ABOVE & BELOW: Investigating Ceiling and Floor for Augmented Reality Content Placement

Appendix

In this appendix we provide (1) additional literature and its analysis with regard to the use of the ceiling and floor in AR, (2) further information regarding the placement of content on both areas, and (3) additional images from the study setup.

Technology	Ceiling	Floor
UbiComp Solutions		
▷ Monitor System	[16, 33, 34]	[15, 21, 28, 36]
▷ Stationary Projector	[4, 11, 19, 22, 29, 32–34, 37]	[1, 3, 5, 8–10, 13, 17, 23]
Personal Augmentation		
▷ Head-mounted Display	[24, 30]	[2, 18, 25, 31]
▷ Mobile Projector	[14]	[6, 7, 12, 20, 26, 27, 35, 38]

Table A1: Overview of 38 papers considering the content placement on the *ceiling* and the *floor*.

A Displaying Virtual Content on Floor and Ceiling

Displaying content above on the ceiling and below on the floor was already explored in several use cases, such as a visit to public spaces (e.g., museum) [25, 29], indoor guidance [1, 15, 25], outdoor guidance [2,38], office work [4,37], smart living spaces [5,11,19,28], gaming [8], industrial applications [21], and for awareness and ambient displays [9, 13, 14, 17, 22, 33, 34]. To display content in these areas, monitor systems, stationary and wearable projectors, and HMDs were mainly used in previous works. We can group these works into *UbiComp solutions* and *personal augmentation* considering the used display technologies (see Tab. A1).

The majority of related work can be classified as *UbiComp solutions* using two display technologies: **(1)** Monitor systems with a single or multiple displays on the ceiling [33, 34] or on the floor [15,28], as well as low-resolution displays consisting of individual LED units [36]; **(2)** Projector setups, either with rear projection on the ceiling [37] and floor [3] to avoid shadowing, or front projection on the ceiling [19] and floor [8]. As both display technologies are stationary and mostly directly embedded into the environment, it is possible to optimize the presentation of the virtual content to the environment. Furthermore, by using additional hardware (e.g., Kinect), it is possible to track further information which can be used for, e.g., foot or touch interaction [3, 5, 28] or position, posture, or gesture tracking [8–10, 17, 19, 36]. However, in these works, the augmentation is limited to the predefined local area and, through the global nature of such installations, presented content is always visible to all persons in this environment. Furthermore, areas of displays or the projection can be occluded by persons or objects.

A smaller group of the related literature could be classified as a *personal augmentation* using the following two display technologies: **(1)** Pico-projectors worn, e.g., in a handbag [14], around the neck [26], or at the waist of the user [7], as well as other mobile projectors, such as a projector-quadcopter [12]; **(2)** Head-mounted displays [25, 31]. These technologies allow a mobile and dynamic augmentation of the environment since they are directly bound to the user by, e.g., wearing such devices. In general, body-bound devices allow the presentation of additional virtual information in any given environment, which is also visible in the number of use cases focused on navigational tasks (e.g., [24, 31, 35]). However, optimizing the display of these devices for the real-world environment is more challenging than using stationary setups embedded in the environment. Wearable projectors allow to augment a specific area on either the ceiling or the floor and are limited to the displayable area. In comparison, despite the low resolution of current OST HMDs, they enable to augment both the ceiling and the floor and other areas of the environment simultaneously while not being limited to the FoV of these devices. While Renner and Pfeiffer [25] and Thi Minh Tran and Parker [31] supported navigation task with the floor visualization, to the best of our knowledge, no previous studies have systematically investigated content placement both on the ceiling and the floor using AR HMDs.

