REDEFINING INTERIOR SPACES POST-COVID: ERGONOMIC DESIGN PRINCIPLES FOR PLANT INTEGRATION

REDEFINIREA SPAȚIILOR INTERIOARE POST-COVID: PRINCIPII DE DESIGN ERGONOMIC PENTRU INTEGRAREA PLANTELOR

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Abstract. *In the wake of the COVID-19 pandemic, the significance of interior spaces has been redefined, emphasizing comfort and well-being more than ever. This review explores the integration of plants within these spaces, drawing from ergonomic design principles. As the pandemic highlighted the importance of mental and physical health, plants have emerged as aesthetic assets and functional contributors to our living spaces. This review examines the role of plants in enhancing mental well-being, the ergonomics of plant-focused design, their contribution to indoor air quality, and their alignment with post-pandemic design trends. The insights provided herein guide the reimagining of interior spaces for a post-pandemic era.*
Keywords: COVID-19; Ergonomics; Plants; Well-being; Air-quality.

Rezumat. *În urma pandemiei COVID-19, semnificația spațiilor interioare a fost redefinită, punându-se mai mult ca niciodată accentul pe confort și bunăstare. Această analiză explorează integrarea plantelor în aceste spații, pornind de la principiile de proiectare ergonomică. Pe măsură ce pandemia a evidențiat importanța sănătății mentale și fizice, plantele au apărut ca atuuri estetice și contribuții funcționale în spațiile noastre de locuit. Această recenzie examinează rolul plantelor în sporirea bunăstării mentale, ergonomia designului axat pe plante, contribuția acestora la calitatea aerului din interior și alinierea lor la tendințele de design post-pandemic. Perspectivele oferite aici ghidează reimaginarea spațiilor interioare pentru o eră post-pandemică.*
Cuvinte cheie: COVID-19; Ergonomie; Plante; Bunăstare; Calitatea aerului.

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INTRODUCTION

Interior design has evolved, influenced by various factors, including cultural differences and housing needs (Kim *et al.,* 2022). The introduction of plants in interior spaces has become essential due to urbanization and the desire for green areas (Kaufmann-Buhler, 2022). In the late 20th century, plants were incorporated into office interiors as a design tool and for their perceived health benefits (Chooi *et al.,* 2022). The use of plants in interior design has also been explored in developing nature-inspired robotic structures for indoor public spaces (Tufekcioglu, 2017). Art Nouveau tenement houses in Sopot featured plant ornaments as elements of decoration and detail (Szumigała and Szumigała, 2022). Understanding the characteristics of interior space, analyzing existing buildings, and considering material and surface qualities are fundamental aspects of interior design (Brooker and Stone, 2010). Despite the popularity of interior design, there is still a lack of legislation and definition in the field. Overall, the historical role of plants in interior design has evolved to include their use as design elements, for health benefits, and for creating stimulating and interactive experiences in indoor spaces.

Interior spaces play a crucial role in our daily lives, and the design of these spaces should prioritize ergonomic considerations. Ergonomics focuses on creating safe, comfortable, and efficient rooms for users. It involves considering physical, environmental, and cognitive elements to balance user preferences and safety standards (da Silva, 2018). Ergonomics in interior design helps implement safety procedures and limit potential threats, both in ordinary use and unforeseen events (Reddy *et al.,* 2012). Additionally, ergonomic design criteria are essential for creating private external spaces in residential areas, considering the general and specific housing needs, including those of people with disabilities (Janowicz, 2019). Furthermore, furniture arrangement in residential interiors should also consider ergonomic principles to ensure visual perception, inter-person visual perception, and the openness of space (Nowakowski, 2020). Overall, ergonomic design in interior spaces is essential for creating functional, safe, and aesthetically pleasing environments.

