Data-driven Home Workspace Design: Interactive DIY Platform Mediating the User and Expert Literature

by

Wangli Yi
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Authored by: Wangli Yi
Department of Architecture
April 29, 2024

Certified by: Takehiko Nagakura
Associate Professor of Design and Computation
Thesis Advisor

Accepted by: Leslie K. Norford
Chair, Department Committee on Graduate Students
Professor of Building Technology

Thesis Committee

Takehiko Nagakura, PhD

Associate Professor of Design and Computation

and reader

George N. Stiny, PhD

Professor of Design and Computation

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ABSTRACT

After COVID-19, some employees have opted to continue working from home (WFH) or have chosen a hybrid working mode. Previous research has shown that satisfaction with the physical environment and characteristics of home workspaces are directly related to mental health, which can affect productivity and well-being. This underscores the need for better designed WFH environments. This study explores the use of data-driven tools in interior design to enhance WFH setups. It posits that these tools can transcend traditional design limitations by incorporating professional expertise and facilitating user-driven design processes.

The tool's backend is built on a comprehensive collection and classification of research literature on WFH environments, creating an interactive platform where users can engage directly in the design process. This is achieved through real-time, machine-mediated suggestions that enhance well-being without the need for professional human designers. Employing a user-centered design framework, the study develops and tests a prototype to assess its effectiveness in empowering users to intentionally and sensitively redesign their home workspaces.

Results show that participating graduate students became more aware of their WFH environment during the design process, but largely it did not change their existing workspace decisions. This observation indicates the potential benefit of this interactive machine-mediated system as a design education tool. Further test on other demographic groups, such as those who need to focus for long hours professionally at home as well as those who are specifically concerned with mental health issues, is anticipated as the next step for the evaluation of this platform.

Thesis Advisor: Takehiko Nagakura

Title: Associate Professor of Design and Computation

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I wish all of you the very best.

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1. Background and Introduction

1.1 Post-Covid-19 and working from home

Since the early 21st century, the concept of working from home (WFH) has gained traction, heralded for enhancing work-life balance and well-being through increased flexibility and improved concentration (Fan Ng, 2010; Grant et al., 2013; Nakrošienė et al., 2019). The COVID-19 pandemic of early 2020 escalated this trend, compelling a significant shift to WFH and thereby increasing the number of remote workers dramatically (Oakman et al., 2020). Initially, this shift was broadly welcomed, with many employees quickly adapting to this new norm. Companies, having invested in the infrastructure for remote working (Bartik et al., 2020), are now evaluating the long-term financial benefits of reduced office space. Debates over the need for offices becoming obsolete overtime gave way to predictions of a more "hybrid" future for office workers (Appel-Meulenbroek et al., 2023). Employees in a hybrid working style are expected to work some hours in the office and some hours at home or in other locations.

The adoption of WFH has not only reduced commuting time but also increased flexibility for employees to manage family responsibilities. It allows workers to optimize their schedules according to peak productivity times and reduce distractions from open office layouts (Kim & de Dear, 2013). Furthermore, individuals can better control their indoor environmental quality (IEQ), such as lighting, temperature, and noise, which are crucial for both physical and mental health (Samani, 2015).

However, the transition to WFH is not without challenges. It can lead to decreased physical activity, extended screen time, and potential social isolation, especially for those living alone, which might contribute to mental health issues like depression and stress (Mann & Holdsworth, 2003). The blurred boundaries between work and life may also hinder psychological detachment from work tasks (Vander Elst et al., 2017), increasing anxiety and stress levels (Evanoff et al., 2020). Additionally, the home environment often lacks the ergonomic design of traditional office spaces, leading to discomfort and potential health issues (Baradaran Mahdavi & Kelishadi, 2020).

Person-environment fit theory suggests that the alignment between an individual's needs and their work environment is crucial for well-being and productivity (Bentley et al., 2016; Carnevale & Hatak, 2020). Therefore, understanding and addressing these mismatches is essential for both employees and employers to minimize potential negative impacts (Williamson & Perumal, 2021).

In summary, the pandemic has changed the context in which work and home life are discussed in relation to WFH. It is crucial to have a thorough awareness of the elements of this new setting that affect both physical and mental health in order to guarantee favorable outcomes for office workers who may soon WFH. In particular, both businesses and employees need knowledge about how to reduce adverse health effects for workers who want or are required to work from home. The impact of the working environment on personal well-being emphasizes how important it is for each person to better create their own WFH environments to satisfy their various preference.

1.2 Barriers to the traditional design process

However, increasing personal working environment quality is challenged by the layperson's limited sensitivity and imagination regarding space and interior design, hindering their ability to visualize and conceive new designs accurately. To improve the design of their WFH environment, they have to seek assistance and advice from professional designers, but communication becomes another problem.

In the realm of traditional design processes, communication challenges are prevalent. As professionals in space design, we possess an acute sensitivity to the physical environment, though expressing our spatial perceptions or desires can sometimes be challenging, even more so for those without any background in space design. Miscommunications between clients and designers are common, largely because clients may have a constrained vision of spatial design and often require assistance in articulating their personal desires. These miscommunications can be unclear briefs, mismatched expectations, or difficulty in visualizing proposed designs. Typically, these interactions involve repetitive exchanges that, more often than not, culminating in the abandonment of design concepts. The risk of misinterpreting people's needs is high, prompting some to attempt designing independently.

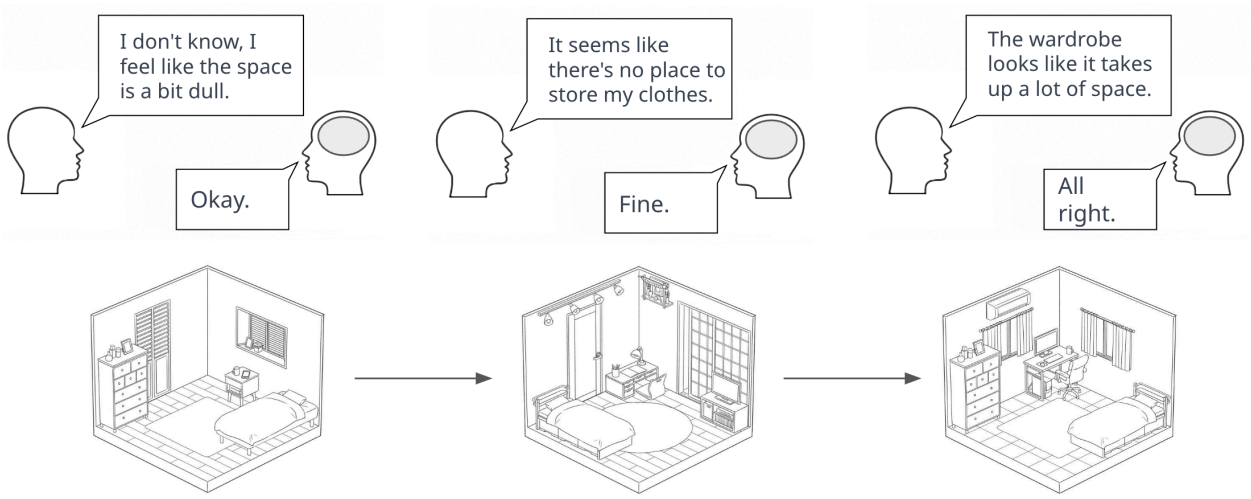

Figure 1.1. Iterative Traditional Design Process – Dialogue between Client and Designer

Since workspaces have more defined and specific functional requirements to enhance productivity and promote well-being compared to other interior spaces, with the introduction of computational design approach, there is potential for leveraging human-machine interactions. This design assistant tool replaces the role of traditional human designers, encapsulating their expertise within the system. The objective is to bridge the gap between a user's capability and professional design knowledge, enabling a more intuitive, direct, and personalized design process that meets the unique needs of remote workers.

1.3 Thesis claim

The traditional design process often presents challenges, especially when it involves interactions between users and human designers. These challenges include communication barriers and the difficulty in accurately translating user needs into tangible designs. In response to these issues, this thesis explores the potential of data-driven tools to revolutionize this dynamic.

The thesis aims to address two key questions: How can data-driven tools directly empower users to design their living and working spaces, catering to their unique preferences and needs? How does the introduction of data-driven tools transform the traditional design process into a user-centric, machine-mediated experience?

This thesis posits that by integrating insights from existing research on work-from-home environments with contemporary computational components, it is feasible to develop an advanced synthetic design assistance tool. This tool, distinct from an autonomous generative design bot, would encapsulate the design intelligence of professional designers and published design knowledge accumulated by research scholars, and facilitate an interactive dialogue with users. Thereby, it is envisioned to aid them in crafting solutions with a sense of authority that are not only satisfying but also aligned with their unique spatial needs and preferences. The thesis tests this claim by building a prototype assistant system, inviting human subjects to use it to redesign their work-from-home environment, and evaluating their feedback.

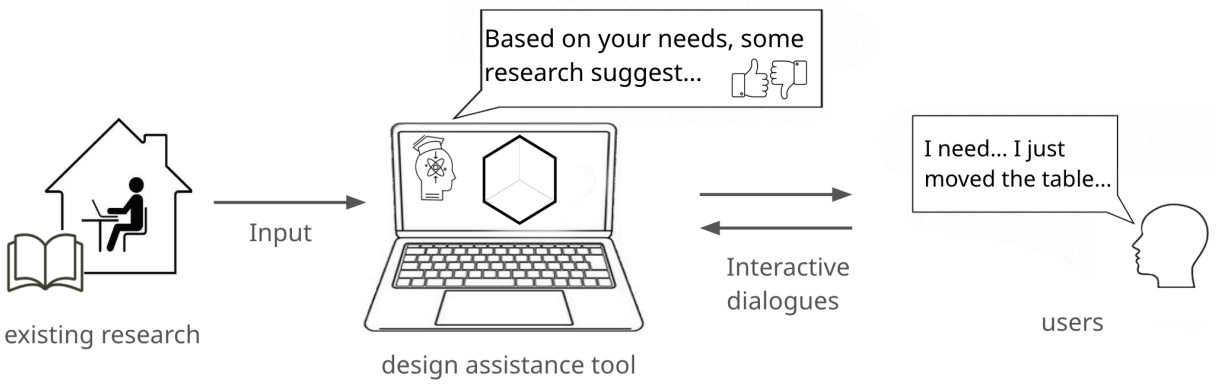

Figure 1.2. Overview of Proposed Computer-Aided Design Assistance Tool

It explores how data-driven tools can facilitate a more direct and efficient design experience, where users interact solely with the machine. This approach aims to empower users to create living and working spaces that resonate with their individual preferences and needs, without the intermediary of a human designer.

2. Literature Review and Gap Analysis

2.1 Precedents of computational models for assisting the design process

2.1.1 Architecture by Yourself

The "Architecture by Yourself" project by MIT's Architecture Machine Group (AMG) was a pioneering venture in computer-aided design for non-architects (Weinzapfel & Negroponte, 1976). This 1975-1977 project aimed to democratize architectural design, allowing users to design their own spaces through an intuitive, graphical interface. It emphasized a step-by-step, user-centric approach, introducing users gradually to design complexities. The project was significant for its innovative use of graphical

interaction and its role in advancing the concept of 'Graphic Conversation,' redefining the human-machine relationship in the design process.

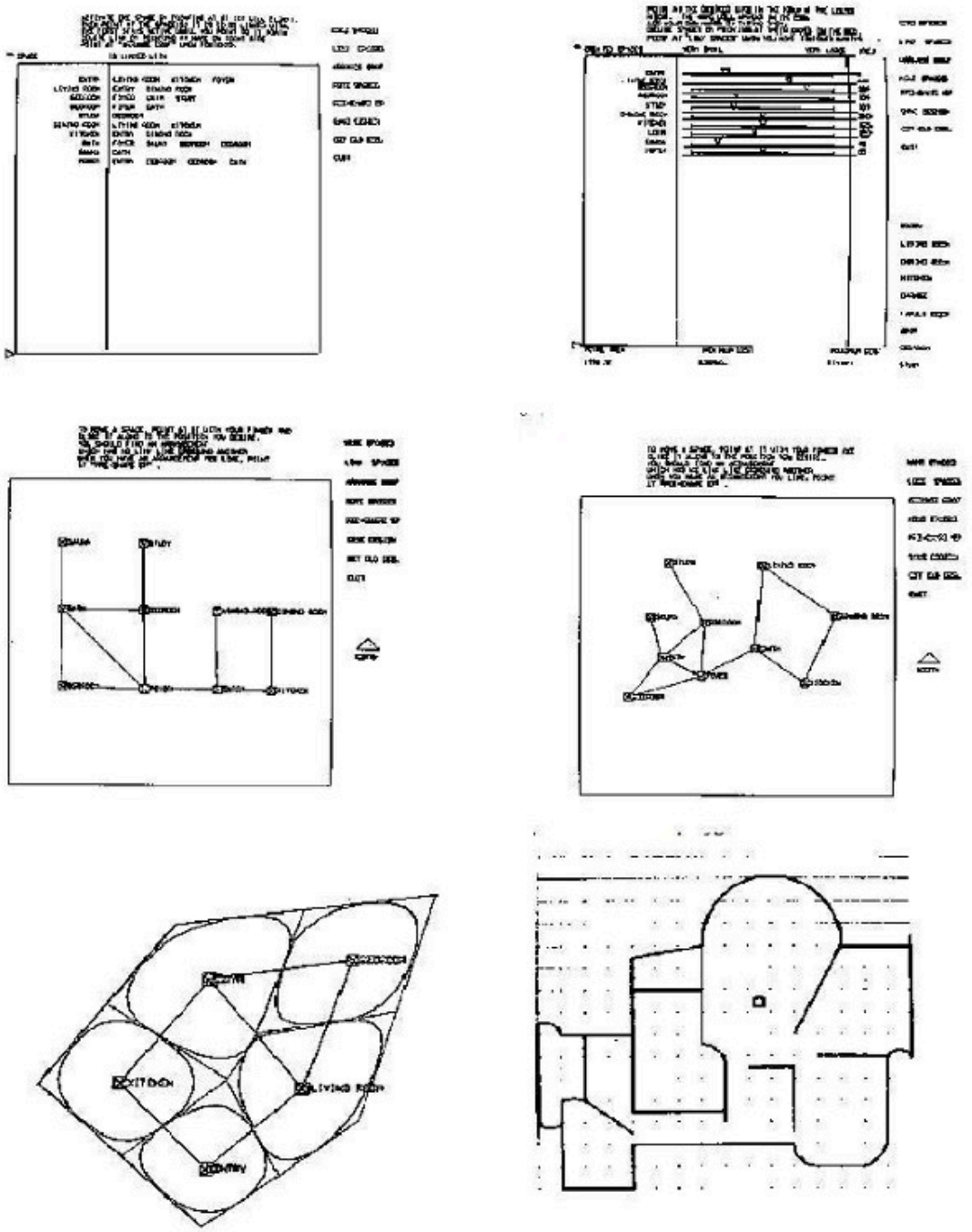

Figure 2.1. the Architecture By Yourself design process. From (Weinzapfel & Negroponte, 1976)

2.1.2 House-GAN++ - Automated Floorplan Generation

House-GAN++ represents a significant advancement in generative adversarial networks, offering an innovative layout refinement mechanism for the automated generation of multiple floorplans (Nauata et al., 2021). This system functions based on input bubble diagrams and operates without the need for human intervention in the generation process, marking a notable stride in autonomous design technology.

