Graph Genome Explorer: Navigating Genomics in Immersive Virtual Reality. In *2021 IEEE 9th International Conference on Serious Games and Applications for Health (SeGAH)*. 1–8. <https://doi.org/10.1109/SEGAH52098.2021.9551857> ISSN: 2573-3060.
- [8] Jialang Victor Li, Max Kreminski, Sean M Fernandes, Anya Osborne, Joshua McVeigh-Schultz, and Katherine Isbister. 2022. Conversation Balance: A Shared VR Visualization to Support Turn-taking in Meetings. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. ACM, New Orleans LA USA, 1–4. <https://doi.org/10.1145/3491101.3519879>
- [9] Lee Lisle, Kylie Davidson, Edward J.K. Gitte, Chris North, and Doug A. Bowman. 2021. Sensemaking Strategies with Immersive Space to Think. In *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*. IEEE, Lisboa, Portugal, 529–537. <https://doi.org/10.1109/VR50410.2021.00077>
- [10] Cayley MacArthur, Arielle Grinberg, Daniel Harley, and Mark Hancock. 2021. You're Making Me Sick: A Systematic Review of How Virtual Reality Research Considers Gender & Cybersickness. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–15. <https://doi.org/10.1145/3411764.3445701>
- [11] G. Elisabeta Marai, Angus Forbes, and Andrew Johnson. 2016. Interdisciplinary Immersive Analytics at the Electronic Visualization Laboratory: Lessons Learned and Upcoming Challenges. <https://doi.org/10.1109/IMMERSIVE.2016.7932384>
- [12] John P. McIntire and Kristen K. Liggett. 2014. The (possible) utility of stereoscopic 3D displays for information visualization: The good, the bad, and the ugly. In *2014 IEEE VIS International Workshop on 3DVis (3DVis)*. IEEE, Paris, France, 1–9. <https://doi.org/10.1109/3DVis.2014.7160093>
- [13] Joshua McVeigh-Schultz and Katherine Isbister. 2022. A “beyond being there” for VR meetings: envisioning the future of remote work. *Human-Computer Interaction* 37, 5 (Sept. 2022), 433–453. <https://doi.org/10.1080/07370024.2021.1994860>
- [14] Kaya Okada, Mitsuo Yoshida, Takayuki Itoh, Tobias Czauderna, and Kingsley Stephens. 2018. Spatio-Temporal Visualization of Tweet Data around Tokyo Disneyland Using VR. In *Proceedings of the 23rd International Conference on Intelligent User Interfaces Companion (IUI '18 Companion)*. Association for Computing Machinery, New York, NY, USA, 1–2. <https://doi.org/10.1145/3180308.3180356>
- [15] Monsurat Olaosebikan, Claudia Aranda Barrios, Blessing Kolawole, Lenore Cowen, and Orit Shaer. 2022. Identifying Cognitive and Creative Support Needs for Remote Scientific Collaboration using VR: Practices, Affordances, and Design Implications. In *Creativity and Cognition*. ACM, Venice Italy, 97–110. <https://doi.org/10.1145/3527927.3532797>
- [16] Steve Sawyer, Joel Farber, and Robert Spillers. 1997. Supporting the social processes of software development. *Information Technology & People* 10, 1 (Jan. 1997), 46–62. <https://doi.org/10.1108/09593849710166156> Publisher: MCB UP Ltd.
- [17] Stephanie Teasley, Lisa Covi, M. S. Krishnan, and Judith S. Olson. 2000. How does radical collocation help a team succeed?. In *Proceedings of the 2000 ACM conference on Computer supported cooperative work (CSCW '00)*. Association for Computing Machinery, New York, NY, USA, 339–346. <https://doi.org/10.1145/358916.359005>
- [18] Julie R. Williamson, Joseph O'Hagan, John Alexis Guerra-Gomez, John H Williamson, Pablo Cesar, and David A. Shamma. 2022. Digital Proxemics: Designing Social and Collaborative Interaction in Virtual Environments. In *CHI Conference on Human Factors in Computing Systems*. ACM, New Orleans LA USA, 1–12. <https://doi.org/10.1145/3491102.3517594>