SliVR: A 360° VR-Hub for Fast Selections in Multiple Virtual Environments

Kevin Linne* Sven Thomas† Jennifer Roth‡ Martin Weigel§

Technische Hochschule Mittelhessen

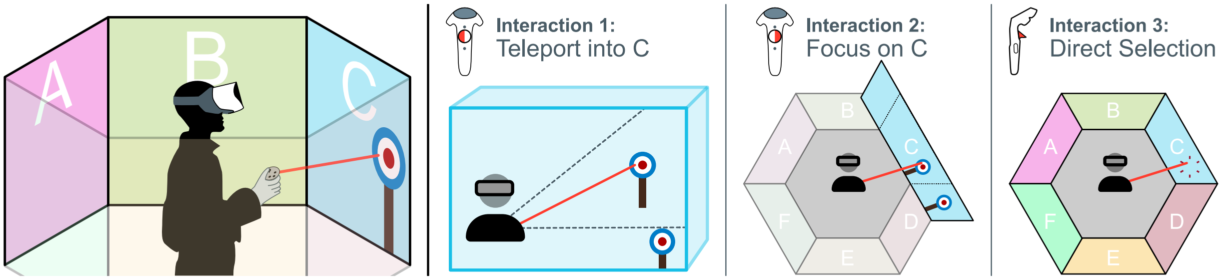

Figure 1: SLIVR is a 360° virtual reality hub, which shows previews of multiple 3D environments in a regular polygon arrangement around the user. It allows for three different interactions: (1) teleportation into a virtual environment (VE), (2) focus on a selected preview to increase the preview size, and (3) direct selection of targets inside a VE without leaving the hub.

ABSTRACT

Current virtual reality (VR) systems limit users to a single virtual 3D environment (VE) at a time, which restricts their ability to engage with multiple VEs simultaneously. We present SLIVR, a VR-Hub designed to enhance multitasking capabilities by arranging multiple VEs in a regular polygon formation around the user. Each VE is visually represented by life-sized 2D previews that facilitate hub-based interactions. *Direct Selection* enables users to select objects within a VE directly from the preview, allowing them to remain within the hub. Additionally, *Focus-mode* enlarges a chosen 2D preview, providing access to objects beyond the initial viewport. In a user study (N=18), we evaluated SLIVR against a conventional grid-based VR app launcher and a hub that utilized SLIVR's visualization but only supported *Teleportation* interactions. Our findings revealed that SLIVR improved target selection performance by 16.8% overall and by 30.5% when engaging with six VEs, compared to the grid-based app launcher. Notably, hub-based interactions accounted for 94.9% of selections, with *Focus-mode* being utilized six times more frequently than *Teleportation*.

Index Terms: Virtual Reality, Multitasking, Input.

1 INTRODUCTION

Exploring and interacting in multiple Virtual Environments (VEs) can be cumbersome, as users must frequently transition and settle in various environments. This challenge becomes even more pronounced when users need to navigate and engage with multiple VEs in quick succession. While existing systems often support transitions between VEs, they restrict the user to one VE at a time. For example, users can switch between VEs using visual transitions [10, 22], portals [12], movable devices such as orbs [14], and virtual headsets [23]. These techniques facilitate intuitive scene changes, but do not allow for simultaneous access. Moreover, observing multiple VEs and switching between them necessitates multiple portals, leading to overhead from portal management (e.g., [26]) or window management (e.g., [25, 24]). Although these solutions enhance flexibility in arranging the VR workspace, they also introduce complexity to the multitasking process. Additionally, their spatial flexibility can result in occlusion and layout challenges. Therefore, concurrent monitoring and interaction across multiple VEs remains a challenge.

Instead of switching, we propose the concept of a VR-Hub to survey and interact with multiple VEs at the same time. This approach is particularly beneficial in scenarios that demand real-time awareness of changes and rapid interactions across various VEs. One notable application is in firefighting missions, where operators oversee and control partially autonomous firefighting robots deployed in hazardous conditions. With a VR-Hub, operators can concurrently evaluate critical information across multiple 3D environments, such as identifying fire hotspots, navigating through smoke-filled areas, and locating trapped individuals. Another use case, involves using such a VR-Hub to oversee semi-autonomous robots in a production facility for Industry 4.0 [13, 7] scenarios. Operators can monitor statuses and assign tasks, such as selecting workflows or adjusting priorities. They can also manage issues remotely, for example when defective parts appear on a conveyor. This helps maintain quality control without disrupting productivity.

VR's immersive properties and natural 3D input make it ideal for these applications, but it lacks multitasking capabilities, which this paper addresses.

Building on portals and window management solutions, we propose SLIVR, a 360° VR-Hub where multiple VE previews are displayed around the user in a regular polygon. This maximizes the preview size and prevents overlapping of previews to avoid the necessity of window management. Previews are life-sized representations designed to enhance spatial perception [15]. This means that the previews faithfully depict VEs at a 1:1 scale, ensuring an accurate and immersive representation. They function as *windows into the VE*, providing users with realistic spatial cues and a seamless transition experience by matching the perceived sizes in VR to real-world proportions. The hub supports three interactions. Users can: (1) use a ray for selecting content in the VE without leaving the hub (*Direct Selection*), (2) increase the preview size of one VE to focus on its contents (*Focus-mode*), and (3) teleport into a specific VE for complex tasks that require full immersion (*Teleportation*). *Focus-mode* and *Teleportation* first require selecting a VE and then a target, which is similar to the idea of progressive refinement [17].

---

*e-mail: kevin.linne@mni.thm.de
†e-mail: sven.thomas@mni.thm.de
‡e-mail: jennifer.roth@mni.thm.de
§e-mail: martin.weigel@mni.thm.de

We conducted a user study to validate the efficiency gains of SLIVR. In the study, we compared it to GRID, a state-of-the-art application launcher, and to POLY, a hub that shares SLIVR's visualization but lacks its hub-based interaction techniques. This helps us to understand the impact of visualization (GRID vs. POLY) on performance, as well as, user preferences and performance differences between teleportation and hub-based interactions (POLY vs. SLIVR). Findings from the user study show a significant higher performance of SLIVR compared to GRID (+16.8%) and POLY (+28.6%). Moreover, they show users prefer hub-based interactions (*Direct Selection* and *Focus-mode*) over *Teleportation*.

To sum up, the two main contributions of this paper are:

1. The concept and implementation of SLIVR – a novel, multitasking-focused VR-Hub – and its design goals.
2. Findings from the user study comparing selection performance, usability, and user preferences.

2 RELATED WORK

2.1 Switching Virtual Environments (VEs)

Efficient and intuitive transitions between multiple VEs are crucial for enhancing user experience [10, 22, 23]. Previous research explored various methods such as visual transitions, including techniques such as cuts, fades, dissolves, and morphs [10, 22]. These transitions are typically activated through user interactions, such as button presses or menu selections. A combination of VEs was investigated by Schjerlund et al., who layered four viewpoints of the same VE and made all but one translucent [29].

Another approach to facilitate VE transitions involves localized portals, which provide users with a preview of the new VE. The transition is triggered when the user physically steps through the portal [12]. Pohl et al. explore distant interaction through portals in Poros [26], which uses spherical portals to interact with distant objects. This flexible approach allows for interaction in multiple VEs, but requires additional portal management. To minimize physical movement, alternative methods such as mobile orbs and virtual headsets have been proposed. These allow users to switch VEs by positioning these portable devices near their heads [14, 23].