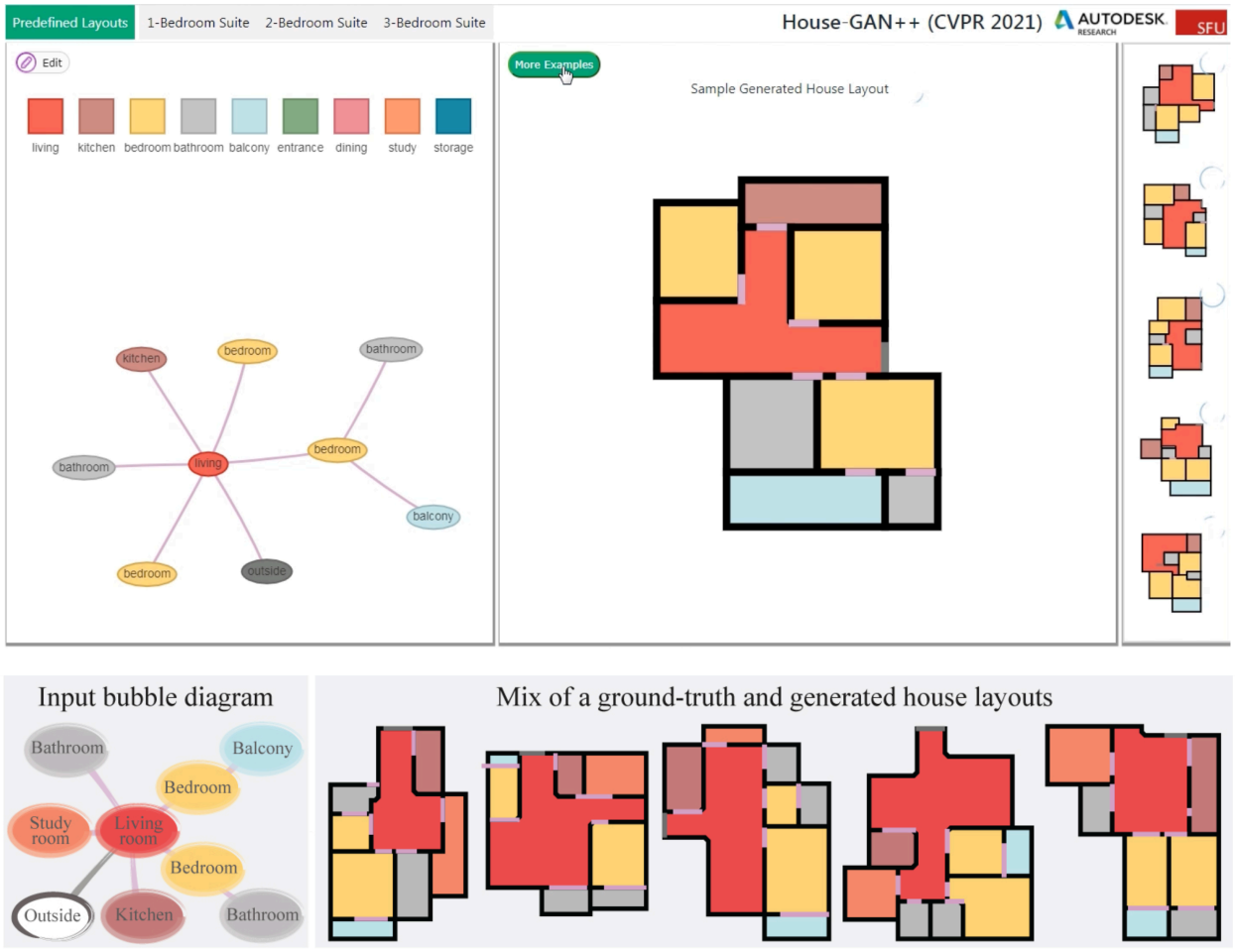

Figure 2.2. the House-GAN++ generative design process. From (Nauata et al., 2021)

2.1.3 IKEA Kreativ - User-Centric Space Design

IKEA Kreativ empowers customers to scan their personal spaces or utilize styled templates as a starting point for online space design with IKEA products. This user-friendly tool facilitates a seamless transition from design conceptualization to procurement by generating a product list and directing users to the purchase page, thus integrating the design and purchasing processes.

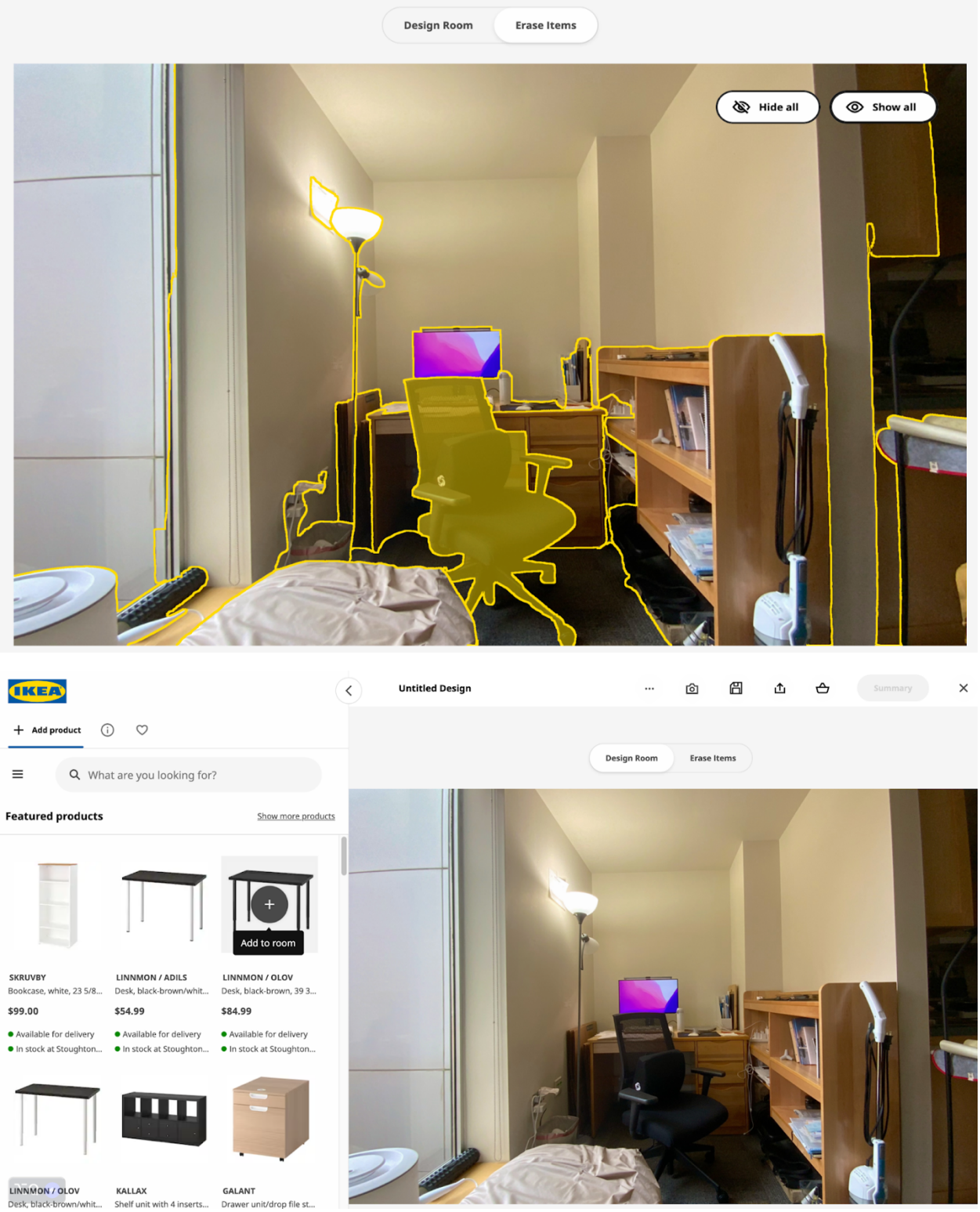

Figure 2.3. Ikea Kreativ online visualization tool. (a) Supports removal of original furniture from the 2.5D image (b) Allows users to visualize new furniture in 2.5D in their own room. From (IKEA Kreativ - Home Design App for Inspired Living Spaces, 2024).

2.1.4 Planner 5D: Comprehensive Interior Design Tool

Planner 5D stands out as an interior design tool equipped with an automatic room generator, AI-based plan recognition, AR-driven 3D interior projection, and automated furniture arrangement features. Additionally, it links to a digital shopping cart, simplifying the process for customers to purchase items from their designs. However, a notable limitation is that these processes lack user control and fine-tuning capabilities, restricting personalization.

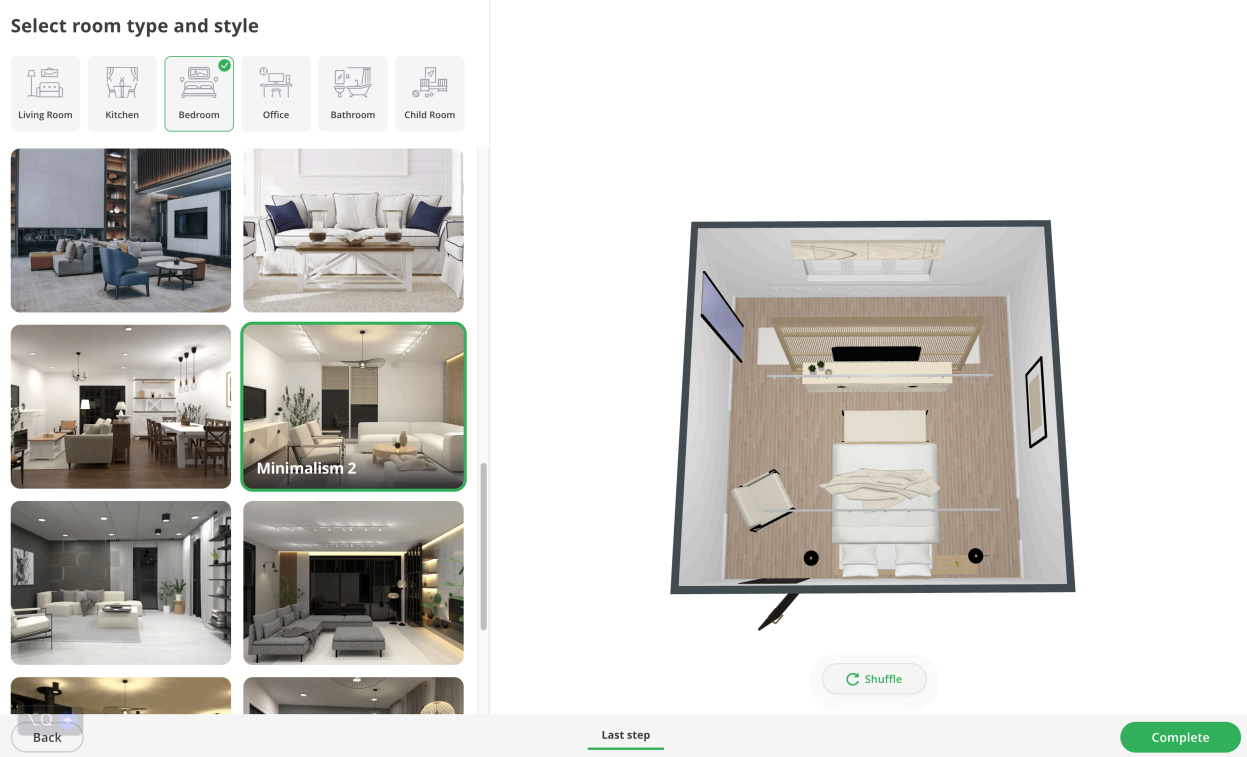

Figure 2.4. the Planner 5D generative design process. Planner 5D supports furniture placement as well as stylization. From (Create Design in a Room Planner Online - Planner 5D, 2024)

2.1.5 General-Purpose Network Models for Task Assistance – ChatGPT

As a general-purpose model, ChatGPT assists in various tasks but demonstrates limitations in specific contexts like interior design (ChatGPT, 2024). When presented with different furniture arrangements in the same layout, ChatGPT struggles to accurately recognize room locations and the relational dynamics of furniture placements. Its responses tend to be generic, highlighting a lack of creative intuition and a limited capacity for complex, creative problem-solving in design-specific scenarios.

For example, in Figure 2.5, the pair of images have the same room boundary, restroom, kitchen, and living room layout. The only difference is that image A's bedroom consists of a bed and a nightstand, while B's bedroom has a bed and a wardrobe, which in the area circled. When successively inputting these two images and asking GPT for suggestions on redesigning the bedroom and comparing the feedback, it cognizes these two pictures with confused logical relationships, saying, "The second feedback seems to build upon the first." When both images were put in at the same time to compare the differences, it felt that both bedrooms had a bed, a nightstand, and a wardrobe.

Bedroom A: bed and nightstand

Bedroom B: bed and wardrobe

Figure 2.5. Example inputs where ChatGPT struggles to differentiate furniture arrangements. From (ChatGPT, 2024)

2.1.6 Conclusion

In summary, while computational models have greatly advanced the capabilities of non-professionals in designing spaces, these tools also illustrate a variety of challenges, particularly in personalization and detailed user control. Future developments in this field could focus on enhancing the interactivity and customization of design tools to better meet individual user needs, thereby further democratizing the design process.

2.2 Research on the impact of the work environment on human well-being

2.2.1 Overview of Recent Studies

The COVID-19 pandemic has necessitated a shift to working from home (WFH), creating a unique opportunity to evaluate the impact of home indoor environmental quality (IEQ) on worker health. Several recent studies have addressed various aspects of this phenomenon, focusing on how physical and social conditions at home affect physical and mental well-being.

2.2.2 Key Findings on Indoor Environmental Quality and Health Outcomes

(Awada, Lucas, et al., 2021) conducted a comprehensive survey, analyzing the satisfaction with home IEQ factors and their association with worker health. They found that low satisfaction with natural lighting, glare, and humidity significantly predicted eye-related symptoms, while noise dissatisfaction was linked to fatigue, headaches, anxiety, and depression. Similarly, dissatisfaction with air quality was associated with mental stress symptoms, and poor noise and temperature conditions correlated with concentration difficulties.

(Xiao et al., 2021) expanded on these findings by considering additional factors like physical exercise, food intake, and communication with coworkers. They observed a decline in both physical and mental health statuses, emphasizing the role of decreased physical activity and increased junk food intake as significant predictors of health issues.

2.2.3 Influence of Workspace Design on Mental Health

(Bergefurt, Weijs-Perrée, Appel-Meulenbroek, & Arentze, 2022) conducted a systematic scoping review to explore how physical workplace characteristics influence mental health. They identified that while certain IEQ factors like light and noise are well-studied, others, particularly biophilia and overall ambiance, need more research. The findings suggested that enhancing workplace design could potentially improve mental well-being.

Another study by (Bergefurt, Appel-Meulenbroek, Maris, et al., 2023) examined the effects of workspace distractions at home, finding that noise and inadequate workspace were major distractions that impacted mental health. They recommended that employers consider more flexible work policies and support in optimizing home workspaces to mitigate these effects.

2.2.4 Economic and Demographic Influences

These studies consistently highlighted that higher income workers reported better satisfaction with IEQ factors and overall mental health. Age also played a role, with older workers generally more satisfied with their home working environments. These demographic factors are crucial in understanding the varied impacts of WFH on different groups.

2.2.5 Practical Applications and Future Research

The combined findings from these studies provide a robust foundation for designing healthier home workspaces. There is a clear need for employers to consider both the physical setup and the social support systems necessary to foster a conducive work environment at home.

2.2.6 Conclusion

This review underscores the significant impact of home IEQ on worker health during the pandemic, highlighting the critical need for effective home workspace design to support employee well-being. As remote work continues to be a prevalent mode of operation, these insights are invaluable for both researchers and practitioners aiming to promote healthier and more productive work environments.

While previous research has provided a wealth of knowledge through extensive literature reviews and experimental studies, there remains a significant gap in the practical application of these findings to real-world settings. Many studies fail to incorporate user-centered approaches, leading to a disconnect between the theoretical benefits of optimized indoor environmental quality (IEQ) and their practical implementation in personal and home office spaces. This oversight hinders the direct application of academic insights to enhance the environments where individuals work and study daily.

To address this deficiency, my research seeks to bridge the gap between academic findings and practical applications by focusing on the development of a data-driven system tailored for home workspace design. This system emulate the decision-making capabilities of human experts by storing and utilizing knowledge to solve complex problems that typically require human expertise. This approach is

particularly suited for designing personalized, health- and productivity-enhancing work environments at home, a need that has become increasingly relevant in the current widespread work-from-home landscape.

By integrating data-driven tool with user-centered design principles, this system will not only leverage academic research for practical application but also enhance personal and home office spaces in ways that align with individual preferences and needs. This approach promises to transform the theoretical benefits of workspace optimization into tangible improvements in mental and physical health for home workers.

