AR Widgets: Exploring Placement Strategies for Persistent Widgets for Augmented Reality

STEFANIE ZOLLMANN, Aarhus University, Denmark
TOBIAS LANGLOTZ, Aarhus University, Denmark
DANIEL WAGNER, Snap Inc., Austria
PAVEL MANAKHOV, Lancaster University, United Kingdom
WEI HONG LO, University of Otago, NZ

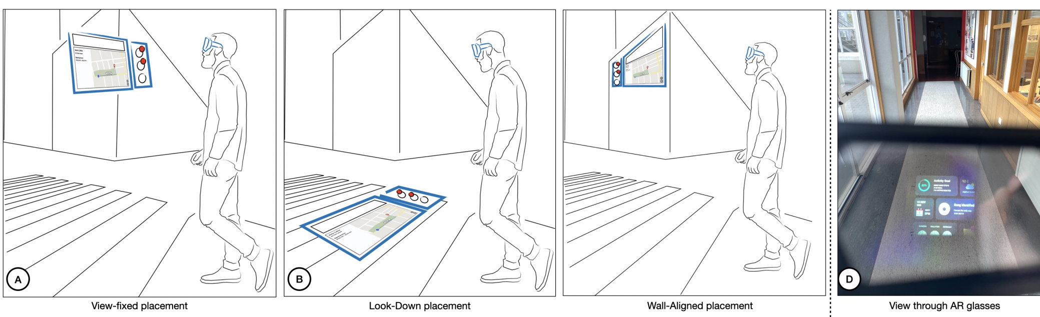

Fig. 1. AR Widgets placement strategies for AR glasses. A) View-Fixed placement: AR Widgets are displayed as a head-anchored overlay in the upper part of the user's field of view (FoV). B) Look-Down placement: AR Widgets are placed on the ground in front of the user when looking downwards. They are fixed in world coordinates but repositioned once the user passes them. C) Wall-Aligned placement: AR Widgets are attached and aligned to the physical wall in front of the user. Similar to the Look-Down strategy, the widgets are fixed to the physical world and repositioned when leaving the user's FoV. D) View as captured through the AR glasses using the Look-Down placement.

Future lightweight smartglasses will enable a continuous augmentation of the user's view with digital information. However, the effective integration of persistent overlays in Augmented Reality (AR) remains insufficiently understood. Where should frequently accessed persistent information, like widgets and information panels that do not refer directly to objects in the environment, be displayed in the user's view? In this work, we explore placement strategies for "AR Widgets" that, similar to traditional information widgets, should be easy to access. We propose two novel environment-aware placement strategies that dynamically reposition world-referenced widgets, and compare them to a more traditional view-fixed placement method with a user study (n=18) across sitting and walking usage scenarios. Our findings indicate that the choice of widget placement strategy impacts user experience, distraction, placement, and clear-view ratings, with the wall-aligned method scoring the highest.

Authors' Contact Information: Stefanie Zollmann, Aarhus University, Aarhus, Denmark, stefanie.zollmann@cs.au.dk; Tobias Langlotz, Aarhus University, Aarhus, Denmark, tobias.langlotz@cs.au.dk; Daniel Wagner, Snap Inc., Vienna, Austria; Pavel Manakhov, Lancaster University, Lancaster, United Kingdom, p.manakhov@lancaster.ac.uk; Wei Hong Lo, University of Otago, Dunedin, NZ.

MobileHCI '26, Swansea, United Kingdom

ACM ISBN 978-x-xxxx-xxxx-x/YYYY/MM
https://doi.org/10.1145/3821712

CCS Concepts: • **Human-centered computing → Interaction techniques**; **Empirical studies in HCI**; **Mixed / augmented reality**.

Additional Key Words and Phrases: Augmented Reality, View Management, Pervasive Augmented Reality, Smart Glasses, UI Placement, Continuous Augmentation

ACM Reference Format:
Stefanie Zollmann, Tobias Langlotz, Daniel Wagner, Pavel Manakhov, and Wei Hong Lo. 2026. AR Widgets: Exploring Placement Strategies for Persistent Widgets for Augmented Reality. In *Proceedings of the 28th International Conference on Mobile Human-Computer Interaction (MobileHCI '26).* ACM, New York, NY, USA, Article MHCI9650, 22 pages. https://doi.org/10.1145/3821712

1 Introduction

Smartglasses or head-mounted displays (HMDs) with an Augmented Reality (AR) interface are often predicted to be the next evolution of mobile and wearable computing [20]. While current products mainly address early adopters and professional use cases, future AR glasses are expected to become smaller, support a broader range of applications, and appeal to a wider audience. Designed for everyday use, they may deliver timely, context-relevant information, much of which is currently accessed via smartphones or smartwatches, without requiring explicit user interaction. Enabled by advanced sensing capabilities, future AR glasses are envisioned to automatically adapt to the user's context, providing a continuous and omnipresent information overlay [20, 28].

When adapting the information presentation in AR glasses for continuous use, it needs to be considered what to present and when (information filtering), how to present it (appearance), but also where to spatially present the information (information placement). Early research primarily focused on AR label placement, aiming to optimize readability, maintain proximity to referenced physical objects, and avoid occluding important real-world information [13, 18, 26, 28]. More recent work has expanded beyond labels to explore adaptive placement and appearance based on the user's current task and cognitive load [33], automatic placement guided by semantic relationships between virtual and physical objects [10], and user preferences for placing digital documents in collaborative AR tasks [38]. However, there is only little work on how persistent digital information should be spatially placed, in particular, if it does not relate to the surrounding environment (e.g., information panels such as weather, music players, or activity information).

The mobility of AR glasses adds further complexity, motivating the exploration of diverse strategies for placing virtual information. Current approaches include anchoring content to body parts such as the hands, forearms, or torso to maintain stable relative positioning during movement [29, 45, 57], as well as head-referenced placements where information is persistently visible or is summoned into the field of view on demand [15, 36]. Other techniques align virtual content with the user's direction of movement [27, 40]. The central challenge in these mobile contexts is presenting *persistent information* that remains quickly accessible without distracting users from their primary task of navigation and movement.

In our work, we investigate placement strategies for this type of information, which we call **AR Widgets** in reference to traditional 2D widgets [54]. On 2D screens, such as laptops, mobile phones or smartwatches (Figure 1a), this type of information is typically shown persistently in fixed screen locations or accessed via specific gestures. In AR glasses, however, naively placing widgets in mid-air without considering user context may occlude real-world obstacles or cause information to be left behind as users move. Requiring gestures can be challenging in mobile, active scenarios, for instance, when walking or jogging while monitoring events, such as activity tracking, messages, or calendar events, via widgets. In some other situations, users might not feel comfortable with mid-air gestures due to social acceptance [1].

The two placement strategies proposed in this paper follow the principle of being *dynamically relocated in the world*: widgets are anchored in world coordinates but are automatically repositioned when certain conditions are met, for example, leaving the field of view (FoV). Early examples of this principle can be traced back to work by Mann and Fung [41], who proposed aligning virtual reminders with physical billboards in outdoor environments. Building on this idea, we explore two conceptually distinct dynamically relocated world-based strategies. The design we refer to as LOOK-DOWN places information on the first horizontal surface found in the downward direction in regard to the user's head, such as a work desk or floor (Figure 1c), so that the user would always find the widgets by simply tilting their head down. Conversely, the WALL-ALIGNED design leverages vertical surfaces and places widgets closer to the user's FoV center (Figure 1d).

We compare the proposed strategies against a commonly used placement where widgets are affixed relative to the user's head, which we refer to as VIEW-FIXED (Figure 1b), in different usage scenarios, i.e., being in a mobile and dynamic context, such as walking inside a building [27], but also working in a stationary context (e.g., an office environment). Our results indicate that 1) widget placement strategies score differently with regard to user experience, with the WALL-ALIGNED method outperforming the others, 2) the usability scores differ between walking and seated conditions, and 3) the placement method has an effect on user distraction, with ratings of placement and ratings of a clear view with the VIEW-FIXED method scoring the lowest.

To summarize, this work contributes: (1) two dynamically relocated world-based placement designs for persistent virtual information in AR and (2) empirical insights from a user study comparing these designs to a conventional view-fixed placement.

2 Related Work

There is a large body of work in the field of AR focusing on where and how to place content. One can generally distinguish between content that has either a *high* or a *low dependence* on the physical environment and content that is either *persistent* and, as such, needs to be permanently visible or *non-persistent* when it is only briefly visible.

Labels - high physical dependence. AR Labels are usually highly dependent on the physical environment as they directly refer to physical objects. The seminal work by Bell et al. introduced spatial constraints to label placement to avoid occlusion issues and also coined the term view management for this problem [4]. This work triggered many other works on view management or related issues, including those that use filtering or clustering techniques to optimize the AR view [2, 26], use gaze data [16, 47], real-world scene appearance [13, 18], or 3D scene analysis with the goal of aligning labels with real-world scene elements [28, 43, 58]. All these works focus on the placement of content that references real-world objects (also referred to as physical referents [56]). Thus, they should ideally be placed close to the object they refer to, and for most scenarios they are persistent to support the user during search tasks, even though some approaches also use non-persistent labels, e.g. by filtering them [26].

Notifications - low physical dependence, non-persistent. There are many cases in which the overlaid information is not directly related to the physical environment (low dependence on the physical environment) [38]. Prior research on information placement with a low physical dependence focused mainly on notifications, which are usually non-persistent as they appear and usually stay only briefly before they disappear, providing again an unobstructed view into the physical environment. Tanaka et al. proposed an information layout system that analyses image information from an external camera and combines this with predefined restrictions to improve the readability of incoming news notifications [53]. Lee et al. investigated notification placement in walking scenarios using different coordinate systems (display-fixed vs. body-fixed) and presentation styles (text or icons). They found body-fixed text to support better walking performance and comprehension, while icon-type notifications were more effective when display-fixed [30]. However, placement was usually at head height, making social interactions challenging, even though this was not explored in this paper, but shown by Rzayev et al. [49]. There also exist multiple other works exploring notifications in different settings: notification placement in a card game context [48], interacting with notifications while walking [37], or peripheral notifications to avoid occluding important information [9]. However, because of their non-persistence, notifications are often not visible, making them easier to hide when their position needs to be updated, while generally being less obstructive.