SLIVR seeks to enable rapid multitasking in multiple VEs without requiring physical movement or reliance on portable devices. Unlike previous methods, SLIVR employs a static portal-like preview combined with remote selection to trigger teleportation, offering a more streamlined and efficient transition mechanism.

2.2 VR Display Layouts

Previous research has compared different layouts of content. Liu et al. evaluated the spatial memory for circular, flat and semi-circular display layouts [21], while Satriadi et al. let users freely arrange map layouts in the 3D space [28]. Other research has explored the effectiveness of window management capabilities in XR settings. Pavanatto et al. demonstrated that using a single virtual canvas in AR can enhance space utilization compared to multiple virtual displays [24]. However, this approach demands more intensive window management. Our work focuses on displaying a large number of VEs. To support this, SLIVR places VE previews around the user in a full 360° layout and automatically adjusts their width based on the total number of VEs. Although larger virtual displays necessitate increased head and eye movements [25], this is essential for maintaining a 1:1 scale in VE previews. Lisle et al. researched what influence display layouts have on the sensemaking process, and found that their approach of freely arranging displays increases satisfaction compared to single flat displays [20]. When displays are freely placeable that requires not only window management, but also occlusion management [33]. By placing previews next to each other we remove the need for both. An alternative approach, not specific to VR, was proposed by Waldner et al., who suggested compositing windows based on the importance of their content [30]. While this method could be adapted for VR, SLIVR avoids window management by using fixed preview positions and sizes. We chose this to improve spatial awareness and minimize the cognitive load associated with managing multiple windows, allowing users to focus on the VEs without unnecessary distractions.

2.3 Multitasking in VR

Launchers in platforms like SteamVR, Meta Quest, and Apple Vision Pro serve as initial gateways, offering access to multiple environments. However, these interfaces often prioritize simplicity over multitasking efficiency. Research has proposed other multitasking strategies, such as Layered Telepresence [27], which overlays distinct environments in augmented reality but is limited by the number of layers it can effectively manage. Another approach, the Ubiquitous Body [16], involves using different body parts to interact with multiple environments simultaneously. Users control different areas by leaning forward for a detailed view, maintaining a clear distinction between VEs. Studies like InteractionAdapt and HoloDoc [4, 18] investigate multitasking in VR by distributing UI elements across 3D space and combining physical and virtual elements. These approaches enhance spatial awareness but may complicate interaction when managing multiple environments. In contrast, SLIVR extends the input space with *Teleportation* and a *Focus-mode*, enabling users to select targets outside their immediate view. RealityLens [31] integrates physical world views into VR. Slice of Light [32] presents VEs in slices around the user, allowing physical movement to switch between them. This setup facilitates intuitive switching, but is designed for shared experiences, hence only used for a limited number of VE. Finally, research on object transfer between environments [6] highlights the importance of interactivity in multitasking. To enhance its multitasking capabilities, we integrated hub-based interactions into SLIVR, enabling users to interact with content in VEs while remaining in the hub and surveying other environments.

3 SLIVR: A VR-HUB FOR MULTITASKING

3.1 Design Goals

SLIVR's design evolved through iterative development, user feedback, and prior implementations, highlighting limitations in existing launchers and portals [14, 19, 10]. Scaled-down visuals hindered size and distance judgments and often required teleportation due to small target sizes. We distinguish visualization (VG) and interaction goals (IG):

3.1.1 Visualization Goals

VG-1 Allow a *flexible number of VEs* and fully utilize the available space for an arbitrary number of VEs.

VG-2 Provide *life-sized* previews of the VEs to allow users to view objects at a 1:1 scale improving presence and spatial perception.

VG-3 *Avoid overlapping* of previews to avoid window management.

VG-4 Keep VEs in the *same order* to provide a spatial consistency.

VG-5 Keep the VE in the *same position and orientation* after teleportation as it was shown in the preview to reduce the need for reorientation.

3.1.2 Interaction Goals

IG-1 Support *teleportation* into a chosen VE for complex tasks that require full immersion. This ensures the hub does not limit the interaction capabilities inside VEs.

IG-2 Support *hub-based interactions* for selecting objects within VEs, enabling multitasking by allowing users to interact with different VEs in quick succession while observing others simultaneously.

IG-3 Support a mechanism to *temporarily increase the preview size* of one VE to allow for hub-based interactions outside the original preview.

3.2 Concept

The central concept of SliVR is to preview multiple VEs at once and placing them in a regular polygon around the user, offering a 360° view (Figure 1 left). Each preview represents a ”sliver” of the target VE in its true scale, hence the name SliVR. This arrangement maximizes the size of each preview (VG-1) and ensures the previews never overlap (VG-3). By adjusting the width of these previews according to the number of VEs, SliVR supports adaptability to different numbers of VEs (VG-1). This design ensures that each preview occupies the maximum possible viewing angle (i.e., 360° / Number of VEs) — for instance, 60° for 6 VEs. The large size of the previews enables life-sized representations at a 1:1 scale of their respective VEs (VG-2). All preview screens are consistently ordered within SliVR, which eliminates the need for any manual window management. A constant order of the previews enables users to quickly learn and memorize the location of each VE, allowing the users to concentrate on the content of the VEs rather than adjusting the interface (VG-4).

SliVR supports three interactions (see Figure 1 right). Users can use *Teleportation* into a specific VE by pointing at the desired environment and pressing a button on the controller to initiate the teleport (IG-1). After teleporting, users find themselves in the new VE with the same position and orientation they saw in the preview before teleportation, minimizing the need for reorientation (VG-5). This also means that the selection ray of the user's controller stays on the same objects, allowing the user to pre-aim at objects on the preview. SliVR also supports two hub-based interactions, named *Direct Selection* and *Focus-mode* (Figure 1, right). With the *Direct Selection*, users can select objects displayed in a preview using ray-casting, one of the most popular techniques for object selection [1]. The interaction is then transferred to the actual VE, where the corresponding object is selected (IG-2).

Selection is “one of the fundamental tasks in in 3D user interfaces and the initial task for most common user interfaces in a VE” [1] and hence the most important interaction for our concept. In future iterations, *Direct Selection* can be extended to support additional interactions, such as drag-and-drop actions within and between VEs (similar to [26]). Furthermore, SliVR provides *Focus-mode*: by selecting a preview with their controller and pressing the focus button, users can expand that specific preview to fill most of their field of view, while the other previews are dimmed. This functionality provides a wider viewing angle into a VE and enables users to concentrate on the content of a single VE without fully teleporting into it. (IG-3).

3.3 Implementation

Based on this concept, we implemented SliVR (see Figure 2 bottom) using the Unity game engine. Our application consists of one scene with an isolated room for SliVR and three VEs. The VEs are freely available from the Unity store and resemble a viking village[1], an outdoor industrial complex[2], and a Japanese school[3]. The user's starting position is in the center of SliVR. He is surrounded by 6, 9, or 12 preview screens, which show dynamic views from virtual cameras distributed inside the three VEs. The preview screens are flat surfaces that all face towards the center of the hub at a distance of 170 cm. The virtual camera is mapped as a texture on the preview screen. The preview screens float 75 cm above the floor and have a height of 150 cm. VEs that require user input are highlighted with green bars on top and bottom of the preview (15 cm each) to guide the user's attention towards them. We chose all values based on our empirical tests to provide a good visual appearance without confining the user.

