Comparing the Agency of Hybrid Meeting Remote Users in 2D and 3D Interfaces of the Hybridge System

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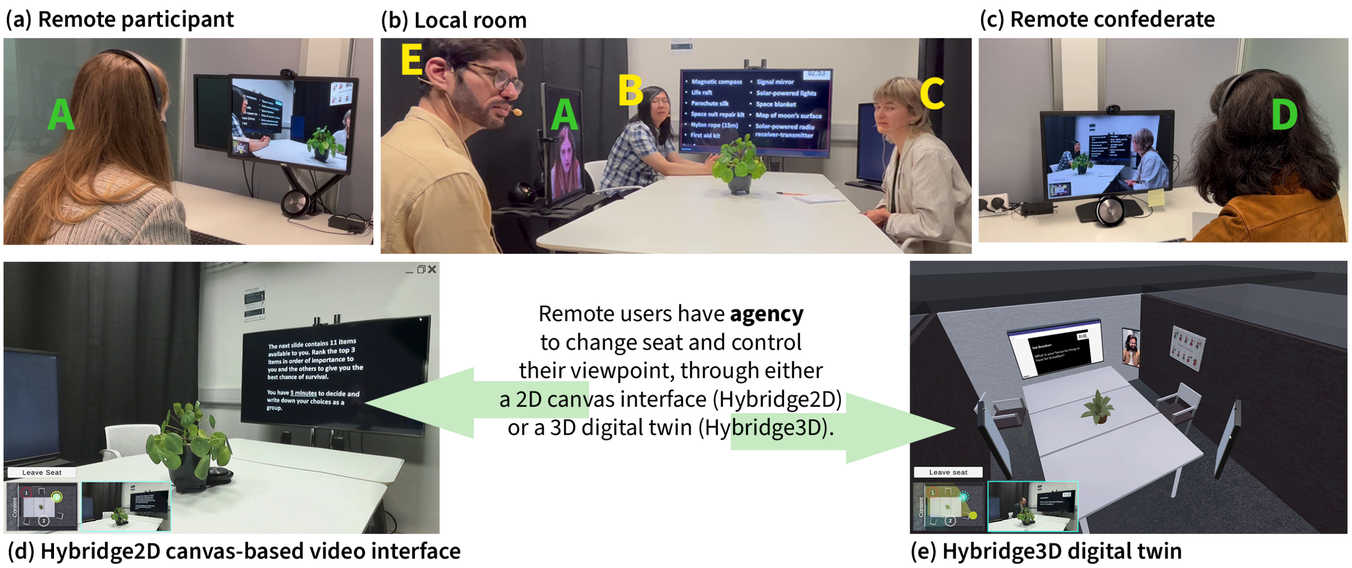

Figure 1: A hybrid meeting using Hybridge. (a, c) show remote users A (study participant) and D (confederate), who may view a Hybridge room from any digital seat. (b) shows the local Hybridge room, with remote users A and D distributed in-room (D is outside camera view). (d) shows the Hybridge2D interface, showing a webcam view from a digital seat. (e) shows the "room view" in Hybridge3D, a digital twin with 3D room representation.

ABSTRACT

Hybridge is an experimental system for exploring the design of remote inclusion for hybrid meetings. In-room users see remote participants on individual displays positioned around a table, and remotes see video feeds from the room integrated into a digital twin of the meeting room. Remotes can choose where to appear in and

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view the meeting room from. We designed two digital interfaces for remote attendees, one using a 2D canvas, and the other using a 3D digital twin of the room as the medium of interaction. To decide which interface to use for future evaluation, we conducted a within-subjects comparison of 24 groups completing survival tasks. We found that 3D outperformed 2D in the participants' perceived sense of awareness, sense of agency, and physical presence. The majority of participants also subjectively preferred 3D over 2D. We discuss design recommendations based on usage patterns and participant comments, and plans for further research.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

agency; asymmetry; collaboration; design; effectiveness; hybrid; inclusion; meetings; spatiality; videoconferencing; 2D; 3D; immersive; virtual

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1 INTRODUCTION

Video-mediated communication often lacks the inclusion enabled by physical presence and simultaneity in a shared physical space.[1] This lack of inclusion is especially apparent during hybrid meetings, where some attendees are located physically together in a room while others join remotely. The most common software solution for hybrid meetings places the videos from all remote participants on a grid, which is displayed on a single display in the meeting room for in-room participants, or on the personal display used by remote participants. This setup places remote participants at a disadvantage by not accommodating the spatial relationships that in-room attendees can leverage. Further, in-room participants are able to navigate the physical space, while remote participants can not.

We developed the Hybridge system to explore these problems through distributed spatial presence of remote users in the meeting room,providing viewpoint and placement agency to remote users. Individual displays around a table provide a place for a remote participant's presence in the meeting room. This paper specifically explores the design of the remote interface for Hybridge through the design and comparison of two interfaces. *Hybridge2D* offers 2D map-based controls for remote users to select their place in the meeting room and a 2D canvas to render the video. *Hybridge3D* offers a 3D digital twin and additional agency by also permitting remote participants to scout a 3D representation of the physical meeting room and pan the camera view from their chosen seat. We compared the usage of the two interfaces with 24 participants and found that Hybridge3D improved perceived ease-of-awareness, sense of agency, and physical presence. We also report usage patterns and discuss design implications for future work.

2 RELATED WORK

Within focused interactions, embodied action in space is used as as communicative resource in a range of ways, from mutual orientation patterns [22], to gaze, head, shoulder, arm position, gestures and expressions [4, 12, 21], and the use of space and artefacts to enact territoriality [33], all of which contribute to conversational flow. Video meetings have struggled to mimic the common interactional space [32] of in-person meetings [1, 9, 20, 40], often fragmenting communication and creating asymmetries [16, 17, 31] that disrupt turn-taking [41, 45] and attention [24]. Asymmetries are exacerbated in hybrid video meetings, where some attendees are remote and others co-located [8, 33, 43, 48]. This can lead to in-room attendees being more active while remote attendees are more passive [2, 7]).