3. Methodology and Framework

3.1 Introduction

The methodology of this study encompasses both backend and frontend development, coupled with user testing, to optimize home workspace design based on environmental quality and user perception. Initially, the backend development focuses on analyzing physical workspace features, such as air quality and lighting, and their impact on user well-being, informing the database that supports the frontend application. Subsequently, the frontend interface is crafted to provide an interactive and intuitive design experience, allowing users to customize their workspace based on empirical data and personal preferences. User testing with diverse participants further refines the system, ensuring it meets practical needs and enhances user understanding and interaction with their environment, ultimately aiming to boost mental and physical health.

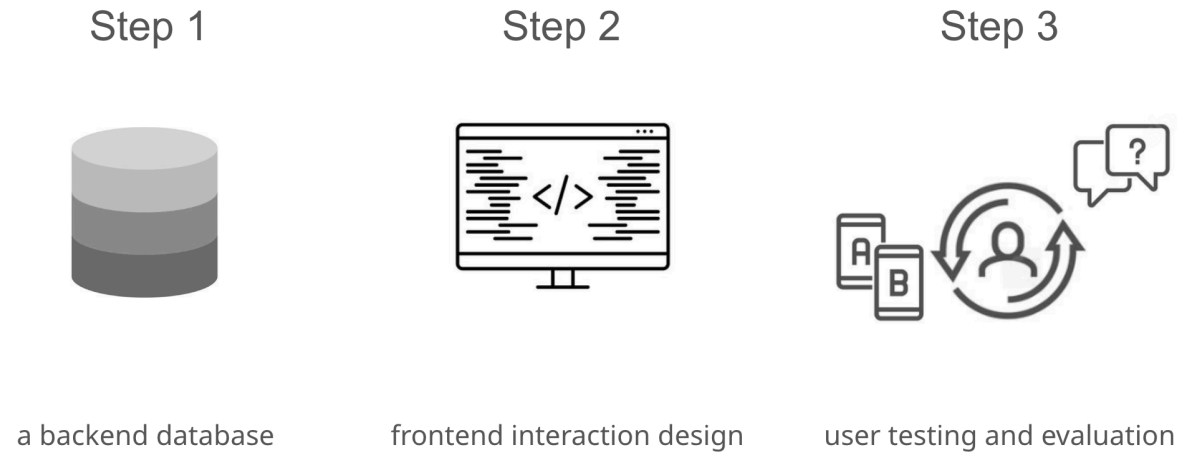

Figure 3.1. Overview of three-step development methodology

3.2 Backend database development

3.2.1 Overview of Backend Development

The backend development process begins with identifying key physical features of the home workspace, which serve as benchmarks for assessing current environmental quality and spatial design. Utilizing a

user-centered research approach, this study focuses on how these physical attributes influence occupants' sensory perceptions and subsequently impact their mental and physiological health. Several studies have detailed the effects of physical workspace attributes on well-being; their findings provide evidence-based guidelines that inform the platform's design recommendations aimed at enhancing specific aspects of well-being. This step is pivotal as it establishes the foundational data that informs the subsequent development stages of our backend database, which is designed to optimize environmental quality for enhanced well-being.

3.2.2 Physical Features of Home Workspace

The physical work environment encompasses all tangible elements and stimuli encountered by individuals in their workspace (Roskams & Haynes, 2019; Sander et al., 2019). It is a complex psychophysical system that includes not only the objective physical stimuli but also how these stimuli are perceived by the occupants (Roskams & Haynes, 2019). Factors contributing to indoor environmental quality (IEQ) include air quality, access to daylight, acoustic conditions, and control over lighting and thermal comfort. The functionality and layout of the workspace, privacy levels, and the materials used for furniture and decorations also significantly influence the overall ambiance and user experience.

Each of these aspects is scrutinized for its potential impact on user experience, referencing a wealth of studies that link environmental quality to well-being. This comprehensive evaluation aids in structuring a backend system that not only captures these variables but also analyzes their interrelationships to guide effective workspace customization.

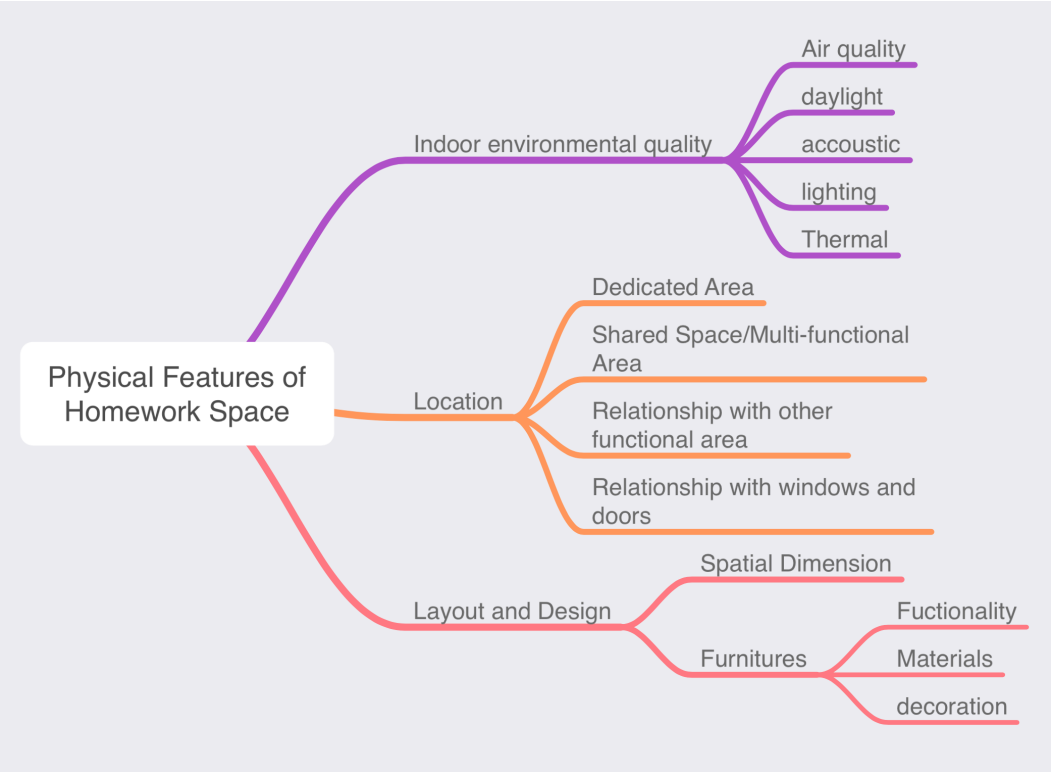

Figure 3.2. Components that make up the physical features of at-home working space

3.2.3 How Humans Perceive Physical Features

Humans interact with their environment through the five senses: touch, hearing, sight, smell, and body. This sensory information, processed along with memory and cognition, forms a unique perceptual experience. This section explores how different environmental features influence these sensory modalities. Based on this, multiple suggestions from the literature are extracted and classified for further study. By correlating these sensory experiences with empirical data from existing literature, our backend development aims to create a robust platform that offers actionable insights and recommendations. These recommendations are tailored to enhance the physical workspace, thereby fostering an environment conducive to better mental and physiological health outcomes.

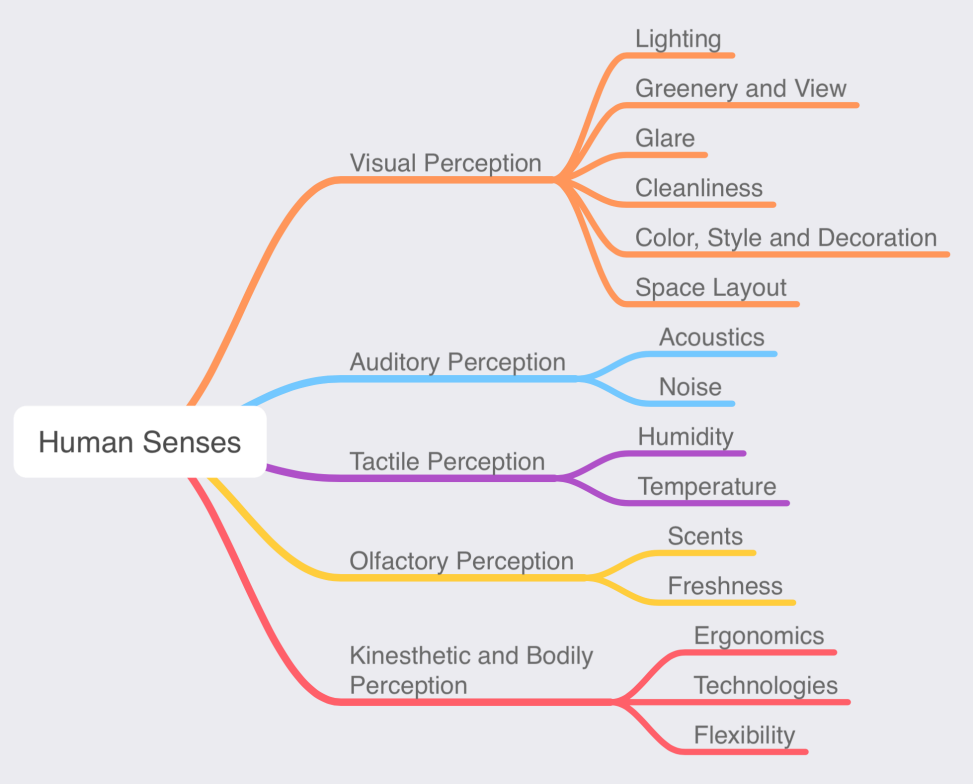

Figure 3.3. The relationship between physical features and different human senses

3.2.3.1 Visual Perception

Visual perception is pivotal, utilizing sight to assess lighting, depth, views, and spatial arrangement, directly affecting emotional and cognitive responses.

Lighting

Optimal lighting, especially natural daylight, enhances productivity, mood, and health, while improper lighting can lead to increased glare, eye strain, and mood disturbances. Adequate lighting, both natural and electric, in the workplace significantly improves worker satisfaction, reduces eye fatigue, and lessens irritation from glare (Choi et al., 2019; Jamrozik et al., 2019). Access to natural light has profound benefits on physical and mental health, improving mood, enhancing sleep quality, and reducing stress and depressive symptoms (Ayuso Sanchez et al., 2018; Bergefurt, Weijs-Perrée, Appel-Meulenbroek,

Arentze, et al., 2022; Boubekri et al., 2014; WÜTSCHERT et al., 2021). However, insufficient daylight can dampen mood and disrupt circadian rhythms, while excessive daylight increases glare and reduces concentration (Jamrozik et al., 2019). Studies have shown that enhancing daylight exposure in office spaces can boost worker performance by up to 13% and decrease fatigue (Heschong et al., 2003). Some workers adjust their environment, such as relocating desks or using daylight lamps, to optimize lighting conditions, which further supports productivity and well-being (Margariti et al., 2021). Additionally, having larger windows or desks near windows has been shown to positively affect productivity (Vischer, 2007).

View

Access to natural views and greenery, including plants, significantly enhances psychological well-being, productivity, and cognitive performance while reducing stress and mood disturbances. Natural views and greenery in the workplace, such as gardens, patios, or simply windows offering views of nature, are linked to numerous benefits including increased productivity, reduced fatigue, and decreased stress and depressive symptoms (Basu et al., 2021; Bergefurt, Weijs-Perrée, Appel-Meulenbroek, Arentze, et al., 2022; Pouso et al., 2021; Smith & Pitt, 2009). Satisfaction with such views correlates strongly with improved concentration and overall well-being (Spano et al., 2021). Exposure to natural elements during stressful tasks has been shown to lower negative stress impacts, both psychologically and physiologically (Douglas et al., 2022). For example, viewing natural scenes for short periods can improve mood, restore attention, and enhance cognitive performance by improving working memory and reducing automatic response tendencies (Jamrozik et al., 2019; Lee et al., 2015). The presence of plants in the workspace, whether through green walls or potted plants, not only boosts mood and concentration but also contributes to a pleasant physical and social environment (Bergefurt, Weijs-Perrée, Appel-Meulenbroek, & Arentze, 2022). However, it is important to balance the amount of greenery to avoid perceptions of clutter and discomfort (Smith & Pitt, 2009). Overall, integrating natural elements into workspaces plays a crucial role in fostering a healthy, productive, and stress-reduced environment.

Glare

Glare can significantly impair vision, create discomfort, and contribute to both visual and musculoskeletal issues due to necessary posture adjustments. Glare presents a major obstacle in visual clarity, often resulting in annoyance and physical discomfort that detracts from concentration and attention (Hamedani et al., 2019; Osterhaus, 2005). Sustained exposure to glare not only leads to eyestrain and fatigue, potentially causing long-term vision impairment, but it also necessitates adjustments in gaze stabilization (Awada, Becerik-Gerber, et al., 2021). This, in turn, can lead to uncomfortable or unnatural head, neck, and body postures, subsequently contributing to the development of muscle pain, particularly in the neck and back areas. Research (Mork et al., 2020) has linked low satisfaction with glare conditions to a higher incidence of musculoskeletal discomfort, underscoring the need for adequate management of lighting conditions to prevent visual and physical health issues.

Cleanliness

Cleanliness in the workspace is crucial for minimizing distractions and enhancing productivity, with clutter particularly detrimental to work focus. Research indicates that a clean workspace significantly impacts employee satisfaction and productivity (Horrevorts et al., 2017). Cleanliness reduces physical

stimuli that can distract workers, such as piles of paper, notes, and unorganized desks, especially in shared desk environments where the presence of clutter can notably decrease productivity (Kim et al., 2016). Cluttered spaces with items like unemptied bins and old coffee cups further distract individuals from their primary tasks (Davis, 1984). On the other hand, workspaces that are clean and tidy, particularly medium- or large-sized home workspaces, are associated with reduced distractions (Bluyssen, 2014; Kim & de Dear, 2013; Mateo et al., 2013). Moreover, working in non-dedicated, cluttered, or crowded areas tends to increase the frequency of disturbances (Bergefurt et al., 2021), highlighting the importance of maintaining cleanliness and organization to foster a conducive work environment.

Color palette

The choice of wall colors in a workspace significantly affects mood, stress levels, and productivity, with specific colors fostering different psychological responses. Research demonstrates that changing wall colors can positively influence teleworkers' productivity and mood (Bergefurt, Appel-Meulenbroek, & Arentze, 2023; Hiyasat et al., 2022). Colors like blue and green are particularly effective at reducing stress and enhancing mood, contributing to a calming environment (Bergefurt, Appel-Meulenbroek, Maris, et al., 2023; Connellan et al., 2013). White-colored walls are perceived as less distracting and stressful (Kwallek et al., 1997). Conversely, warm colors like red may increase anxiety and stress, whereas cool colors like blue could potentially heighten depressive symptoms (Kwallek et al., 1997). The optimal use of color in office environments, including the selection of pale shades such as gold, orange, green, and sandstone, can positively impact employees' mood and stress levels (Mahnke, 1996). Furthermore, while high chroma colors may not significantly reduce stress, high brightness colors and natural materials have been shown to lower negative arousal and support creativity (Hsiao et al., 2013), highlighting the importance of thoughtful color selection in enhancing workplace productivity and well-being.

Space layout

Designating a specific workspace at home enhances productivity by creating psychological boundaries, improving concentration, and reducing stress and distractions. Dedicated workspaces at home are crucial for establishing physical and psychological boundaries that differentiate work from personal life, thereby enhancing focus and privacy. Research underscores the importance of having a distinct area for work to mentally transition between professional tasks and home activities smoothly (Songsangyos & Iamamporn, 2022; Vander Elst et al., 2017). This setup not only fosters a productive work atmosphere but also signals to household members the need for uninterrupted focus (Lopez-Leon et al., 2020). The layout and design of the workspace significantly impact psychological and physical comfort (Xiao et al., 2021); for instance, private office spaces are generally more conducive to productivity and concentration than open-plan offices (Awada, Lucas, et al., 2021; De Been & Beijer, 2014; Di Blasio et al., 2019; Haapakangas et al., 2018). Additionally, workspace dimensions and density play a role in workers' psychological well-being. Larger, well-organized spaces that minimize noise and interruptions tend to enhance satisfaction and reduce distractions (Bergefurt, Appel-Meulenbroek, Maris, et al., 2023; Kaushik, 2020). Conversely, high-density environments can exacerbate stress, decrease environmental satisfaction, and lead to cognitive difficulties (Aries et al., 2010; De Croon et al., 2005). The strategic design of the workspace, including adequate space and privacy, is thus essential for maintaining high productivity levels and minimizing stress and cognitive overload in home settings.