The user interacts with four buttons of one HTC Vive controller: (1) trigger button; (2) left touchpad; (3) right touchpad; and (4) menu button. Inside the hub and the VEs, a white ray is shown from the controller in the pointing direction to help the user aiming. The *trigger button* is used to interact with the VEs from inside the hub (*Direct Selection*). When pressed, we calculate the corresponding position and orientation of the controller in the VE and perform a raycast to find out if the user selected an interactive object. The *left side of the touchpad* teleports the user inside the selected VE. The user is teleported into the VE keeping the user's offset from the hub's center and the user's orientation intact. Hence, ensuring the previewed portion of the VE remains at the same location. The *right side of the touchpad* is used to focus on one VE and enlarge the preview. The width of the selected VE is increased to 90° to fill a large part of the user's field of view. All other screens were deactivated and grayed out. The user can exit a VE or *Focus-mode* by pressing the same button again or using the *menu button*.

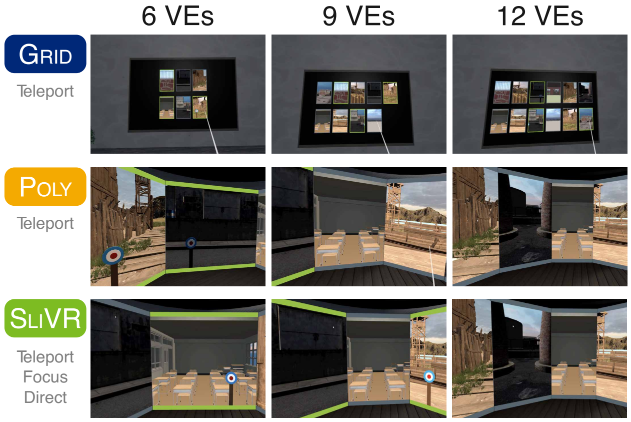

Figure 2: The nine conditions of the user study: three Hubs (Grid, Poly, and SliVR) with different Number of VEs (6, 9, and 12).

4 User Study

We evaluated the potential of SliVR for fast selections in multiple VEs in a user study. The study was conducted within a VR laboratory, utilizing an HTC Vive Pro 2 headset connected to a high-performance desktop computer equipped with an Intel i9-12900K processor, 32 GB of RAM, and a GeForce RTX 3080 graphics card. The application was refreshed at constant 90 Hz. Four base stations mounted at the ceiling tracked the headset and controller inside a 3×2.5 m tracking space from all directions.

The controlled experiment resembles a pointing study, where participants try to select as many targets appearing inside the VEs during 60 seconds as possible. Targets are circular shaped and have

---

[1] Viking Village URP by Unity Technologies

[2] Industrial Set v2.0 by Dmitrii Kutsenko

[3] Japanese School - Stylized by Sherman Waffle Studios

The final version of this record is available at: 10.1109/ISMAR67309.2025.00065

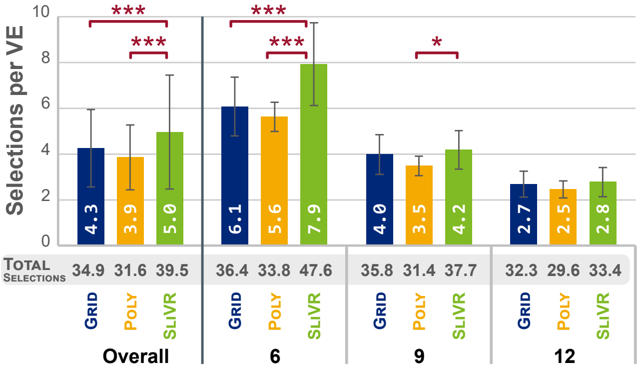

Figure 3: Average target selections per VE in 60 s and split for 6, 9 and 12 environments (mean and SD; $* = p < .05$; $*** = p < .001$). Total selections are the average number of selections per participant independent of the Number of VEs (i.e., Total = Selections per VE · Number of VEs).

a bulls eye surrounded by two rings as visible in the previews in Figure 2 and sketched in Figure 4. We included targets at six distinct locations in each VE at an angle of ±7.5°, ±16.5°, and ±31.5°. The target angles cover a wide range (∢ 70°) and ensure the targets will be either fully visible, partially visible (30%, see Figure 4), or invisible for the different Number of VEs. All targets had a distance of 2.5 m from the user and were angled towards the user's position. Their center was positioned 1 m above the ground. The targets had a diameter of 30 cm (≈6.9°), sectioned in three equally sized rings. This distribution of targets is valid for our use cases, as each VE in SliVR could represent an environment focused on task-relevant areas. In Industry 4.0, these VEs emulate production zones, ensuring that relevant information is presented within the operator's immediate visual field to support efficient monitoring and intervention. Similarly, in fire-fighting operations, the VEs simulate drone views, where critical regions of interest are prioritized, making target placement outside the user's frontal view unnecessary.

The target selection task was chosen as a representative measure for multitasking, as it simulates real-world scenarios where users need to make quick, targeted interactions across multiple VEs. In the use cases mentioned above, operators frequently face time-sensitive requirements to assess and respond to information across various sources or VEs. Similarly, our selection task replicates this need for quick decision-making and interaction, allowing us to measure the efficiency and ease with which users can manage simultaneous targets in a VR-Hub context.

SliVR was compared to an application launcher (Grid, see Figure 2 top) to understand its benefits compared to the state of the art. The design of Grid was inspired by the widely-used SteamVR app launcher, which similarly presents applications in a tiled format with up to 12 applications displayed across two rows of up to six. This arrangement avoids the need for complex navigation or scrolling, aligning with familiar VR interface patterns and ensuring intuitive usability for participants accustomed to SteamVR-like environments. A large display containing Grid's previews was positioned 4.2 m in front of the user and floated 40 cm above the ground. It was 4 m wide and 2.5 m high. Each preview had a width of 50 cm and a height of 70 cm. They were spaced 10 cm horizontally and 20 cm vertically. State-of-the-art application launchers typically display icons instead of live previews. To ensure a fair comparison, we added live environment previews and green borders for VEs with active targets to Grid.

Moreover, we compared both to Poly (see Figure 2 middle), which shares the same visualization as SliVR. However, it only supports *Teleportation* (like Grid) and does not support *Direct Selection* or *Focus-mode*. This condition was included to separate the effects of SliVR's input and output features. It helps us determine whether performance improvements result from the new visualization or from the added interaction capabilities. We evaluated each hub for 6, 9, and 12 VEs, where each preview screen in SliVR and Poly covered 60°, 40°, or 30° of the hub. Poly and Grid used the same controller mapping as SliVR with *Focus-mode* and *Direct Selection* disabled. In addition to the performance evaluation, we collected subjective feedback through a System Usability Scale (SUS, [3]), ranking, and open-ended questions.

4.1 Hypothesis

In the study we investigate the following hypothesis:

H1 **SliVR has a higher target selection performance compared to Poly and Grid.** We believe this because its *Direct Selection* capabilities eliminate the need for *Teleportation*, enabling faster and more efficient interactions.

H2 **Poly has a higher target selection performance compared to Grid.** We think the life-sized previews provide users with a clearer view of targets and the ability to pre-aim at a target before using *Teleportation*. Thus, times between a teleport and the selection are anticipated to be reduced.