Widgets - low physical dependence, persistent. While there is a lot of research on notifications, there is another type of user interface (UI) element that is of high relevance in mobile and stationary computing: widgets. Widgets provide continuously updated information at a glance without requiring users to open a full application [54]. In AR, these properties suggest that widgets could serve as an effective method for delivering persistent and accessible information in everyday contexts [34]. Grubert et al. demonstrated the feasibility of using widgets during interactions with physical displays [19]. However, there is limited research on the broader spatial integration of widgets in AR. This stands in contrast to gaming and VR applications, where the integration of UI elements such as widgets has been extensively studied [22, 23, 46, 50]. Here, designers have developed strategies to balance immersion and usability by using diegetic elements integrated into the game world (e.g., a character's wrist-mounted map) and non-diegetic overlays that sit outside the narrative space (e.g., health bars or mission objectives in the heads-up display) [46]. However, it is unclear whether the findings from gaming and VR would directly apply to how widgets are placed in continuous AR use.

This is the focus of our work, which explores placement strategies in AR for widgets: persistent information with a low or no dependency on the physical environment. There are already a few works on widgets or similar information with a low physical dependence. However, they focus mainly on appearance rather than spatial placement [11, 33]. Other works focus on the placement of documents [32, 38], in-situ visual analytics [14], photographs [7] and video call UI elements [25]. Most of these works are in indoor or office environments, which is reflected in the users' preferences, e.g. participants used existing furniture as orientation aids [38]. However, this requires either manual alignment or a complex 3D understanding, both being challenging, particularly in constantly changing environments. Cheng et al. addressed this by using an optimization-based approach for automatically adapting mixed reality (MR) interfaces to different physical environments once they are configured for one space [10]. However, their work focuses again on stationary office scenarios and does not explore a constantly changing environment (e.g. walking).

Lu et al. introduced the concept of *Glanceable AR*, in which virtual information is either fixed to the user's head or appears at the periphery of their display to support rapid, low-effort access [34, 36]. While their research focused on methods of information activation rather than spatial placement, they found that an "always-on" display, visible at all times, was the most preferred by users, though many participants reported that having the content in a fixed position could become distracting or obstructive over time. Davari et al. extended the concept of Glancable AR by combining it with face recognition to provide context awareness and to avoid information panels being rendered on top of a person [12], which aligns with findings from earlier research by Hoellerer et al. [21] and Orlosky et al. [44].

In this work, we explore placement strategies based on the principle of *dynamic relocation in the world*, which involves instantiating UIs in world coordinates, i.e., stationary relative to the environment, and repositioning them as the user moves through it. One of the earliest placement

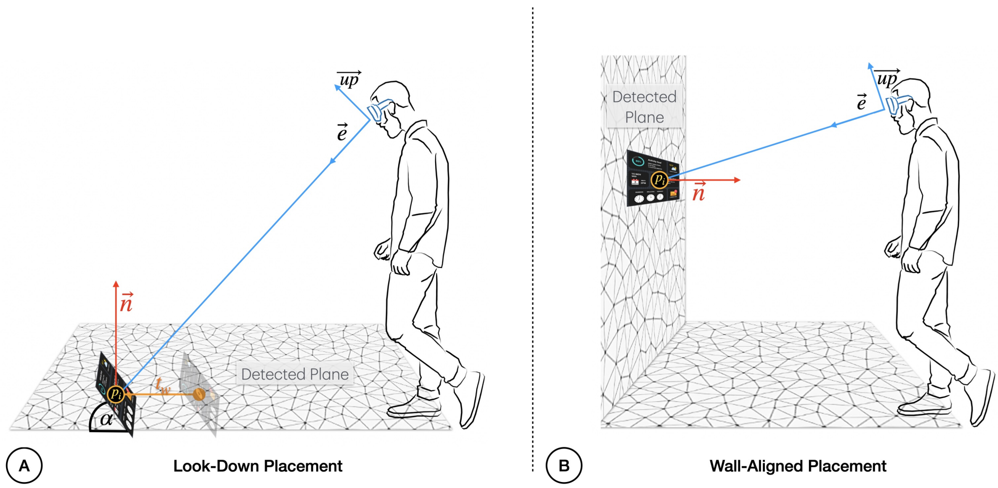

Fig. 2. Concept of the placement techniques. A) Look-Down placement: When the user looks down towards the ground, a ray ($\vec{e}$) is cast from the middle of the headset into the 3D mesh of the environment and an intersection point is computed. If the normal ($\vec{n}$) of the intersection point is vertical and the intersection point (p_i) is not further than d_{max} and not closer than d_{min}, an AR Widget is placed at that intersection point and rotated by angle α to face the user. B) Wall-Aligned placement: When the user looks forward, a ray from the middle of the AR glasses ($\vec{e}$) is cast into the 3D representation of the environment (detected plane), and the intersection point (p_i) is computed. If the normal ($\vec{n}$) of the intersection point is horizontal and the intersection point is not further than d_{max} and not closer than d_{min}, an AR Widget is placed at that intersection point and aligned to the intersection plane.

designs following this principle was proposed by Mann and Fung [41], who positioned virtual reminders to coincide with physical billboards found outdoors. Beyond surface detection, such an approach requires automatic identification of object types in order to distinguish billboard surfaces from other environmental surfaces.

Prior work has also explored approaches that "bring the UI with the user," such as head-referenced placements [8, 15, 39, 40] or placements aligned with the user's movement direction [27, 40]. While these techniques are well-suited for persistent information, they keep the UI visually attached to the user. By contrast, dynamically relocated UIs remain embedded in the environment, blending with it and avoiding occlusion, without requiring an explicit linkage to environmental objects. In addition, unlike hand-fixed UIs [29, 45], they do not require manual gestures to bring the UI into view. In this work, we investigate two novel strategies that dynamically reposition AR widgets either directly in front of the walking user (Look-Down) or on the surrounding walls (Wall-Aligned).

3 Placement Strategies for AR Widgets

In this work, we focus on exploring different placement strategies for persistent AR content, which itself has low dependence on the physical environment. We propose two novel strategies — Look-Down and Wall-Aligned — which dynamically reposition widgets in two principally different ways during walking and sitting. We compare these strategies against an existing View-Fixed baseline. We detail the designs of all three strategies below.

3.1 Look-Down Placement

In the Look-Down strategy, widgets are automatically placed only near horizontal surfaces. Placement occurs when the user tilts their head more than 45 degrees below the horizon line, and a ray representing the head's pointing direction intersects a horizontal surface (Figure 2a). The placement method relies on the head-mounted display's integrated plane detection, which provides estimates of dominant planar surfaces such as floors and walls. On Snap Spectacles (2021), this functionality is handled by the device's built-in spatial understanding pipeline; however, the placement logic itself is independent of the underlying detection algorithm and can be implemented using alternative approaches (e.g., depth sensing, SLAM-based plane fitting, or semantic scene understanding) on other AR platforms such as Meta Quest.

The system instantiates the UI along this ray such that (a) the UI faces the user to improve legibility by aligning the UI element's normal with the viewing direction and (b) is positioned at a height above the horizontal surface so that the tilted UI rests just above the surface without overlapping it.

Importantly, the UI is instantiated in world coordinates, meaning that it does not change its position relative to the environment. At the same time, the UI dynamically rotates to always face the user, which is also known as billboarding behavior [42], and scales to maintain its apparent size regardless of the user's distance [5]. When displaying multiple widgets, the system places them in a cluster centered on the head-pointing direction from the user's standpoint, arranged on a plane that faces the user. The system maintains this placement until the user passes by the UI or the UI leaves the user's FoV. This is implemented by a predefined threshold, testing how far away the user moved from the last location where a placement happened.

The behavior of the described placement strategy is designed to support a simple mental model: users see the interface, stabilized in world coordinates, whenever they look down (hence, the name). When sitting at a desk, this results in widgets being placed closer to the near edge of the desk. Due to the additional threshold, widgets remain in the same position even when they briefly leave the glasses' FoV. When walking, looking down instantiates a world-fixed, user-facing set of widgets that users can quickly glance at to access necessary information. The world-fixed nature of widgets during mobility helps enhance the readability of information [40].

3.2 Wall-Aligned Placement

In the Wall-Aligned strategy, the UI is dynamically placed only on vertical surfaces. The initial placement occurs when a ray representing the head's pointing direction intersects a vertical surface large enough to accommodate the UI (Figure 2b). Vertical surfaces are again computed by using the smartglasses' plane detection methods. The UI is instantiated in world coordinates at the intersection point and rotated to align with the surface. The UI's roll always coincides with the world's up direction. By using the same orientation as the real-world surfaces, we make sure that the user finds it easier to relate the AR Widget to the real-world structure (this is inspired by the findings by Luo et al. [38] recommending attaching virtual documents to real-world furniture). To prevent the UI from extending beyond the surface boundaries, it is instantiated at least half the UI's width away from the vertical edges of the surface and at least half the UI's height away from the horizontal edges. The placement is maintained until the UI leaves the user's FoV, with an additional threshold beyond it. Similar to the Look-Down strategy, the UI is scaled to maintain a constant angular size. It is important to note that, in contrast to the Look-Down strategy, where ground planes will always be available, there might be situations where no suitable vertical structures can be found, making Wall-Aligned more suitable for indoor spaces.

The behavior of this placement strategy aims to create an "at-a-wall-in-front-of-me" mental model, which, when sitting at a desk, results in widgets being placed on the wall behind the desk, regardless of whether it is directly adjacent to the desk. During walking, widgets are placed on the wall in front of the user or on side walls. Similar to the Look-Down strategy, this allows users to quickly read information by keeping the widgets within their FoV before looking ahead.

