Immersive Computing: Perspectives on Spatial Design Strategies for Individual Virtual Reality Workspace Platforms

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Abstract

Background The rapid increase in remote work due to COVID-19 has recently become one of the general work cultures. The remote working environment (RWE), including emails, messengers, and videoconferencing, has communication limitations, such as less random encounters and synchronous and spontaneous communication. Virtual Office (VO) has emerged as an alternative to overcome the limitations, but it has partially coped with the issues. Virtual reality workspaces (VRWS) have the potential to break through limitations. However, they still need to be actively utilized. Therefore, this paper aims to investigate the current state of VRWS's spatial design and to identify its problems and limitations. In addition, the authors suggest a design direction for the proliferation of VRWS with respect to spatial design based on the design factors from the semi-structured review of previous literature.

Methods Among 42 commercial VRWS platforms, six VRWS platforms including individual workspace are finally selected for design analysis. Design criteria and factors are identified from a semi-structured review of the literature related to design methodologies and assessment, and a framework for design is suggested. The framework analyzes the six targeted platforms, and the design direction for each factor for the future VRWS is claimed from the findings.

Results The insights acquired from the investigation are as follows: First, the significance of individual workspace in VRWS should be emphasized. Second, user activities and interactions should be carefully considered in the spatial design of VRWS for user comfort and improvement of work productivity. Third, the imitation of the spatial design of workspaces in physical reality and the degree of compatibility with existing work tools are inversely proportional. Fourth, the ambience design of a virtual workspace is as significant to job satisfaction and work productivity as the aesthetic design of a physical workspace. Based on these insights, the authors proposed the design direction from the perspectives of spatial structure and usability, task objects and interaction, ambience design controllability, and personalization.

Conclusions The study explores the current issues of VRWS and proposes the design direction of a personal workspace in VRWS via a design framework for its proliferation in the future. This research contributes to academia by laying the groundwork for further research on spatial design methodologies for workspaces in virtual reality and to the industry by providing virtual reality space designers and architects with a baseline for designing virtual reality workspaces.

Keywords Continuous Working Experience, Remote Work, Virtual Reality Workspaces, Working Environment, Work Productivity

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1. Introduction

The COVID-19 pandemic has significantly increased the prevalence of remote working, maintaining higher levels compared to pre-pandemic times even after lockdowns ended. In South Korea, the proportion of remote workers is currently about 20%, up from 5% before the pandemic (KOSIS, 2023). In the United States, this figure has risen from 7% to approximately 35% three years post-outbreak (Parker, 2023, March). Social changes and digital technology advancements have facilitated this shift, making remote work a standard option (Fereydooni & Walker, 2020; Luebstorf et al., 2023; Statista Research Department, 2024). The Virtual Working Environment (VWE), increasingly adopted for remote work, shows its limitations. Initially, the Remote Working Environment (RWE), consisting of messengers, emails, video conferencing, and shared document platforms, was a quick solution to facilitate remote work. However, it has reduced synchronous communications, such as random encounters and spontaneous communications, while enhancing asynchronous communications that are typically more structured and purpose-specific (Yang et al., 2022). Given that workspace is a small society for employees occupying a substantial portion of their time a day (Samani, 2015), this shift in communication has resulted in practical issues, such as decreased belongingness and fewer opportunities for career advancement, which lead to psychological problems, such as feeling loneliness, social isolation, and depressions (Bloom et al., 2015; Fereydooni & Walker, 2020; Galanti et al., 2021; Kłopotek, 2017; Park et al., 2023; Toscano & Zappalà, 2020).

The problem in the current remote working environment is the separation of working experience between individual and communal tasks. While working remotely, RWE was utilized only for communication with others, and it remained inactive while workers were conducting individual tasks. The Virtual Office (VO), another type of VWE represented by Gather, Soma, and Kumospace, has emerged to solve the problem with virtual space and avatars to provide continuous work experience, and it seemed practical shortly, but it has also shown to be not effective on integrating the individual and communal working environments (Cho et al., 2022; Figure 1). For instance, an employee at Zigbang, a company well-known for its rapid transition to a total remote work system with VWE platform Soma, said she had to keep Soma running on her computer inactive even while doing personal work (Nam, 2022). The advent of Virtual Reality Workspace (VRWS) has the potential to overcome the limitations of separate working experiences. VRWS provides users with a comprehensive environment for working with an immersive 3-dimensional virtual reality technology, thereby enabling workers to get continuous working experience (Aufegger et al., 2022; Kim, 2021; Park et al., 2023; Figure 1) by performing tasks with entailing various activities without leaving or changing the working environment for designated daily working hours. Furthermore, working with colleagues in a comprehensive VRWS environment enables synchronous communication, which can solve the psychological problems of RWE by making employees feel a sense of belonging, co-existence with colleagues, and social existence.