3.2.3.2 Auditory Perception

A comfortable acoustic environment is essential for maintaining psychological well-being, productivity, and health in the workplace. Noise is a primary factor causing dissatisfaction in work environments (Kim & de Dear, 2013), originating from both indoor sources like conversations and outdoor noises such as street traffic . Certain outdoor sounds may enhance productivity by serving as beneficial background noise (Torresin et al., 2022). Studies have consistently shown that lower noise levels correlate with reduced cognitive stress, fewer health complaints such as fatigue, headaches, and improved psychological states including decreased feelings of depression and stress (Awada, Becerik-Gerber, et al., 2021; Thach et al., 2020). Positive responses to noise conditions are linked to enhanced worker engagement and well-being (Bergefurt, Appel-Meulenbroek, & Arentze, 2023; Boegheim et al., 2022). Conversely, negative effects of noise include increased risks of mood deterioration (Lamb & Kwok, 2016), musculoskeletal disorders due to lack of movement (Evans & Johnson, 2000), decreased motivation, and cognitive impairments like reduced memory span (Jahncke et al., 2011). Furthermore, dissatisfaction with noise levels in office settings, particularly open-plan offices, has been associated with increased anxiety, depression (Alimohammadi et al., 2010), and difficulties in concentration and attention, directly impacting productivity (Awada, Becerik-Gerber, et al., 2021). Strategies for improving acoustic comfort include measures such as closing windows, using noise-canceling headphones, and playing music to mitigate the disruptive impacts of excessive noise (Torresin et al., 2022).

3.2.3.3 Tactile and Thermal Perception

Optimal thermal and humidity conditions are critical for enhancing productivity and well-being, while deviations can lead to various physical and cognitive issues. Research indicates that maintaining indoor temperatures between 20–24°C and relative humidity levels between 40–55% is crucial for maximizing productivity, mood, and overall well-being, while deviations from these ranges can result in decreased concentration, poor sleep quality, and increased fatigue and stress (Bergefurt, Weijs-Perrée, Appel-Meulenbroek, & Arentze, 2022). Uncomfortable thermal conditions in workplaces are associated with higher incidences of headaches and irritation in the eyes and throat (Witterseh et al., 2004). Furthermore, control over one's thermal environment significantly boosts satisfaction and productivity (Awada, Lucas, et al., 2021). Extreme temperatures and rapid temperature changes can exacerbate health issues such as cardiovascular problems and sick building syndrome, affecting cognitive performance (Clements-Croome, 2006; Phung et al., 2016). Similarly, appropriate humidity levels are essential, as low humidity can cause discomfort like dry eyes and skin irritation (Barabino et al., 2005; Wolkoff, 2018), while high humidity fosters mold growth, aggravating respiratory issues (Jones et al., 2011). Overall, maintaining thermal comfort not only supports physical health but also enhances mental well-being and the ability to focus, especially important for teleworkers and those in variable environments.

3.2.3.4 Olfactory Perception

Maintaining high indoor air quality is vital for enhancing cognitive function, mood, sleep quality, and overall health, while poor air quality leads to various short-term and long-term health issues. Exposure to indoor gases like radon, carbon monoxide, and volatile organic compounds can lead to immediate health effects such as irritation of the eyes, nose, and throat, as well as headaches and vomiting. Over the long term, these pollutants can contribute to serious health conditions including cancer, organ damage, asthma, and chronic obstructive pulmonary diseases (Mandin et al., 2017; Tham, 2016;

Wargocki, 2016). Poor air quality has also been shown to impair cognitive functions, reducing clarity of thought, slowing response times, and diminishing the accuracy of responses in cognitive tests (Zhang et al., 2017). Studies indicate that lower levels of indoor contaminants like CO2 and particulate matter, coupled with higher ventilation rates, improve sleep quality by reducing sleep latency and nocturnal awakenings (Liao et al., 2019; Strøm-Tejsen et al., 2016). Better air quality in living and working environments not only boosts cognitive function and reduces symptoms of sick building syndrome but also enhances overall well-being by decreasing stress and fatigue (MacNaughton et al., 2016, 2017; Zhang et al., 2017). For teleworkers, satisfactory air quality at home is associated with fewer sleep disturbances, less mental stress, improved mood, and higher productivity.

3.2.3.5 Kinesthetic and Bodily Perception

Properly designed and adjustable furniture and workspaces are crucial for reducing health issues, enhancing comfort, and improving productivity for employees working from home. Ergonomically designed furniture that allows for personal adjustments, such as adjustable desks, chairs, and monitor screens, is essential for preventing physical discomforts like back and joint pain (Moretti et al., 2020). Researchers emphasize the importance of engagement with well-set-up workstations at home to maintain comfort and health. Factors such as the comfort of the keyboard, monitor position, and desk size significantly affect stress levels and overall satisfaction with the workspace (Seva et al., 2021). Moreover, having a dedicated and ergonomically sound room for work, along with knowledge on how to properly adjust the furniture, correlates with a lower incidence of new health issues (Xiao et al., 2021). Prolonged sitting at a poorly adjusted workstation increases the risk of bodily pain and other physical ailments (Baradaran Mahdavi & Kelishadi, 2020). Furthermore, an optimal physical setup that includes necessary adjustments and adequate storage space not only boosts productivity but also enhances the ability to work longer without discomfort (Awada, Lucas, et al., 2021). The use of non-traditional seating like sofas or floor cushions has been associated with increased discomfort and diminished work performance (Du et al., 2022), highlighting the importance of dedicated, well-equipped workspaces for home workers.

3.2.4 How Physical Features Impact Health

During the literature review and suggestion data extraction process, numerous mental and physical health issues relevant to indoor environment were identified. These issues serve as categories for organizing and applying the insights gained from existing research to provide tailored recommendations for users.

3.2.4.1 Mental Health

According to a previous study, ten indicators of mental health were identified based on World Health Organization standards, including well-being, stress, depression, engagement, burnout, concentration, fatigue, mood, sleep quality, and productivity (Bergefurt, Weijs-Perrée, Appel-Meulenbroek, Arentze, et al., 2022). However, burnout, largely influenced by individual characteristics rather than environmental factors, and fatigue, more related to physical health, have been excluded from subsequent analyses. Literature reviews revealed that physical spaces could affect cognitive functions and sometimes induce psychological distress. For instance, exposure to noise has been shown to diminish work motivation and memory span (Jahncke et al., 2011). Consequently, a new category, "cognitive effect," has been incorporated into this study. Ultimately, nine mental health categories are defined: stress,

concentration, well-being, productivity, depression, sleep quality, engagement, cognitive effect, and mood.

3.2.4.2 Physiological Discomfort

Previous research identified nine categories of physical ailments: musculoskeletal issues (discomfort, injury), cardiovascular symptoms (chest pain, blood pressure, heart rate), respiratory symptoms (shortness of breath, chest tightness/pain), gastrointestinal problems (changes in appetite, abdominal discomfort, irregularity), eye-related symptoms (burning, blurry and/or dry eyes), general fatigue or tiredness, headaches or migraines, ENT issues (dry, runny, or bloody nose; hoarseness), and skin conditions (chapped, itchiness, redness) (Xiao et al., 2021). Additionally, symptoms related to Sick Building Syndrome (SBS)—including dizziness, nausea, headaches, eye, nose, and/or throat irritation, concentration issues, and fatigue—are often linked to workspace environments, though they can also manifest in residential settings.

Given that the majority of the study's participants are young and typically free of chronic physical conditions, this research focuses on physical discomfort factors likely influenced by workspace design. The categories considered for physiological discomfort are: eye-related issues, skin conditions, ENT symptoms, headaches, fatigue, musculoskeletal pains (back pain, neck pain, lower back pain, shoulder pain), Sick Building Syndrome, and other general health concerns.

3.2.5 Labeling

Following the categorization, each recommendation derived from the literature is tagged with relevant health impacts, illustrating how specific physical features of workspaces influence these health outcomes. For example, the suggestion “Direct nature exposure through plants helps to create a pleasant physical and social environment (Bjørnstad, Patil, and Raanaas 2015), which may result in a positive mood, increased productivity (Smith, Tucker, and Pitt 2011; Smith and Pitt 2009), and reduced stress levels (Ayuso Sanchez, Ikaga, and Vega Sanchez 2018; Elsadek and Liu 2021)” was connected with these four labels “well-being, mood, productivity, stress”.

3.3 Frontend development

The user interface was collaboratively developed by Chenyue “xdd44” Dai(MArch’26), an expert in computer science and Unity development. I provided a detailed explanation of the logical rules that govern the interface, supplied the necessary backend files, and led the design efforts. My collaborator contributed significantly to the interactive elements development of the user interface.

3.3.1 Workspace personalization inquiry

Prior to initiating the design process, participants are required to complete a preliminary survey through this platform. This survey gathers information about the current state of their home workspaces, enabling the system to tailor its responses to their specific needs and preferences.

The first section of the questionnaire focuses on their physical workspace setup. Participants are asked whether they have a dedicated room or a specific area used solely for work, if they share this workspace with others, whether they use non-traditional furniture for work, and if they frequently change their

workspace configuration at home. Specific questions regarding ergonomic factors are also posed, such as the daily duration of work from home and the presence of ergonomic furniture, like desks and chairs.

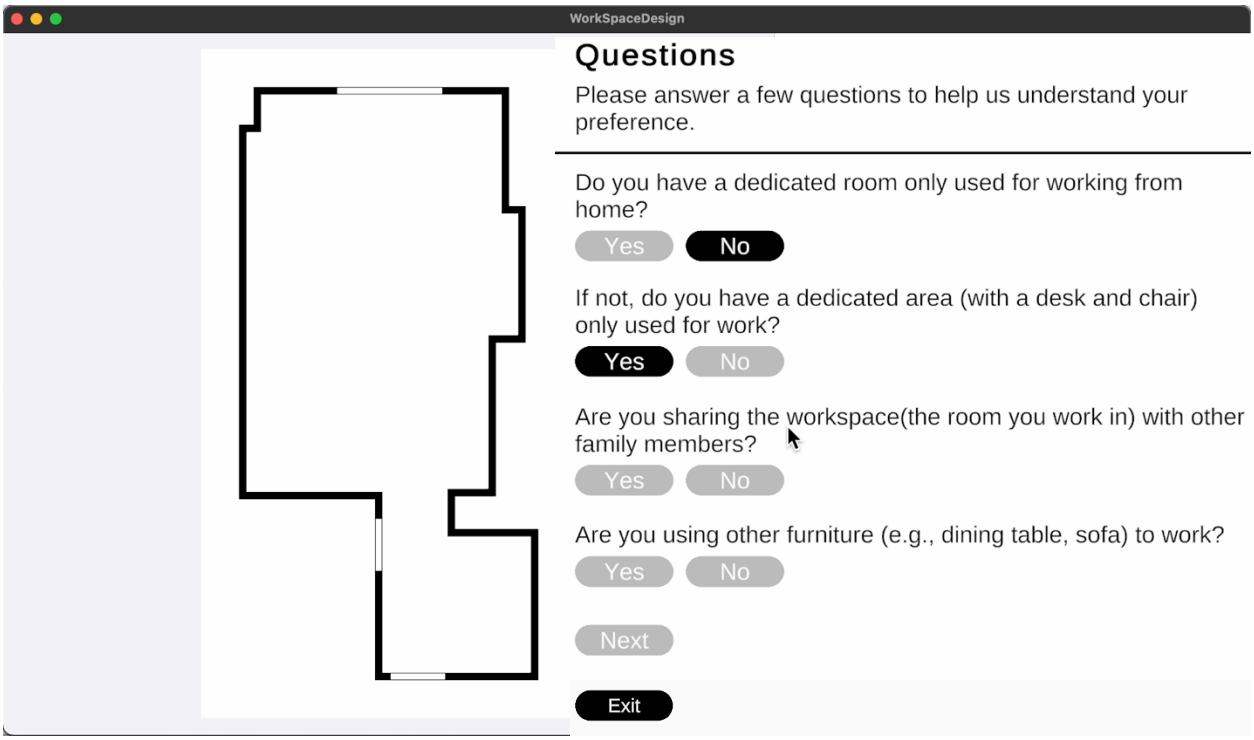

Figure 3.4. Questionnaire used to investigate current state of user's physical workspace setup

Acknowledging the significant impact of indoor environmental quality on health, the second section collects data on environmental preferences. Participants answer questions about their preferences for natural versus artificial lighting, desired noise levels (quiet or moderate background noise), the street noise level outside their window, their satisfaction with the current noise level, their methods of ventilation to enhance air quality, and their preferred room temperature.

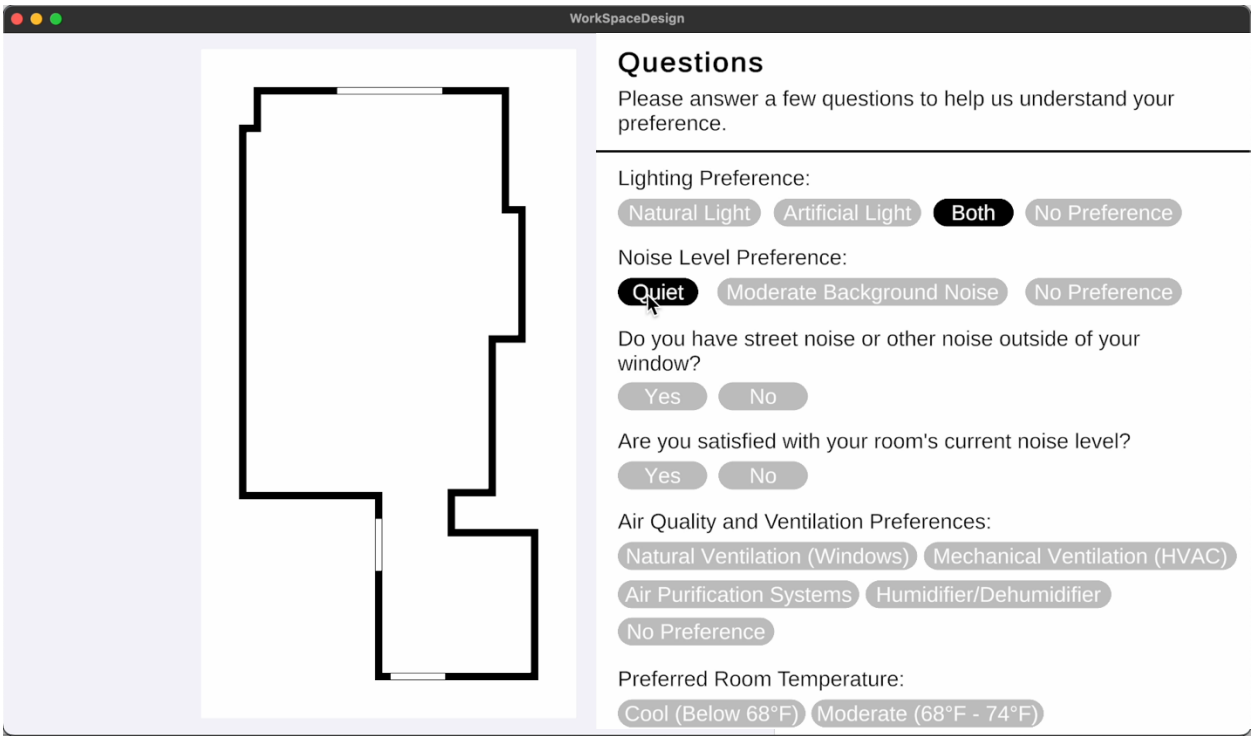

Figure 3.5. Questionnaire to determine user preferences for indoor environment

The final section addresses concerns related to mental well-being and work performance in the context of home workspace design. Participants are asked to rate various mental health concerns on a scale from 1 to 10, with higher numbers indicating greater concern. This rating method is similarly applied to assess their physiological health conditions.