H3 **Users will use *Direct Selection* more often than *Focus-mode* and *Teleportation* in SliVR.** This is because SliVR provides a more streamlined approach to target selection, eliminating the extra steps involved in *Focus-mode* and *Teleportation*, making it the preferred choice.

H4 **Users prefer SliVR over Grid.** We think so due to SliVR's combination of larger previews and efficient selection mechanisms.

4.2 Participants

An a-priori power analysis using G*Power version 3.1.9.7 [9] was conducted to determine the sample size for a repeated-measures ANOVA. With an anticipated medium effect size ($f = 0.25$), an alpha level of 0.05, and a desired power of 0.90 the analysis indicated that a total sample size of 18 participants is required to detect a significant effect. We recruited 9 female and 9 male participants between 18 and 31 years ($mean = 23.39, SD = 2.97$). Thirteen participants had normal sight, four used glasses, and one contact lenses. We measured the interpupillary distance (IPD) for all participants before the study to calibrate the VR headset (mean=63.2 mm, SD=2.1 mm). Participants could choose the hand to hold the controller: 16 chose the right hand and two the left hand. The VR-experience of the participants was roughly evenly distributed, ranging from no prior exposure to significant experience. On average the study took 45 minutes per participant. Participants received no compensation. The study followed local ethical guidelines and complied with institutional and legal requirements. Formal ethics approval was not needed for this anonymized, non-invasive user study under local regulations.

4.3 Study Design

Our study follows a within-subject design with two independent variables: Hubs (Grid, Poly, and SliVR) and Number of VEs (6, 9, and 12). This resulted in 9 conditions (3 Hubs × 3 Number of VEs) as shown in Figure 2. The dependent variables were the amount of target hits, errors, used interaction types, time intervals between interactions, SUS score and the ranking. We chose 2–4 non-overlapping perspectives from a viking village, an outdoor industrial complex, and a Japanese school as VEs inside the study. The VEs were selected to encompass a variety of geometries. They

The final version of this record is available at: 10.1109/ISMAR67309.2025.00065

include indoor and outdoor perspectives and varying lighting conditions. The order of the VEs was alternated to avoid two similar perspectives be shown next to each other.

The study was divided in three blocks, one for each hub. A Latin-square was used to balance out potential learning effects from previous hubs. Inside each block, the three values (6, 9, and 12) of Number of VEs were counterbalanced to ensure different orders. We chose this design to minimize how often participants had to relearn the Hubs. The SUS questionnaire was selected to provide a straightforward measure of SliVR's overall usability as an integrated multitasking interface. We prioritized user experience as a whole over workload-specific factors that are better suited to other questionnaires. By focusing on ease of use across multiple interaction types, SUS aligns with SliVR's goal of universal applicability across diverse scenarios.

4.4 Procedure

After obtaining informed consent from the participants, we collected their demographic data through a questionnaire. To ensure optimal configuration of the VR equipment, the experimenter measured each participant's interpupillary distance and adjusted the headset's lens accordingly.

Participants began the study positioned at the center of the VR tracking space, instructed to remain stationary throughout the study tasks. The task was to select as many targets as fast and precisely as possible in 60 seconds. Before each block, the experimenter described the usage of the hub and its interaction capabilities. Participants were asked to practice the usage of each hub in the beginning of each block and (optionally) before each condition. There were three active targets at any point during the study. Each VE with an active target within had green highlights to indicate the need for intervention. Once a target was selected, it disappeared and the next target appeared. Targets could appear in any VE at one of six positions (see Figure 4 top). We created nine lists—one for each condition—with 200 tupels (target environment × target position) that determined the order in which the targets appeared. All target VE and target position combinations had the same chance and were counterbalanced. The list order was counterbalanced across the Hubs conditions. All interactions with the hub and inside the VEs were logged into a CSV-file for later evaluation. After each block, the participant was asked to fill out a System Usability Scale (SUS) questionnaire [3] translated into the local language. In the end, participants filled out a questionnaire that asked to rank the three hubs based on their subjective experiences and provided feedback through open-ended questions.

4.5 Data analysis

We confirmed the normality of our measurements through both visual inspection using Q-Q plots and the Shapiro-Wilk test. Sphericity was assessed, and when violated, we applied the Greenhouse-Geisser correction to adjust the degrees of freedom. Depending on the results of the normality tests, we conducted either a repeated-measures ANOVA (RM ANOVA) or a non-parametric equivalent, such as the Wilcoxon signed-rank test, Friedman test, or ART ANOVA, depending on the number of factors. For significant effects, we performed post-hoc analyses using Tukey-corrected pairwise t-tests where appropriate.

5 RESULTS

5.1 Target Selections per VE

A target selection was successful when the participant pointed anywhere on the target when triggering the selection. The target selection performance was assessed by measuring the amount of successful target hits per 60 seconds per VE. Measuring performance per VE ensures that the focus remains on how effectively users can handle each individual environment within the given time.

The successful average target selections per VE were evaluated for both variables individually and for each of the nine conditions (see Figure 3). Of all Hubs, SliVR had the highest successful target selection per VE ($mean = 5.0, SD = 0.9$), followed by Grid ($mean = 4.3, SD = 0.8; -14.0\%$), and Poly ($mean = 3.9, SD = 0.4; -22.0\%$). Due to violations of sphericity for Number of VEs (Mauchly's $W = 0.50, p < .01$) and the interaction Hubs × Number of VEs (Mauchly's $W = 0.18, p < .01$), Greenhouse-Geisser corrections were applied. For the factor Hubs, the assumption of sphericity was met (Mauchly's $W = 0.94, p = .60$) and no correction was required. A repeated-measures ANOVA identified significant main effects between the Hubs ($F(2,34) = 22.5, p < .001, \eta_p^2 = .57$). Tukey corrected post-hoc tests found significant differences between SliVR and Grid ($p < .001$), as well as SliVR and Poly ($p < .001$). No significant differences could be found between Grid and Poly ($p = .10$).

Comparing the Number of VEs, conditions with 6 VEs had the highest successful target selections per VE ($mean = 6.5, SD = 1.6$), followed by 9 VEs ($mean = 3.9, SD = 0.8; -40.0\%$), and 12 VEs ($mean = 2.6, SD = 0.5; -60.0\%$). A repeated-measures ANOVA identified significant main effects between the Number of VEs ($F(1.33, 22.69) = 325.2, p < .001, \eta_p^2 = .95$). Tukey corrected post-hoc tests found significant differences between 6 VEs and 9 VEs ($p < .001$), 6 VEs and 12 VEs ($p < .001$), and 9 VEs and 12 VEs ($p < .01$).

In order to understand possible interaction effects, we compare the three Hubs for each Number of VEs. Figure 3 details on the mean and standard deviation of each condition. A repeated-measures ANOVA identified significant interaction effects between hubs and VEs ($F(2.11, 35.80) = 22.0, p < .001, \eta_p^2 = .56$). Tukey corrected post-hoc tests found significant differences between SliVR×6 and Grid×6 ($p < .001$), SliVR×6 and Poly×6 ($p < .001$), as well as SliVR×9 and Poly×9 ($p < .05$). No significant differences could be found between Grid×6 and Poly×6 ($p = .77$), Grid×9 and Poly×9 ($p = .29$), Grid×9 and SliVR×9 ($p = .72$), Grid×12 and Poly×12 ($p = .70$), Grid×12 and SliVR×12 ($p = 1.0$), and Poly×12 and SliVR×12 ($p = .54$) We omitted differences between conditions with different Number of VEs since these differences are not relevant for our analysis.