The COVID-19 pandemic has had a transformative impact on interior spaces, leading to a re-evaluation of design principles and the integration of plants for health and wellness. Evidence-based arguments suggest that the design of interior and exterior spaces should prioritize human health and well-being (Aresta and Salingaros, 2021). The pandemic has prompted a shift in thinking about interior and architectural spaces, focusing on the lessons learned from the situation and their application in future designs (Atmodiwirjo and Yatmo, 2020). Home vegetable gardens have been recognized as a valuable resource during periods of isolation, providing recreational, health, economic, and environmental benefits (Sofo and Sofo, 2020). The pandemic has highlighted the need for design strategies that respond to the risk of virus transmission, including developing air ventilation systems, changes in spatial patterns, and selecting materials that inhibit

transmission (Rahim *et al.,* 2022). Additionally, cultivating and contemplating flowers and ornamental plants have been shown to aid mental health care, with hortitherapy and biophilia incorporated into the architectural design as potential solutions (Reis *et al.,* 2020).

This study focuses on the redefined importance of interior spaces, especially during the COVID-19 pandemic. Central to this examination is:

- The role of plants as both aesthetic enhancers and functional elements in interior environments.
- The ergonomic principles driving the effective integration of plants into these spaces.
- An exploration of how plants contribute to mental well-being and indoor air quality.
- The alignment of plant-integrated designs with emerging trends in the post-pandemic world.

MATERIAL AND METHOD

In our research approach, we first turned to well-known academic databases such as Google Scholar, Web of Science, and Science Direct to find articles focusing on the role of plants in interior spaces, especially in the context of the post-COVID era. To ensure our review was both relevant and comprehensive, we primarily chose articles that touched upon comfortable and efficient design principles, known as ergonomics, those that detailed the multiple advantages of integrating plants indoors, and ones that shed light on how the pandemic has reshaped interior design concepts. We generally bypass older publications beyond 20 years unless they present crucial insights. Once we gathered the necessary articles, we categorized them based on their core themes. By comparing and contrasting the ideas and recommendations across these articles, we aimed to offer a rounded understanding of optimal ways to incorporate plants into interior designs.

RESULTS AND DISCUSSIONS

Impact of COVID-19 on Interior Spaces

The impact of the COVID-19 pandemic on interior spaces and the shift in interior design post-COVID has been a topic of research and analysis. Studies have focused on various aspects, such as furniture design standards, movement paths, and restaurant support service spaces (Ali and Saddiq, 2022). The pandemic has highlighted the need to reconsider the design of interior and exterior spaces to improve human health and well-being (Aresta and Salingaros, 2021). Residential areas have become more critical than ever, with the need to accommodate multiple functions and roles within a single dwelling (Taha, 2021). Architects and urban designers believe that the pandemic will affect the future of architecture and urban design, leading to new design features and a focus on living, working, learning, leisure, and teaching spaces (Alhusban *et al.,* 2022). The future of interior design will involve considerations such as transparency, natural daylighting and

ventilation, healthy indoor air quality, the use of plants and natural materials, and the integration of touchless and intelligent technologies.

Ergonomic Design Principles

Ergonomic design principles play a crucial role in contemporary interior design. Designers often use a holistic approach to create products based on customer needs and market demands (Tosi and Tosi, 2020). However, ergonomics aspects are sometimes overlooked during the ideation stage due to the lack of easily accessible ergonomics tools and knowledge for designers (Luximon *et al.,* 2019). Developing ergonomics tools and methods that designers can quickly adapt is essential, fostering collaboration between designers and ergonomists (Soares and Rebelo, 2016).

In the formal environment, in the sphere of work, it has been noted that meeting the correct specifications for the design of furniture and ergonomic space planning increases the productivity of individuals (Bridger, 2008; Grandjean, 1972). In other words, the study of ergonomics takes care of the correct organization of work in environmental space, making traffic flow more smoothly, but also making the handling of objects more efficient, reducing the accident rate in the workplace.

Color

Color in interior design is more than just visual. It has emotional and psychological effects on people. Colors can evoke immediate emotional responses in humans, attracting or repelling them (Reddy *et al.,* 2012).

Colors can affect emotions differently depending on cultural associations, trends, age, and personal preferences. Additionally, different cultures assign unique symbolic meanings to specific colors. For instance, ancient Indian traditions used colors to represent emotions and directions (Nair, 2014; Ambrose and Harris, 2011; Don, 2001).

When choosing colors for interiors, it is essential to consider factors such as climate, orientation, and room usage. The same color can evoke different emotions depending on where it is used. Warm colors are preferred in residential spaces since color affects how people perceive size, distance, and weight (Ulusoy *et al.,* 2020; Ćurĉić *et al.,* 2019; Reddy *et al.,* 2012).

