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Potential risks and beneficial impacts of using indoor plants in the biophilic design of healthcare facilities: A scoping review

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ABSTRACT

Despite the wealth of scientific research on the health-promoting values of nature in space, incorporating indoor plants in the design of healthcare facilities has significant challenges. Given the dispersion of studies spanning several disciplines and lack of evidence, healthcare building designers often ignore beneficial impacts in favour of preventing nosocomial infections, resulting in indoor plants being used conservatively or substituted for artificial ones. Via a cross-disciplinary approach, this scoping review aimed to provide an overview of scholarly works that have examined the risks and benefits of integrating natural indoor plants in the design of healthcare facilities as one of the prime biophilic design elements commonly used for creating restorative environments. Twenty-eight peer-reviewed articles were selected through a systematic process in accordance with the eligibility criteria (studies examining the impacts of indoor plants on health risks and benefits for healthcare users) for final analysis. Health risks of the presence of natural indoor plants were explored concerning poor indoor air quality caused by pathogenic fungal/bacterial components released from potting soils. Benefits of physical and/or visual access to indoor plants were discussed in relation to improved non-light visual comfort and air quality, resulting in reduced emotional stress/anxiety, as well as enhanced general health, subjective wellbeing, and cognitive performance. This paper argues that multidisciplinary research is warranted on the application of biophilic design principles, particularly the use of natural elements, in the design of healthcare facilities. The finding of this research provides significant evidence that the use of natural indoor plants in the biophilic design of healthcare facilities is an efficient, low-cost, highly effective, and sustainable strategy for creating healing and therapeutic environments.

1. Introduction

Over the last three decades, there has been a growing interest in research highlighting the beneficial impacts of different building design attributes associated with biophilic design [1–5] and restorative environmental design [6–8] on the physiological and psychological health of occupants. Despite long interests in the theoretical and empirical value of natural environments to humans [9–11], no major breakthroughs have been made in building design providing humans with the experience of natural systems and processes, especially in one of the most complex building typologies – the healthcare facility [12–18]. This issue is particularly important to understand due to the vital health-promoting role of healthcare buildings in both human/society and environment/ecology [19–22]. Indeed, the application of the principles of biophilic design is crucial not only due to the high rate of critical and stress factors in healthcare facilities requiring therapeutic support of reconnecting with nature or improving the efficiency levels of an organisation, but also because the hospital and the city are two interconnected systems to a regenerative future [5,12,23].

According to the biophilic design principles, experiences of nature in the built environment can fall into three prime categories: "Nature in the Space", "Natural Analogues", and "Nature of the Space", which gave rise to 16 biophilic design patterns [5,24]. Here, the integration of natural indoor plants in the design of healthcare facilities can address some of the prime patterns, including visual and non-visual connections with nature, non-rhythmic sensory stimuli, and connections with natural

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systems [1], thereby merits more attention. Despite the benefits brought by the presence of natural indoor plants, healthcare building design guidelines lack thorough explanations of design requirements for the adoption of plants in indoor spaces [25,26]. According to Refs. [27,28]; there is limited evidence that links the presence of indoor plants to nosocomial infection, and as Clinical Excellence Commission [29] highlighted, "for the vast majority of patients in hospitals and other healthcare facilities, fresh flowers or potted plants do not represent a risk of infection". Nevertheless, it is strongly recommended that "plants and dried or fresh flowers are not allowed" in "intensive care units" and the hospital rooms of "immunocompromised patients". Further, Queensland Health [30] considered indoor plants as *loose furnishings* and stressed that "the design team is responsible for implementing indoor plant principles in interior planning and design: 1) proximity to and availability of plants in rooms; and 2) microbial risk assessment associated with the introduction of indoor plants"; however, no evidence and details of design considerations are provided. Thus, due to the critical contribution of building design to the rates of healthcare-associated infections, designers often ignore indoor natural plants in clinical areas, use them conservatively and only in waiting areas, or substitute them for artificial ones.

Turning to the research investigating the role of indoor plants in the built environment, six review articles explored a wide range of studies, mostly on working and learning environments, and highlighted the significant impacts of indoor plants on improved task performance and cognition, increased positive emotions, enhanced pain management, and reduced stress and negative feelings [31–37]. Moreover, some studies discussed the role of indoor plants in reducing the health risks associated with poor indoor environmental qualities (IEQ), including improvements in indoor air quality, and acoustic and thermal control, as well as increasing building energy efficiency and its associated economic benefits [38–45]. However, review research on healthcare building design is largely limited to different aspects of healing gardens and window views of natural environments [46–52], there is a lack of reporting on both risks and benefits of integrating natural indoor plants in this complex building typology [15].