The error rates were analyzed to assess selection accuracy. An error was defined as a selection made while not pointing at a target. The corresponding error rate was calculated as $E = \frac{errors}{errors+hits}$. The average error rates were as follows: 6.6% ($SD = 0.05$) for Grid, 5.5% ($SD = 0.06$) for Poly and 7.7% ($SD = 0.06$) for SliVR. Due to the non-normal distribution of the error rates, a non-parametric ART ANOVA was conducted. The analysis revealed no significant differences between the Hubs ($F(2,136) = 1.33, p = .27$) and Number of VEs ($F(2,136) = 1.88, p = .16$). Additionally, there was no significant interaction effect ($F(4,136) = 1.88, p = .88$).

To better understand the differences in selection counts, we analyzed two time intervals. First, the time needed to identify a relevant VE before teleportation. Second, the time to identify, aim at, and select a target after teleportation. Average time before teleportation was 879ms ($SD = 155.6$) for Poly and 652ms ($SD = 165.6$) for Grid. A Shapiro-Wilk test indicated that the data was not normally distributed, so we conducted a non-parametric ART ANOVA with Hubs and Number of VEs as factors for both time intervals, which suggested a significant main effect for the Hubs ($F(1,85) = 129.3, p < .001, \eta_p^2 = .60$). We observed no main effect for the Number of VEs ($F(2,85) = 1.52, p = 0.22, \eta_p^2 = .03$) and no interaction effect ($F(2,85) = 3.07, p = .052, \eta_p^2 = .07$). Tukey-corrected pairwise comparison revealed significant differences between Grid and Poly, favoring Grid ($p < .001$). Average time between teleportation and target selection was 874ms ($SD = 155.2$) for Poly and 880ms ($SD = 164.6$) for Grid. An ART ANOVA indicated a main effect of Number of

VEs ($F(2,85) = 3.41, p < .05, \eta_p^2 = .07$), but no significant main effect for HUBS ($F(1,85) = 0.01, p = 0.91, \eta_p^2 < .01$) and no interaction effect ($F(2,85) = 0.19, p = .83, \eta_p^2 < .01$). As only significant differences between the HUBS were relevant for our analysis, we did not perform post-hoc pairwise comparisons.

5.2 Preferred Interaction Types in SLIVR

When using SLIVR, you can either select targets directly or indirectly by first using *Teleportation* or *Focus-mode*. We evaluated how often each technique was used for successful target selections. When targets were visible in the hub, participants preferred *Direct Selection*. On average participants selected 62.8% of targets with *Direct Selection*, 32.1% during *Focus-mode*, and 5.2% after *Teleportation* into the VE. Compared to indirect selection (*Focus-mode* + *Teleportation*), a Wilcoxon Test indicates that *Direct Selection* was used significantly more often for 6 VEs ($W = 146.0, p < .001, r_b = .91$) and for 9 VEs ($W = 144.5, p < .001, r_b = .89$). For 12 VEs, indirect selections were used more often than *Direct Selection* ($W = 31.5, p < .05, r_b = -.59$). Furthermore, there were significant differences between *Focus-mode* and *Teleportation* for 6 VEs ($W = 89.0, p < .05, r_b = .70$), 9 VEs ($W = 165.5, p < .001, r_b = .94$), and 12 VEs ($W = 151.5, p < .01, r_b = .77$).

Depending on the NUMBER OF VEs, the number of completely visible targets decreased (see Figure 4). With it, the number of *Direct Selection* decreased from 80.7% (6 VEs) to 60.1% (9 VEs), and 40.2% (12 VEs). Completely visible targets were selected via *Direct Selection* in 88.1% of times, while partially visible targets (only in conditions with 6 and 12 VEs) were selected in 49,2% of cases using *Direct Selection*. We further investigated these results to understand which interaction technique was used for the different targets depending on the NUMBER OF VEs (see Figure 4).

5.3 SUS and Ranking

The System Usability Scale (SUS) was utilized to assess the usability of the distinct VR multitasking hub concepts. SLIVR received the highest SUS score with 89.6 ($SD = 9.9$), followed by the GRID receiving 88.1 ($SD = 10.3$), and POLY receiving 81.7 ($SD = 15.7$). A non-parametric Friedman test was conducted to evaluate differences between the three HUBS. The results indicated no significant differences between them ($\chi^2(2) = 4.16, p = .13$).

We asked participants to rank the three HUBS according to their potential for multitasking in VR. SLIVR was ranked first place by 9 participants (50.0%), second by 7 (38.9%), and third place by 2 participants (11.1%). The second most popular was GRID with 7 participants ranking it first (38.9%), 5 second (27.8%), and 6 third (30.0%). The mean rank of SLIVR was 1.61, followed by GRID with a mean score of 1.94, and POLY with 2.44. A Friedman test revealed a significant difference between the hubs ($\chi^2(2) = 6.33, p < .05$) with a small effect size ($W = 0.18$). Post-hoc pairwise comparisons using the Durbin-Conover method showed a significant difference between POLY and SLIVR ($p < .05$), but no significant difference between GRID and SLIVR ($p = .12$) as well as GRID and POLY ($p = .29$).

6 DISCUSSION

6.1 Performance

One of our goals was to study the performance of SLIVR for multitasking in multiple VEs and how it compares to GRID and POLY. SLIVR achieved the highest successful target selections per VE of all HUBS across all NUMBER OF VEs. Overall, the successful target selection rate with SLIVR is significantly better than GRID (by 16.8%) and POLY (by 28.6%). The increased performance was particularly visible for 6 VEs, where SLIVR performed 30.5% better than GRID. However, for 9 and 12 VEs no significant difference between GRID and SLIVR could be found. Hence, H1 "SLIVR has a higher target selection performance" can only be supported for 6 VEs. The performance improvement in SLIVR was achieved without a significant increase in error rates.

The observed differences were not only statistically significant but also practically meaningful. The main effect of HUBS yielded a partial eta squared of $\eta_p^2 = .57$, which represents a large effect size according to conventional benchmarks [5, 11]. Similarly, the effect of NUMBER OF VEs was extremely large ($\eta_p^2 = .95$), indicating that the number of VEs had a substantial impact on performance. The interaction effect was also large ($\eta_p^2 = .56$), further emphasizing the differential influence of hub design depending on the NUMBER OF VEs.

Although we expected the life-sized previews to enhance users' overview of the VEs and thereby improve performance, POLY resulted in fewer successful target selections per VE compared to the other hubs. On average, POLY performed 9.2% worse than GRID. An analysis of the time differences revealed that participants required more time to select a VE with an active target, potentially due to the need for additional rotations. We anticipated that the time interval from teleportation to target selection would be shorter in POLY compared to GRID, as the life-sized preview could allow users to pre-aim at the target. However, this expectation was not supported by our data. These findings contradict our initial hypothesis H2, which proposed that POLY would outperform GRID.

Based on analyzed time intervals and subjective feedback from our participants, we assume the advantage of the large preview compared to the GRID was canceled out by the additional rotations needed to observe all VEs. Participants mentioned "the 360° [viewport] required a lot of rotations and sometimes required some searching to see the green indicators [for the VEs with active targets]" [P15] and that "it might be annoying during longer usage to rotate completely to reach these areas" [P5]. Since H2 has been rejected and POLY shares the same 360° layout and life-sized previews as SLIVR, it is unlikely that the visualization alone explains the performance difference. This supports the conclusion that spatial arrangement, while helpful for providing an overview, is not sufficient to enable efficient multitasking. Instead, SLIVR's performance gains are primarily driven by its interaction design—specifically the ability to interact directly from the hub using *Direct Selection* or to temporarily enlarge previews using *Focus-mode*. These techniques reduce the need for transitions, which appears to be key for multitasking across multiple VEs.