Texture

Texture plays a vital role in a room's appearance and ambiance. Merging different surfaces, such as rough concrete, polished marble, or studded rubber, can create an impressive effect. In addition, texture creates a bond between individuals and their surroundings (Barani and Dastranj, 2023; Gagg, 2011).

Mixing different textures, such as velvet, steel, or stone, can create captivating effects in a room. Harmonizing texture with color is crucial for a cohesive environment and affects light absorption, ultimately altering color perception. Balancing lighting with textures is vital to avoid dulling texture and compromising surface definition (Reddy *et al.,* 2012).

The texture is a crucial aspect of interior design. Coarse textures can make

objects appear heavier, while smoother surfaces can make them seem lighter. Moreover, texture adds personality and enhances the overall design aesthetic (Reddy *et al*., 2012; Gagg, 2011).

In an interior space, objects define form, contribute to stability and weight, and establish balance while creating focal points and encouraging movement (Brooker and Stone, 2007).

Light

Proper lighting is crucial for safety, comfort, and productivity. Each room has unique lighting needs, and inadequate lighting can harm well-being. Adhere to recommended guidelines for optimal illumination. Lighting significantly impacts emotions, health, and perception of space. While historical illuminance recommendations vary, policies are available for everyday activities. Additionally, colors and daylighting should be considered since lighting is interconnected with other interior elements (Bellia *et al.,* 2011; Jaglarz, 2011).

Natural daylight regulates various human physiological systems, including circadian rhythms, hormone secretion, and body temperature. Disruption of these cycles can cause symptoms ranging from temporary jet lag to severe depression. Building design should incorporate windows and doors to allow natural light while balancing technical lighting requirements with user preferences (Potter *et al.,* 2016; Webb, 2006; Küller, 2002).

Sound

Proper acoustics are crucial for interior spaces and their function. Sound affects health, safety, comfort, and productivity. Music can evoke emotions, while disruptive noises can result in health problems (Mohammad Alizadeh *et al.,* 2021; Siskova and Juricka, 2013). Soft materials absorb sound in quiet environments, while hard surfaces create noise. Noise can be managed with appropriate flooring, wall treatment, and ceiling materials. Carpets, rugs, draperies, and furniture can absorb or reduce sound. Wall composition varies based on building or room type (Binggeli, 2008).

Interior Climate

Monitoring indoor climate factors such as temperature, humidity, and pollutants is crucial for well-being and productivity. Technological advancements in temperature control and ventilation have significantly improved indoor environments, offering benefits for refurbishment, operational costs, and overall health and productivity (Al horr *et al.,* 2016; Safin *et al.,* 2020). Maintaining a comfortable indoor temperature of 20-24°C in summer and 20-21°C in winter is ideal. Overheating can cause tiredness and errors, while over-cooling can lead to restlessness and reduced concentration. Keep the relative humidity at 40-50% in heated rooms to ensure comfort and prevent adverse effects on the respiratory system (Parsons, 2019).

Benefits of Plant Integration

Integrating plants in interior spaces offers a range of benefits. Physically,

plants can improve indoor air quality, regulate temperature, and reduce the concentration of volatile organic compounds (Mahyuddin *et al.,* 2022). Psychologically, plants have been shown to enhance engagement, work efficiency, job satisfaction, mental health, and stress reduction (Persiani, 2021). Aesthetically, plants provide an aesthetic element to indoor spaces, making them more visually appealing (Hall and Knuth, 2020). Additionally, plants have the potential to mitigate climate effects, provide acoustic benefits, and contribute to energy savings (Husti *et al.,* 2015). Using plants indoors can also positively influence physiological, psychological, cognitive, and social well-being constructs, ultimately improving quality of life (Franek and Jarský, 2021). Employees perceive plants in the workplace as providing a sense of relaxation, changing the work environment to resemble home, and increasing work motivation. Furthermore, plants can contribute to potential energy savings in intelligent buildings by reducing carbon dioxide concentration and decreasing the supplied air required.