Issues of space, agency, and symmetry are often intertwined in video-mediated communication research [11, 15, 47]. Some systems have aimed at full spatial faithfulness for fully remote meetings at desk scale [44] or room-scale [53]. For hybrid meetings with MatrixView [18] and Halo [37], full-room configurations are used to connect groups at each endpoint. This is achieved via very large displays that effectively form one side of a table.

Other systems have explored how mutual spatial faithfulness [34] may not require imitating natural configurations. OmniGlobe [29] uses 360° camera and globe displays to enable users at each endpoint to move freely in their own space and see the full remote space in its entirety, providing agency to focus on specific points. Remotely controlled camera views have been found to improve the agency, awareness and presence of remote participants in hybrid meetings. Licoppe *et al.* [30] employ a Kubi TelePresence Robot operated via a touch tablet interface, demonstrating that maneuverable displays can ease the process for remote participants to locate, identify, and focus on various objects within a physical environment.

MirrorBlender [13] endpoints leverage transparency and background subtraction to create layers of person and task space [5]. Here, remote agency is provided by the relative positioning of video on the mirrored canvas, but in the 3D space. Perspectives [48] displays remote users on a large display screen as background-extracted video sitting on one side of a desk in a virtual room. In-room users face the remote users so that the virtual space appears contiguous with the local space, while remote users see *all* other users (remote or co-located) in the virtual room, with every user having a unique first-person view.

Inspired by this prior work, and with the aim of improving remote users' inclusion in hybrid meetings, we believe that there are two key design principles for hybrid meeting systems. First, remote users' presence should be spatially distributed in the meeting room. Second, remote users should have heightened agency to choose their viewpoint and where they appear in the room. As we describe in the following section, we used these principles to design an experimental system called Hybridge with 2D and 3D interfaces for remote users.

[1] Inclusion here refers to the equity of potential participation in a meeting. This can be a subset of deeper workplace inclusion issues (e.g. [35, 46])

3 DESIGN

Distributed spatial presence of remote users in meeting room: Hybrid meetings are imbalanced because remote participants are in their own separate physical spaces, whereas those in the meeting room share a common space. Remote attendees are shown together on front-of-room display, limiting individual presence and exacerbating separation. We emphasize remote attendees' spatial presence by giving them virtual access rooted in the shared physical space.

In our implementation, this manifests through 27" display, camera, and speakers units positioned around a table among the physical seats. These "digital seats" can be occupied by a single remote participant, who can be seen and heard as if they were sitting at the table. This arrangement creates a dedicated space for each remote attendee in the physical meeting room, and affords them a unique visual and aural perspective from this position. It also aids implicit non-verbal cues within conversations, e.g. addressing one other by facing them or pointing (Figure 2).

Heightened agency for remote users: Spatiality is intertwined with agency. In hybrid meetings, remote users often lack control over their view of the room, requiring others to make adjustments. This dependency can foster a sense of diminished participation in the meeting [7, 42]. To level the playing field, designing for hybrid meetings should provide remote users with as much or even more agency than the in-room users. Providing remote attendees heightened agency should enhance their participation in the meeting, and enhance their feeling of being present in the meeting room. In our implementation, we designed both a 2D canvas interface and a 3D virtual space to explore how best to afford remote users with agency.

Hybridge2D (H2D) enables remote users to choose a "digital seat", and offers a perspective from that vantage point in the room (Figure 1(d)). A minimap at the bottom-left corner of the screen shows a top-down view of the room, with the current location of the user marked with a yellow circle and any other occupied displays with a red circle. In-room participants are not shown on the map. The user can left-click on any of the unoccupied displays to occupy that "digital seat". Once seated, users see a view of the meeting room through the webcam attached to that digital seat. Users are offered a second viewpoint (the "*peek view*") in a small window beside the minimap.

Right-clicking any of the digital seats switches the *peek view* to that seat. Holding right click on a seat on the map expands the peek view to fill most of the screen, allowing the user to move in and out of zoomed-in view of a second seat, including those occupied by another remote participant. The minimap marks the peek view seat with a blue circle (Figure 4(1a)).

Hybridge3D (H3D) offers additional features for agency. Remote users participate through a digital twin of the meeting room, which blends remote and in-room participants through camera and virtual representations. As the user joins the meeting, they see the *room view*: a 3D replica of the meeting room with a freely movable camera (Figure 1(e)). Occupied "digital seats" show other remote participants' video, and chairs signify where in-room participants are seated around the table. In addition to the map, the user can select an empty digital seat to occupy by clicking on the display in the *room view*. Upon selecting a digital seat, the remote user's view smoothly transitions from the *room view* to the *seated view* (Figure 3). In the *seated view*, the user is able to control their viewpoint by panning the camera left and right. This affordance is indicated by displaying the user's current field-of-vision (FOV) via a cone on the minimap (Figure 4(2a-2e))—otherwise the minimap is the same as in Hybridge2D.