3.3 View-Fixed Placement

The View-Fixed placement strategy is well known and has been widely adopted [8, 36, 39, 40]. It involves affixing the interface within the user's FoV. In our implementation, the interface is positioned in the upper central region of the glasses' FoV at a distance of 5 m from the user's head. The behavior when displaying multiple widgets is identical to that of the previous strategies. The premise of this placement is that information is readily available and always just a glance away.

4 User Study

To explore which placement methods are suitable for placing AR Widgets in the users' view for continuous AR usage, we designed a user study. Inspired by findings from previous work on user experience [30] and on usability [34], we were interested in answering the following research questions: (RQ1) Which placement strategy provides the best user experience? (RQ2) Which placement strategy provides the best usability? (RQ3) How do users rate the strategies in terms of distraction, placement and familiarity? Based on these questions, we formulated the following hypotheses:

H1: User Experience: User experience will be higher for Look-Down and Wall-Aligned compared to View-Fixed.

H2: Usability: Usability will be higher for Look-Down and Wall-Aligned compared to View-Fixed.

H3: Distraction and Clear View: Users will rate Look-Down and Wall-Aligned better than View-Fixed with regard to distraction and clear view.

H4: Placement: Users will rate the placement for Look-Down and Wall-Aligned better than View-Fixed.

H5: Familiarity and Unusualness: Users will report lower familiarity and higher perceived unusualness of the AR Widgets for conditions Look-Down and Wall-Aligned compared to View-Fixed.

The study was approved by the ethical board of the University of Otago (ID D23/338).

4.1 Study Design

We designed two scenarios with different primary tasks. In the first scenario, participants remained seated in a room and were tasked with assembling a small Lego Christmas ornament. The task was designed to require some mental demand. Participants were provided with 3 minutes to do as much as they could, but we emphasized that the results of the Lego building were not taken into consideration for this study to prevent participants from feeling stressed. The second scenario involved a more dynamic task where participants navigated an office building environment to locate specific rooms identified by the room numbers. This tested their ability to integrate and navigate around while having augmentations on the AR glasses. Participants experienced the scenarios in counter-balanced order to mitigate sequence effects.

For each scenario, we used three conditions — View-Fixed, Look-Down, and Wall-Aligned — whose order was also counter-balanced. Participants were asked two questions at approximately the 1:00 and 2:00 minutes marks into the experience. These questions were basic questions, such as

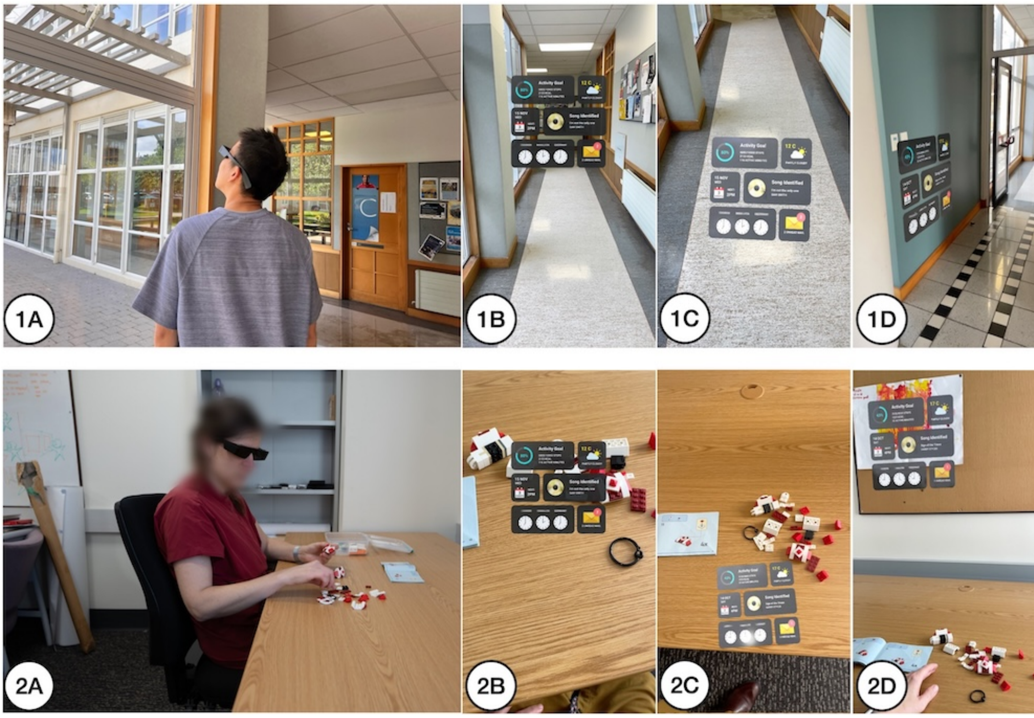

Fig. 3. Experimental Setup in User Study. 1A) Dynamic Scenario: A participant wearing AR glasses is searching for a room in a building. 1B) View-Fixed placement. 1C) Look-Down placement. 1D) Wall-Aligned placement. 2A) Stationary scenario: Participant is building Lego blocks according to a manual while being asked about information from the AR Widgets. 2B) View-Fixed placement. 2C) Look-Down placement. 2D) Wall-Aligned placement.

"How many active minutes have been done today?" with answers displayed in the AR Widgets. All participants were able to answer all questions correctly. The data displayed in the AR Widgets was also designed to be different for each condition to minimize the learning effect. After each condition, they were presented with the short version of the User Experience Questionnaire (UEQ-S) [52] and the System Usability Scale (SUS) questionnaire [31] to evaluate the user experience as well as usability.

We also designed a set of additional questions based on a suitable subset of the plausibility questionnaire (subgroup external plausibility focusing on familiarity) [55] and inspired by questions from the Augmented Reality Immersion (ARI) questionnaire [17], we asked about distractions, placement, and view obstruction. These additional rankings all used a 7-point Likert scale.

In total, all participants experienced three conditions in two different scenarios (2x3 trials). Upon completing the final conditions, participants were given one more questionnaire comprising of their preferences and comments.

4.2 Apparatus and Implementation Details

For the study, we used Snap Spectacles 2021 AR glasses[1] with a 480 x 564 display resolution, a 26.3 diagonal FOV, and a refresh rate of 30-120 Hz. We chose this model due to its lightweight form factor (weight: 134g) and being able to run AR Widgets standalone on-device.

We implemented the AR Widget placement techniques using Lens Studio v4.28 and deployed as "lenses" (equivalent to applications) on the device. For both the Look-Down and Wall-Aligned placement strategies, we leveraged the plane detection capabilities of Snap Spectacles. Detected planes were classified as horizontal or vertical using a tolerance of 21° in world coordinates, preventing slightly inclined surfaces from being excluded by the placement algorithms. To avoid positioning widgets too close to the user, placement distance was constrained to 0.5–5 m from the head in the Look-Down condition and to 0.9–5 m in the Wall-Aligned condition.

Widget scaling was handled adaptively to ensure a consistent apparent size. Specifically, we defined a reference distance $d_{ref} = 0.5\,\text{m}$ and computed the scale factor as $s = \frac{d_{cam}}{d_{ref}}$, where d_{cam} denotes the distance between the widget and the camera. This adaptive scaling ensured that AR widgets maintained a similar size in screen space regardless of their placement distance, resulting in identical widget sizes across all experimental conditions.

The experiments were conducted in a hallway indoors (Figure 3, 1A) and in an office environment (Figure 3, 2A). The hallway was a U-shaped corridor that was cleared of obstacles to provide a safe walking area. The office space was configured with a desk and a chair. Before each session, the AR glasses were cleaned and checked to ensure comfort for each participant.

4.3 Participants

We recruited 18 participants (12 male, 6 female; mean age = 27.72 ± 9.45 years, ranging from 18-56; 7 had previous AR experience) through advertisements and word of mouth for this study. The exclusion criteria were lack of English proficiency and the use of prescription glasses, as participants were asked to wear Snap Inc.'s Spectacles AR glasses. The study, with a duration of 45 minutes, was conducted in and around an office building foyer. Participants received a voucher ($20) as a token of appreciation for their time. We excluded the results of one participant due to multiple ratings entered into the questionnaire[2], and replaced this participant to maintain a final sample size of 18. This sample size is in line with those used in similar AR and mixed reality studies, such as [34], [33], and [35].

4.4 Procedure

Participants were handed an information sheet and a consent form before participating. Upon agreeing to participate, individuals were briefed on the project's objectives and procedures. This briefing included detailed explanations of the tasks and the questionnaires. Before the start of the experience, participants received an introduction to the hardware. After the introduction, participants were presented with a demographic questionnaire.

Participants then experienced the three placement conditions in predetermined order (Balanced Latin Square). They were interrupted by the researcher at the 1-minute and 2-minute marks of their scenario and were asked questions regarding the information shown in the AR glasses. Upon completion of each condition, the participants are given a questionnaire to fill in before the next condition starts.

[1] https://newsroom.snap.com/introducing-the-next-generation-of-spectacles

[2] The issue was discovered when transferring the data for data analysis.

Table 1. Descriptive statistics (*M* and *SD*) for UEQ-S across placement strategies and scenarios. Benchmark categories and color coding follow Schrepp et al. [51].

Scenario	VIEW-FIXED		LOOK-DOWN		WALL-ALIGNED	
	M	*SD*	*M*	*SD*	*M*	*SD*
Sitting	0.38 (bad)	1.41	0.75 (below avg.)	1.06	1.31 (good)	0.96
Walking	0.44 (bad)	1.36	0.59 (bad)	1.27	1.06 (above avg.)	1.26

5 Results

We used R Studio with the `rstatix`, `ez`, `emmeans`, and `ART` packages to analyze the results. Analyzing the preferences of participants, we found that 44.4% preferred LOOK-DOWN and 55% preferred WALL-ALIGNED. None of the participants preferred VIEW-FIXED. In their comments, participants highlighted that VIEW-FIXED widgets were the most distracting, especially while walking, being "distracting and blurry when moving" (P10), "blocking vision" (P9), and "too close and jittery"(P17). LOOK-DOWN was appreciated for requiring "less work" (P9), "providing more control" (P11) and "not blocking the field of view" (P17), though some found it "harder to find" (P18). WALL-ALIGNED was seen as "least obstructive" (P15), "less distractive" [sic] (P6) and well-integrated into the environment, yet criticized for unpredictability and the need to move physically to access content. Overall, participants found AR Widgets promising for short, hands-free tasks, like navigation or video calls.