Error rates of all conditions were low and their differences insignificant. We believe SLIVR's slightly higher error rate could come from being the condition with the highest number of selections and participants chose performance over precision.

6.2 Interaction Techniques

The advantages of *Direct Selection* are also shown in the analysis of the interaction techniques chosen by the participants. *Direct Selection* was used significantly more often than *Focus-mode* and *Teleportation* for 6 and 9 VEs and was the most common technique overall (62.8%), followed by *Focus-mode* (32.1%), and *Teleportation* (5.2%). This finding supports H3 for 6 and 9 VEs, demonstrating that users show a clear preference for *Direct Selection* over indirect methods such as *Focus-mode* and *Teleportation*.

These differences were accompanied by large effect sizes. For example, the Wilcoxon tests comparing Direct Selection versus indirect methods revealed $r_b = .91$ for 6 VEs and $r_b = .89$ for 9 VEs, indicating very strong effects. For 12 VEs, the pattern reversed ($r_b = -0.59$), also reflecting a medium-to-large effect. This highlights that users' interaction behavior is strongly influenced by target visibility and preview size.

Looking at which targets were selected using *Direct Selection* (Figure 4) one can observe it depends on the visibility of the target in the preview. Visible targets have been primarily selected using

© 2026 IEEE. This is the author's version of the article that has been published in the proceedings of IEEE ISMAR conference. The final version of this record is available at: 10.1109/ISMAR67309.2025.00065

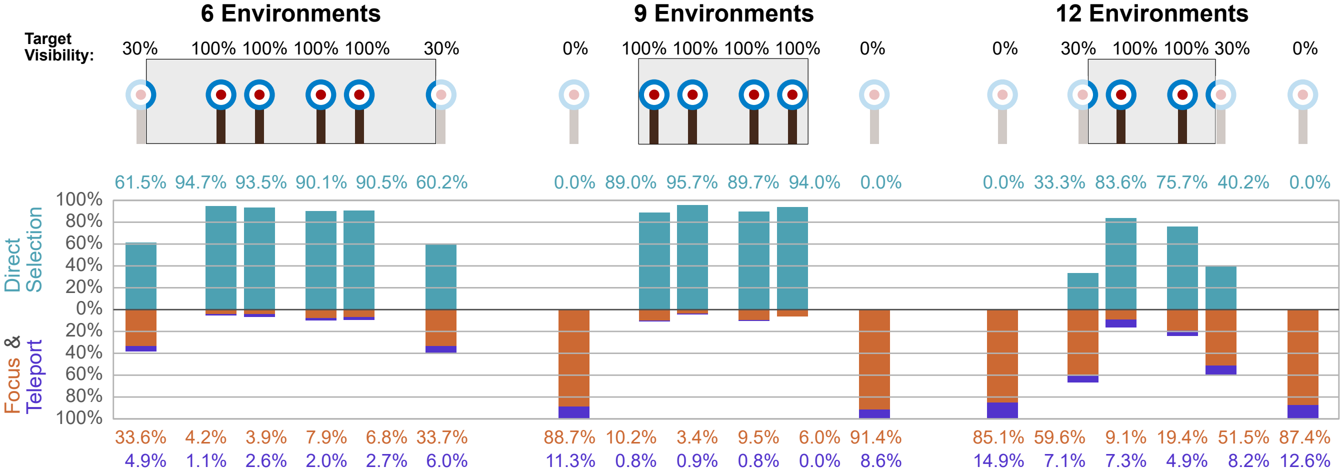

Figure 4: Target visibility and interaction choices in SLIVR for 6, 9, and 12 VEs. The top row illustrates how the visibility of the same six target positions changes depending on the number of VEs shown. The stacked bar charts below indicate which interaction method was used to successfully select each target. *Direct Selection* is contrasted against grouped indirect methods—*Focus-mode* and *Teleportation*.

Direct Selection in 88.1% of all cases. Meanwhile, partially visible targets (30%) were selected directly only in 51.5% of all cases. Since the number of partially visible and invisible targets increase with the NUMBER OF VES, the number of *Direct Selection* is reduced for more VEs. This correlates with the total number of selected targets, which decreased from 47.6 to 37.7 and 33.4.

While we expected *partially visible targets* (30%) sharing the same percentage in *Direct Selection* for all NUMBER OF VES this was not supported by our data. For 6 VEs 60.8% of partially visible targets were selected using *Direct Selection*. For 12 VEs this percentage dropped to 36.7%. This drop might be due to the change in the user's behavior. For 6VEs, most targets were selected directly (80.7%), whereas for 12 VEs, less than half were (40.2%). Hence, the primary interaction in a condition might have influenced the behavior for the partially visible targets. A similar effect can be observed for the two targets in the middle (±7.5°), which show a lower percentage of *Direct Selection* for the conditions with 12 VEs (≈ 80% compared to more than 90% for 6 and 9 VEs).

We further compared the participants' usages of the hub-based interactions (*Direct Selection* and *Focus-mode*) with the use of *Teleportation*. This revealed that 94.9% of all interactions in SLIVR were performed from inside the hub on the previews. Either using *Direct Selection* (62.8%) or a selection in *Focus-mode* (32.1%). *Focus-mode* was used over 6 times more frequently than *Teleportation* (5.2%). Only 6 of 18 participants (30%) used SLIVR's *Teleportation* at all during the study. This shows that in general participants preferred hub-based interactions for faster input over full immersion into the VEs. Although the usage was low, some participants heavily relied on *Teleportation*. Two participants used it consistently more often than *Focus-mode*. Two other participants used it only in one condition (SLIVR×12 and SLIVR×6) and the remaining two participants used it sporadically (1–2 selections per condition). Hence, *Teleportation* is important to ensure flexibility in the usage of SLIVR.

6.3 SUS and Ranking

We expected that our participants would prefer SLIVR over GRID (H4). Concerning the ranking, SLIVR received half of the first ranks across all HUBS and the least number of third ranks (11.1%), GRID achieved a lower number of first ranks (38.9%) and a much higher number of third places (30.0%). While SLIVR and GRID received a SUS score being in the *excellent* category (A–B), POLY was still evaluated as being *good* (B–C) [2]. The insignificant difference in SUS scores among the three concepts suggests that users' perceptions of usability were not significantly influenced by the arrangement of the previews or the introduction of the new interactions (*Direct Selection* and *Focus-mode*). This might be partially due to the simplicity of the task chosen for our study. Another possible explanation for the similar SUS scores could be that we included most of SLIVR's convenience features in GRID and POLY (e.g., live previews showing the target locations and highlighting of VEs with active targets inside). Comparing SLIVR to app launchers that only show static icons—which are used in most current VR-systems, e.g., SteamVR—and not live previews, might have led to greater differences in the perceived usability.

While these results suggest an overall preference for SLIVR over GRID, the lack of statistically significant differences in both the SUS scores and the rankings prevents us from fully confirming H4 based solely on the observed mean differences. As POLY was ranked lowest of these three options, that indicates participants only preferred the large previews in combination with *Direct Selection* and *Focus-mode* (as used in SLIVR).