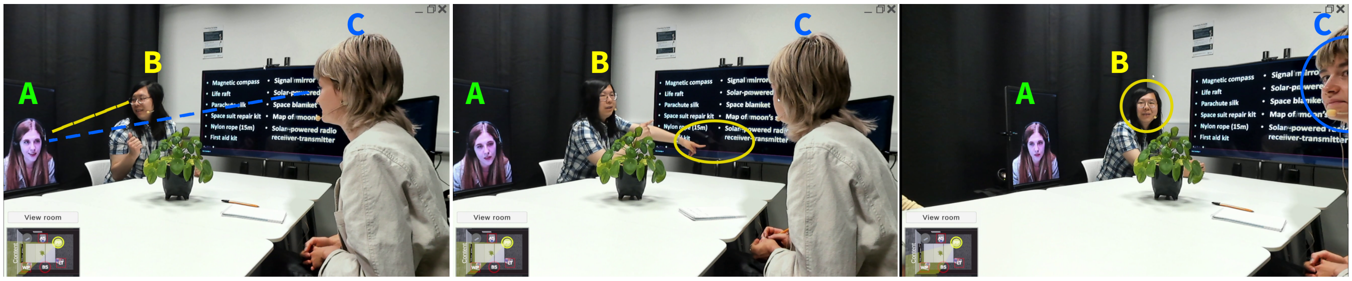
4 USER STUDY METHODS

Design and participants. To determine which of the two designs afforded greater agency for remote users, we conducted an IRB-approved within-subjects study comparing the H2D and H3D prototypes on factors like agency, ease of awareness, and physical presence for the remote user. Each session consisted of a meeting with four attendees, 1 remote participant joined by 3 confederates (2 in-room and 1 remote). A basic Latin square design was used for counterbalancing the two experimental conditions. The study involved 24 participants (16 male, 8 female), who were students and staff sourced from university mailing lists (n = 10) and industry professionals in research and computing (n = 14). See Appendix C for further participant details.

Protocol. Each study session lasted around 60 minutes. After obtaining informed consent and demographic information participants were familiarised with the prototypes in short training periods, guided by a researcher. After verbal confirmation that participants understood how to use the prototype, if it was the first condition, the 'meeting group' was asked to introduce themselves and conduct an ice-breaker exercise for two minutes (i.e., "What did you eat for breakfast today?"). The study moderator then introduced the first of two discussion tasks (hypothetical survival scenarios [14]): "Survival in the Desert" and "Survival on the Moon" (see Appendix B). The group had to choose 3 items from a list of 11 options to maximise their chances of survival, requiring them to deliberate their options and strategies. The group had five minutes to reach a decision. Once finished, participants completed an online survey about their sense of agency, ease-of-awareness, and physical presence (see Appendix D). Participants then had a short break before repeating all steps for the second condition. After both conditions, a semi-structured interview was conducted to gather subjective feedback and overall preference. Participants then received a gift voucher as thanks.

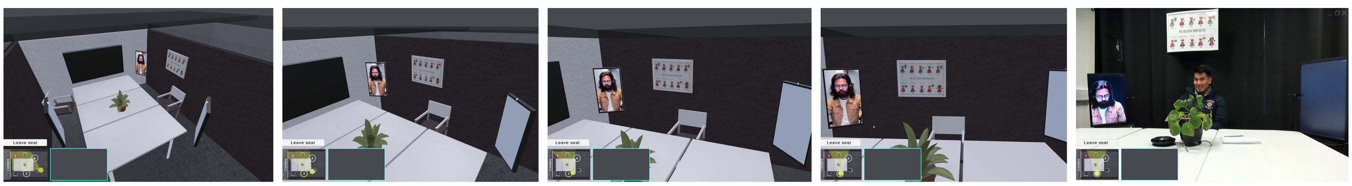
5 RESULTS

Results are based on 23 participants, where one session was excluded from data analysis due to technical issues. **Twenty out of 23 (87%) participants preferred H3D over H2D for future meetings.** Below, we report on the factors underlying their preferences: agency, ease of awareness, and physical presence. To reduce the number of statistical comparisons, for each coherent set of items (e.g., 4 items asking about ease of awareness) we computed a summary score averaging (or summing, for the Slater, Usoh and Steed scale (SUS) questionnaire [50]) each participant's responses across the items (see Appendix D for means and standard deviations for individual items). Statistical analyses were conducted on these summary scores using a non-parametric aligned rank transform (ART) repeated-measures analysis of variance [52], with *condition* (Hybridge2D, Hybridge3D) as a within-subjects factor. To support



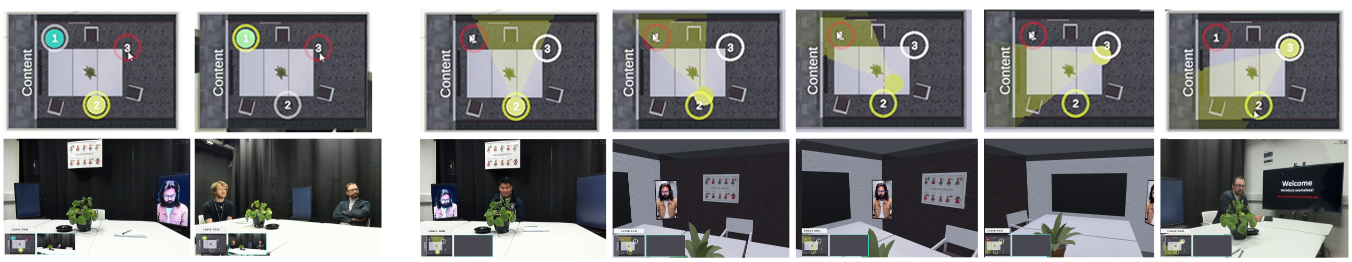
(a) Users B and C interact with A (b) User B points at screen (c) Users B and C look at user ("me")

Figure 2: Spatially distributing remote users in the meeting room while keeping content separate in its own location allows remote users to unambiguously identify attention targets. These images are shown from the viewpoint of a remote participant, from which one can gauge when (a) B and C talk to A, (b) B refers to the content being shared by pointing, and (c) B and C turn their attention to the user.



(a) (b) (c) (d) (e)

Figure 3: Seat selection: the user smoothly transitions from the *room view* in Hybridge3D (a) to the *seated view* (e).



(1a) (1b) (2a) (2b) (2c) (2d) (2e)

Figure 4: Seat change: (1a-1b): In Hybridge2D, the user "jumps" from one seat to another, with no transition. (2a-2e): In Hybridge3D, the user smoothly transitions from one seated view to another. The minimap in both Hybridge2D and Hybridge3D are shown—note the FOV cones in the Hybridge3D minimaps.

the quantitative results, we include subjective statements concerning what users liked best about each condition, what they thought needed the most improvement in each condition, and the reason for their preferences. More detailed qualitative data is provided in Appendix E.