5.1 User Experience (UEQ-S)

The analysis of the overall UEQ-S[3] (Table 1) showed that mean scores in the "Sitting" scenario were *bad* ($M = 0.38$) for VIEW-FIXED, *below average* ($M = 0.75$) for LOOK-DOWN, and *good* ($M = 1.31$) for WALL-ALIGNED. The "Walking" scenario had mean scores of *bad* ($M = 0.44$) for VIEW-FIXED, *bad* ($M = 0.59$) for LOOK-DOWN, and *above average* ($M = 1.06$) for WALL-ALIGNED. The Shapiro-Wilk test on the data indicated that the data does not significantly deviate from normality across all groups ($p > 0.05$).

We used a two-way repeated measures ANOVA. It revealed a significant main effect of *Placement* on the dependent variable ($F_{2,34} = 10.81$, $p < 0.001$), and a generalized eta-squared of ges = 0.068, indicating a small to medium effect size. In contrast, the main effect of *Scenario* was not statistically significant ($F_{1,17} = 0.29$, $p = 0.59$, and was associated with a negligible effect size ges = 0.0024), suggesting that *Scenario* alone does not have a substantial impact on the user experience. The interaction *Placement* × *Scenario* was also non-significant ($F_{2,34} = 0.92$, $p = 0.409$, with a similarly negligible effect size ges = 0.0028) indicating that the effect of placement was consistent across sitting and walking conditions.

To further explore significant effects of *Placement*, we conducted pairwise comparisons using the estimated marginal means (EMMeans) derived from the repeated-measures ANOVA model. This approach accounts for the within-subjects structure of the data and ensures that comparisons are consistent with the overall model, rather than based solely on raw means. Please note, degrees of freedom are reported using the Kenward-Roger approximation.

[3]Please note: to avoid cluttering the paper, further analysis of the UEQ-S subscales is available in an appendix that can be found in the supplementary materials.

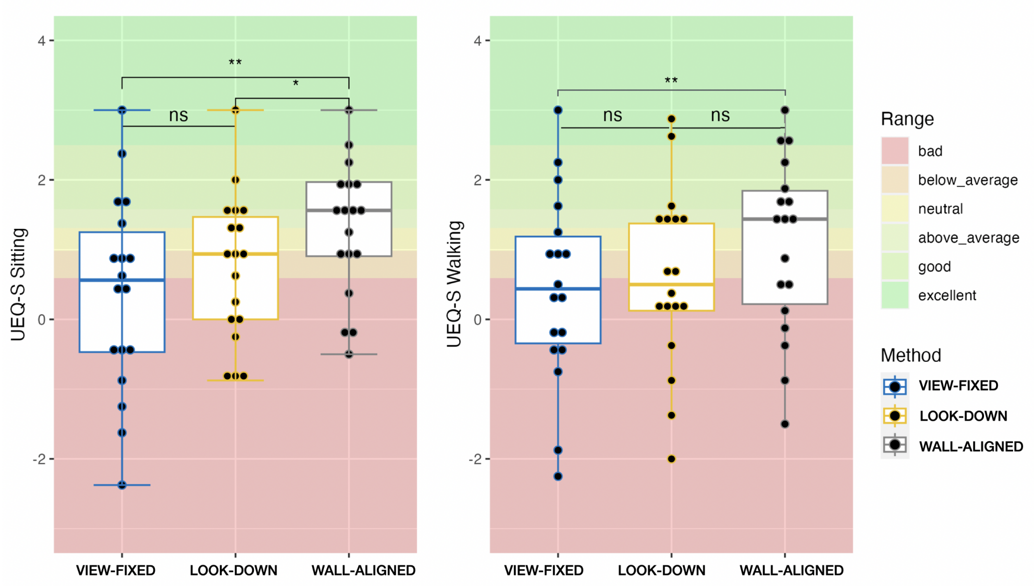

Fig. 4. UEQ-S results for both scenarios. Left) UEQ-S results for the sitting scenario. Right) UEQ-S results for the walking scenario. Significant differences are highlighted with either * ($p < 0.05$) or **($p < 0.01$). We use the benchmarking categories and colour coding for the UEQ as described by Schrepp et al. [51].

The pairwise comparisons (using Tukey correction for multiple testing) revealed significant differences between specific conditions within each scenario. For *Sitting*, significant differences were found between View-Fixed and Wall-Aligned ($t(59.9) = -4.52$, $p = 0.0001$) and between Look-Down and Wall-Aligned ($t(59.9) = -2.73$, $p = 0.0222$). However, the difference between View-Fixed and Look-Down was not significant ($t(59.9) = -1.79$, $p = 0.1826$). For *Walking*, significant differences were observed between View-Fixedand Wall-Aligned ($t(59.9) = -3.03$, $p = 0.0098$), while no significant differences were found between View-Fixed and Look-Down ($t(59.9) = -0.74$, $p = 0.7397$) and between Look-Down and Wall-Aligned ($t(59.9) = -2.29$, $p = 0.0645$).

Effect sizes for pairwise comparisons are reported as Cohen's d_z. Across conditions, Wall-Aligned showed consistently large advantages over View-Fixed in both Sitting ($d_z = 1.07$) and Walking ($d_z = 0.72$). Comparisons between Wall-Aligned and Look-Down yielded medium effects in Sitting ($d_z = 0.64$) and Walking ($d_z = 0.54$), while differences between ViewFixed and LookDown were small to negligible in Sitting ($d_z = 0.42$) and Walking ($d_z = 0.17$).

Overall, these results suggest that *Placement* variable has a meaningful impact on the overall UEQ-S score, particularly in relation to Wall-Aligned across both scenarios, while the *Scenario* variable itself does not significantly influence the outcomes. Wall-Aligned showed the highest UEQ-S score in both scenarios (Figure 4).

5.2 System Usability Scale (SUS)

The SUS scores are within the "good" range for the *Sitting* scenario and within the "OK" range for the *Walking* scenario for all three placement conditions (Table 2). We used the 7-point adjective scale as proposed by Bangor et al. [3] for the descriptive interpretation (Figure 5). The Shapiro-Wilk test

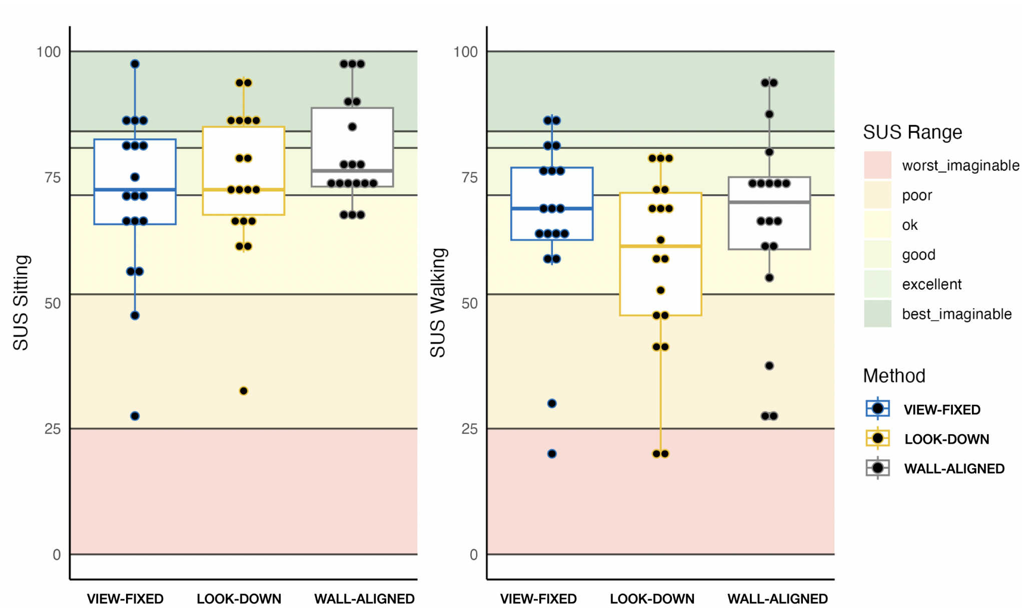

Fig. 5. SUS results for the Sitting and the Walking scenarios. We did not find significant differences between the placement conditions. Scores are within the "good" range for Sitting and within the "OK" range for Walking for all strategies. The 7-point adjective scale as proposed by Bangor et al. [3] and the color-coding of Blattgerste et al. [6] were used.

Table 2. SUS scores (*M* and *SD*) for each placement method and scenario. Ratings in parentheses follow the SUS adjective rating scale. The 7-point adjective scale as proposed by Bangor et al. [3] and the colour-coding of Blattgerste et al. [6] was used.

Scenario	View-Fixed		Look-Down		Wall-Aligned	
	M (Rating)	*SD*	*M* (Rating)	*SD*	*M* (Rating)	*SD*
Sitting	71.1 (good)	16.7	74.2 (good)	14.7	79.9 (good)	10.4
Walking	66.1 (ok)	17.5	57.8 (ok)	18.6	66.1 (ok)	19.5

indicated that most groups did not significantly deviate from normality ($p > 0.05$), except for two groups showing deviations. To address these deviations and ensure robust inference, we analyzed the data with a two-way repeated measures ANOVA on aligned rank-transformed data using a mixed-effects model. This approach preserves the factorial structure while relaxing normality assumptions[4].