Despite its advantages, the VRWS has not yet been widely adopted compared to the VWE (Morning Consult., 2022). As of 2022, sales figures for seven leading Head-mounted Display (HMD) models, which is an essential device for immersive virtual reality, in the VR headset market totaled about 22 million units (VR.Space, 2022, April; Boland, 2023).

With projections of sales reaching around 40 million by 2024, the penetration rate of HMDs among the global workforce, which is estimated to be 3.51 billion (ILO., 2023), is only about 1.14%. The high initial cost, often cited as a barrier, is no longer a significant deterrent, as the financial outlay for establishing VRWS environments is comparable to that of a traditional workstation with desktops in physical offices (Tomlinson, 2021, September), and even more efficient for long-run maintenance.

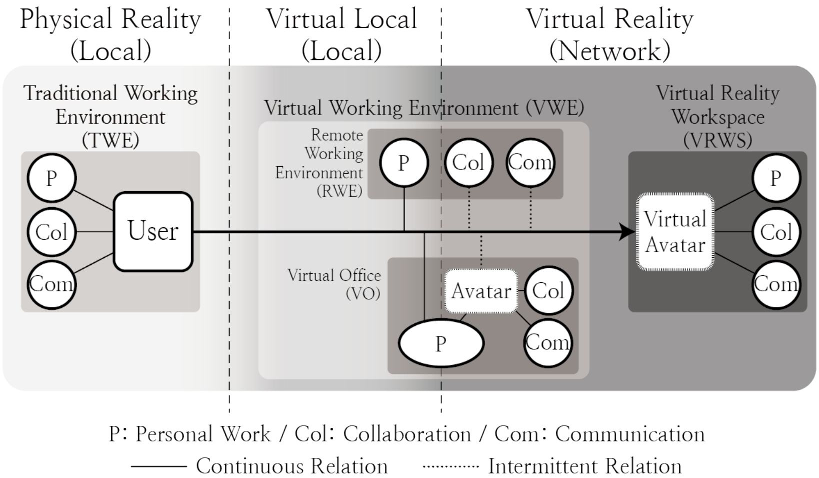

Figure 1 Relationship of User's Work Activities and Spaces within each Working Environment Type

More importantly, it is due to the fact that VRWS still needs to be able to provide a better working experience than VWE. The current VRWS platforms do not yet take advantage of the two benefits of immersive virtual reality, utilizing spatial attributes for working and providing continuous working experience to employees. Indeed, numerous studies have shown the inefficiency of the current VRWS platforms for individual working experience (Biener et al., 2022; Knierim et al., 2018; Grubert et al., 2018b), and there is a noticeable lack of design strategies, guidelines, and even research on design methodologies for an optimal VRWS design. Therefore, the study investigated the significance of spatial attributes in VRWS and proposed a design framework by reviewing the precedented research. Based on the framework, it aims to analyze the existing VRWS platforms in terms of spatial design and initiate a discourse on how to advance the VRWS to support continuous work experiences and improve the spatial experience.

2. Related Works

Numerous studies have demonstrated the value of spatial attributes in enhancing individual task performance by organizing information, streamlining workflows, and improving memory. Spatial Cognition Theory (Hart & Moore, 1973) underscores the importance of these attributes in designing work environments. Further, research shows the effectiveness of spatial cognition in education (Wang et al., 2022) and interface design (Schoeffmann et al., 2014), while a recent study on professional word processing highlights how graphical user interfaces that utilize spatial labeling enhance document efficiency (Muylle et al., 2023). Barkley (2020) noted that externalizing complex information onto a device enhances memory storage and recall. These findings relate to the "method of loci" or "Memory Palaces," proven to significantly boost memory for unfamiliar information through spatial association (Cho, 2018, November; Tomlinson, 2021, September). Thus, integrating spatial attributes into virtual workspace design can substantially improve workers' efficiency, productivity, and satisfaction.