5.1 Sense of Agency

We measured participants' sense of agency using a 3-item scale that asked about their sense of control over *their view* of the conference room, *other people's view* of them, and their *position* in the conference room. We found a significant effect of condition ($F_{1,22}$ = 10.62, p = 0.004), with participants rating H3D as higher (5a). Additionally, we asked participants to rate their sense of agency (for the three items above) *relative* to the local participants. Again, there was a significant effect of condition ($F_{1,22}$ = 6.47, p = 0.02), with participants rating their sense of agency higher in H3D (Figure 5b). Finally, participants rated how much they felt they had a place in the physical conference room, which was also higher in H3D ($F_{1,22}$ = 5.6, p = 0.03; 5c), and likely contributed to their sense of physical presence (Section 5.3).

Overall, H3D was recognized as offering enhanced agency and control, with many participants (n = 14) emphasising the advantages of its additional features. Participants particularly appreciated Hybridge3D's affordance of panning around the room, as it provided a "single continuous perspective (and not) a combination of detached views" **(P19)**. This felt "more natural" **(P5)**, "fluid" **(P11)**, and "very lifelike" **(P16)**, and accordingly, involved "less mental overhead" **(P20)** and "much less effort" **(P24)** (thereby also affecting their ease of awareness as per Section 5.2). In contrast, H2D's function of peeking from different viewpoints felt "abrupt" **(P3)** and therefore "distracted" **(P19)** people from the flow of the meeting.

While some participants (n = 6) appreciated having more agency in H2D when compared to "usual" meetings, many (n = 12) reported on the lack of flexibility provided by H2D. This was related to participants needing to "peek at different positions" **(P2)** to be able to see content. Several participants (n = 8) also expressed a sense of limited agency in H3D, with comments predominantly focused on the arrangement of the physical meeting space. This included having the "ability to avoid occlusions" **(P15)** and control "how close [others appeared]" **(P8)**.

5.2 Ease of Awareness

Perceived ease of awareness was measured using a 4-item scale. We found a significant effect of condition, with participants rating H3D as higher ($F_{1,22}$ = 16.08, p = 0.001; Figure 5a). Participants reported experiencing enhanced spatial awareness in H3D (n = 9), with the representation of the physical meeting room and the ability to pan the camera view allowing for more intuitive navigation of the meeting space when compared to H2D. Participants noted that they "liked having a feeling for people's "place" in the room" **(P14)** and the ease of "locating everything in the meeting room" **(P13)**. This was contrasted by many participants (n = 20) emphasizing the FOV restrictions in H2D, which hampered meeting awareness, with participants having to "jump seats" **(P24)** to effectively follow the meeting and finding it difficult to navigate "by just looking at the map" **(P18)**.

Although ease of awareness was significantly higher with H3D, participants (n = 11) still noted frustration over not being able to always follow the meeting, being required to "swerve my view back and forth" **(P24)** and having difficulties "seeing everyone at the same time" **(P12)**. The lack of spatial audio also made it "hard to tell" **(P3)** the identity and location of speakers. This added cognitive load, with attendees making an effort to either "[pay] attention to who opened their mouth" **(P3)** or put in effort to "recognize their voice" **(P4)**. Further, despite never being physically present in the meeting room, in-room attendees' lacked awareness when the remote participants were looking around the room with the Hybridge prototypes. One participant likened a remote attendee to being "a ghost in the room" **(P8)**, having the freedom to observe from different angles without being seen, which they found to be "intimidating" **(P8)**.

5.3 Physical Presence

We measured physical presence using an adapted 6-item SUS questionnaire [3]. We found a significant effect of condition ($F_{1,22}$ = 9.84, p = 0.005), with participants rating H3D as higher (Figure 5d). This was supported by several comments made by participants (n = 6), where the ability to pan around the room was considered key to increasing the sense of presence and feeling "really there" **(P4)**. Participants "felt more connected" **(P7)**, with the prototype making it "easy to talk to everyone and make eye contact" **(P16)**. Although H3D provided stronger immersion, some participants (n = 6) noted that H2D still provided a "stronger feeling of presence" **(P7)** compared to their previous meetings, with participants feeling "mixed in with the others" **(P19)**. As these comments suggest, both prototypes also increased participants' sense of *co-presence*, or sense of being with others.

6 DISCUSSION

Our overarching motivation is to understand how to improve hybrid meetings by bridging the gap between remote and in-person attendees. The purpose of this preliminary investigation was to determine the ideal remote interface features for our second design principle: heighten agency for remote attendees via a digital interface. To this end, we focus our discussion on how design features in H2D and H3D were received and provide recommendations for improvement.

Remote attendees appreciated the ability to control their viewpoint in H3D, which enhanced their sense of control, awareness, and presence. H3D mapped camera movement to holding down the mouse button and dragging the viewpoint around, as in a video game. Participants found this relative view adjustment easier to use than the more absolute view adjustment of H3D, which required clicking on seats to change or peek. Relatedly, when a remote attendee adjusted their view left or right, their in-room displays did not match this with physical left or right turning, creating an information asymmetry between in-room and remote participants. This indicates that kinetic displays would be superior to static displays in increasing awareness and presence (e.g. as in MMSpace [38]). If kinetic displays are not feasible, software interface techniques could be used, such as rendering visual indicators (e.g. arrows), or rotating the video of remote attendees using a billboard effect to match the direction of a remote attendee's gaze (e.g. as in GAZE-2 [51]). This could be significantly enhanced if the video itself was not limited to 2D, but rendered in 3D (e.g. as in [6]). Further, speaker identification could have also been improved by implementing spatial audio [19, 36] to mimic the natural dynamics of sound in a physical environment.