The ART ANOVA revealed a significant main effect of *Scenario* on SUS scores, $F(1, 85) = 20.43$, $p < .001$, $\eta_p^2 = .19$, indicating a large effect of scenario on perceived usability. In contrast, the main effect of *Condition* was not statistically significant, $F(2, 85) = 2.60$, $p = .081$, $\eta_p^2 = .06$, suggesting that differences between placement methods did not reliably influence SUS scores. The interaction between *Condition* and *Scenario* was also not significant, $F(2, 85) = 1.94$, $p = .149$, $\eta_p^2 = .04$, indicating that the effect of placement was consistent across both scenarios.

[4]Denominator degrees of freedom are approximated using the Satterthwaite method, which explains why they differ from those in classical repeated-measures ANOVA)

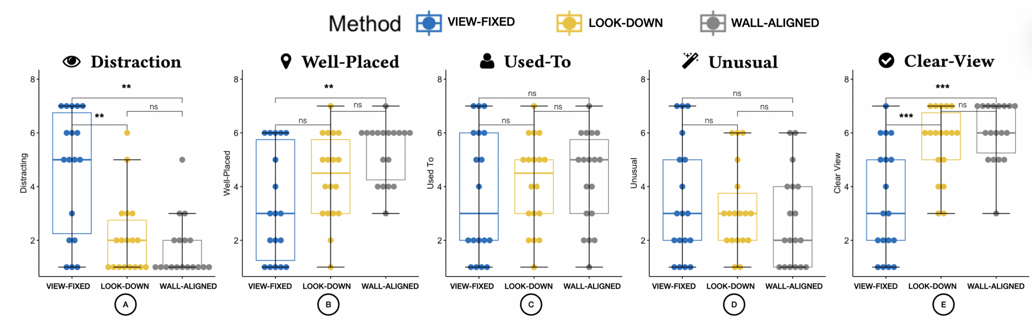

Fig. 6. Ratings for Sitting: A) Rating for the amount of Distraction (a lower value is better). B) Rating for how well-placed the AR Widgets were perceived. C) Rating for how used the participants were to each condition. D) Ratings of how unusual the Placement Condition was perceived. D) Rating of clear view.

Table 3. Descriptive statistics (*M* and *SD*) for additional questions in the Sitting scenario. ↑ = larger values are better, ↓ = lower values are better. Best scores are in bold.

Question	View-Fixed		Look-Down		Wall-Aligned	
	M	*SD*	*M*	*SD*	*M*	*SD*
Distracting (↓)	4.61	2.30	2.11	1.45	**1.67**	1.09
Well-Placed (↑)	3.28	2.05	4.33	1.61	**5.33**	1.09
Used To (↑)	3.72	2.37	4.11	1.71	**4.28**	1.74
Unusual (↓)	3.44	2.20	3.17	1.62	**2.72**	1.74
Clear View (↑)	3.44	2.06	5.61	1.34	**6.06**	1.11

5.3 Distraction, Placement and Familiarity Questions

For the additional questions, we were interested in the impact of *Placement*, as well as the impact of *Scenario*, on the ratings. All results were tested for normality using the Shapiro-Wilk test. Because the ratings were not normally distributed[5] ($p < .05$), we analyzed the data using the aligned rank transform (ART), which enables non-parametric testing of factorial designs while retaining the interpretability of ANOVA. The ART ANOVAs[6] revealed significant main effects of *Scenario* for *Distraction* ($F_{1,85} = 22.10$, $p < .001$), *Well-Placed* ($F_{1,85} = 7.55$, $p = .007$), *Used-To* ($F_{1,85} = 6.64$, $p = .012$), *Unusual* ($F_{1,85} = 21.23$, $p < .001$), and *Clear-View* ($F_{1,85} = 10.55$, $p = .002$). Significant effects of *Placement* were found for *Distraction* ($F_{2,85} = 20.70$, $p < .001$), *Well-Placed* ($F_{2,85} = 11.81$, $p < .001$), and *Clear-View* ($F_{2,85} = 28.59$, $p < .001$). No significant interactions between *Scenario* and *Placement* were observed for any question, suggesting that placement effects were consistent across scenarios.

Effect sizes for the ART ANOVA are reported as partial eta-squared. Scenario showed large effects on *Distraction* ($\eta_p^2 = .21$), *Unusual* ($\eta_p^2 = .20$), and *Clear-View* ($\eta_p^2 = .11$), and smaller but significant effects on *Well-Placed* ($\eta_p^2 = .08$) and *Used-To* ($\eta_p^2 = .07$). Placement also showed large effects on *Clear-View* ($\eta_p^2 = .40$) and *Distraction* ($\eta_p^2 = .32$), as well as for *Well-Placed* ($\eta_p^2 = .21$).

To get a better understanding of the placement strategies on the rating of each question, we conducted post-hoc pairwise comparisons using the `emmeans` package with Tukey adjustment

[5]Details on Shapiro–Wilk test *p*-values are available in the appendix (see the supplementary materials).
[6]Denominator degrees of freedom are Satterthwaite-approximated from the mixed-effects ART model, which explains why they differ from those in a classical repeated-measures ANOVA.

for multiple testing[7]. The results showed that Wall-Aligned placement consistently reduced distraction and provided higher ratings of placement and clear view compared to View-Fixed placement in both scenarios (Figure 6, Figure 7).

Sitting. For the sitting scenario (Table 3), we made the following observations:

- **Distraction:** Participants rated View-Fixed as most distracting (M = 4.61), compared to Look-Down (M = 2.11) and Wall-Aligned (M = 1.66). Post-hoc tests confirmed that View-Fixed differed significantly from both Look-Down ($M_{\text{diff}} = 29.11$, $t(85) = 3.65$, $p = .0013^{**}$) and Wall-Aligned ($M_{\text{diff}} = 27.06$, $t(85) = 3.40$, $p = .0030^{**}$). No difference was found between Look-Down and Wall-Aligned.
- **Well-Placed:** Ratings increased from View-Fixed (M = 3.27) to Look-Down (M = 4.33) and were highest for Wall-Aligned (M = 5.33). Post-hoc tests showed that Wall-Aligned was rated significantly higher than View-Fixed ($M_{\text{diff}} = -26.67$, $t(85) = -3.13$, $p = .0066^{**}$). Other contrasts were not significant.
- **Used-To:** All conditions were above the midpoint: View-Fixed (M = 3.72), Look-Down (M = 4.11), and Wall-Aligned (M = 4.27). No significant differences were found.
- **Unusual:** Ratings decreased slightly from View-Fixed (M = 3.44) to Look-Down (M = 3.17) and Wall-Aligned (M = 2.72). No significant differences were found.
- **Clear-View:** Wall-Aligned (M = 6.05) and Look-Down (M = 5.61) were rated clearer than View-Fixed (M = 3.44). Post-hoc tests confirmed significant differences between View-Fixed and Look-Down ($M_{\text{diff}} = -33.83$, $t(85) = -4.60$, $p < .001^{***}$) and between View-Fixed and Wall-Aligned ($M_{\text{diff}} = -32.06$, $t(85) = -4.36$, $p < .001^{***}$). No difference was found between Look-Down and Wall-Aligned.

Walking. For the walking scenario (Table 4), we made the following observations:

- **Distraction:** View-Fixed was rated most distracting (M = 5.50), compared to Look-Down (M = 3.78) and Wall-Aligned (M = 3.72). Post-hoc tests confirmed that View-Fixed differed significantly from both Look-Down ($M_{\text{diff}} = 32.39$, $t(85) = 4.07$, $p = .0003^{***}$) and Wall-Aligned ($M_{\text{diff}} = 36.94$, $t(85) = 4.64$, $p < .0001^{***}$). No significant difference was found between Look-Down and Wall-Aligned.
- **Well-Placed:** Ratings increased from View-Fixed (M = 3.89) to Look-Down (M = 4.39) and were highest for Wall-Aligned (M = 4.83). Post-hoc tests showed that Wall-Aligned was rated significantly higher than View-Fixed ($M_{\text{diff}} = -31.00$, $t(85) = -3.64$, $p = .0013^{**}$). Other contrasts were not significant.
- **Used-To:** Means were 3.44 (View-Fixed), 3.11 (Look-Down), and 3.17 (Wall-Aligned). No significant differences were found.
- **Unusual:** Ratings were 4.06 (View-Fixed), 4.67 (Look-Down), and 4.33 (Wall-Aligned). No significant differences were found.
- **Clear-View:** View-Fixed received the lowest rating (M = 3.72), while Look-Down (M = 5.06) and Wall-Aligned (M = 4.89) were rated higher. Post-hoc tests confirmed significant differences between View-Fixed and Look-Down ($M_{\text{diff}} = -32.22$, $t(85) = -4.38$, $p = .0001^{***}$) and between View-Fixed and Wall-Aligned ($M_{\text{diff}} = -38.06$, $t(85) = -5.17$, $p < .0001^{***}$). No significant difference was found between Look-Down and Wall-Aligned.

5.4 Sample Size and Statistical Power

A sensitivity analysis using G*Power was conducted to contextualize the design's ability to detect effects in the 2 × 3 repeated-measures ANOVA ($\alpha = .05$, $n = 18$, assumed correlation among

[7] Detailed results available in the appendix (see the supplementary materials).

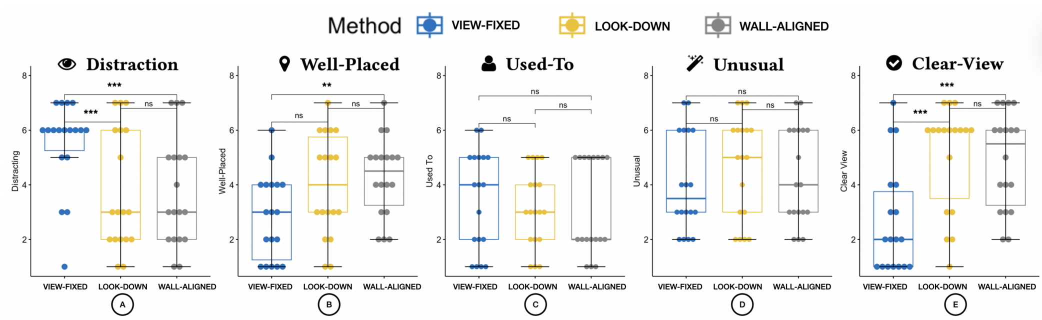

Fig. 7. Ratings for the walking scenario: A) Distraction (a lower value is better). B) Well-placed. C) Rating for how used to each condition the participants were. D) Ratings of how unusual the behavior of the AR Widgets was perceived. E) Rating of clear view.