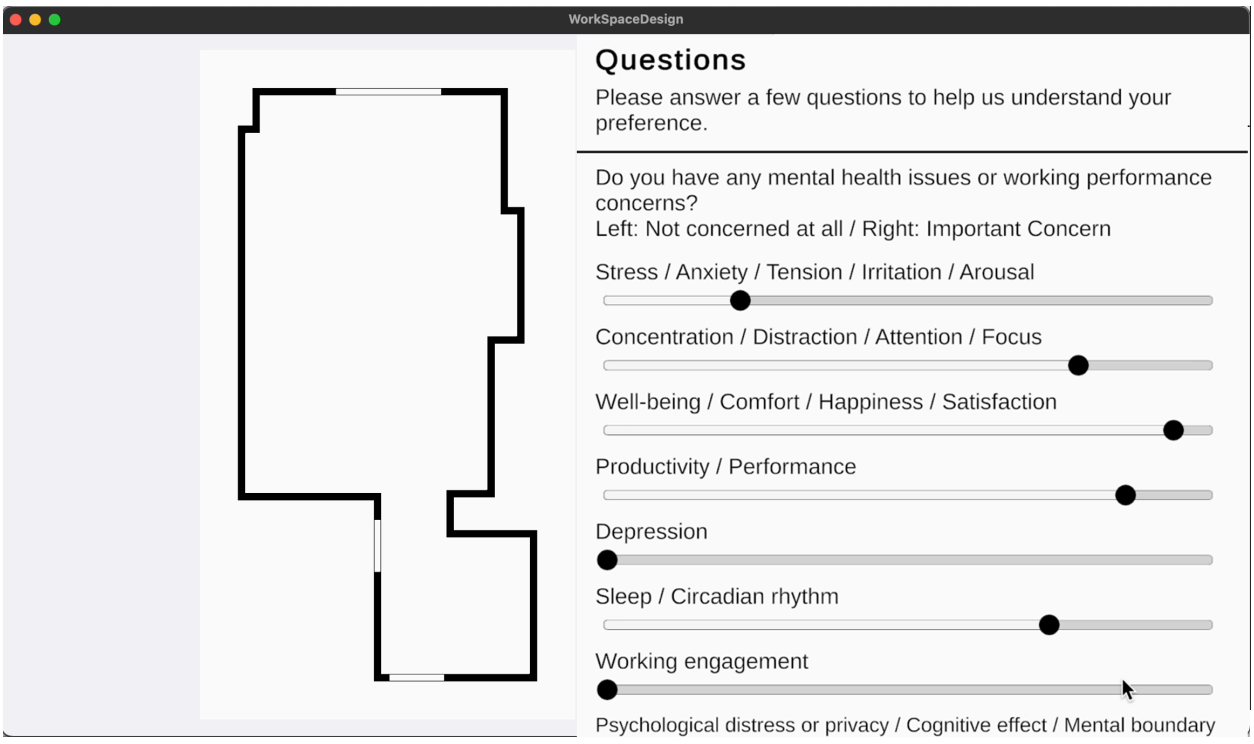

Figure 3.6. Questionnaire to determine the relative importance of different psychological factors

Responses from this survey are utilized as parameters in the backend, influencing the system's recommendations and ensuring they are pertinent to each individual's situation.

3.3.2 Interactive process and user interface design

Before initiating the design process, it is essential to mention a significant technological advancement. Polycam has recently developed a new functionality for its iPhone application that leverages Lidar technology to scan rooms (Polycam - LiDAR & 3D Scanner for iPhone & Android, 2024). This function can accurately determine the room's dimensions, the locations of walls, windows, and doors and create a precise 3D model. It can also provide a basic reconstruction of the furniture within the room. Users have the option to hide these furniture items from the view, leaving only the main structural elements visible. The resultant scene can be exported as an OBJ file, serving as the foundational model for further interactive design on the user interface.

In the beginning, I worked with xdd44 and wanted to scan the room using standard 3D scanning software, export an OBJ file, and then use our algorithm to remove furniture and clutter, extract the room boundaries, and reattach materials and textures. In this operation step, the user must define their door and window positions and sizes. But then we discovered the existence of Polycam, which simplifies the steps our users have to take before they start designing. So, in the end, we decided to use it to assist in building the base model. Files are exported and uploaded to our user platform.

Figure 3.7. (a) 3D scan result of PolyCam (b) resulting layout after hiding furniture. From (Polycam - LiDAR & 3D Scanner for iPhone & Android, 2024)

The user interface is divided into three primary sections:

1. On the left, a window displays the layout and 3D model of the user's room, facilitating visual design.
2. The top right section offers guidance, indicating the current step in the design process and suggesting possible actions within the design system.
3. The bottom right section is dedicated to suggestions, which dynamically appear based on user interactions in the left window. These suggestions are backed by citations and literature sources, enhancing their reliability.

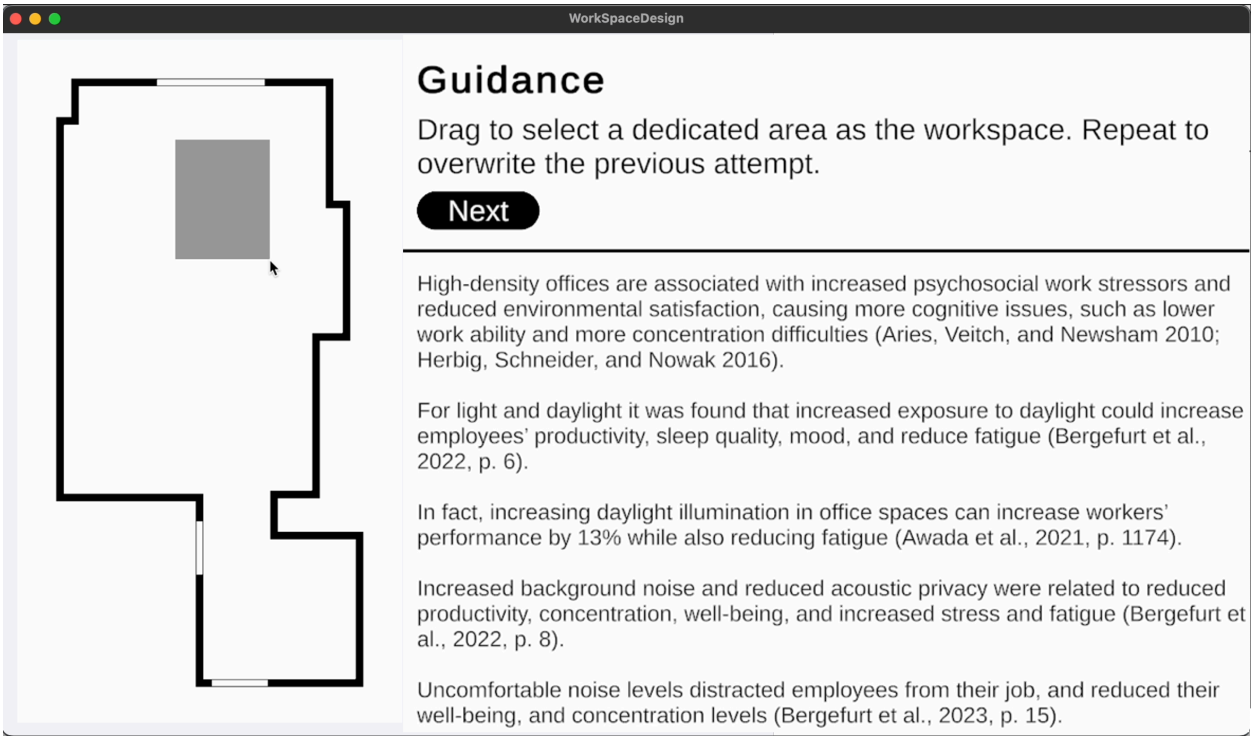

Figure 3.8. User interface for selecting dedicated working area

Participants begin by selecting a dedicated working area, recognizing the importance of having a designated space for home workers. They have the freedom to choose any size and location within their room. As they make adjustments, the system evaluates the design in real-time, offering tailored advice and explanations about the physical features of the current setup, allowing participants to refine their choices until they are satisfied.

Following the selection of a working area, participants move on to choose the color palette for the room. As with the previous step, selecting a color triggers relevant suggestions based on the properties of that color—warm and cool colors elicit different types of advice.

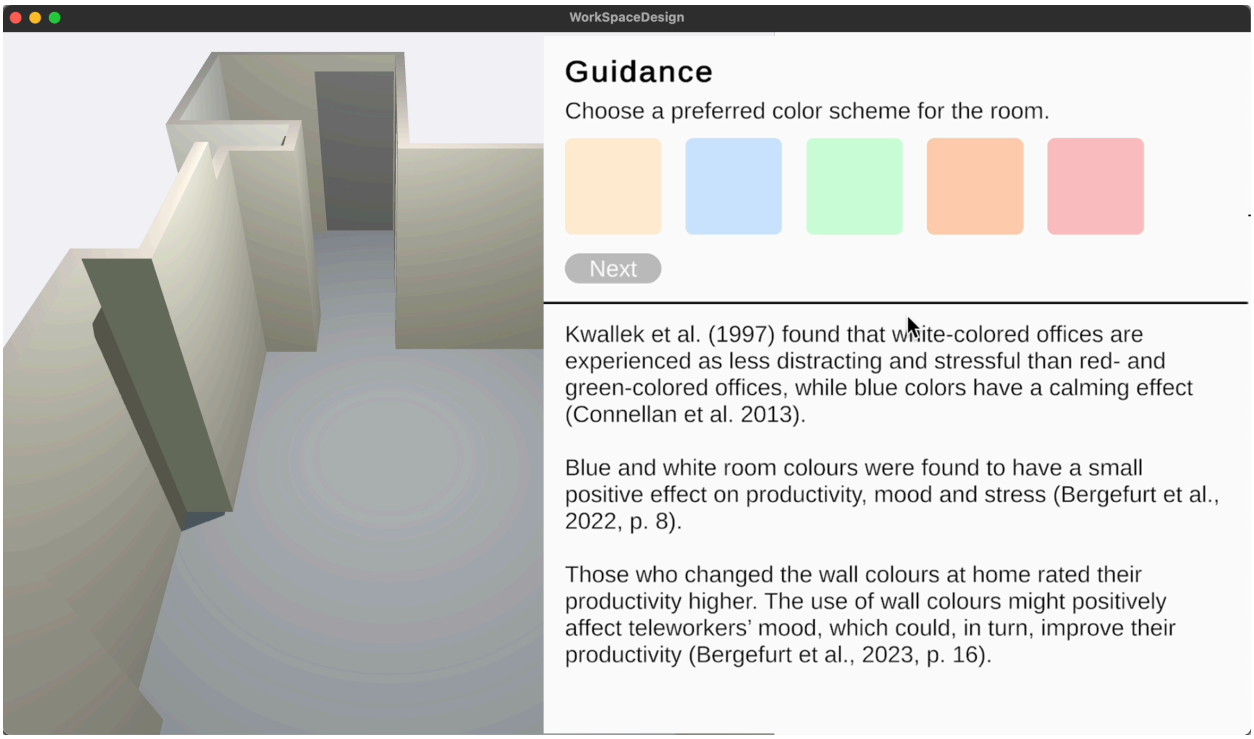

Figure 3.9. User interface for choosing color palette

The next phase involves arranging furniture, starting with the desk, which is a central element in any workspace. Participants can choose the type of desk and specify its dimensions, such as height, width, and length, and whether it is adjustable. The orientation of the desk is crucial as it affects the user's field of view. To aid in visualizing this, the system displays the coverage of a quadrangular cone, shaded to show which parts of the room fall within the user's field of view. This visualization helps participants understand how the placement of the desk influences perceptions of cleanliness, glare, and spatial density. For instance, placing the desk against a wall limits the visible area to just the wall and nearby surroundings.

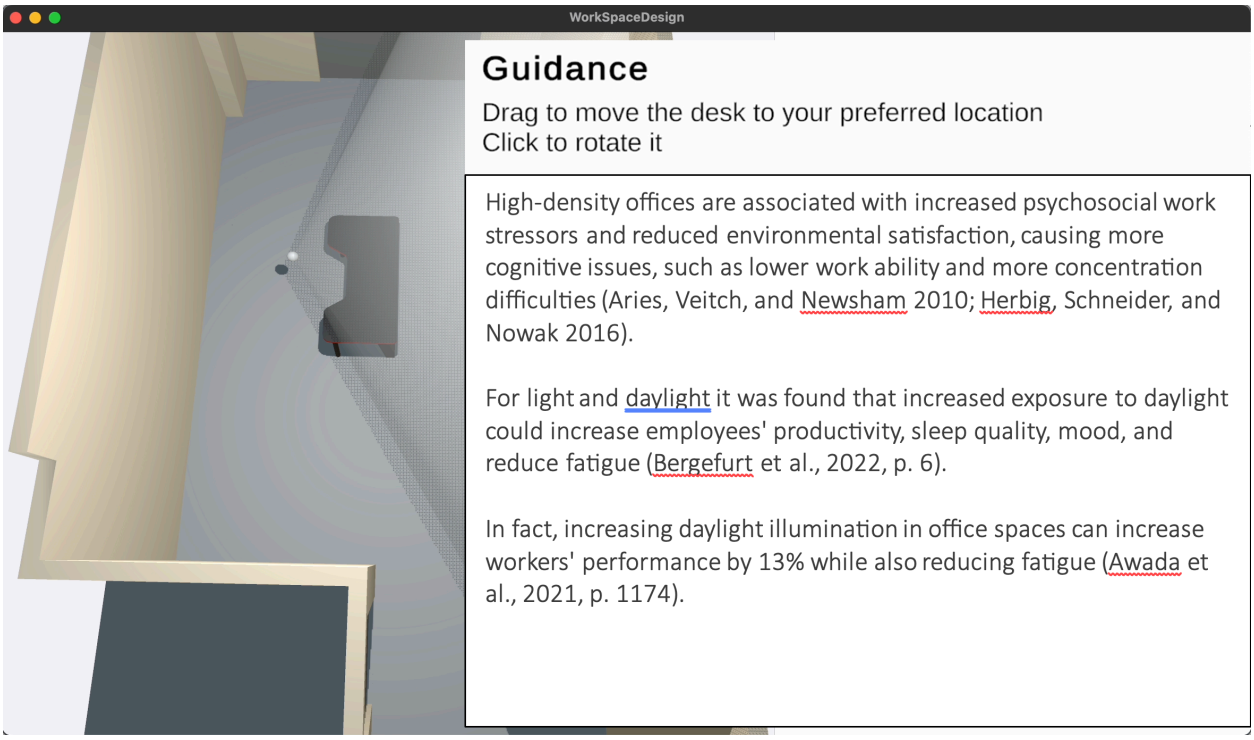

Figure 3.10. User interface to arrange desk orientation and location

Subsequently, participants select chairs, choosing from various materials, styles, and types, and defining their dimensions. The system assesses the ergonomic relationship between the chosen chair and the desk. If there is a mismatch in dimensions, it alerts participants to potential musculoskeletal issues.

As more furniture is added, the system repeats the interaction process based on the properties of the new items and their relationship with existing furniture, as well as their overall impact on the workspace. Suggestions from previous interactions may be reiterated to address the effects of new additions and interactions.

The design process concludes when participants are satisfied with their workspace setup. They have the option to exit the system at any point during the design phase, providing flexibility and control over their workspace creation.

3.3.3 Rules for displaying suggestions

3.3.3.1 Order for displaying suggestions

As participants interact with the user interface, suggestions are dynamically categorized and displayed according to their relevance to the ongoing design choices. Initially, when selecting a working area, suggestions concerning the necessity of a dedicated space, along with its optimal size and density, are presented. The location of this workspace in relation to windows, doors, and walls influences suggestions related to natural light, noise levels, and ventilation options. Upon choosing a color palette for the area, the system generates suggestions specific to color effects and psychological impacts.

Following these preliminary steps, participants proceed to arrange furniture, beginning with the desk. The choice of the desk's size and type determines the user's positioning and field of view, impacting

ergonomic considerations and views, including aspects like outside visibility, plant interactions, potential glare, and overall cleanliness of the workspace. Subsequent ergonomic suggestions are linked to decisions about chairs and office technology.