The minimap feature was included in both prototypes and was intended to provide remote users with a more comprehensive understanding of the seating arrangement, especially when moving around and potentially becoming disoriented. However, feedback (see table 5) suggests that this feature did not always succeed at sustaining remote user awareness of where they and other users were, and who was sitting in any given seat, partially because digital seats were only numbered. System awareness is a primary consideration for remote participants during hybrid meetings, however, neither the minimap nor the 3D room view showed which in-room participants were seated where. Instead, remotes had to rely on the webcam in seated view for this information. A more descriptive approach to indicate occupied seats, such as incorporating profile pictures or initials, would have offered a clearer representation of the seating arrangement. More detailed visual indicators have been shown to reduce the effort required during seat selection and ease the process of reorienting attention when needed (e.g., to address individual participants) in 3D virtual environments and 2D interfaces [27, 28]. To enhance awareness, in-room attendees could be represented as full-body avatars seated around the table in the 3D room view, matched by a minimap marker.

Although participants often noted their desire to see how they appear to others in the meeting, some highlighted that not seeing

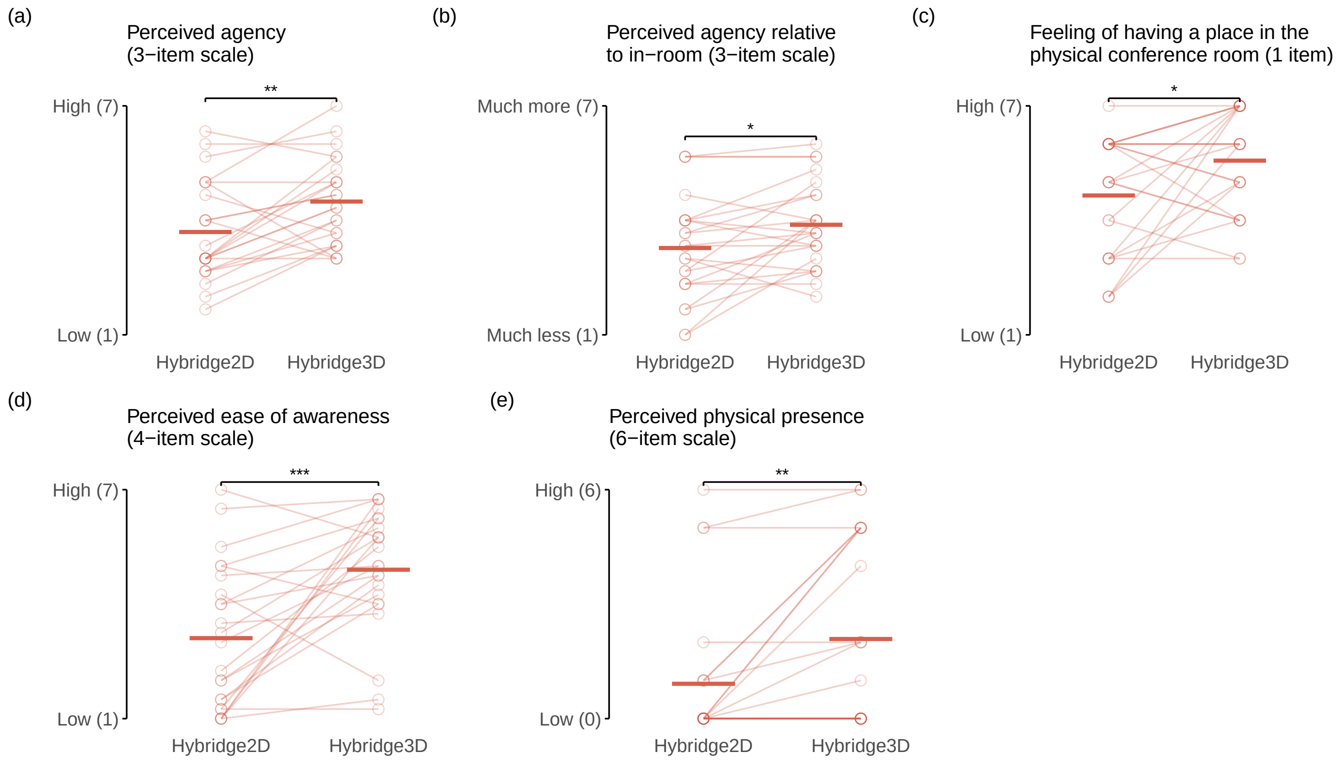


Figure 5: Perceived (a) agency, (b) agency relative to local participants, (c) feeling of having a place in the room, (d) ease of awareness, and (e) physical presence as a function of condition. Horizontal bars indicate averages, and circles and lines indicate individual data points. * is p < 0.001, ** is p < 0.01, * is p < 0.05**

themselves all the time added to their feeling of immersion (see table 6). This result stands in contrast to the responses of some participants in the Perspectives [48] study, who found conversational value in the first-person view but missed not having a self-view. It may be that since Perspectives was depicted as a virtual room but was effectively a flattened representation of room and people, it lacked an immersive quality and heightened some anxiousness based on knowing that they would appear to others as they saw those others (although sf. the constant mirror effect [23]). This suggests further work is needed to adequately balance naturalistic first-person immersion and confidence in self-view. Additionally, users often expressed frustration and confusion in using the "peek view" feature. We often noticed users having the peek view set to the same viewpoint as the main seated view, indicating that it might be adding too much cognitive load for participants to enable more than one view, even if one is intended to be only temporary. Future iterations might explore removing this functionality in favor of an easier-to-navigate meeting experience.