Ergonomic Design Principles for Plant Integration

Ergonomic design principles for plant integration focus on optimizing the interaction between humans and systems to ensure safety, usability, productivity, health, and wellness (You, 2021). Ergonomics aims to improve people's well-being and the system's overall performance by evaluating and designing interventions that align with people's needs, abilities, and limitations (Bendixen and Benktzon, 2015).

The strategic application of ergonomic principles in selecting, placing, and arranging plant and floral elements is central to enhancing aesthetics, comfort, and ambiance within interior spaces. Studies highlight the importance of considering sightlines, spatial distribution, and sensory engagement when integrating vegetation. Proper placement of plants and flowers can mitigate discomfort caused by harsh artificial lighting, improve air quality, and create visually appealing focal points. Furthermore, the ergonomic arrangement of these elements promotes natural movement patterns and encourages positive interactions with the environment (Wang *et al*., 2023; Grecu and Purcaru, 2014; Reddy *et al*., 2012; Chebykin *et al.*, 2008).

A pivotal shift towards user-centered design has emerged by integrating ergonomic insights, particularly by incorporating natural elements like plants and flowers. Adopting biophilic design principles aligns with this trend, recognizing the innate human affinity for nature. Integrating plants and flowers into interior spaces enhances aesthetics and fosters occupants' well-being, reducing stress, increasing productivity, and promoting mental restoration. This shift towards nature-centered design signifies a holistic approach that considers both functional and emotional aspects, further elevating the overall quality of interior environments (Cameron, 2014; Qin *et al*., 2014; Van den Berg *et al*., 2010; Grinde and Patil, 2009; Park and Mattson, 2009; Dijkstra *et al*., 2008; Khan et al., 2005; Park *et al.*, 2004; St Leger, 2003).

In a formal space, on the desk of a workstation, a well-placed and correctly chosen plant can relax the atmosphere and create an environment conducive to work giving employees a sense of achievement (Bridger, 2008; Chebykin et al., 2008; Panero and Zelnik, 1979).

When sitting, females have a distance from the saddle to the horizon line of 69.5-79.6 cm and ground to the seat of 37.8-44.2 cm, while males have 76.4-86.5 cm and 40.4-47.8 cm, respectively. Both distances combined show a comparison of gaze between male and female individuals (Panero and Zelnik, 1979). If a desk is 73.7 - 76.2 cm high, and the above calculation gives a size of 107.3 - 123.8 cm for females and 116.8 - 134.3 cm for males, then the maximum suitable height of the plant sitting on the desk can be between 23.8 and 29 cm. In other words, a plant placed on a desk should be of a height that does not obstruct eye contact with the other person, as can be seen in Figure 1.

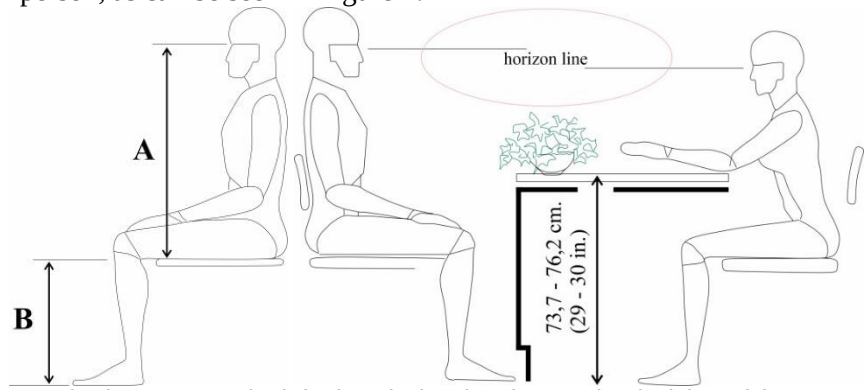

Fig. 1 - The free space to be left after placing the plant on the desk in a visitor reception area (A- distance from the seat to the horizon line of vision; B - ground-to-seat distance) (Panero and Zelnik, 1979)

Plants play several important ergonomic roles in interior design, contributing to occupants' physical and psychological well-being. Here are some of the critical ergonomic roles that plants can fulfill in interior design:

Improved Air Quality

Air pollution harms human health, and it mainly comes from two sources: industry and motor vehicles. The World Health Organization has identified six major air pollutants: lead, sulfur oxides, nitrogen oxides, carbon monoxide, ozone, and particulates. The toxic effects of these pollutants on human health vary depending on the duration of exposure (Diaconu et al., 2023).