As the design process continues, participants select lighting options, triggering suggestions related to artificial lighting preferences. Simultaneously, suggestions concerning thermal comfort—such as the ideal temperature and humidity levels—are activated when participants consider incorporating air conditioners, fans, or humidifiers into their design. Ventilation-related suggestions are also revisited; however, those specifically tied to natural ventilation are withheld if the setup does not involve direct interactions with windows or doors, ensuring that only the most relevant advice is provided based on the current configuration of the workspace.

3.3.3.2 Criteria for displaying suggestions

The display of suggestions is contingent upon participant responses to the initial survey. For instance, if a participant indicates a solitary working environment, suggestions concerning noise mitigation from cohabitants will be omitted. Conversely, if a preference for mechanical ventilation is expressed, the system will suppress suggestions pertaining to natural ventilation. Furthermore, if participants are already equipped with ergonomic desks, related ergonomic advice will be excluded to avoid redundancy.

Suggestions concerning visibility are triggered by objects detected within the participant's field of view. Cleanliness recommendations will be offered if the system identifies clutter within the visual area. If a participant's workstation orientation results in their back facing a window, glare-specific guidance will be provided. Additionally, if a window falls within the lateral view, suggestions will address external vistas and the integration of plant life, enhancing the occupant's connection with the outside environment.

The pertinence of suggestions regarding natural light, ventilation—such as those emphasizing the benefits of proximity to windows for natural ventilation—and ambient noise levels are determined by the spatial relationship of the work area with windows and doors. Thus, the proximity of the selected workspace to these architectural features dictates the nature of the suggestions. Furthermore, the system generates advice on the optimal size and density of the workspace, tailored to the dimensions defined by the participant.

3.3.3.3 Prioritization of Suggestions by Label Weights

Suggestions are systematically weighted and prioritized based on the participants' ratings of specific labels related to mental and physical health attributes. Each suggestion is assigned a score that corresponds to the label it represents. In instances where a suggestion correlates with a single label, the suggestion's score is equivalent to that of the label. Conversely, when a suggestion encompasses multiple labels, the system calculates its score by averaging the scores of all applicable labels. Suggestions with higher scores are given precedence, ensuring that the most pertinent advice is presented to the participant. To maintain focus and avoid overwhelming users, the interface restrictively displays only a subset of the highest-weighted suggestions at any one time.

In situations where several suggestions attain identical scores, they hold an equal probability of being presented. Given that participants will engage in a multitude of actions throughout the design phase,

each action will catalyze the display of a suggestion. This sequential presentation ensures a balanced rotation of equally scored suggestions, providing users with comprehensive guidance as they navigate through the design process.

3.3.3.4 Challenges in Defining Specific Metrics

Determining specific numerical guidelines is challenging due to the scarcity of evidence in the existing literature. When developing the program, it is necessary to define specific distances and geometric relationships. For instance, the geometric center of the workspace is used as a reference point to measure the shortest distances to windows and doors.

However, the literature lacks clear guidance on the optimal proximity for adequate sunlight and natural ventilation. Notably, objective metrics are generally absent in the literature, with the exception of parameters related to thermal comfort. For example, (Bergefurt, Weijs-Perrée, Appel-Meulenbroek, & Arentze, 2022) noted that temperatures below 20°C or above 24°C, along with relative humidity levels below 40% or above 55%, can adversely affect productivity, concentration, sleep quality, mood, and well-being, while increasing fatigue and stress. Most designers rely on intuition and experiential knowledge to make these decisions, as the literature provides few objective measures or detailed guidelines in this regard. Consequently, I was compelled to estimate a specific distance and document it myself.

3.4 User subject testing

3.4.1 Participants introduction

In the introduction of the user test, the preferences and feedback of 12 individuals at MIT were examined, including 4 with a background in architecture design and 8 PhD students in science or engineering fields. The test was structured to assist participants in creating an optimal home workspace tailored to their mental needs through a platform providing space design advice. Initially, participants started by scanning their room and uploading the data to the platform. A pre-questionnaire survey was then administered to tailor the system's suggestions to each individual's specific preferences and requirements. Following this, the platform would recover the original room design to provide initial guidance. Participants were then given the freedom to rearrange their working area and other elements within the room, allowing them to observe and evaluate the suggestion changes in real-time, thereby assessing the system's functionality and usefulness in adapting to their unique needs.

After completing the test, participants were asked a series of questions to gather detailed feedback on their experience and the effectiveness of the system. The questions included:

Did you get some new insights during the design process? Did you learn something?

This question aimed to assess whether the participants gained any new understanding or knowledge from using the platform and interacting with the various design suggestions.

What do you think this system can improve to help you understand which action improves the design?

Here, participants were prompted to provide feedback on how the system's functionality could be enhanced to more clearly demonstrate the impact of their design choices, thus helping them make more informed decisions.

Do you have any other suggestions based on the design process?

This open-ended question was designed to capture any additional thoughts or ideas from the participants on how to refine the platform, based on their personal experience during the test.

These questions were intended to elicit constructive feedback to guide further development and improvements of the system, ensuring it effectively meets the needs of users in creating optimal living and working spaces.

3.4.2 Design intention

When individuals design their rooms, they prioritize various functions based on their personal interests and lifestyle needs. This can include areas dedicated to working, which may require a quiet and organized space conducive to productivity. In contrast, areas meant for relaxing might feature comfortable seating and a more casual ambiance. Similarly, spaces for exercising need to accommodate equipment and allow for movement, while those designed for watching TV are often arranged for optimal viewing and comfort. Additionally, a balanced and overall arrangement takes into consideration the flow between these various areas, ensuring a cohesive environment that supports a range of activities. Lastly, pet keeping influences room design by necessitating pet-friendly materials and space for pets to play and rest, integrating their needs into the room's functionality. Each of these aspects reflects different priorities that shape how a room is organized and used.

Participants in the study exhibited varied approaches to room design when they moved into a new space. Some actively chose to redesign their rooms according to their preferences and needs, while others preferred to maintain the original layout. Interestingly, the decision to alter the room's design did not correlate with having a background in design. Over time, as occupants accumulated more furniture, the placement of items often became more about convenience than intentional design. This trend suggests that prolonged residence and increased possessions could lead to a more static room arrangement, either due to the complexity of reorganizing or a decrease in motivation to alter the established layout. This observation highlights that personal disposition and practical circumstances can significantly influence room design choices, irrespective of professional design knowledge.

3.4.3 Evaluation of user test feedback

In the design process, it was clear that some users were firm in their design choices, choosing to place the workspace where their current one is right from the start. Other participants experimented with different design plans and observed how suggestions in the sidebar changed, gaining new insights along the way. I noticed that the order of suggestions and UI design greatly influenced user perception; many ended up deciding to buy a plant because plant-related suggestions consistently appeared first due to the backend recommendation settings when arranging the desk.

After completing this test, none of the twelve participants changed their physical workspace layout. Nine felt that their existing design was already optimal after interacting with the design, and three believed there was room for improvement but were too lazy to rearrange their furniture. As the primary

users of their rooms and having lived there for a while, they had a better sense of what environment and interior design worked best for them. The way workspace optimization differs from room to room varies greatly depending on the layout.

The user testing revealed distinct learning outcomes between designers and other participants. Designers reported that their primary new insight was the mental effect of colors within a space. This focus is likely due to their pre-existing awareness and sensitivity to other spatial and environmental factors, such as glare, plant placement, and ergonomic furniture, which are already integral considerations in their professional field.

In contrast, other participants—those without a professional background in design—exhibited a broader range of new learnings in these fields. These participants gained insights into aspects that designers might take for granted or consider standard knowledge, such as the importance of environmental quality and the strategic use of elements like glare and ergonomic furniture to enhance a space's functionality and comfort.

This comparison highlights how professional expertise influences the focus and depth of learning in user testing, with designers honing in on specific, perhaps more nuanced aspects of design like color psychology, while non-designers derive significant new understanding from a wider range of basic design principles.

3.4.4 What to improve

To improve the design and functionality of the app based on user feedback, several enhancements can be considered. These suggestions aim to tailor the app more effectively to individual user needs and enhance the overall design process:

Incorporate Multi-Functional Design Options:

To support users with diverse expectations for their rooms, the app should offer design solutions that accommodate multiple functions such as working, relaxing, exercising, and entertainment. This could include suggestions for multi-purpose furniture, layout configurations that clearly separate different activity zones, and adjustable settings that users can modify based on their immediate needs.

Consider Existing Furniture:

To enhance the app’s functionality and relevance, it is important to integrate a feature that allows users to specify which pieces of furniture are fixed or immovable. This adaptation will enable the app to account for these constraints when generating design suggestions, ensuring that the recommendations are not only creative but also practical and applicable to the user's specific space. Users could mark these items on their uploaded room layout, and the app could then automatically adjust the design suggestions to work around these fixed elements, optimizing the use of available space while respecting the existing setup.

Enhanced Visual Feedback for Changes:

To clearly demonstrate the impact of user actions on the room design, the app should feature a robust visual feedback system. Options like a split-screen view or a slider feature would allow users to directly

compare the room's layout before and after their modifications, making the consequences of their decisions more tangible and immediate.

Highlight Key Information:

Enhancements should be made to ensure that key elements within the suggestions are highlighted. Simplifying the language used in the app will help ensure that users can easily grasp the advice provided, reducing the need for technical or complex explanations.

Visual Stimulation for Lighting and Ventilation:

Introducing simulations or visual aids that show the effects of different lighting and ventilation settings will aid users in making more informed choices about these critical aspects. Such visual tools can demonstrate the practical impact of different options on the comfort and usability of the space.

Labeling and Measurements:

Clear labeling of scales and main measurements within the app's interface is crucial. This will help users better understand the dimensions and spatial layout of their environment, facilitating more accurate and effective room designs.

By implementing these improvements, the app can provide a more personalized, intuitive, and effective design experience, enabling users to create spaces that better meet their individual needs and preferences.

4. Conclusions

4.1 Observations on design decision-making

During the design game, it was observed that most participants initially believed their current workspace location was the most satisfying option. After engaging in the design activity, this belief largely remained unchanged, suggesting that their original choices were perceived as optimal. Several factors contributed to this outcome:

Room Constraints: For some participants, the small size of the room and the presence of other furniture limited the possibility of redesigning or relocating their workspace. This lack of flexibility often meant that even if participants wished to explore alternative setups, the spatial constraints made significant changes impractical.

Perceived Optimality: In cases where the room was empty, participants still considered the placement of hypothetical furniture in other areas of the room, leading them to view their workspace location as a 'forced choice'. This indicates a mental adaptation to their environment, where they have considered various scenarios and settled on what they believe to be the most feasible option.

Familiarity and Adaptation: Long-term residence and familiarity with the room's layout seemed to play a significant role in their decision-making. Being the primary users of the space, participants had likely experimented with different arrangements over time and settled on the layout that maximized the

room's utility based on their personal needs and experiences. They have already set up their room to meet their needs.

4.2 Impact of user demographics and needs

These observations underscore the importance of considering the specific demographics and needs of the user group when evaluating the app's effectiveness. The user subjects, being graduate students at MIT, often have access to alternative workspaces such as labs, libraries, and common study rooms. This multiplicity of options reduces the reliance on their personal room as a primary workspace, particularly post-COVID, when many have returned to in-person environments. As such, their rooms serve multiple purposes beyond just working, which dilutes the impact of optimizing solely for work-related functionality.

Moreover, the lack of significant focus issues among this demographic means that the perceived benefits of enhancing the working environment might not be compelling or noticeable. Given this context, other groups such as high school and elementary students, who typically spend long hours studying at home, might derive more value from the app. These students often lack access to alternative study spaces and could significantly benefit from an optimized study environment.

This platform's unique interactive nature allows users with mental health issues or environmental sensitivities to tailor their workspaces to suit personal needs and preferences, potentially alleviating stress and promoting mental well-being. For instance, users who are particularly sensitive to their environment can adjust lighting, sound, and even furniture arrangements interactively to create a workspace that minimizes anxiety and maximizes comfort. This is crucial as the design of a personal workspace can significantly impact one's mental health, especially for those who spend prolonged periods in these environments.

4.3 Implications and future directions

4.3.1 Potential New Application: Design Education Tool

Another potential application for this platform could be in the realm of design education. Given that participants reported learning new aspects of design through the app, it can be repurposed as a teaching tool for studio students. The platform could help students experiment with space design in a controlled, virtual environment, allowing them to see the consequences of different design choices in real-time.

4.3.2 Proposed experimental validation

To explore this educational application and further validate the platform's utility, a comparative study could be designed. This study would involve participants using the platform to design a room, comparing their outcomes with those who do not use the platform.

The focus would be on understanding: Whether the platform helps users make better design decisions. How the platform influences their decision-making processes. How does the different needs of the main user affect the decision making of design. The specific learning outcomes facilitated by using the platform in a design education context.

Such a study would not only provide insights into the platform's educational value but also help refine its features to better support learning and design thinking skills.

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6. Appendices

Appendix A – Backend Data Classification and Labeling

	## Location of the workspace and sense of privacy
	#### having a dedicated room
health	Having a dedicated room for work, having an ergonomically correct workstation, knowledge of how to adjust a workstation, and increased satisfaction with IEQ factors in the workspaces were associated with lower chance of experiencing new health issues (Xiao et al., 2021, p. 189).
concentration	Working in a dedicated room minimizes the chance of being distracted and interrupted, and likely increases the chance that the workstation is well-designed to support work (Xiao et al., 2021, p. 189).
productivity	Our results suggest that productivity levels were higher for workers who have a dedicated workspace at home in comparison to those who do not have a dedicated workspace (Awada et al., 2021, p. 1184).
concentration, well-being, engagement	Having a dedicated workspace that is not intended for other uses decreases the probability of workers being interrupted by distractions, and that having a dedicated desk and adjustable chair may result in increased comfort allowing workers to spend more hours at their workstations (Awada et al., 2021, p. 1184).
productivity, concentration, stress	For office layout and design, it was found that private offices could stimulate productivity and concentration and reduce stress, while openplan offices could reduce productivity and concentration and increase stress (e.g. Refs.)
	#### having a dedicated area
concentration, productivity, engagement, cognitive effect	Research also shows that separating the workspaces from living spaces is an important factor when working remotely. It is recommended to have a dedicated workspace to create physical boundaries, help workers establish a productive work atmosphere, increase workers desire to stay longer hours at their workstation and signal to other household members that they do not want to be distracted (Awada et al., 2021, p. 1173).
cognitive effect, concentration, productivity	Previous research studies about WFH have recommended that workers create their own home work area and recognize it as their workspace, which would help workers mentally shift from the home to the work atmosphere, reduce distractions and improve their productivity and performance (Awada et al., 2021, p. 1184).

concentration, productivity	In fact, the lack of a dedicated workspace when working from home can disrupt the work experience, increase family-work conflicts and degrade worker productivity (Awada et al., 2021, p. 1184).
	#### Sharing the workspace with others
cognitive effect, stress	Blurred work-life boundaries can make it difficult to detach mentally from work which can increase stress and anxiety (Xiao et al., 2021, p. 181).
concentration	
stress	As Seva, Tejero, and Fadrilan-Camacho (2021) argued, employees who shared their homework space were more stressed, tense, and irritated because they had to switch locations more frequently (e.g. when the dining table is needed to serve lunch/dinner).
concentration	People who worked in non-dedicated work areas that were small, had a cluttered desk, or who worked with more persons in the room were more frequently disturbed(Bergefurt et al., 2021, p. 4).
musculoskeletal discomfort	Those who do not have a dedicated space are therefore more likely to be spending extended periods of time at the workstation without appropriate adjustments, increasing the odds of bodily pain and other physical health conditions (Xiao et al., 2021, p. 189).
sleep quality	Those who were dissatisfied with the privacy at home indicated more sleep problems.
depression, sleep quality, mood, engagement, concentration	As Xiao et al. indicated, those who did not have a dedicated workroom at home had a larger chance of reporting new mental health issues, including depression, trouble sleeping, mood swings, decreased social engagement, and trouble concentrating.
stress, productivity, well-being	In shared rooms, employees might have been more annoyed by noise, which reduced their well-being and productivity. Some employees indicated to work in a variety of rooms at home, which might have reduced their productivity even further (Bergefurt et al., 2023, p. 15).
productivity	Our results also suggest that sharing the workspace with another household member decreases the worker's productivity (Awada et al., 2021, p. 1184).
	#### Density and size of the workspace
cognitive effect	Fornara et al. showed that satisfaction with the spatial dimensions of the home (i.e., in general, square footage, privacy, and natural light) reduced psychological distress.