In practical settings, space is widely utilized to enhance workers' task performance. According to an office furniture corporation analysis, workers preferred the 120-degree desk with an expansive desk area, which allowed them to put catalogs and reference papers together and work with them (Fursys, 2020). Additionally, spatial elements such as partitions, office walls, and whiteboards are used to pin up materials. When handling document tasks, the use of physical paper has been found to improve memory by providing spatio-temporal information (Mangen et al., 2013). Notably, an experiment demonstrated that students reading on paper outperformed those using electronic displays regarding memory capability (Myrberg & Wiberg, 2015).

While computers offer convenience in creating, editing, and saving task materials, they are limited by the 2-dimensional space of the display, which is smaller and more restrictive than a physical workspace. This limitation is evident when handling long documents that require scrolling, causing distraction (Mangen et al., 2013), and switching between multiple windows with documents, which increases cognitive effort (Seong et al., 2009). Computer-based environments make it difficult to access specific document sections simultaneously due to operating system constraints (Stoop et al., 2013). Remote working without a separate physical workspace also hampers productivity (Park et al., 2023). Workers often attempt to overcome the restrictions by using multiple monitors (Ling et al., 2017; Owens et al., 2012), or utilizing monitors with printed documents (Seong et al., 2009). However, these solutions pose financial, physical, and functional challenges.

Meanwhile, it is known that the aesthetic aspects of spatial design also influence employees' well-being and work productivity. Research has shown that the customization of the working environment with personal preference is positively related to workers' well-being and productivity. Accordingly, new work cultures are emerging that allow workers to customize their work environment to their personal preferences, such as Workation (Kim, 2023; Lee, 2022; Voll et al., 2023), a culture referring to that workers are free to choose the space where they work, and Desk-terior (Borzykowski, 2017, February; Lee, 2022; Yoon, 2022), a culture explaining that workers decorate their workspace, the desk, to their taste.

In VRWS, using spatial attributes enhances the creation of personal workspaces that mirror the convenience and efficiency of physical work environments, which was previously the limitation of VWE. This capability enables a comprehensive space providing continuous work experience by supporting diverse work activities. By leveraging advanced VR technologies, these workspaces can be customized to fit the unique needs of each worker, thereby fostering increased work productivity, engagement, and satisfaction. Consequently, VRWS can bridge the gap between virtual and physical office setups, offering a seamless transition for workers and ensuring consistent work performance across different platforms. This integration promises a significant advancement in how virtual workspaces are perceived and utilized in professional fields.

3. Analysis of the Current VRWS Platforms based on the Design Framework

3. 1. Design Criteria and Framework for VRWS Design

There are no specific guidelines or framework for designing Virtual Space, especially VRWS, since virtual spaces have long been utilized as analyzing tools for the simulation of physical phenomena in physical spaces. Recently, virtual reality became famous as an alternative world for users during the pandemic, which led to research on the methodologies of spatial design in immersive virtual reality, identifying the limitations and practical issues in use (Berki et al., 2019; Biener et al., 2022), and establish theoretical foundation for the design of virtual workspaces (Aufegger et al., 2022; Ens et al., 2014; Fereydooni & Walker, 2020). Lenk, D. (2023) mentioned three design elements: layout, aesthetics, and interactive elements when designing a virtual office in the Metaverse. These can be compatible with three principles of architecture known as Structure, Function, and Beauty, which have long been the foundation for architecture design in physical reality. Meanwhile, Casteel (2022) proposed a framework for the analysis from the perspective of personal performance and productivity described with Architecture, Productivity Tools, and Soft Factors, explaining how to operate the system, interact with information, and communicate with space and people. Besides, Fujita et al. (2023) asserted the definition of "Human-Workspace Interaction," and they applied seven categories (Visual, Physical, Postural, Social, Interactivity, Atmosphere, and Design) to analyze the interactions of humans in workspaces. Considering the results and opinions, the authors proposed a design framework for VRWS consisting of 3 design criteria.

Structure design is defined as a skeleton of a spatial configuration of VRWS wherein users can ascertain their location and engage with virtual space and objects. Within the realm of virtual reality workspaces, two distinct spatial dimensions exist: cognitive space and interactive space. Cognitive space is a sort of passive space perceived by users with sensory organs, specifically visual sensors, through the incorporation of design elements such as floors, walls, and ceilings. In contrast, interactive space serves as the domain where users practically engage with one another and manipulate objects present within the cognitive space. This conceptual distinction aligns with the structure elucidated in the three principles of architecture, encompassing the 'Visual, Physical, and Postural' categories by Fujita et al. (2023).