Factors such as the type/scale of the meeting, and an attendee's role in a meeting will have an impact on the value of Hybridge. This was highlighted by some participants who noted that platforms would ideally provide the flexibility to switch between Hybridge and the standard gallery meeting types to maximise the benefits of each application. Although ideal, physical technological implementations mean Hybridge would require planning, to set up and deliver a meeting effectively. There is precedent in this, such as Cisco Telepresence rooms [10], and interest in systems such as Google's Project Starline [26] and Logitech's Project Ghost [39]. However, all of those systems require purpose-built equipment and rooms, and require symmetrical systems at each endpoint. Hybridge can be created entirely from commodity hardware at the in-room end, and is an asymmetrical system in which remote endpoints see a software-only representation that can function entirely on a commodity desktop or laptop. As such, it may represent a more cost-effective way forward for organizations that want to elevate their hybrid meetings without committing to significant infrastructural cost and effort.

7 CONCLUSION

We set out to overcome limitations surrounding the inclusivity of hybrid meetings, introducing distributed spatial presence and enhanced agency for remote participants. Comparing two versions of Hybridge (H2D and H3D) with 24 participants, our preliminary results indicate a clear preference for H3D. Having the ability to manipulate one's view of the meeting room and a representation of the 3D space significantly enhanced perceived ease of awareness, sense of agency, and physical presence. As hybrid work environments continue to evolve, Hybridge presents a promising avenue for the creation of more inclusive and immersive collaborative meeting spaces. The insights derived from this study can guide future efforts toward developing more innovative and cost effective hybrid meeting solutions, with recommendations emphasizing the importance of addressing meeting asymmetry and prioritizing equitable participation regardless of attendees' physical locations. We plan to use findings from this research to iterate on Hybridge and conduct a more in-depth study comparing other meeting modalities and considering both remote and in-person endpoints.

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A PROTOTYPE SYSTEM IMPLEMENTATIONS

A.1 The Hybridge ecosystem

Refer to Figure 6 for a diagram of the various system-level components in the Hybridge set up. In order to enable the kinds of interactions that we wanted to implement, we needed a way to create our own meeting roster that could be kept up-to-date across all machines. To this end, underneath the interactive software we have a Seating Server that maintains an updated meeting roster and seat assignments in the meeting.

Broadly, each "visible" machine (i.e. seen / interacted with by a meeting participant—the two remote machines, and the three digital seats in the meeting room) in the Hybridge setup requires a similar set of software:

(1) **Microsoft Teams**: Rather than build our own A/V stack, we rely upon an off-the-shelf software, Microsoft Teams, to manage the transmission of audio-video content. This has the advantage of us not having to solve hard video communication challenges like compression, managing sync issues between audio and video etc. We take advantage of the NDI transport offered by Teams—all machines join the same Teams call and broadcast their A/V locally via NDI. These streams are picked up by the Hybridge front-end software (described below) and rendered appropriately.

(2) **Hybridge prototype**: The Hybridge front-end prototype is built with the Unity3D game engine. On a system level, this software serves two roles on both the remote and in-room machines (in addition to enabling all the interactions described in section 3): (1) first, it communicates to the Hybridge seating server to determine the current roster, and updates the roster when there is a seat change event, and (2) second, it renders the appropriate A/V streams on the audio-visual display connected to the machine. This involves selecting the current set of streams to render, and managing the camera pan angles for the remote users.

B DISCUSSION TASKS

For the three conditions, the following discussion topics were presented during each session in a counter-balanced order.

B.1 Survival on the moon

You are part of a 4-member team traveling to the station on the moon. Something is wrong with your navigation system, so you land safely, but 80km away from the station. Your survival depends on reaching the station, protecting yourself until someone finds you, or meeting a rescue party on the way to the station.

The moon has no atmosphere and no magnetosphere. Gravity is only 1/6 as strong as Earth's. The soil is a mixture that includes sharp, glassy particles. More than 80% of the moon is made of heavily cratered highlands. Temperatures vary widely, from -193°C to 111°C depending on time and location.

The next slide contains 11 items available. Rank the top 3 items in order of importance for the survival of you and your crew. You have 5 minutes to decide and write down your choices as a group.

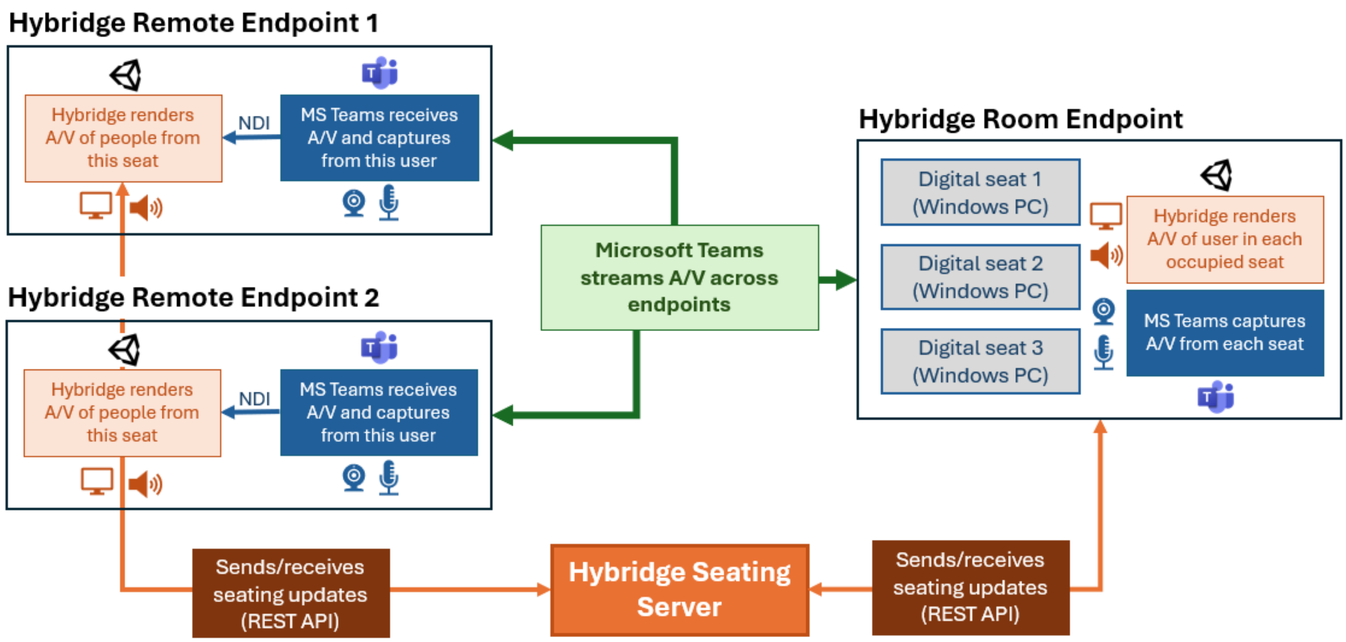

Figure 6: System diagram for the Hybridge prototype showing connections between various parts of the system.