concentration	Current research showed that medium- or large-sized home workspaces that are clean and tidy, without noise interruptions, appear to reduce workspace distractions (Bergefurt et al., 2021, p. 6).
concentration, productivity	A higher spatial density means that the available space per workstation is larger, which might lead to less distractions and a higher concentration rate (Veitch 2018). In contrast, a higher social density might increase the frequency of social interactions but should be lim ited to prevent concentration-and productivity-issues (Hua et al. 2010; Veitch 2018).
stress, cognitive effect, concentration	High-density offices are associated with increased psychosocial work stressors and reduced environmental satisfaction, causing more cognitive issues, such as lower work ability and more concentration difficulties (Aries, Veitch, and Newsham 2010; Herbig, Schneider, and Nowak 2016).
stress, fatigue	Employees with a small workspace were less exhausted than employees who worked in medium or large-sized workspaces. Employees who were stressed were also found to be less exhausted(Bergefurt et al., 2021, p. 4).
cognitive effect	High-density workspaces with limited space between workstations have been reported to increase cognitive overload and reduce psychological privacy(de Croon et al. 2005).
	#### Changing the workspace
engagement, concentration	Rudnicka et al. found that some respondents felt that constantly changing the workspace helped them focus and enhanced their work performance.
	## Natural light
	#### Satisfaction with the daylight
cognitive effect	Fornara et al. showed that satisfaction with the spatial dimensions of the home (i.e., in general, square footage, privacy, and natural light) reduced psychological distress.
eye related symptoms	Respondents with higher satisfaction with natural lighting, glare, and humidity were less likely to present eye-related symptoms.
eye related symptoms	Workers who are satisfied with the spatial distribution of light in their indoor environment—whether electric or natural lighting—are less irritated by glare and present less eye fatigue.
well-being, mood, sleep quality, eye related symptoms	Access to natural lighting has been associated with long-lasting effects on the physical and mental well-being of occupants, such as improved mood, better sleep quality, and reduction in eye strain.

concentration, mood, well-being	Another COVID-19 study showed that satisfaction with daylight and artificial light, having a view outside, and greenery were also important for employees' mental health, specifically for their concentration, mood, and well-being (Bergefurt et al., 2023, p. 2).
depression	Satisfaction with daylight reduces stress and depressive symptoms (Bergefurt et al., 2023, p. 15).
mood, concentration	While too limited daylight reduces employees' mood, too much daylight may increase the risk of glare, thereby reducing concentration levels (Jamrozik et al. 2018).
productivity	The entrance of daylight provides a pleasant environment which may increase people's productivity (Fasi and Budaiwi 2015).
	#### Increase exposure to daylight (strategy)
productivity, sleep quality, mood, fatigue	For light and daylight it was found that increased exposure to daylight could increase employees' productivity, sleep quality, mood, and reduce fatigue (Bergefurt et al., 2022, p. 6).
productivity, fatigue	In fact, increasing daylight illumination in office spaces can increase workers' performance by 13% while also reducing fatigue (Awada et al., 2021, p. 1174).
mood, productivity	Some of them relocated their desk to improve ambient conditions, while others used daylight lamps to improve their mood and productivity (Bergefurt et al., 2023, p. 15).
productivity	larger windows and proximity to a window positively influence productivity (Vischer 2007).
	#### Poor access to daylight (harmful effects)
depression	In our study, depression was also predicted by low satisfaction with natural lighting.
depression	Similar findings were reported by Ref. who found that subjects reporting inadequate natural lighting in their residential apartments were 1.4 times more likely to show symptoms of depression compared with those who have sufficient access to daylight.
sleep quality	Poor access to daylight can disturb the human circadian rhythm.
	## Noise
	#### Satisfaction with noise

well-being, concentration	The comfort of the acoustic environment was found to be important for employees' psychological well-being and concentration (Bergefurt et al., 2023, p. 15).
concentration	Employees experienced lower noise levels when they had a dedicated workroom, resulting in less home-workspace distractions.
stress, health	On the psychological aspect, office employees subjected to lower levels of noise experience less cognitive stress and hypertension.
fatigue, head realted symptoms	Furthermore, our results suggest that respondents who were more satisfied with noise presented less prevalence of fatigue, tiredness, headaches, and migraines.
stress	We also found that the prevalence of mental stress symptoms was predicted by low satisfaction levels with air quality and noise. Similarly, Ref. conducted an environmental health assessment of several office buildings and concluded that higher satisfaction with air quality and noise levels was associated with reduced stress.
fatigue, depression, stress, mood, concentration, productivity, well-being, engagement	Those who were satisfied with noise felt less fatigued, depressed, stressed, indicated to have fewer mood swings and concentration difficulties and felt more productive. Boegheim et al. also found that satisfaction with the noise level increased employees' well-being and engagement and diminished feelings of tension.
well-being, engagement	Some noise sources, such as natural and outdoor sounds, might increase their work engagement and well-being by alleviating feelings of loneliness(Torresin et al. 2022).
	#### exposure to noise
mood, head related symptoms	Also, Ref. found that noise results in deteriorated mood and increased risk of headaches.
musculoskeletal discomfort	Behaviorally, a study showed that when workers are exposed to prolonged durations of noise, they were less likely to make postural adjustments which could increase their risk to be affected by musculoskeletal disorders.
productivity	Regarding the cognitive effects, an experiment conducted by Ref. showed that the exposure to noise reduces the motivation to work and reduces the memory span.
fatigue, head related symptoms	Reference found that workers reported increased levels of fatigue and headache intensity and dissatisfaction with acoustic conditions of their workspace when background noise levels increased in their open-plan office.

stress, depression, concentration	We found that lower satisfaction levels with noise predicted higher prevalence of anxiety and depression among respondents. Reference also found that disturbance and annoyance caused by excessive noise were associated with an increased tendency to show symptoms of anxiety and depression among white-collar employees in office buildings.
concentration, productivity	Our results show that low satisfaction with noise and indoor temperature predicted the prevalence of symptoms related to trouble concentrating and maintaining attention or focus. The ability to concentrate and be attentive is directly related to productivity; therefore, many research studies examined the effect of IEQ on workers' concentration and attention capabilities in office buildings.
well-being, concentration	Uncomfortable noise levels distracted employees from their job, and reduced their well-being, and concentration levels (Bergefurt et al., 2023, p. 15).
productivity, concentration, well-being, stress, fatigue	Increased background noise and reduced acoustic privacy were related to reduced productivity, concentration, well-being, and increased stress and fatigue (Bergefurt et al., 2022, p. 8).
mood	Both indoor and outdoor noise disturbed employees' sleep and negatively affected their mood.
	#### indoor noise
cognitive effect	High intelligibility (i.e. irrelevant speech) increases the mental demand on employees and is observed as even more disturbing than background noise(Liebl et al. 2012).
concentration	Noise from doorbells, visitors, or telephones ringing, conversations between household members or sounds from televisions could distract employees and reduce their concentration(Puglisi et al. 2021).
mood	Respondents who were less satisfied with noise conditions in their houses were more likely to present symptoms related to mood swings. Reference showed that background noise caused by irrelevant speech in open-plan offices can lead to an increased sense of annoyance, which builds up negative effects. When workers were forced to work from home, many of them were sharing the workspace with others in their household, creating a similar scenario to open-plan offices.
concentration	the significant relationship between noise and distractions indicated that the experience of noise in the home workplace could lead to distractions in employees' work(Bergefurt et al., 2021, p. 4).

concentration, well-being	Especially noise by teleworkers' children, partner or roommates made it difficult for them to concentrate on their job. These sounds also had a negative effect on people's well-being (Bergefurt et al., 2023, p. 13).
productivity, wellbeing, concentration	Especially in shared rooms, noise annoyance was found to be higher, which could reduce teleworkers' productivity, wellbeing, and concentration (Bergefurt et al., 2023, p. 15).
	#### Strategy
	Torresin et al. argued that the acoustic comfort could be improved by closing windows and doors, listening to music, and wearing noise-canceling headphones.
	## Ventilation
	#### Suboptimal air quality
eye, head, nose, throat related symptoms, health	Indoor gases like radon, carbon monoxide, ozone and oxides of nitrogen, volatile organic compounds and particulate matters can cause short-term health issues such as eye, nose, and throat irritation, headaches, and vomiting. They can also cause long-term health problems associated with cancer, and damage to the liver, kidney, and central nervous system, asthma and chronic obstructive pulmonary diseases.
mood, concentration, fatigue, depression, stress	Both observational and experimental procedures have proven that indoor air contaminants are linked with deteriorated mood, amplified aggressive behaviors, degraded attention, mental fatigue and higher depression and stress rates.
cognitive effect, productivity	Reference found that degraded air quality lessens the ability to think clearly, while decreasing the answering speed, response time, and number of correct answers in several cognitive tests.
sleep quality, concentration	Our results show that respondents who were less satisfied with the air quality were more likely to have insomnia and to experience trouble sleeping. This is in agreement with previous studies that lower concentrations of CO2 and particulate matter and higher ventilation rates in the sleeping area showed an improvement in the quality of sleep and sleep latency (time needed to go from being fully awake to sleeping) while reducing the number of awakenings during the night.
productivity, concentration, stress, fatigue	Suboptimal air quality and ventilation conditions could reduce individuals' productivity, concentration, and increase stress and fatigue (Bergefurt et al., 2022, p. 7).

	#### Satisfaction with the air quality
cognitive effect	Ref. concluded that office workers showed higher cognitive function scores when carbon dioxide and total volatile organic compounds concentrations were minimal.
sick building syndrome, sleep quality, cognitive effect	Similarly, other studies found that better indoor air quality in green buildings is associated with fewer sick building syndrome symptoms, higher sleep quality, and higher cognitive test scores.
stress	We also found that the prevalence of mental stress symptoms was predicted by low satisfaction levels with air quality and noise. Similarly, Ref. conducted an environmental health assessment of several office buildings and concluded that higher satisfaction with air quality and noise levels was associated with reduced stress.
sleep quality, stress, mood, productivity, concentration	Teleworkers who were satisfied with the air quality at home had less trouble sleeping and experienced less mental stress. They also experienced a more positive mood, rated their productivity to be higher, and indicated enhanced concentration due to better air quality (Bergefurt et al., 2023, p. 16).
depression, sleep quality, mood, engagement	The chance of teleworkers reporting new mental health issues, such as depression, trouble sleeping, mood swings, decreased social engagement, and trouble concentrating, was lower when they were satisfied with the air quality at home (Bergefurt et al., 2023, p. 16).
	## Color palette
productivity, mood	Those who changed the wall colours at home rated their productivity higher. The use of wall colours might positively affect teleworkers' mood, which could, in turn, improve their productivity (Bergefurt et al., 2023, p. 16).
	#### white or neutral colors
concentration, well-being	Kwallek et al. (1997) found that white-colored offices are experienced as less distracting and stressful than red- and green-colored offices, while blue colors have a calming effect (Connellan et al. 2013).
	#### warm and cold colors
stress, depression	Kwallek, Lewis, and Robbins (1988) show that using warm colours (e.g. red) in the office increases anxiety and stress levels, and that cool colours (e.g. blue) increase depressive symptoms.

mood, stress, concentration	K€ uller et al. (2006) argue that good colour design in the office might positively contribute to employees' mood. In general, cool colours are associated with concentration and attention, and warm colours with arousal.
stress, well-being	Blue or green wall colours both have a positive effect on stress and mood, which indicates that employees felt more stressed, but also felt happier and more satisfied when their wall colours at home were blue or green (Bergefurt et al., 2023, p. 16).
productivity, mood, stress	Blue and white room colours were found to have a small positive effect on productivity, mood and stress (Bergefurt et al., 2022, p. 8).
	#### natural materials
stress	Natural materials significantly decreased participants' immediate stress response in both self-report of negative arousal and physiological (CDA.SCR) measures. Windows also significantly lowered self-reported negative arousal. Strong trends for natural materials and diverse representations lowering self-reported stress were observed as well (Douglas et al., 2022, p. 13).
productivity	Natural materials exhibited a trend for increasing divergent creativity (Douglas et al., 2022, p. 13).
	#### other colors
stress	While high chroma colours do not effectively reduce stress, highbrightness colours do so (Hsiao, Hsiao, and Wang 2013).
	Mahnke (1996) argues, furthermore, that pale colours, such as pale gold, orange, green, and sandstone are also appropriate for office environments.
	## View
	#### satisfaction with views outside
productivity, fatigue, stress	Views outside, specifically natural outdoor views, could increase productivity and reduce fatigue and stress (Bergefurt et al., 2022, p. 8).
concentration, mood ,well-being	Another COVID-19 study showed that satisfaction with daylight and artificial light, having a view outside, and greenery were also important for employees' mental health, specifically for their concentration, mood, and well-being (Bergefurt et al., 2023, p. 2).
well-being	Satisfaction with greenery predicted higher well-being (Bergefurt et al., 2023, p. 16).
stress, depression	Having access to greenery (e.g., a garden or patio) reduced teleworkers' feelings of stress and depressive symptoms (Bergefurt et al., 2023, p. 16).

concentration, depression, mood, sleep quality	Generally, satisfaction with views outside was found to be related to higher concentration. More specifically, having natural views outside was associated with fewer depressive symptoms, a more positive mood, and lower self-reported moodiness, concentration, and sleep disturbance (Bergefurt et al., 2023, p. 16).
stress	Participants exposed to natural materials and windows during a stress-inducing task had lower negative stress impacts across various metrics (Douglas et al., 2022, p. 1).
stress	Natural materials significantly decreased participants' immediate stress response in both self-report of negative arousal and physiological (CDA.SCR) measures. Windows also significantly lowered self-reported negative arousal. Strong trends for natural materials and diverse representations lowering self-reported stress were observed as well (Douglas et al., 2022, p. 13).
well-being, mood, productivity, stress	Direct nature exposure through plants helps to create a pleasant physical and social environment (Bjørnstad, Patil, and Raanaas 2015), which may result in a positive mood, increased productivity (Smith, Tucker, and Pitt 2011; Smith and Pitt 2009), and reduced stress levels (Ayuso Sanchez, Ikaga, and Vega Sanchez 2018; Elsadek and Liu 2021).
cognitive effect, concentration	As Kaplan (1993) argues, a window view functions as a microrestorative experience and may recover individual's attention. For instance, viewing a green roof for only 40s already has several cognitive benefits and can restore individuals' attention (Lee et al. 2015).
well-being, stress	Beute and de Kort (2014) indicate that viewing natural scenes for only three minutes improves individuals' hedonic tone (i.e. pleasantness or happiness) compared to viewing urban scenes. These findings show that views on natural scenes, such as green areas, clouds, and the sky (Jamrozik et al. 2019) or forest views (Shin 2007), provide a restorative (Smith, Fsadni, and Holt 2017) and calming effect (An et al. 2016), and decrease brain activity and stress (Bjørnstad, Patil, and Raanaas 2015; Jo, Kim, and Jeon 2019).
stress, productivity	As Sadick and Kamardeen (2020) argue, reducing employees' stress through nature may have several psychological and cognitive consequences that could improve health, such as better cognitive performance through improved working memory and inhibition of automatic responses (Jamrozik et al. 2019).
	#### size of the window
mood, well-being	Employees perceive their workspace more positive overall when windows are large. They rate a workspace with larger windows as more pleasant, interesting, complex, spacious, and bright (Moscoso et al. 2021).