Ambience Design is a sensory area of spatial design influencing users' cognitive psychological states, which are relevant to employees' work productivity and satisfaction. It deals with all aspects of aesthetic design available in VRWS, including the location of the office by changing the background scenery over the windows, such as an office with a city view, a beautiful park, mountains, and the cosmos and galaxy space, and user's autonomy to modify the spatial design elements such as texture, color, and brightness, and to decorate the work area with accessories and ornaments. It represents Beauty from three principles of architecture, and includes the 'Atmosphere' and 'Design' among the seven categories.

Interaction Design is to define the interactions among users, objects, and space in a virtual reality environment. It is closely related to worker's productivity and satisfaction with spatial experience. It has generally been called a "productivity tool" by previous research. This criterion deals with layouts and frames of the space, in which virtual objects are able to be located in order, arranged and rotated or zoomed in and out, and compatible with other types of data, programs, applications, or hardware devices. It is the same with Function from the three principles of architecture, and includes the 'Physical', 'Social', and 'Interactivity' among the seven categories.

3. 2. Analysis of the Current VRWS Platforms

In this paper, the authors defined four types of working environments (TWE, RWE, VO, VRWS) to classify the current platforms and limit the scope of design analysis. Based on the definitions, 42 platforms in service using HMDs in virtual reality environments were first selected as the targets for spatial design analysis (Lang, 2021; Traqq Team, 2024, January; XR4Work, n.d.). Among these, the platforms with specific purposes such as 3D visualization, digital twin, simulation test, education, socializing entertainment, or not concerned with work were filtered, and 14 remained. Again, platforms not supporting personal work were excluded, and six platforms (Ⅰ. Virtual Desktop VR, Ⅱ. Horizon Workrooms, Ⅲ. Immersed, Ⅳ. vSpatial, Ⅴ. Softspace, Ⅵ. Noda) were finally chosen as candidates for spatial design analysis (see Figure 2). The case analysis is predicated on the authors' experiential engagement with the Meta Quest Pro devices and the empirical examination of spatial configurations. Additionally, insights have been derived from user comments and reviews, ensuring a comprehensive and objective assessment.

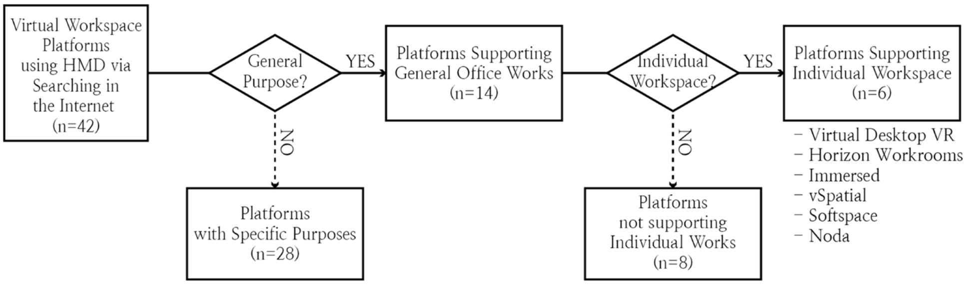

Figure 2 Research Flow Chart for Scope of Analysis

In the context of Structure Design, four platforms (Ⅰ, Ⅱ, Ⅲ, Ⅳ) adhere to a "desk-type" structure (Figure 3, Left), akin to a traditional computer-based workstation environment in the physical realm. Within this configuration, users are encouraged to maintain a sedentary posture, and a virtual screen, mirroring a conventional monitor display, serves as the interactive space. While users can employ multiple virtual screens in this design, spatial utilization remains suboptimal, since the quantity of the display varies from only a solitary screen (Ⅰ) to as many screens as the cognitive space permits (Ⅳ). Conversely, two platforms (Ⅴ, Ⅵ) adopt a "space-type" structure (Figure 3, Right), which liberates users from posture constraints. In this design, information and materials manifest as virtual objects suspended in the air. Notably, the interactive space closely aligns with the cognitive space, suggesting a High-level portion of space utilization.