Table 4. Descriptive statistics (*M* and *SD*) for additional questions in the Walking scenario. ↑ = higher values better, ↓ = lower values is better. Best scores are in bold.

Question	View-Fixed		Look-Down		Wall-Aligned	
	M	*SD*	*M*	*SD*	*M*	*SD*
Distracting (↓)	5.50	1.62	3.78	2.18	**3.72**	1.99
Well-Placed (↑)	2.83	1.54	4.00	1.88	**4.28**	1.45
Used To (↑)	**3.44**	1.82	3.11	1.41	3.17	1.72
Unusual (↓)	**4.06**	1.80	4.67	1.88	4.33	1.78
Clear View (↑)	2.67	1.97	**5.06**	1.92	4.89	1.78

repeated measures $r = .5$). The analysis indicated that the study was sensitive to medium-sized effects (Cohen's $f = 0.25$), with estimated power of approximately 0.79, increasing to about 0.88 for medium-to-large effects ($f = 0.30$). These estimates suggest that the design was primarily powered to detect moderate or larger effects, while smaller effects would be less reliably detected.

6 Discussion

As AR glasses continue to miniaturize, many anticipate a shift from sporadic, task-specific use toward more continuous and ubiquitous AR interfaces [20]. Worn like traditional glasses, such systems will be used across contexts and locations, making information placement increasingly challenging. Prior work has largely focused on environment-dependent information or on scenarios that allow users to manually assign content to preferred locations (e.g., surface-anchored windows in HoloLens 2 or Apple Vision Pro). In contrast, our work targets scenarios in which information is environment-independent and users lack the time or motivation to manually customize placement. In the following, we provide a summary of our key findings with respect to our developed placement strategies and initial hypotheses before discussing the relevance of the findings, recommendations, and limitations.

Summary of Results. Our results for the UEQ-S showed that the placement strategy has an effect on the user experience, with significantly better scores for the Wall-Aligned strategy in both scenarios (sitting and walking). The ratings for Wall-Aligned were good in the sitting scenario and above average in the walking scenario. Surprisingly, there was no significant difference between the Look-Down and View-Fixed strategies in both scenarios, with Look-Down showing a below-average UX rating in the sitting scenario and both strategies (View-Fixed and Look-Down) showing a "bad" rating in the walking scenario. The results confirm **H1** for the Wall-Aligned placement. However, we cannot confirm **H1: User Experience** for the Look-Down strategy.

The SUS revealed significant differences in usability across the two scenarios, though no significant differences were observed for the placement strategy. The scores indicate that usability in general is lower, but rated "OK" in the walking scenario. It is also interesting to mention that the scores indicate "good" usability for the sitting scenario. The results reject **H2: Usability**. It is worth discussing the interaction effect observed for SUS ($p = 0.05$). This effect appears to be driven primarily by a drop in ratings for the Look-Down and Wall-Aligned conditions during walking, while the View-Fixed condition remained relatively stable. Interestingly, this pattern contrasts with the results for the Distraction and Clear-View measures, where no significant differences were observed between the Look-Down and Wall-Aligned strategies, but the View-Fixed strategy scored significantly lower than both methods. With these significant differences between View-Fixed and Look-Down, as well as the significant differences between View-Fixed and Wall-Aligned, we can confirm **H3: Distraction and Clear-View**.

For the question about how well-placed the AR Widgets were, we found there was an effect of placement strategy on the rating in both scenarios. Notably, there was a significant difference between View-Fixed and Wall-Aligned placement in both scenarios. In all these cases, the rating on the placement was the lowest for the View-Fixed condition. It worth mentioning that there was no significant difference between the Look-Down and Wall-Aligned strategies in both scenarios. Overall, with these results, we only partly confirm **H4: Placement**.

While we anticipated that the users would perceive the behaviour of the Look-Down and Wall-Aligned AR Widgets to be less familiar and more unusual, we did not find significant differences in terms of how used-to users were and in terms of unusualness. It is important to note that responses to these questions varied widely. It could be that using AR glasses themselves could have contributed to these ratings, as all conditions could be perceived as somewhat unusual. Thus, we cannot confirm **H5: Used-to and Unusualness**.

Context within the literature. Contrasting our findings with the relevant literature, we clearly show that View-Fixed is the lowest rated placement strategy with regard to multiple aspects. This is surprising and in contrast to prior work on glanceable interfaces that required gaze activation, where View-Fixed placement (there called Eye-Glance interface) was the overall best-rated interface [36]. However, even in this earlier study, participants commented "that it was too cluttered, crowded, and occluding my view" [36], suggesting that its apparent strengths may have been accompanied by fundamental usability issues. We also saw similar feedback in our study on the View-Fixed strategy (see earlier comments on “distracting and blurry when moving”, “blocking vision”). Contrary to the prior work, these concerns are also clearly visible in the general preference when facing other placement options that have not been studied before. This is an important finding as they challenge earlier quantitative results but confirm qualitative feedback already present in earlier work.

Our technique for Look-Down information placement performed generally better than the conceptually related head-glanceable interface in earlier studies (when being compared to a View-Fixed strategy). We think this can be easily explained by two key differences in our design. First, we would argue it is easier to look down (in particular when walking), as in our implementation, rather than to look up as in Lu et al. In fact, Lu et al. already mentioned possible bad ergonomics in their discussion. Second, when placing overlays above head-level (as in Lu et al.), there is a large chance these are in front of the bright sky or ceiling headlights, thus reducing readability specifically in optical-see-through HMDs [24]. While surprisingly not considered in earlier work, these reasons were a major reason for us to have a different design that puts overlays down in-front of the users. These aspects are likely to have caused a generally improved performance and should be considered in future work.

Our novel technique for Wall-Aligned placement, which continuously updates the best possible location for information placements by analyzing surfaces in the physical environment, is fundamentally different from prior techniques in the literature. However, we still see support and indicators for its good performance in the literature. For example, in earlier works that explore document sharing and placement strategies, users preferred placing documents on physical objects, such as tables, whiteboards and walls [38]. Similarly, in a formative study by Cheng et al.'s users also preferred physical surfaces to place virtual elements [10]. Participants also seemed to like that the information is always visible, something that was brought up as positive for other techniques in previous studies [36]. As such, it seems that utilizing the physical environment as a surface, even for placing semantically unrelated information, is preferred compared to interfaces where information is floating in space or is not clearly spatially referenced to the physical environment.

Design Implications. Our findings suggest that environment-anchored widgets (e.g., Wall-Aligned) should be preferred for persistent information that benefits from spatial stability and low distraction, such as status dashboards. The View-Fixed placement may be appropriate for transient alerts requiring immediate attention, but risks occlusion and visual clutter during extended use. The Look-Down placement offers a compromise for content that users may want to intentionally access without occupying the central field of view.

Study Summary and Recommendations. Even though AR glasses are currently promoted for spontaneous indoor use, it is already obvious that continuous information access will be a main advantage for future AR glasses when compared to current mobile technology. This raises the question of where information should be placed. Our prototype and study on AR Widgets, exploring placement strategies for persistent information with a low semantic dependence on the physical environment, generated the following findings and recommendations:

1. A placement that automatically aligns to real-world surfaces is preferred (Wall-Aligned), even when there is no semantic link between the widget and the surface used for placement.
2. Having the information constantly in view is seen as preferable even when this comes at a cost of a dynamic adjustment of the information placement.
3. When no suitable surface is available or cannot be detected, placing the information in-front of the user but slightly out of view (Look-Down) is preferred over the View-Fixed placement. However, care must be taken to place the information below the head to:
   (a) Increase ergonomics specifically in walking scenarios;
   (b) Increase readability specifically against bright backgrounds (ceiling lamps, sky).
   (c) Address occlusions and vergence-accommodation issues, specifically when seated and facing close-by objects
4. View-Fixed placement seems to be less preferred due to information blocking vision and blurred vision. However, future generations of AR glasses with a larger field of view might warrant revisiting these specific findings.

Limitations. Our research also showed several limitations that are worth discussing. Firstly, we explored a continuous AR interface and the findings of our study might only be valid for such a continuous use. Secondly, the relatively narrow FoV of the AR glasses used in our study (26.3 degree diagonal FOV) may have influenced the results. While the FOV varies across currently available AR glasses, it is always only a fraction of the human visual field [24]. Increasing the FoV typically requires larger optical components and more complex display systems, which in turn increase device weight and bulk. Heavier head-mounted displays have been shown to affect comfort and may limit longer-term usage, particularly in mobile or task-oriented scenarios.

However, an increase in the usable FOV could affect our results, as AR Widgets in the View-Fixed condition can be shifted further into the periphery, reducing occlusion of the central visual area and distraction effects. It could also affect the other placement conditions, as AR Widgets are more likely to remain visible at all times, potentially changing users' perception of persistence and distraction as widgets might be visible for a longer time.

Finally, in the current study setup, we only explore AR Widgets in isolation and not in combination with other AR overlays (e.g., information with a strong dependence on the physical environment). We also grouped our widgets into one widget panel instead of placing each widget individually. However, we argue that these are reasonable decisions that reflect the actual usage because, specifically in continuous and mobile usage scenarios, it is unlikely that there is another overlay continuously shown (isolation) and widgets are usually also grouped in dedicated panels on existing 2D interfaces such as phones, smartwatches, or desktop interfaces (grouping).