- Magnetic compass
- Life raft
- Parachute silk
- Space suit repair kit
- Nylon rope (15m)
- First aid kit
- Signal mirror
- Solar-powered lights
- Space blanket
- Map of moon's surface
- Solar-powered radio receiver-transmitter

B.2 Survival in the desert

Your airplane has crash-landed in the desert in southwestern US. You and 3 others have survived unharmed. Before you crashed, you heard the pilot say that you are 110km away from the nearest town. Your survival depends on reaching the town or protecting yourself until someone finds you.

The immediate area is quite flat and appears barren, except for occasional cacti. The last weather report you heard said temperatures would reach 54°C. You are dressed in light-weight clothing—short-sleeved shirt, trousers, socks, and shoes.

The next slide contains 11 items available to you. Rank the top 3 items in order of importance to you and the others to give you the best chance of survival. You have 5 minutes to decide and write down your choices as a group.

- Sectional air map for area
- Two pairs of sunglasses
- Plastic raincoat
- Compress kit with gauze
- Magnetic compass
- Red and white parachute
- Flashlight
- Book: "Edible Animals for the Desert"
- .45 Caliber pistol (loaded)
- Bottle of salt tablets (1000)
- Jack knife

C PARTICIPANT DETAILS

Most participants were aged 30-44 (n = 13) or 18-29 (n = 9), while one participant was aged 45-59, and one was 60 or older. No participant reported to have any uncorrected visual or auditory impairments.

All participants were experienced with remote meetings, with most attending them daily (n = 13) or weekly (n = 8). Time spent video calling and in video meetings varied, spanning from more than 10 hours (n = 5) to less than 1 hour (n = 2) per week. Others attended meetings between 6-10 hours (n = 10), 3-5 hours (n = 2), and 1-2 hours (n = 5) per week. All participants had also taken part in at least one hybrid meeting, with most attending them on a weekly (n = 14), monthly (n = 6) or daily (n = 2) basis. Platforms used notably included Microsoft Teams (n = 23), Zoom (n = 13), and Google Meet (n = 8). Although many (n = 13) had experienced virtual meetings on both desktop and mobile platforms, others had used solely desktop (n = 11).

D STUDY INSTRUMENTS

After each condition, participants completed survey items about their sense of agency, ease-of-awareness, and physical presence. By *agency*, we mean a user's sense of control over their engagement in the meeting, including presentation of self [23, 49], one's view of others and (3) one's position in the meeting with respect to others [13, 25, 48, 49] (see Table 1 for all items). We also measured participants' ability to be aware of people and activities throughout the meeting using a 4-item questionnaire (see Table 2). Finally, to measure physical presence, we used 5 items from the Slater-Usoh-Steed (SUS) questionnaire [50], adapting them to refer to presence in the *physical* meeting room (see Table 3). After both conditions, we also asked participants which one they preferred and why.

Table 1: Sense of Agency: survey items and summary scores indicating *mean (standard deviation)*

	Hybridge2D	Hybridge3D
How much in control did you feel of *your view of the physical conference room?* [7-point scale: 'Not at all' to 'Very much so']	3.52 (1.81)	5.7 (1.29)
How much in control did you feel of *other people's view of you in the physical conference room?* [7-point scale: 'Not at all' to 'Very much so']	3.35 (1.8)	3.17 (1.75)
How much in control did you feel of *your position in the physical conference room?* [7-point scale: 'Not at all' to 'Very much so']	4.22 (1.57)	4.61 (1.47)
Compared to the people physically in the room, did you feel you had less or more control over *your view of the physical conference room?* [7-point scale: 'Much less' to 'Much more']	2.57 (1.75)	3.96 (1.55)
Compared to the people physically in the room, did you feel you had less or more control over *others' view of you in the physical conference room?* [7-point scale: 'Much less' to 'Much more']	3.26 (1.21)	3.57 (1.04)
Compared to the people physically in the room, did you feel you had less or more control over *your position in the physical conference room?* [7-point scale: 'Much less' to 'Much more']	4 (1.78)	4.13 (1.74)
To what extent did you feel you had a place in the physical conference room? [7-point scale: 'Not at all' to 'Very much so']	4.65 (1.58)	5.57 (1.38)

Table 2: Ease of Awareness: survey items and summary scores indicating *mean (standard deviation)*

	Hybridge2D	Hybridge3D
How easy was it to *see everyone you needed to throughout the meeting?* [7-point scale: 'Not at all easy' to 'Very easy']	2.57 (1.9)	5.17 (1.8)
How easy was it to *see everything going on in the meeting all the time?* [7-point scale: 'Not at all easy' to 'Very easy']	2.83 (2.06)	4.61 (1.8)
How easy was it to *stay oriented on what was happening where throughout the meeting?* [7-point scale: 'Not at all easy' to 'Very easy']	3.57 (1.97)	5.04 (1.66)
How easy was it to *see everything you needed to track what was going on throughout the meeting?* [7-point scale: 'Not at all easy' to 'Very easy']	3.48 (2.02)	4.78 (1.73)

E QUALITATIVE COMMENTS

We list participant responses that are related to the primary factors of Agency (Table 4), Ease of Awareness (Table 5), and Physical Presence (Table 6). Each table lists a "secondary factor", being a sub-theme within the primary factor, and the prototype that the participant is referring to (Hybridge2D or Hybridge3D). We also analyzed the general sentiment of the participant response as being positive, negative, or neutral.