Figure 3 Desk–type (Left, Horizon Workrooms) and Space–Type (Right, Softspace)

Regrettably, the flexibility of ambience design within VRWS is limited. Users can switch places, yet this is constrained to pre-designed options with a minimum of three to a maximum of thirteen choices, and users cannot edit them or import their own scenery or images of places. In general, desk-type platforms offer a more extensive array of location choices compared to space-type platforms. The feasibility of incorporating interior design functionality is more apparent in desk-type platforms, as the implementation of primary functions for task performance is simplified by connecting a personal computer to the virtual environment. It is also noteworthy that the personal embellishment of the interactive space through accessory and ornament objects is unavailable across all platforms.

In the realm of interaction design, desk-type platforms exhibit limitations in the disposition and arrangement of information. This constraint stems from the confined interactive space, primarily dedicated to virtual screens, each with an allocated frame for screen disposition. While Ⅲ and the focus mode in Ⅳ permit users to position and rotate screens freely, Ⅰ allows only one virtual display, and Ⅱ allows up to 3 screens with fixed layout. Nevertheless, they demonstrate heightened compatibility through seamless integration with personal computers.

Contrary to their desk-type counterparts, space-type platforms afford greater freedom in disposition. Task materials and information snippets are represented as virtual objects floating in the air in the virtual space. Users can easily extract the information from the objects and position, scale, transform, and edit freely regardless of the type of information, such as texts, images, videos, and others. However, they need predefined layouts or frames to arrange the objects in order, potentially causing confusion. The compatibility of the platforms is comparatively diminished as they operate independently within the HMD. While Ⅴ is designed to utilize contents from the internet and existing work tools in the form of virtual objects, Ⅵ requires users to create content entirely using objects within the platform.

The authors found two common factors in the individual workspace of VRWS for each criterion. In Structure Design, there are Spatial Configuration and Spatial Utilization. The former one is categorized with desk-type and space-type, as seen in figure 3. The latter classified the candidates with low-level (same number of screens with physical environment), medium-level (the number of screens can exceed that in physical environment), and high-level (user can interact with infinite volume in 3-dimensional virtual space).

Ambience Design has a Diversity of Places and Freedom of Interior Design. The former is the number of options that users can change the office location, divided into low-level (fewer options up to five, only pre-designed realistic scene), medium-level (pre-designed scene, supporting realistic, hyper-realistic, and abstract scene), and high-level (diverse scene types, support pre-designed and customizable scenes). The latter is freedom of the customization of design elements in VRWS, from N/A (not available), low-level (only adding virtual ornaments on the table or locating them in the space), medium-level (available to change texture, color of finish, changing furniture), high-level (transform the form, height, area of VRWS).

Interaction Design consists of two factors, such as Disposition and Layouts, and Compatibility. The former is the freedom of virtual objects to be positioned and arranged, divided by low-level (fixed layout, not movable), medium-level (location changeable within the fixed layout), and high-level (freely positioning without any obstacles). In terms of Compatibility, It is divided into low-level (purely independent from the outer environment), medium-level (information and files can be imported), and high-level (software and programs can be operated). The results of the analysis are summarized in Table 1.

Table 1 Results of Case Anlayses based on Design Framework

Design Framework			Virtual Desktop VR	Horizon Workrooms	Immersed	vSpatial	Softspce	Noda
Spatial Design	Structure Design	Spatial Configuration Type	Desk	Desk	Desk	Desk	Space	Space
		Spatial Utilization	Low	Low	Medium	Medium	High	High
	Ambience Design	Diversity of Places	Medium	Low	Medium	Medium	Medium	Low
		Freedom of Interior Design	N/A	N/A	N/A	N/A	N/A	N/A
	Interaction Design	Disposition and Layouts	Low	Low	Medium	Medium	High	High
		Compatibility	High	High	High	High	Medium	Low

4. Discussions and Conclusions

The case analysis yields the following insights: First, the current platforms for VRWS do not yet seriously consider the importance of individual workspaces. In order to provide a continuous working experience to users, the platform needs to contain various working activities such as individual task performance, meetings, conferences, workshops, socializing, and relaxation. However, the current platforms tend to focus only on communication and collaboration, which is the same as the aim of VWE. Furthermore, the inadequate design of individual workspaces in VRWS incurs inconvenience and discomfort in use and leads users to avoid the platform.