7 Conclusion and Future Work

In this paper, we focused on the gap in AR research on placement techniques for persistent digital content that is not attached to physical objects. With future AR glasses in mind, we aimed at the use case of pervasive AR usage. As part of this, we highlighted that there is a need to research how to place widgets in pervasive AR, an aspect that is still under-explored. We proposed new strategies for placing widgets based on the principle of *dynamic relocation in the world* and found out through our user study that while there is no significant difference in usability, the Wall-Aligned placement can contribute to a higher user experience. We also found that users perceived less distraction and a clearer view when using our automatic placement strategies compared to a more traditional View-Fixed placement. Overall, the Wall-Aligned strategy outperformed View-Fixed and Look-Down placements. Building on the current study, future research will include the investigation of activity recognition and context analysis to allow the placement to respond to the user. Furthermore, combining our placement methods with appearance modulation techniques [11], may offer additional benefits by dynamically enhancing content visibility and reducing visual clutter.

Author Contributions

Stefanie Zollmann: Writing - Original Draft, Conceptualization, Methodology, Software, Formal Analysis, Visualization, Project administration; **Tobias Langlotz:** Writing - Original Draft, Conceptualization, Methodology, Visualization **Daniel Wagner:** Writing - Review & Editing, Conceptualization; **Pavel Manakhov:** Writing - Review & Editing, Conceptualization **Wei Hong Lo:** Writing - Review & Editing, Methodology, Software, Investigation.

Acknowledgments

Stefanie Zollmann's work was supported by the Novo Nordisk Foundation (NNF24OC0099086). Tobias Langlotz' work was supported by the Independent Research Fund Denmark (Grant No. 5284-00197A). Pavel Manakhov was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant No. 101021229 GEMINI).

References

[1] David Ahlström, Khalad Hasan, and Pourang Irani. 2014. Are you comfortable doing that? acceptance studies of around-device gestures in and for public settings. In *Proceedings of the 16th International Conference on Human-Computer Interaction with Mobile Devices & Services* (Toronto, ON, Canada) *(MobileHCI '14)*. Association for Computing Machinery, New York, NY, USA, 193–202. doi:10.1145/2628363.2628381

[2] R. Azuma and C. Furmanski. 2003. Evaluating label placement for augmented reality view management. In *The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, 2003. Proceedings.* IEEE, Tokyo, Japan, 66–75. doi:10.1109/ISMAR.2003.1240689

[3] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining what individual SUS scores mean: adding an adjective rating scale. *J. Usability Studies* 4, 3 (may 2009), 114–123.

[4] Blaine Bell, Steven Feiner, and Tobias Höllerer. 2001. View Management for Virtual and Augmented Reality. In *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology* (Orlando, Florida) *(UIST '01)*. Association for Computing Machinery, New York, NY, USA, 101–110. doi:10.1145/502348.502363

[5] João Marcelo Evangelista Belo, Mathias N. Lystbæk, Anna Maria Feit, Ken Pfeuffer, Peter Kán, Antti Oulasvirta, and Kaj Grønbæk. 2022. AUIT – the Adaptive User Interfaces Toolkit for Designing XR Applications. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22)*. Association for Computing Machinery, New York, NY, USA, 1–16. doi:10.1145/3526113.3545651

[6] Jonas Blattgerste, Jan Behrends, and Thies Pfeiffer. 2022. A Web-Based Analysis Toolkit for the System Usability Scale. In *Proceedings of the 15th International Conference on PErvasive Technologies Related to Assistive Environments* (Corfu, Greece) *(PETRA '22)*. Association for Computing Machinery, New York, NY, USA, 237–246. doi:10.1145/3529190.3529216

[7] Han Joo Chae, Youli Chang, Minji Kim, Gwanmo Park, and Jinwook Seo. 2020. ARphy: Managing Photo Collections Using Physical Objects in AR. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–7. doi:10.1145/3334480.3382885

[8] Yu-Cheng Chang, Yen-Pu Wang, Chiao-Ju Chang, Wei Tian Mireille Tan, Yu Lun Hsu, Yu Chen, and Mike Y. Chen. 2024. Experience from Designing Augmented Reality Browsing Interfaces for Real-world Walking Scenarios. *Proc. ACM Hum.-Comput. Interact.* 8, MHCI, Article 255 (Sept. 2024), 26 pages. doi:10.1145/3676500

[9] Isha Chaturvedi, Farshid Hassani Bijarbooneh, Tristan Braud, and Pan Hui. 2019. Peripheral vision: a new killer app for smart glasses. In *Proceedings of the 24th International Conference on Intelligent User Interfaces* (Marina del Ray, California) *(IUI '19)*. Association for Computing Machinery, New York, NY, USA, 625–636. doi:10.1145/3301275.3302263

[10] Yifei Cheng, Yukang Yan, Xin Yi, Yuanchun Shi, and David Lindlbauer. 2021. SemanticAdapt: Optimization-Based Adaptation of Mixed Reality Layouts Leveraging Virtual-Physical Semantic Connections. In *The 34th Annual ACM Symposium on User Interface Software and Technology* (Virtual Event, USA) *(UIST '21)*. Association for Computing Machinery, New York, NY, USA, 282–297. doi:10.1145/3472749.3474750

[11] Shakiba Davari, Feiyu Lu, and Doug A. Bowman. 2020. Occlusion Management Techniques for Everyday Glanceable AR Interfaces. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. 324–330. doi:10.1109/VRW50115.2020.00072

[12] Shakiba Davari, Feiyu Lu, and Doug A Bowman. 2022. Validating the benefits of glanceable and context-aware augmented reality for everyday information access tasks. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, Christchurch, New Zealand, 436–444.

[13] Gerlinde Emsenhuber, Tobias Langlotz, Denis Kalkofen, Jonathan Sutton, and Markus Tatzgern. 2023. Eye-Perspective View Management for Optical See-Through Head-Mounted Displays. In *2023 CHI Conference on Human Factors in Computing Systems, CHI 2023*. ACM, Hamburg, Germany, 1–16.

[14] Barrett Ens and Pourang Irani. 2017. Spatial Analytic Interfaces: Spatial User Interfaces for In Situ Visual Analytics. *IEEE Computer Graphics and Applications* 37, 2 (2017), 66–79. doi:10.1109/MCG.2016.38

[15] Steven Feiner, Blair MacIntyre, Marcus Haupt, and Eliot Solomon. 1993. Windows on the World: 2D Windows for 3D Augmented Reality. In *Proceedings of the 6th Annual ACM Symposium on User Interface Software and Technology* (Atlanta, Georgia, USA) *(UIST '93)*. Association for Computing Machinery, New York, NY, USA, 145–155. doi:10.1145/168642.168657

[16] Christoph Gebhardt, Brian Hecox, Bas van Opheusden, Daniel Wigdor, James Hillis, Otmar Hilliges, and Hrvoje Benko. 2019. Learning Cooperative Personalized Policies from Gaze Data. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) *(UIST '19)*. Association for Computing Machinery, New York, NY, USA, 197–208. doi:10.1145/3332165.3347933

[17] Yiannis Georgiou and Eleni A. Kyza. 2017. The development and validation of the ARI questionnaire: An instrument for measuring immersion in location-based augmented reality settings. *International Journal of Human-Computer Studies* 98 (2017), 24–37. doi:10.1016/j.ijhcs.2016.09.014

[18] Raphaël Grasset, Tobias Langlotz, Denis Kalkofen, Markus Tatzgern, and Dieter Schmalstieg. 2012. Image-driven view management for augmented reality browsers. In *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, Atlanta, GA, USA, 177–186. doi:10.1109/ISMAR.2012.6402555

[19] Jens Grubert, Matthias Heinisch, Aaron Quigley, and Dieter Schmalstieg. 2015. MultiFi: Multi Fidelity Interaction with Displays On and Around the Body. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 3933–3942. doi:10.1145/2702123.2702331

[20] Jens Grubert, Tobias Langlotz, Stefanie Zollmann, and Holger Regenbrecht. 2017. Towards Pervasive Augmented Reality: Context-Awareness in Augmented Reality. *IEEE Transactions on Visualization and Computer Graphics* 23, 6 (2017), 1706–1724. doi:10.1109/TVCG.2016.2543720

[21] Tobias Höllerer, Steven Feiner, Drexel Hallaway, Blaine Bell, Marco Lanzagorta, Dennis Brown, Simon Julier, Yohan Baillot, and Lawrence Rosenblum. 2001. User interface management techniques for collaborative mobile augmented reality. *Computers & Graphics* 25 (10 2001), 799–810. doi:10.1016/S0097-8493(01)00122-4

[22] Ioanna Iacovides, Anna Cox, Richard Kennedy, Paul Cairns, and Charlene Jennett. 2015. Removing the HUD: The Impact of Non-Diegetic Game Elements and Expertise on Player Involvement. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play* (London, United Kingdom) *(CHI PLAY '15)*. Association for Computing Machinery, New York, NY, USA, 13–22. doi:10.1145/2793107.2793120

[23] Cory Ilo, Stephen DiVerdi, and Doug Bowman. 2024. Goldilocks Zoning: Evaluating a Gaze-Aware Approach to Task-Agnostic VR Notification Placement. In *Proceedings of the 2024 ACM Symposium on Spatial User Interaction* (Trier, Germany) *(SUI '24)*. Association for Computing Machinery, New York, NY, USA, Article 13, 12 pages. doi:10.1145/3677386.3682087

[24] Yuta Itoh, Tobias Langlotz, Jonathan Sutton, and Alexander Plopski. 2021. Towards Indistinguishable Augmented Reality: A Survey on Optical See-through Head-mounted Displays. *ACM Comput. Surv.* 54, 6, Article 120 (jul 2021), 36 pages. doi:10.1145/3453157

[25] Christoph Albert Johns, João Marcelo Evangelista Belo, Clemens Nylandsted Klokmose, and Ken Pfeuffer. 2023. Pareto Optimal Layouts for Adaptive Mixed Reality. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI EA '23)*. Association for Computing Machinery, New York, NY, USA, Article 223, 7 pages. doi:10.1145/3544549.3585732

[26] S. Julier, Y. Baillot, D. Brown, and M. Lanzagorta. 2002. Information filtering for mobile augmented reality. *IEEE Computer Graphics and Applications* 22, 5 (2002), 12–15. doi:10.1109/MCG.2002.1028721

[27] Wallace S. Lages and Doug A. Bowman. 2019. Walking with adaptive augmented reality workspaces: design and usage patterns. In *Proceedings of the 24th International Conference on Intelligent User Interfaces* (Marina del Ray, California) *(IUI '19)*. Association for Computing Machinery, New York, NY, USA, 356–366. doi:10.1145/3301275.3302278

[28] Tobias Langlotz, Thanh Nguyen, Dieter Schmalstieg, and Raphael Grasset. 2014. Next-generation augmented reality browsers: rich, seamless, and adaptive. *Proc. IEEE* 102, 2 (2014), 155–169.