While investigating foot-tap interaction with an interface displayed on the floor, Müller et al. [18] found that this kind of interface should be used for short-term and fine-grained interactions. Renner and Pfeiffer [25] showed that interfaces requiring the user to permanently look at the floor for the navigation task are not optimal considering the ergonomics. However, while comparing map locations for a simulated AR pedestrian navigation interface in a fully immersive virtual environment, Thi Minh Tran and Parker [31] found that participants prefer the display location on the floor in front of them than on their hands or as a floating display. In their study, Reiner et al. [24] compared displaying a 2D map in front of the user and a topographic layout of the terrain in the upper visual field in a route confirmation task. While simulating the task in a fully immersive virtual environment, they found that participants with prior virtual reality experience were more accurate during the task with the presentation in the upper visual field.

B Content Placement Parameters and Constrains

To define the placement using the *world-stabilized*, or exocentric, reference frame (see Fig. A1, top row), we use a Cartesian coordinate system with rotation (α, β, γ) and translation (X, Y, Z) parameters. For the *body-stabilized*, or egocentric, reference frame (see Fig. A1, bottom row), we propose using a cylindrical coordinate system with the user's position as its point of origin, a translation combined from the radius (r), azimuth (ϕ) and height (Z), and the rotation (α, β, γ) parameters, accordingly.

Those coordinate systems can be applied to both areas, splitting the coordinate systems into *floor* and *ceiling* variants that are mirrored to each other. This split and the need to keep the virtual content visible lead to a few constraints on the coordinate system parameters. First, as both variants are mirrored, the height (Z) and pitch (α) are also mirrored. Second, the pitch (α) is limited to the range of $0°$ to $90°$. Hence, an angle of $90°$ means that the content is perpendicular to both areas, while at $0°$, the content lies flat on either area and faces inwards. Third, the roll (β) should be blocked and always perpendicular aligned with either area to prevent the content from pervading the physical areas. Finally, the pivot point for the virtual content differs between both areas to ensure that content is always connected to the corresponding plane regardless of its orientation

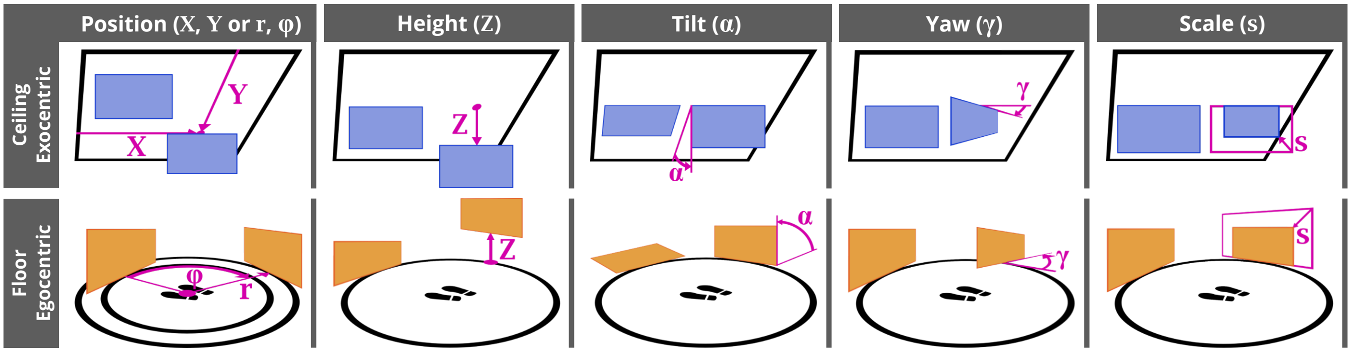

Figure A1: The placement parameters usable on *ceiling* and *floor*. Roll (β) is not included since it is not useful for a good placement. While the first row shows an *world-stabilized*, or exocentric, placement on the *ceiling*, the second shows an *body-stabilized*, or egocentric, placement on the *floor*. However, the opposite is also possible, which means to place content body-stabilized on the *ceiling* or world-stabilized on the *floor*.

Figure A2: Scene 3 of our first study. **(A-C)** illustrates the proximity-based interaction, while they also show show the point of view of the participants.

as long as the height (Z) is 0. This pivot point is at the top center or the bottom center for virtual content on the *ceiling* and the *floor*, respectively.

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