Secondly, the spatial design of virtual workspaces should consider user activity and interaction, reflecting a solid interdependence between structure and interaction design. Physical constraints such as gravity, irreversibility, the fixed spatial arrangements are no more significant factors for design in virtual reality, allowing user activity to influence spatial design predominantly. As such, in VRWS, spatial design should evolve to enhance the efficiency and comfort of user interactions within the workspace.

Thirdly, as VRWS evolve from traditional desk-type setups to more expansive space-type configurations, compatibility issues emerge. In order to facilitate quick adaptation and popularization of VRWS, it is essential that applications and software familiar in a computer-based environment be usable in VR. However, mimicking physical desk settings in VRWS limits the capabilities of the 3-dimensional virtual space, constraining both its design potential and deteriorating work productivity, comfort and satisfaction. Therefore, achieving a balance between compatibility and interactivity is crucial for leveraging the full potential of virtual environments.

Lastly, this analysis underscores the often overlooked significance of the ambience design of VRWS, which is a pivotal determinant for enhancing work productivity and satisfaction. Constraints, such as a limited array of place options and the absence of micro-scale customization for interior design details impede effective spatial atmosphere control. The current landscape confines users to pre-configured spaces curated by platform creators devoid of user autonomy. To fully exploit the potential of virtual reality in ambience design, it is imperative that users have the capacity to customize it independently.

Based on the insights derived from the analysis, the study proposes critical considerations for the spatial design of VRWS. First, in structure design, it is crucial not to limit spatial design to a single configuration, as the needs for posture and interaction vary based on business types, specific situations, and individual work styles. The intended use and target users of the VRWS should guide the design process. Moreover, extending the interactive space to the maximum extent that cognitive capacities allow but within a sensible range is advisable. In virtual environments, users may struggle to interact with objects that are too distant. Therefore, the design should ensure all objects are within a reachable and easily recognizable area to facilitate effective user engagement and interaction.

From the interaction design perspective, VRWS should be designed with structured frameworks or clusters to organize virtual objects systematically, preventing user confusion and reducing cognitive effort by grouping related information. Additionally, research into the three-dimensional positioning and scalability of virtual objects is crucial for providing a superior user experience compared to traditional screen-based environments. Maintaining compatibility with existing computer-based processes is critical for productivity and a significant barrier in transitioning from VWE to VRWS. Efforts should be made to develop applications that can operate effectively within VRWS or enable these systems to use computer-based software seamlessly, without direct integration with personal computers, thus enhancing the functionality and efficiency of the virtual workspace.

Lastly, personalizing the design to control the atmosphere and user comfort is vital to spatial design in VRWS. Contrary to a physical office setting, users are authorized to fully control every perceivable aspect of the space within a VRWS. Nevertheless, it is crucial to acknowledge that VRWS is not inherently a spatial design tool, rendering it impractical to customize the entire virtual space. It becomes imperative to discern the scope of spatial design, striking a balance between optimizing work efficiency, ensuring convenience, and fostering psychological satisfaction.

Integrating Artificial Intelligence (AI) into VRWS significantly enhances user interaction and spatial design. AI's ability to process user-collected data—such as posture, bio-signals from simple sensors, and voice commands—enables real-time, adaptive responses that improve comfort, health monitoring, and workflow optimization. As Fukumura et al. (2021) suggest, workers anticipate AI to manage their working conditions for enhanced comfort and productivity automatically. AI not only acts as an assistant by suggesting healthier work habits and managing sub-tasks but also revolutionizes workspace customization through generative AI, which tailors environments to individual preferences, thereby expanding design flexibility and increasing user satisfaction. This adaptive approach makes VRWS more intuitive and personalized, meeting the unique needs of each user.

The study investigated the current state of VRWS design, proposed a trajectory for the progress of spatial design in VRWS, and especially highlighted the significance of designing individual workspaces in VRWS for providing continuous working experience, which needs to be improved in VWE. The study still has several limitations in that it needs to deal with the physical facets associated with prolonged HMD use, such as ergonomics of physical posture and technical feasibility, which are not included in the scope of this study. This issue should be resolved before the VRWS design is discussed. It should be carefully considered for future research via collaboration with relevant fields to develop physical devices and the environment together. Nevertheless, the findings in this study are remarkable for its analytical investigation of design methodologies for VRWS from a spatial standpoint, establishing the groundwork for objective and quantitative research of VRWS design.

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