[29] Irina Lediaeva and Joseph LaViola. 2020. Evaluation of Body-Referenced Graphical Menus in Virtual Environments.

[30] Hyunjin Lee, Sunyoung Bang, and Woontack Woo. 2022. Effects of coordinate system and position of AR notification while walking. *Virtual Real.* 27, 2 (Sept. 2022), 829–848. doi:10.1007/s10055-022-00693-9

[31] James R. Lewis and Jeff Sauro. 2009. The Factor Structure of the System Usability Scale. In *Human Centered Design*, Masaaki Kurosu (Ed.). Springer, Berlin, Heidelberg, 94–103. doi:10.1007/978-3-642-02806-9_12

[32] Zhen Li, Michelle Annett, Ken Hinckley, Karan Singh, and Daniel Wigdor. 2019. HoloDoc: Enabling Mixed Reality Workspaces that Harness Physical and Digital Content. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3290605.3300917

[33] David Lindlbauer, Anna Maria Feit, and Otmar Hilliges. 2019. Context-Aware Online Adaptation of Mixed Reality Interfaces. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology* (New Orleans, LA, USA) *(UIST '19)*. Association for Computing Machinery, New York, NY, USA, 147–160. doi:10.1145/3332165.3347945

[34] Feiyu Lu and Doug A. Bowman. 2021. Evaluating the Potential of Glanceable AR Interfaces for Authentic Everyday Uses. In *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*. 768–777. doi:10.1109/VR50410.2021.00104

[35] Feiyu Lu, Shakiba Davari, and Doug Bowman. 2021. Exploration of Techniques for Rapid Activation of Glanceable Information in Head-Worn Augmented Reality. In *Proceedings of the 2021 ACM Symposium on Spatial User Interaction* (Virtual Event, USA) *(SUI '21)*. Association for Computing Machinery, New York, NY, USA, Article 14, 11 pages. doi:10.1145/3485279.3485286

[36] Feiyu Lu, Shakiba Davari, Lee Lisle, Yuan Li, and Doug A. Bowman. 2020. Glanceable AR: Evaluating Information Access Methods for Head-Worn Augmented Reality. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, Atlanta, GA, USA, 930–939. doi:10.1109/VR46266.2020.00113

[37] Andrés Lucero and Akos Vetek. 2014. NotifEye: using interactive glasses to deal with notifications while walking in public. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology* (Funchal, Portugal) *(ACE '14)*. Association for Computing Machinery, New York, NY, USA, Article 17, 10 pages. doi:10.1145/2663806.2663824

[38] Weizhou Luo, Anke Lehmann, Hjalmar Widengren, and Raimund Dachselt. 2022. Where Should We Put It? Layout and Placement Strategies of Documents in Augmented Reality for Collaborative Sensemaking. In *CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New Orleans, LA, USA, 1–16.

[39] Nils Adrian Mack, Markus Heun, and Marion Rose. 2023. Head-Anchored Text Placements and Cognitive Load in Information-Rich Virtual Environments. In *Proceedings of Mensch Und Computer 2023 (MuC '23)*. Association for Computing Machinery, New York, NY, USA, 27–36. doi:10.1145/3603555.3603575

[40] Pavel Manakhov, Ludwig Sidenmark, Ken Pfeuffer, and Hans Gellersen. 2024. Gaze on the Go: Effect of Spatial Reference Frame on Visual Target Acquisition During Physical Locomotion in Extended Reality. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 373, 16 pages. doi:10.1145/3613904.3642915

[41] Steve Mann and Fung. 2001. Videoorbits on Eye Tap Devices for Deliberately Diminished Reality or Altering the Visual Perception of Rigid Planar Patches of a Real World Scene. *International Symposium on Mixed Reality, 2001* (2001), 48–55.

[42] Microsoft. 2021, Nov 30. Billboarding and Tag-along - Mixed Reality. https://web.archive.org/web/20250604055920/https://learn.microsoft.com/en-us/windows/mixed-reality/design/billboarding-and-tag-along.

[43] Benjamin Nuernberger, Eyal Ofek, Hrvoje Benko, and Andrew D. Wilson. 2016. SnapToReality: Aligning Augmented Reality to the Real World. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1233–1244. doi:10.1145/2858036.2858250

[44] Jason Orlosky, Kiyoshi Kiyokawa, Takumi Toyama, and Daniel Sonntag. 2015. Halo Content: Context-aware Viewspace Management for Non-invasive Augmented Reality. In *Proceedings of the 20th International Conference on Intelligent User Interfaces* (Atlanta, Georgia, USA) *(IUI '15)*. Association for Computing Machinery, New York, NY, USA, 369–373. doi:10.1145/2678025.2701375

[45] Ken Pfeuffer, Jan Obernolte, Felix Dietz, Ville Mäkelä, Ludwig Sidenmark, Pavel Manakhov, Minna Pakanen, and Florian Alt. 2023. PalmGazer: Unimanual Eye-hand Menus in Augmented Reality. In *Proceedings of the 2023 ACM Symposium on Spatial User Interaction (SUI '23)*. Association for Computing Machinery, New York, NY, USA, 1–12. doi:10.1145/3607822.3614523

[46] Linda Pfister and Sabiha Ghellal. 2018. Exploring the influence of non-diegetic and diegetic elements on the immersion of 2D games. In *Proceedings of the 30th Australian Conference on Computer-Human Interaction* (Melbourne, Australia) *(OzCHI '18)*. Association for Computing Machinery, New York, NY, USA, 490–494. doi:10.1145/3292147.3292190

[47] Robin Piening, Ken Pfeuffer, Augusto Esteves, Tim Mittermeier, Sarah Prange, Philippe Schröder, and Florian Alt. 2021. Looking for Info: Evaluation of Gaze Based Information Retrieval in Augmented Reality. In *Human-Computer Interaction – INTERACT 2021*, Carmelo Ardito, Rosa Lanzilotti, Alessio Malizia, Helen Petrie, Antonio Piccinno, Giuseppe Desolda, and Kori Inkpen (Eds.). Springer International Publishing, Cham, 544–565.

[48] Lucas Plabst, Sebastian Oberdörfer, Francisco Raul Ortega, and Florian Niebling. 2022. Push the Red Button: Comparing Notification Placement with Augmented and Non-Augmented Tasks in AR. In *Proceedings of the 2022 ACM Symposium on Spatial User Interaction* (Online, CA, USA) *(SUI '22)*. Association for Computing Machinery, New York, NY, USA, Article 17, 11 pages. doi:10.1145/3565970.3567701

[49] Rufat Rzayev, Susanne Korbely, Milena Maul, Alina Schark, Valentin Schwind, and Niels Henze. 2020. Effects of Position and Alignment of Notifications on AR Glasses during Social Interaction. In *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society* (Tallinn, Estonia) *(NordiCHI '20)*. Association for Computing Machinery, New York, NY, USA, Article 30, 11 pages. doi:10.1145/3419249.3420095

[50] Rufat Rzayev, Sven Mayer, Christian Krauter, and Niels Henze. 2019. Notification in VR: The Effect of Notification Placement, Task and Environment. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Barcelona, Spain) *(CHI PLAY '19)*. Association for Computing Machinery, New York, NY, USA, 199–211. doi:10.1145/3311350.3347190

[51] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. 2017. Construction of a Benchmark for the User Experience Questionnaire (UEQ). *International Journal of Interactive Multimedia and Artificial Intelligence* 4 (06 2017), 40–44. doi:10.9781/ijimai.2017.445

[52] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. 2017. Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence* 4 (01 2017), 103. doi:10.9781/ijimai.2017.09.001

[53] Kohei Tanaka, Yasue Kishino, Masakazu Miyamae, Tsutomu Terada, and Shojiro Nishio. 2008. An information layout method for an optical see-through head mounted display focusing on the viewability. In *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*. 139–142. doi:10.1109/ISMAR.2008.4637340

[54] Lars Vising. 2008. Mobile Widget Architecture.

[55] Franziska Westermeier, Larissa Brübach, Marc Erich Latoschik, and Carolin Wienrich. 2023. Exploring Plausibility and Presence in Mixed Reality Experiences. *IEEE Transactions on Visualization and Computer Graphics* 29, 5 (2023), 2680–2689. doi:10.1109/TVCG.2023.3247046

[56] Wesley Willett, Yvonne Jansen, and Pierre Dragicevic. 2017. Embedded Data Representations. *IEEE Transactions on Visualization and Computer Graphics* 23, 1 (2017), 461–470. doi:10.1109/TVCG.2016.2598608

[57] Qiushi Zhou, Difeng Yu, Martin N Reinoso, Joshua Newn, Jorge Goncalves, and Eduardo Velloso. 2020. Eyes-Free Target Acquisition During Walking in Immersive Mixed Reality. *IEEE Transactions on Visualization and Computer Graphics* 26, 12 (Dec. 2020), 3423–3433. doi:10.1109/TVCG.2020.3023570

[58] Stefanie Zollmann, Christian Poglitsch, and Jonathan Ventura. 2016. VISGIS: Dynamic situated visualization for geographic information systems. In *2016 International Conference on Image and Vision Computing New Zealand (IVCNZ)*. IEEE, Palmerston North, New Zealand, 1–6. doi:10.1109/IVCNZ.2016.7804440