6.4 Participant Feedback and Quotes

In the open feedback, participants stated that they liked SLIVR because "unnecessary change of environment was avoided" [P9] and "[direct] interaction allowed me to access the elements quickly [...and] to focus better" [P1]. They mentioned the "selection inside the previews is very good for simple tasks" [P13]. Some participants highlighted that GRID had the advantage of being "familiar" [P7] and that there was a "lower need for getting used to the system" [P11]. Another advantage participants saw in GRID was the "faster overview of all environments" [P2]. In comparison to GRID, SLIVR "felt more efficient [...] as you didn't have to align yourself a second time with the controller" [P15]. Instead of a full 360° preview arrangement in SLIVR and POLY, they suggested to use "the field of vision or up to 270°" [P15] and "only 120–180°, since that requires less movement" [P14]. Two participants stated that the HMD's cable played a significant role in the usability of SLIVR and POLY. They mentioned that "the cable interfered with rotations" [P9] and that "the cable was annoying" [P17]. A cable suspension from the ceiling (as mentioned by P17) or wireless headset might have increased the usability.

6.5 Hypotheses Summary

Our findings support H1 for conditions with 6 VEs, where SLIVR significantly outperformed both GRID and POLY. It was not supported for 9 and 12 VEs. H2 could not be confirmed, as POLY showed lower performance than GRID. H3 was supported: participants predominantly used *Direct Selection* over *Focus-mode* and *Teleportation*. H4 is partially supported, as SLIVR received the most first-place rankings, but no significant difference was found in SUS scores.

7 LIMITATIONS AND FUTURE WORK

Our future work falls into three main directions: (1) extending interaction complexity (e.g., object manipulation across VEs), (2) validating SLIVR in more dynamic, real-world environments (e.g., drone feeds or busy scenes), and (3) exploring alternative preview layouts and adaptive designs (e.g., spiral arrangements, gaze-driven resizing, or wireless deployment).

In this paper we compared the performance of the VR-Hubs based on a selection task, where the participants selected targets as fast and precisely as possible. We chose this task as a simplified proxy for multitasking in VR, since target selection is a fundamental building block of many real-world workflows, including directing robots, assigning tasks, or acknowledging alerts. In domains such as emergency response or industrial operations, such selections often trigger higher-level actions—making it a meaningful abstraction. However, typical VR applications require additional input, such as manipulation, navigation, and changing system settings [8]. Additionally, SLIVR could benefit from more multitasking interaction concepts (e.g. drag-and-drop across multiple VEs). Adding these could provide additional insights into concurrent task capabilities. Such advanced interaction concepts pose additional challenges to SLIVR's implementation - like more flexible and precise input modalities (e.g. gesture-based controls and haptic feedback). As task complexity increases, so does the need for clear visual cues and intuitive controls to prevent cognitive overload. Future iterations of SLIVR could explore context-sensitive interfaces that dynamically adjust to the user's intent, balancing multitasking efficiency with the flexibility required for complex interactions.

The targets used in our study were designed to be easy to identify and to stand out from the VEs. This might not be the case in more realistic scenarios, where targets can be occluded, ambiguous, or visually embedded in complex scenes. The chosen VEs cover a diverse set of environments, including indoor/outdoor scenes, different lighting, and color schemes. However, these scenes were static, their geometries rather simple, and the viewpoints were fixed. These simplifications allowed us to isolate interaction effects under controlled conditions, but they limit generalizability to more dynamic or cluttered environments. In real-world multitasking scenarios (e.g., emergency response or robot supervision), users may face additional cognitive demands and reduced visibility. Here, *Direct Selection* might become less effective, while *Focus-mode* or full immersion via *Teleportation* may gain importance. Moreover, performance might decrease across all hubs as users take more time to interpret scene content and identify task-relevant elements. To further improve ecological validity, future work should investigate how SLIVR supports multitasking in moving perspectives (e.g., drone feeds) and busy environments (e.g., cities) without visually overstimulating the user or reducing interaction efficiency. In most state-of-the-art applications and in SLIVR's VEs, users are teleported to predetermined entry points with a defined accessible view. For SLIVR's VEs, these points are selected to ensure a coherent transition from the preview to the VE. Therefore, the camera positions are configured to represent real, navigable locations. However, as the complexity of VEs increases, so too might the need for flexible teleportation points that adapt dynamically based on context.

While SUS provided a general usability assessment of the VR-Hub, future studies could benefit from using NASA-TLX or SSQ to more closely examine the temporal load and workload distribution associated with selection performance. This could offer insights into stress factors encountered during time-sensitive interactions within VEs.

Finally, while SLIVR advances multitasking in VR, the number of VEs is limited by the viewing angle of a regular polygon. Participants noted that the 360° layout required frequent head rotations, which may cause physical strain over longer usage periods. This highlights a trade-off between maximizing preview coverage and maintaining ergonomic comfort. Future work could explore more adaptive layouts that reduce physical demand while preserving overview—e.g., by limiting the horizontal range (e.g., 120–270°), or by dynamically resizing or prioritizing previews based on importance or gaze direction. Alternative preview arrangements, such as spirals or stacked layouts, may also improve accessibility and scalability in dense VE setups.

8 CONCLUSION

We introduced SLIVR, a 360° VR-Hub with *Direct Selection* capabilities and *Focus-mode* for multitasking in multiple VEs. We compared SLIVR to a conventional application launcher (GRID) and a variant of SLIVR without hub-based interactions (POLY). Our results show that users achieved the best performance using SLIVR, especially for the condition with 6 VEs. These performance improvements can be primarily attributed to the *Direct Selection* capabilities of SLIVR. Moreover, we observed that most participants preferred hub-based interaction on an enlarged 2D preview (*Focus-mode*) over *Teleportation* into the 3D environment for fast multitasking selections.

REFERENCES

[1] F. Argelaguet and C. Andujar. A survey of 3d object selection techniques for virtual environments. *Computers & Graphics*, 37(3):121–136, 2013. doi: 10.1016/j.cag.2012.12.003 3

[2] A. Bangor, P. Kortum, and J. Miller. Determining what individual sus scores mean: Adding an adjective rating scale. *Journal of usability studies*, 4(3):114–123, 2009. 7

[3] J. Brooke. Sus: a quick and dirty usability scale. *Usability evaluation in industry*, 189(3):189–194, 1996. 4, 5

[4] Y. F. Cheng, C. Gebhardt, and C. Holz. Interactionadapt: Interaction-driven workspace adaptation for situated virtual reality environments. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology*, UIST '23. Association for Computing Machinery, NY, USA, 2023. doi: 10.1145/3586183.3606717 2

[5] J. Cohen. *Statistical power analysis for the behavioral sciences (2nd ed.)*. routledge, 1988. doi: 10.4324/9780203771587 6

[6] R. Cools, A. Esteves, and A. L. Simeone. Blending spaces: Cross-reality interaction techniques for object transitions between distinct virtual and augmented realities. In *2022 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 528–537, 2022. doi: 10.1109/ISMAR55827.2022.00069 2

[7] L. Damiani, M. Demartini, G. Guizzi, R. Revetria, and F. Tonelli. Augmented and virtual reality applications in industrial systems: A qualitative review towards the industry 4.0 era. *IFAC-PapersOnLine*, 51(11):624–630, 2018. 16th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2018. doi: 10.1016/j.ifacol.2018.08.388 1