	#### vertical plants
mood	Some studies also considered the effect of vertical plants or green walls and found that they have a more positive influence on people's mood than potted plants (Gunn, Vahdati, and Shahrestani 2022).
	#### potted plants inside
productivity, concentration, well-being, stress, depression	Plants in the office and the satisfaction with views outside were mainly used as indicators of biophilia and views. The presence of plants could increase employees' productivity, concentration, and well-being, and could reduce stress and depression (Bergefurt et al., 2022, p. 8).
mood, sleep quality	Spano et al. argued that the presence of potted plants within the home-workspace was associated with lower self-reported moodiness and sleep disturbance.
	#### negative effect
mood	However, some studies (e.g. Ref.) indicated that too many plants were perceived as chaotic and uncomfortable, and should therefore be prevented.
	## glare
mood, concentration, eye related symptoms	Glare limits people's ability to see clearly and creates a feeling of annoyance and discomfort that can lead to a loss of concentration and attention. Sustained exposure to glare can result in eyestrain and eye fatigue that can lead to impaired vision and, in extreme cases, eye injuries.
musculoskeletal discomfort	Our analysis shows that low levels of satisfaction with glare predicted higher prevalence of musculoskeletal discomfort. When a person is exposed to glare, gaze stabilization becomes challenging which requires head, neck, or even body posture adjustment to reach a comfortable visual state. These adjustments might not be optimal and can contribute to muscle pain development.
eye related symptoms, musculoskeletal discomfort	Recently, Ref. concluded that constant exposure to direct glare conditions leads to visual discomfort, affects the trapezius muscle (back muscle), and leads to the development of neck pain.
	## Cleanliness
concentration	Workspace cleanliness might influence employees' distractions while also influencing their productivity (Horrevorts, van Ophem, and Terpstra 2018).

productivity	Kim and de Dear (2013) argued that employees in all office types are satisfied with the cleanliness of the workspace, but when sharing a desk with others, the presence of unclean desks may decrease their productivity (Kim et al. 2016).
concentration	Piles of paper, notes, or to-do lists on the desk might especially be distracting because these introduce too many physical stimuli in the workspace.
concentration	Cluttered workspaces, with unemptied bins, old coffee cups, and loose papers, might also distract people from their primary job (Davis 1984).
concentration	Current research showed that medium- or large-sized home workspaces that are clean and tidy, without noise interruptions, appear to reduce workspace distractions (Bergefurt et al., 2021, p. 6).
concentration	People who worked in non-dedicated work areas that were small, had a cluttered desk, or who worked with more persons in the room were more frequently disturbed(Bergefurt et al., 2021, p. 4).
	## ergonomics
health	Furniture that can be adjusted to personal preferences might increase employees' satisfaction with the workspace(Marquardt, Veitch, and Charles 2002).
engagement	Moretti et al. explained that workers are expected to engage extensively with their workstations while working from home, and therefore presented their suggestions for a comfortable workstation (i.e., an adjustable desk and chair to prevent back and joints pain, along with a footrest, and an adjustable monitor screen).
stress	Seva, Tejero, and Fadrilan-Camacho (2021) showed that not only the adjustability of the chair, but also the comfort of the keyboard, the position of the monitor, and the size of the desk could influence employees' stress levels significantly.
health	Having a dedicated room for work, having an ergonomically correct workstation, knowledge of how to adjust a workstation, and increased satisfaction with IEQ factors in the workspaces were associated with lower chance of experiencing new health issues (Xiao et al., 2021, p. 189).
musculoskeletal discomfort, health	Spending extended periods of time at workstation without appropriate adjustments, increasing the odds of bodily pain and other physical health conditions (Xiao et al., 2021, p. 189).
productivity, engagement	Having the optimal physical setup, proper ergonomics and the necessary equipment is crucial to create an effective workspace that boosts productivity

	and increases the workers' engagement with their workstation (Awada et al., 2021, p. 1173).
productivity	Research shows that productivity decreases with lack of ability to adjust/personalize workspace as well as lack of storage space (Awada et al., 2021, p. 1173).
productivity	Having a dedicated workspace that is not intended for other uses decreases the probability of workers being interrupted by distractions, and that having a dedicated desk and adjustable chair may result in increased comfort allowing workers to spend more hours at their workstations (Awada et al., 2021, p. 1184).
musculoskeletal discomfort, productivity	Use of other tables, sofas, floor chairs, floor cushions, and other computers were found to be associated with the neck/shoulder pain, low back pain, and poor work performance among homeworkers (Du et al., 2022, p. 967).
	### desks
low back pain	Previous studies reported that lack of space on the desk is associated with higher odds of low back pain among homeworkers (Du et al., 2022, p. 968).
low back pain, shoulder muscles	The desk plays an important role when working in a sitting position because it provides support and carries the weight of the arms and upper torso. A sitting position without arm support was reported to increase the load on the lumbar spine and may increase the risk of low back pain. The height difference between the desk and the seat affects arm posture and the load on the shoulders (Du et al., 2022, p. 968).
shoulder muscles	A desk height above the elbow results in arm abduction while working, and this increases the muscle active contraction of the deltoids. On the other hand, a desk height lower than the elbow results in static contraction of the shoulder muscles while supporting the weight of the upper arms (Du et al., 2022, p. 968).
neck pain	Prolonged stressful posture leads to muscle fatigue and poor work posture, which may ultimately result in musculoskeletal problems. In addition to this, the desk height also determines the location of the display, hence affecting the neck angle. A neck flexion angle greater than 25 degrees is a critical zone according to the ISO 11226 ergonomics evaluation of static working (Du et al., 2022, p. 968).
neck/ shoulder pain or low back pain	Improper postures when using "other tables" with disproportionate size and height is a possible reason for severe neck/ shoulder pain or low back pain (Du et al., 2022, p. 968).
	### chairs

distraction	Janneck et al. (2018) argued that uncomfortable seating is one of the main distracting factors while WFH.
musculoskeletal discomfort, stress	The presence of adjustable chairs at home could reduce musculoskeletal problems (Awada, Lucas, et al. 2021), and decrease stress (Seva, Tejero, and FadrilanCamacho 2021).
concentration	those who had a non-adjustable chair seemed to be less disturbed in their work tasks (Bergefurt et al., 2021, p. 5).
musculoskeletal discomfort, engagement	Importantly, owning an adjustable chair can reduce musculoskeletal risk, which in can increase workers engagement at the workstation (Awada et al., 2021, p. 1184).
neck/ shoulder pain	Using floor cushions and sofas was found to have a high risk for mild neck/shoulder pain (Du et al., 2022, p. 968).
low back pain	Using the floor chairs and cushions were found to increase the risk twofold for developing severe low back pain compared with work chair. A recent experimental study showed that the lower back flexion angles when using a floor cushion or floor chair were in the stressful range of motion (Du et al., 2022, p. 968).
low back pain	Without a backrest to support the weight of the upper body when seated on a floor cushion, the stressful low back flexion would be a harmful posture that can lead to the development of low back pain (Du et al., 2022, p. 968).
	## technologies
engagement	They found that higher functionality of the home-work environment increased teleworkers' work engagement significantly (Bergefurt et al., 2023, p. 15).
productivity, engagement	Having the optimal physical setup, proper ergonomics and the necessary equipment is crucial to create an effective workspace that boosts productivity and increases the workers' engagement with their workstation (Awada et al., 2021, p. 1173).
low back pain, neck pain	A study reported that the location of the computer monitor (not in front of the operator) is associated with low back pain. Experimental studies reported that using a laptop computer developed a large angle of neck flexion compared with using a desktop computer (Du et al., 2022, p. 968).
	## artificial light

mood	Ref. found that bright and cool color lighting induced positive effects and improved the mood of office workers.
concentration, mood, well-being	Another COVID-19 study showed that satisfaction with daylight and artificial light, having a view outside, and greenery were also important for employees' mental health, specifically for their concentration, mood, and well-being (Bergefurt et al., 2023, p. 2).
sleep qualtiy, engagement	This shows that low light exposure levels increase the chance of insomnia, while illuminance levels above 575lux lead to higher engagement (Bergefurt et al., 2023, p. 15).
mood	Satisfaction with artificial light significantly improves employees' mood (Bergefurt et al., 2023, p. 15).
productivity, concentration, sleep quality, mood, well-being, fatigue, depression, stress	Previous research also showed that increased illuminance, higher circadian stimulus (CS) values (i.e. the effectiveness of a light source in providing circadian stimulus) and increased correlated colour temperature (CCT) values (i.e. cooler colours) could increase employees' productivity, concentration, sleep quality, mood, well-being and reduce fatigue, depression, and stress. Both daylight and artificial light contribute to individuals' daily light exposure, which could enhance their mental health (Bergefurt et al., 2022, p. 7).
	## Thermal
productivity, concentration, sleep quality, mood, and well-being, fatigue, stress	For thermal comfort and temperature, it was found that temperatures below or above 20–24 ◦C and a relative humidity below or above 40–55% could decrease an individual's productivity, concentration, sleep quality, mood, and well-being, and increase fatigue and stress (Bergefurt et al., 2022, p. 8).
eye, head, nose, throat related symptoms	Reference found that office workers who were uncomfortable with typical thermal conditions in their workspace showed a higher prevalence of headache, throat, and eye irritation.
productivity, engagement	We found that the satisfaction with IEQ parameters, especially the thermal environment, and having a dedicated workspace were positively associated with productivity, while having a desk and adjustable chair were associated with increased time spent at the workstation (Awada et al., 2021, p. 1184).
productivity	Geng et al. [66] showed that thermal satisfaction increases office workers' productivity while postulating that it is the most influential IEQ parameter affecting productivity.
productivity	Research supports that the more control individuals have over their environments, the more satisfied they are with it, thus having access to

	environmental controls might also improve worker productivity (Awada et al., 2021, p. 1174).
	#### Temperature
concentration, well-being	Distractions can be caused by discomfort and stress from ambient conditions, such as high indoor temperatures(Clements-Croome 2006; Roper and Juneja 2008).
concentration	According to Varjo et al. (2015), the indoor temperature should range between 21 and 25 C to decrease distractions.
sleep quality, productivity	In the absence of air conditioning or circulating systems at home, employees' perception of air quality and humidity was lower, which also reduced their sleep quality and productivity(Buomprisco et al. 2021).
sick building syndrome, cognitive effect	In addition, Ref. suggested that rapid temperature swings aggravate sick building syndrome symptoms and have detrimental effects on cognitive performance.
health	Furthermore, extreme thermal events can result in conditions such as hypothermia or heat stroke and can increase cardiovascular mortality, especially among children and the elderly.
concentration, productivity	Our results show that low satisfaction with noise and indoor temperature predicted the prevalence of symptoms related to trouble concentrating and maintaining attention or focus. The ability to concentrate and be attentive is directly related to productivity; therefore, many research studies examined the effect of IEQ on workers' concentration and attention capabilities in office buildings.
concentration	Our results are also in agreement with the findings of Ref. who concluded that workers' concentration and alertness levels increased with a higher level of thermal satisfaction in office buildings.
concentration	Those who were dissatisfied with the temperature at home had trouble concentrating (Bergefurt et al., 2023, p. 16).
productivity	Thermal satisfaction (i.e., indoor temperature and humidity) and thermal comfort was important for teleworkers' productivity (Bergefurt et al., 2023, p. 16).
depression, sleep quality, mood, engagement, concentration	satisfaction with the thermal environment might have prevented employees from developing new mental health issues, such as depression, trouble sleeping, mood swings, decreased social engagement, and trouble concentrating (Bergefurt et al., 2023, p. 16).

	#### Humidity
eye related symptoms	Low humidity levels can stimulate the evaporation of the tear film leading to a dryness sensation of the eye, which results in increased irritation and eyestrain.
skin, nose, lips related symptoms	Also, low humidity levels can cause the skin and nose to dry out and lead to itching, chapped lips, and skin and nose irritation.
health	On the other hand, high humidity levels accelerate the growth of mold which can reduce overall air quality and aggravate allergies, asthma, and cause other breathing problems.
eye related symptoms	Our results also agree with Shin et al. (2018) who found that workers who reported low satisfaction with humidity were prone to more eye problems in office buildings.
skin, nose, throat related symptoms	In addition, our results show that low satisfaction levels with humidity predicted a higher prevalence of skin (chapped skin, itchiness, and redness) and nose/throat-related symptoms (dry, runny, or bloody nose, hoarseness). Similar findings were reported in Ref., where low satisfaction with humidity was associated with a feeling of irritation at the level of noise and throat.

Appendix B – Questionnaire

1. physical setup

Do you have a dedicated room only used for working from home? Y/N

If not, do you have a dedicated area (with a desk and chair) only used for work? Y/N

Are you sharing the workspace(the room you work in) with other family members? Y/N

Are you using other furniture (e.g., dining table, sofa) to work? Y/N

Are you using an ergonomic/adjustable desk to work from home? Y/N

Do you usually change your workspace at home? Y/N

How long do you need to work from home per day?

2. environmental preference

Lighting Preference: [Checkbox: Natural Light, Artificial Light, Both, No Preference]

Noise Level Preference: [Dropdown: Quiet, Moderate Background Noise, No Preference]

Do you have street noise or other noise outside of your window? Y/N

Are you satisfied with your room's current noise level? Y/N

Air Quality and Ventilation Preferences: [Checkbox: Natural Ventilation (Windows), Mechanical Ventilation (HVAC), Air Purification Systems, Humidifier/Dehumidifier, No Preference]

Preferred Room Temperature: [Dropdown: Cool (Below 68°F), Moderate (68°F - 74°F), Warm (Above 74°F), No Preference]

3. mental well-being, work performance

Do you have any mental health issues or working performance concerns? Rating the following options on a scale of 1 to 10. "10" represents that this is an important concern when designing your home workspace.

stress/anxiety/tension/irritation/arousal

concentration/distraction/attention/focus

well-being/comfort/happiness/satisfaction

productivity/performance

depression

sleep/circadian rhythm

working engagement

psychological distress/psychological privacy/cognitive effect/mental boundary

fatigue/exhausted

annoyance/mood swings/mood/moodiness

4. Physiological discomfort

Are you suffering from any of the following physical health symptoms? Rating the following options on a scale of 1 to 10.

eye strain/irritation/fatigue, headache, throat, skin, nose

sick building syndrome symptoms

Back pain/neck pain/low back pain/shoulder pain

Other health issues

Appendix C – Feedback of User Test Subjects

Subject 1:

"In the design process, I learned about how a person's distance from the window affects noise and ventilation. I want to incorporate existing furniture into the design scene to see how it impacts the workspace. The suggested sentences should be simpler, or the UI could be designed better for easier access."

Subject 2:

"During the design process, I learned about indoor environmental quality, such as lighting, ventilation, and noise. It's crucial to consider the room's orientation; for instance, southwest-facing rooms can cause glare. Suggestions from the literature should be summarized more simply because they take too long to read. Label the room's dimensions and mapping data for better understanding, and incorporate existing furniture to assess the harmony between the workspace and other furniture."

Subject 3:

"Through the design process, I realized that adding plants to the room and having a height-adjustable desk would be better, and a sofa might also work well for studying. The font size is too small and there are too many items, making it hard to read."

Subject 4:

"I learned that buying plants helps improve mood, adjustable desks benefit musculoskeletal health, and I can recognize when glare occurs. It would be useful to know how other furniture interferes with the workspace and to have instant visual feedback on adding a plant to the scene."

Subject 5:

"I learned how glare affects the eyes. There's no need to include citations in the suggestions, as it saves words. I want to know how other furniture affects each area and how to arrange it to save space, like leaving one wall open for a projector. My design goals are different since I rarely study at home, so maximizing workspace efficiency isn't my priority."

Subject 6:

"I don't usually care about air quality since I have a humidifier and heater, but this design made me realize how important environmental factors are. I didn't care about wallpaper colors before, but I noticed that they affect mood. I spent a lot of time figuring out furniture placement after moving in, and improving the workspace quality is vital. I also learned about the impact of glare."

Subject 7:

"I learned that the position of the desk affects work efficiency. I'm curious about which suggestions change, disappear, or are new after each action. Maybe different colors could indicate that. I'd like to see instant visual feedback on adding plants."

Subject 8:

"I learned how natural light impacts people's happiness. Summarize all suggestions with subheadings, and highlight those that change after each design action."

Subject 9:

"I learned how different colors affect people's psychological perceptions. Consider adding features that recognize the interactions between furniture. The text is too long, so highlighting important keywords would be helpful."

Subject 10:

"I learned how wall color plays a role, and I recognized how the desk's direction and window position impact environmental factors. Summarize the literature's main conclusions with subheadings because users don't care about who said it or have the patience to read through everything."

Subject 11:

"I learned the benefits of using teal as the primary color for the workspace. I'm curious about how other furniture arrangements could interfere with the workspace, and I'd like to see the visual simulation of lighting and ventilation effects. Organize suggestions into categories for easier reading."

Subject 12:

"Display immovable furniture in the scene, like the kitchen stove. Simulate the lighting effect in the design, and summarize the points from the literature."