Plants improve indoor air quality by removing pollutants and enhancing the overall environment. They can absorb and metabolize volatile organic compounds (VOCs), carbon dioxide (CO2), formaldehyde, and particulate matter, reducing their concentrations in the air (Sharma *et al.*, 2022; Gunasinghe *et al.*, 2021; Taemthong, 2021; Yeo, 2021). Plants also promote the growth of beneficial microorganisms that help degrade and detoxify pollutants, further improving air quality (Yang *et al.*, 2022). Additionally, plants can reduce indoor ozone levels and

enhance indoor environment quality (IEQ) by reducing CO2 levels (Hamdan and Hanim, 2020). Overall, plants offer a practical, economical, and environmentally friendly solution for improving indoor air quality and creating a healthier and more pleasant indoor environment.

According to different authors, the following plants can be used indoors to improve air quality and well-being (Sharma *et al.*, 2022; Asali and Alotaiby, 2022; Lee *et al.*, 2021; Gunasinghe *et al.*, 2021; Hamdan and Hanim, 2020; Shitole *et al.*, 2018): Golden Photos (*Epipremnum aureum*), *Eugenia* sp., Mountain Long Pepper (*Piper porphyrophyllum*), *Peperomia* sp., Satin Pothos (*Scindapsus pictus*), Purple Heart (*Tradescantia pallida*), Silver Squill (*Ledebouria socialis*), *Eugenia* sp., Zenmai (*Osmunda japonica*), Common Ivy (*Hedera helix*), Mums (*Chrysanthemum morifolium*), Dumb Cane (*Dieffenbachia compacta*), and Spider Plant (*Chlorophytum comosum*).

Humidity Regulation

Plants regulate humidity in indoor environments by increasing the overall humidity in the room. Plants, particularly in vertical greenery systems, lead to higher air humidity levels near the green wall, expanding the room's humidity (Nguyen *et al.*, 2021). Additionally, plant irrigation helps reduce the room temperature and further regulates humidity (Liu *et al.*, 2022). Using a humidity control system can also create an excellent indoor humidity environment. Using a humidifier, such a system can detect indoor humidity conditions in real-time and adjust the humidity according to user control (Liang *et al.*, 2015). Overall, plants and humidity control systems are crucial in maintaining optimal humidity levels in indoor environments.

Thermal Comfort

Plants offer indoor thermal comfort by improving occupant satisfaction and reducing energy consumption. Several studies have found that the presence of plants in indoor environments leads to increased thermal comfort for occupants (Sampath *et al.*, 2021). Participants in office buildings with a substantial quantity of plants reported being approximately 12% more thermally comfortable when plants were in the room (Sugiono *et al.*, 2017). Additionally, occupants were more likely to be thermally comfortable when plants were present (Mangone *et al.*, 2014). Incorporating plants in office buildings allows for adjusting temperature setpoints, reducing energy consumption and carbon emissions (Marino *et al.*, 2015). These findings highlight the role of plants in enhancing indoor thermal comfort and promoting sustainable energy use.

Noise Reduction

Plants reduce indoor noise by absorbing sound waves. Certain plant species effectively absorb noise due to their characteristics, such as leaf thickness, surface area, width, and length (Fard *et al.*, 2020; Jamaludin *et al.*, 2021). The effectiveness of noise absorption varies depending on the specific plant species and their morphological parameters (Yand *et al.*, 2010). Studies have shown that plants with thicker leaves, larger surface areas, and longer leaf lengths have higher sound

absorption capabilities (Pipal *et al.*, 2012). The noise levels can be significantly reduced by strategically placing these plants in indoor spaces. Additionally, using covered walls with plants can further improve sound absorption. Overall, plants provide a natural and sustainable solution for reducing indoor noise pollution.