Table 3: Physical Presence: survey items and summary scores indicating *mean (standard deviation)*

	Hybridge2D	Hybridge3D
Please rate your sense of "being there" in the physical conference room, on a scale of 1 to 7, where 7 represents your normal experience of being in a place. I had a sense of being there in the physical conference room... [7-point scale: 'Not at all' to 'Very much']	0.17 (0.39)	0.43 (0.51)
To what extent were there times during the meeting when you felt that you were in the physical conference room? There were times during the experience when the physical conference room was the reality for me... [7-point scale: 'At no time' to 'Almost all the time']	0.17 (0.39)	0.35 (0.49)
When you think back to the meeting, do you think of the physical conference room more as images that you saw or more as somewhere that you were visiting? The physical conference room seems to me to be more like... [7-point scale: 'Images that I saw' to 'Somewhere that I visited']	0.09 (0.29)	0.22 (0.42)
During the meeting, which was the strongest on the whole: your sense of being in the physical conference room or of being elsewhere? I had a stronger sense of... [7-point scale: 'Being elsewhere' to 'Being in the physical conference room']	0.17 (0.39)	0.43 (0.51)
During the meeting, did you often think to yourself that you were actually in the physical meeting room?During the meeting, I often thought that I was really in the physical conference room... [7-point scale: 'Not very often' to 'Very much so']	0.13 (0.34)	0.26 (0.45)

Table 4: Sense of Agency: Participant responses related to the affordance of each prototype.

Secondary Factor	Sentiment	Prototype	Participant	Comment
Ability to Pan the Camera View	Positive	Hybridge3D	P19	"I could pan around! It was so much more natural [...] I didn't have to keep messing around with peeking."
	Positive	Hybridge3D	P18	"I loved being able to [...] moving my head to look at other people or the board. This was especially helpful as I couldn't read the writing on the board from the small screenshot (peek view)."
Flexibility	Positive	Hybridge2D	P9	"I really like the fact that I can switch places, that's not something you can normally do in a physical meeting without annoying the other participants."
	Negative	Hybridge2D	P22	"There is no option to view the whole room and the screen. I - obviously - did not like that there was not a view from which I could see the screen naturally, but had to use the 'peek' function to see the screen."
	Negative	Hybridge2D	P2	"I had to 'peek' at different positions to be able to see the screen. In the usual virtual meetings, once a screen is shared, it appears on the screen for everyone to see and one does not have to make extra efforts."
Control to Manipulate the Room	Negative	Hybridge3D	P17	"I was too close to the presentation screen and thus had a very distorted view."
	Negative	Hybridge3D	P15	"The ability to slightly move own position to avoid occlusions of other people/objects would be helpful."
	Negative	Hybridge3D	P8	"It was a little bit intimidating how close I could see the people in the physical space."

Table 5: Ease of Awareness: Participant responses related to ease of awareness of the meeting.

Secondary Factor	Sentiment	Prototype	Participant	Comment
Spatial Orientation	Positive	Hybridge3D	P14	"I liked having a feeling for people's 'place' in the room."
	Positive	Hybridge3D	P17	"Ability to rotate made it significantly easier to understand my position in the room."
	Positive	Hybridge3D	P13	"It's a lot easier to locate everything in the meeting room if you can just pan around a bit."
	Negative	Hybridge2D	P18	"Clarity on where exactly I am seated, and the person directly seated next to me. I found it difficult to place my positioning by just looking at the map."
FOV Limitations	Negative	Hybridge2D	P24	"I had to jump seats to change my views from the (content) screen to the participants."
	Negative	Hybridge3D	P12	"I had difficulty seeing everyone at the same time."
	Negative	Hybridge3D	P24	"The screen was the opposite direction to the participants, so I had to swerve my view back and forth."
Aural Cues	Negative	Hybridge3D	P3	"The audio of the room also only came from one source, so it was hard to tell if someone was speaking from my left or right unless I paid attention to who opened their mouth."
	Negative	Hybridge3D	P4	"Sometimes it is not immediately obvious who was speaking if I didn't recognize their voice."
Awareness of in-room atendees	Negative	Hybridge3D	P8	"It is still intimidating that I can just look around without been seen. A little bit like a ghost in the room."
	Negative	Hybridge3D	P3	"When I pan my view to look at someone, the other participants are not able to tell that I am attempting to face them."
	Negative	Hybridge3D	P14	"Being able to display to others where remote participants are looking. I feel like the other participants could not see where my focus was"

Table 6: Physical Presence: Participant responses related to feeling present in the meeting space.

Secondary Factor	Sentiment	Prototype	Participant	Comment
Immersion	Positive	Hybridge3D	P16	"I felt more present in the meeting room than in a 'normal' video call. [...] made it easy to talk to everyone in the room and feel like I was making eye contact with them."
	Positive	Hybridge3D	P7	"The spatial relationships in the room were very clear and enjoyable. I felt more connected to the other virtual participants."
	Positive	Hybridge3D	P4	"Ability to turn my camera around to feel like I am really there."
	Positive	Hybridge3D	P16	"I was initially surprised by the fact I couldn't see myself at all, but I think that actually improved the immersiveness of the meeting."
	Negative	Hybridge2D	P7	"If the participant next to me turns toward me, the first-person view in the meeting does not allow me to see this, whereas in real life I would notice that in peripheral vision."
Improvement Over Previous Meetings	Positive	Hybridge2D	P19	"It was nice to feel like I was 'mixed in' with the other participants in the meeting, and it felt more natural than some other experiences I've had of hybrid meetings."
	Positive	Hybridge2D	P11	"Felt like people could more directly address me than typical remote situations."