[8] R. Dörner, C. Geiger, L. Oppermann, V. Paelke, and S. Beckhaus. *Interaktionen in Virtuellen Welten*, pp. 219–265. Springer Berlin Heidelberg, Berlin, Heidelberg, 2019. doi: 10.1007/978-3-662-58861-1_6 8

[9] F. Faul, E. Erdfelder, A.-G. Lang, and A. Buchner. G* power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior research methods*, 39(2):175–191, 2007. 4

[10] N. Feld, P. Bimberg, B. Weyers, and D. Zielasko. Keep it simple? evaluation of transitions in virtual reality. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*, CHI EA '23. Association for Computing Machinery, New York, NY, USA, 2023. doi: 10.1145/3544549.3585811 1, 2

[11] A. Field. *Discovering Statistics using IBM SPSS Statistics*. Sage Publications Ltd., 4th ed., 2013. 6

[12] S. Freitag, D. Rausch, and T. Kuhlen. Reorientation in virtual environments using interactive portals. In *2014 IEEE Symposium on 3D User Interfaces (3DUI)*, pp. 119–122, 2014. doi: 10.1109/3DUI.2014.6798852 1, 2

[13] N. Ghodsian, K. Benfriha, A. Olabi, V. Gopinath, and A. Arnou. Mobile manipulators in industry 4.0: A review of developments for industrial applications. *Sensors*, 23(19), 2023. doi: 10.3390/s23198026 1

[14] M. Husung and E. Langbehn. Of portals and orbs: An evaluation of scene transition techniques for virtual reality. In *Proceedings of Mensch Und Computer 2019*, MuC '19, p. 245–254. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3340764.3340779 1, 2

[15] V. Interrante, B. Ries, J. Lindquist, M. Kaeding, and L. Anderson. Elucidating factors that can facilitate veridical spatial perception in immersive virtual environments. *Presence: Teleoper. Virtual Environ.*, 17(2):176–198, apr 2008. doi: 10.1162/pres.17.2.176 1

[16] Y. Iwasaki and H. Iwata. Ubiquitous body: Effect of spatial arrangement of task's view on managing multiple tasks. In *Proceedings of the Augmented Humans International Conference 2021*, AHs '21, p. 40–44. Association for Computing Machinery, New York, NY, USA, 2021. doi: 10.1145/3458709.3458935 2

[17] R. Kopper, F. Bacim, and D. A. Bowman. Rapid and accurate 3d selection by progressive refinement. In *2011 IEEE Symposium on 3D User Interfaces (3DUI)*, pp. 67–74, 2011. doi: 10.1109/3DUI.2011.5759219 1

[18] Z. Li, M. Annett, K. Hinckley, K. Singh, and D. Wigdor. Holodoc: Enabling mixed reality workspaces that harness physical and digital content. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI '19, p. 1–14. Association for Computing Machinery, New York, NY, USA, 2019. doi: 10.1145/3290605.3300917 2

[19] K. Linne, S. Thomas, and M. Weigel. Off-the-shelf: Exploring 3d arrangements of see-through masks to switch between virtual environments. In *Proceedings of the 30th ACM Symposium on Virtual Reality Software and Technology*, VRST '24. Association for Computing Machinery, New York, NY, USA, 2024. doi: 10.1145/3641825.3689501 2

[20] L. Lisle, K. Davidson, L. Pavanatto, I. A. Tahmid, C. North, and D. A. Bowman. Spaces to think: A comparison of small, large, and immersive displays for the sensemaking process. In *2023 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 1084–1093, 2023. doi: 10.1109/ISMAR59233.2023.00125 2

[21] J. Liu, A. Prouzeau, B. Ens, and T. Dwyer. Effects of display layout on spatial memory for immersive environments. *Proc. ACM Hum.-Comput. Interact.*, 6(ISS), Nov. 2022. doi: 10.1145/3567729 2

[22] L. Men, N. Bryan-Kinns, A. S. Hassard, and Z. Ma. The impact of transitions on user experience in virtual reality. In *IEEE Virtual Reality (VR)*, 2017. doi: 10.1109/VR.2017.7892288 1, 2

[23] S. Oberdörfer, M. Fischbach, and M. E. Latoschik. Effects of ve transition techniques on presence, illusion of virtual body ownership, efficiency, and naturalness. In *Proceedings of the 2018 ACM Symposium on Spatial User Interaction*, SUI '18, p. 89–99. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3267782.3267787 1, 2

[24] L. Pavanatto, F. Lu, C. North, and D. A. Bowman. Multiple monitors or single canvas? evaluating window management and layout strategies on virtual displays. *IEEE Transactions on Visualization and Computer Graphics*, pp. 1–15, 2024. doi: 10.1109/TVCG.2024.3368930 1, 2

[25] L. Pavanatto, C. North, D. A. Bowman, C. Badea, and R. Stoakley. Do we still need physical monitors? an evaluation of the usability of ar virtual monitors for productivity work. In *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*, pp. 759–767, 2021. doi: 10.1109/VR50410.2021.00103 1, 2

[26] H. Pohl, K. Lilija, J. McIntosh, and K. Hornbæk. Poros: Configurable proxies for distant interactions in vr. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, CHI '21. Association for Computing Machinery, New York, NY, USA, 2021. doi: 10.1145/3411764.3445685 1, 2, 3

[27] M. Y. Saraiji, S. Sugimoto, C. L. Fernando, K. Minamizawa, and S. Tachi. Layered telepresence: Simultaneous multi presence experience using eye gaze based perceptual awareness blending. In *ACM SIGGRAPH 2016 Posters*, SIGGRAPH '16. Association for Computing Machinery, New York, NY, USA, 2016. doi: 10.1145/2945078.2945098 2

[28] K. A. Satriadi, B. Ens, M. Cordeil, T. Czauderna, and B. Jenny. Maps around me: 3d multiview layouts in immersive spaces. *Proc. ACM Hum.-Comput. Interact.*, 4(ISS), Nov. 2020. doi: 10.1145/3427329 2

[29] J. Schjerlund, K. Hornbæk, and J. Bergström. Ovrlap: Perceiving multiple locations simultaneously to improve interaction in vr. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI '22. Association for Computing Machinery, New York, NY, USA, 2022. doi: 10.1145/3491102.3501873 2

[30] M. Waldner, M. Steinberger, R. Grasset, and D. Schmalstieg. Importance-driven compositing window management. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '11, p. 959–968. Association for Computing Machinery, New York, NY, USA, 2011. doi: 10.1145/1978942.1979085 2

[31] C.-H. Wang, B.-Y. Chen, and L. Chan. Realitylens: A user interface for blending customized physical world view into virtual reality. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology*, UIST '22. Association for Computing Machinery, New York, NY, USA, 2022. doi: 10.1145/3526113.3545686 2

[32] C.-H. Wang, C.-E. Tsai, S. Yong, and L. Chan. Slice of light: Transparent and integrative transition among realities in a multi-hmd-user environment. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, UIST '20, p. 805–817. Association for Computing Machinery, New York, NY, USA, 2020. doi: 10.1145/3379337.3415868 2

[33] L. Wang, H. Zhao, Z. Wang, J. Wu, B. Li, Z. He, and V. Popescu. Occlusion management in vr: A comparative study. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 708–716, 2019. doi: 10.1109/VR.2019.8798025 2