Stress Reduction

Indoor plants reduce office stress by providing a natural and calming environment. Studies have shown that plants in the workplace can reduce psychological and physiological stress (Toyoda *et al.*, 2023). Daily lighting at nearby plants can positively impact office workers, decreasing anxiety levels and improving overall well-being (Kubota *et al.*, 2017). Additionally, indoor plants have been found to enhance productivity and reduce visual fatigue (Yeo, 2021). Overall, including indoor plants in office spaces can create a more pleasant and stress-free environment for employees, improving mental health and job satisfaction.

Enhanced Aesthetics

Indoor plants enhance aesthetics by improving the visual appeal of indoor and outdoor living spaces. Plants with unusual foliage and flowers are highly sought after by horticulturists and ornamental plant enthusiasts, as they enhance the natural beauty of certain plants and increase their commercial value (Smith *et al.*, 2017). Furthermore, research has shown that indoor plants positively affect the perception of work environment aesthetics, as users of a large office building perceived improvements in the overall environment when living plants were present (Valverde *et al.*, 2012). These findings demonstrate the potential of indoor plants to enhance aesthetics and create a visually pleasing environment in both indoor and outdoor spaces.

Visual Comfort

Indoor plants offer a visual barrier by being placed between the pot for a plant and the supporting surface, creating a protective arrangement. They can also be used in a structure for providing a physical or visual barrier, where plants are secured to posts by slats and wedges (Kurazumi *et al.*, 2018).

Productivity and Creativity Boost

Indoor plants have positively influenced productivity and creativity through various mechanisms. Studies suggest that the presence of plants in indoor environments can enhance positive feelings and improve overall well-being, leading to increased productivity (Yeo, 2021). Additionally, indoor plants have been shown to reduce stress levels and improve pain tolerance, further enhancing productivity (Pipal *et al.*, 2012). Furthermore, plants can help improve indoor air quality by reducing carbon dioxide, ozone, volatile organic compounds, and particulate matter, directly impacting cognitive function and creativity (Han, 2019; Bringslimark *et al.*, 2009). The biophilic effect, which refers to the innate human connection with nature, may also play a role in promoting creativity and productivity in the presence of indoor plants (Bringslimark *et al.*, 2007). Overall, the combination of improved well-being, reduced stress, and enhanced air quality contribute to the positive effects of indoor plants on productivity and creativity.

Cultural Significance

Indoor plants reflect the cultural values of a society by their use in interior design and their impact on the well-being of individuals. Introducing exotic species of indoor plants is seen as a way to diversify the assortment of plants and improve interior design, which positively affects human benefits (Cantor *et al.*, 2012). In Japanese culture, the names of plant parts are used in proverbs, reflecting cultural values such as respect for life, hard work, and vigilance (Fitri and Ihan Rini, 2022).

When incorporating plants into interior design, it is essential to consider factors such as the types of plants, their maintenance requirements, lighting conditions, and the overall design theme. Striking a balance between aesthetics and functionality will ensure that the plants effectively contribute to the ergonomic well-being of the occupants while complementing the design of the space.

Challenges and Limitations

Implementing plant integration in interior spaces may face several challenges and limitations. One potential challenge is space constraints, as interior spaces may have limited areas available for plants (Kim *et al.,* 2022). Another challenge is the maintenance requirements of plants, as they need regular care and attention to thrive indoors (Persiani, 2021). Additionally, potential allergies can be a limitation, as some individuals may be allergic to certain types of plants or their pollen (Yeo, 2021). However, despite these challenges, the benefits of integrating plants in interior spaces are significant. Plants have been found to improve indoor air quality, enhance productivity, reduce stress, and contribute to spatial branding and marketing (Franek and Jarský, 2021; Tian *et al.,* 2023). Therefore, planning and consideration can address these challenges to create healthy and aesthetically pleasing interior environments.

CONCLUSIONS

1. Integration of plants in interior spaces can enhance mental well-being and contribute to the overall comfort and well-being of occupants.

2. Ergonomic design principles should be considered when incorporating plants into interior spaces, considering plant types, maintenance requirements, lighting conditions, and the overall design theme.

3. Striking a balance between aesthetics and functionality is crucial to ensure that plants effectively contribute to the ergonomic well-being of occupants while complementing the design of the space.

4. The review provides insights and guidance for reimagining interior spaces in the post-pandemic era, emphasizing the importance of comfort, well-being, and the integration of plants as aesthetic assets and functional contributors.

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