The literature examining the impacts of indoor plants in healthcare facilities remains relatively sparse despite spanning disciplines, including microbiology, environmental medicine, nursing, agriculture, horticulture, environmental engineering, health and social science, immunology, epidemiology, psychology, and architecture. These studies are fragmented with different concepts, metrics, and analytic methods, generating low-impact knowledge in the realm of design practice. In this paper, a cross-disciplinary approach is adopted to better understand the scope of the literature, map the existing evidence, and identify knowledge gaps. This paper used a systematic process to address the prime research question: What are the risks and benefits of incorporating natural indoor plants in the design of healthcare facilities as one of the prime biophilic design elements commonly used for creating restorative environments? This question is significant in that it directly addresses the several shortcomings of the current state of the body of knowledge discussed above, namely through cross-disciplinary synthesis of the state of the art.

We first represented the systematic methodological steps followed to narrow the sample from 642 to 28 articles for the main dataset and 64 articles for the supplementary dataset. Next, an analysis is provided of the experiment settings and methodologies employed, before summarising the risks and benefits in relation to the physical and psychological health of occupants. This paper ends with an overview of the emerging literature and knowledge gaps in this area, informing future research and policies.

2. Method and materials

Due to the vast nature of our research question, the lack of a broad map of the evidence, and the need to understand the cross-disciplinary body of literature in this area to inform design practice [53–55], a scoping review methodology was selected. The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist extension [55]. The prime objectives were to: 1) explore the health- and safety-related risks of incorporating indoor plants in healthcare facilities; 2) classify the beneficial impacts of indoor plants on physical and psychological health and wellbeing, and cognitive performance in relation to different IEQ factors; 3) classify the experiment settings and how research was conducted; and 4) provide an overview of the literature and identify knowledge gaps in this field. This study was conducted in July 2022 and updated in January 2023, involving two prime stages: developing and conducting a search strategy, and extracting and synthesising the datasets.

2.1. Search strategy

An initial search was conducted using keywords developed from the key resources and authors' collective knowledge (from the perspective of Architecture and Construction, Environmental Psychology, and Health). The keywords were refined based on the quantity and relevance of returned items. Here, Boolean operators were employed to narrow or broaden the search by using synonyms, acronyms, and other alternative terms. The final list consisted of three sets of search terms describing: indoor plants, healthcare settings, and health impacts (see Table 1).

Peer-reviewed articles (excluding conference papers and dissertations) in English were exported from nine major online databases relevant to health and design disciplines (Scopus, Web of Science, and EBSCO: CINAHL Complete, Global Health, Medline Complete, Avery Index Architecture, Art and Architecture Complete, APA PsychInfo, and SocIndex). Furthermore, backward and forward snowball searches were conducted on the articles returned from full-text assessment (see Refs. [56,57]. The results from each database are provided in Fig. 1. Here, the Covidence online tool was used to manage and organise the results [58].

2.2. Data extraction and synthesis

Two reviewers independently identified, reviewed, and selected relevant literature for eligibility assessment following PRISMA's four-step guidelines for scoping reviews. Using Covidence, after removing duplications, the returned items were filtered by comparing the titles and abstracts to the eligibility criteria. The full text of relevant records was then reviewed for final selection, with reasons for exclusion documented. Here, records were excluded principally on relevance to the research question (i.e., the links between the presence of indoor plants and risks and benefits for healthcare users) and without any limitation

Table 1
List of search terms.

Search Concept	Search Terms[a]
Indoor plants	biophili[a], greenery, potted/indoor ornamental/foliage plants, potting soil/mix, or green/living walls
Healthcare settings	healthcare or hospital medical centre/clinic/facilit[a], clinical area/space, inpatient unit, ward, or patient room waiting area/room/space, reception, or lobby outpatient/cancer/rehabilitation centre/clinic/unit/facilit[a] mental health facility[a]/unit/ward/setting/architecture, mental care/healthcare/clinic/institution, psychiatric ward/unit/facilit[a], or behavioural health facilit[a]/setting
Health impacts	health[a]/wellbeing/comfort/safety, infection/contamination/bacteria[a]/microb[a]/mould/fung[a]/aeroallergen/pathogen[a]/dust/pest, or illness/disease/disorder/symptom/syndrome, performance/productivity/cognitive/satisfaction, or stress/anxiety/mood/emotion/feeling
Workplace settings	office, working area, workplace, work/working environment, or meeting room/area

[a] To include all variations of search terms, we refined the search string using advanced search features of each database.

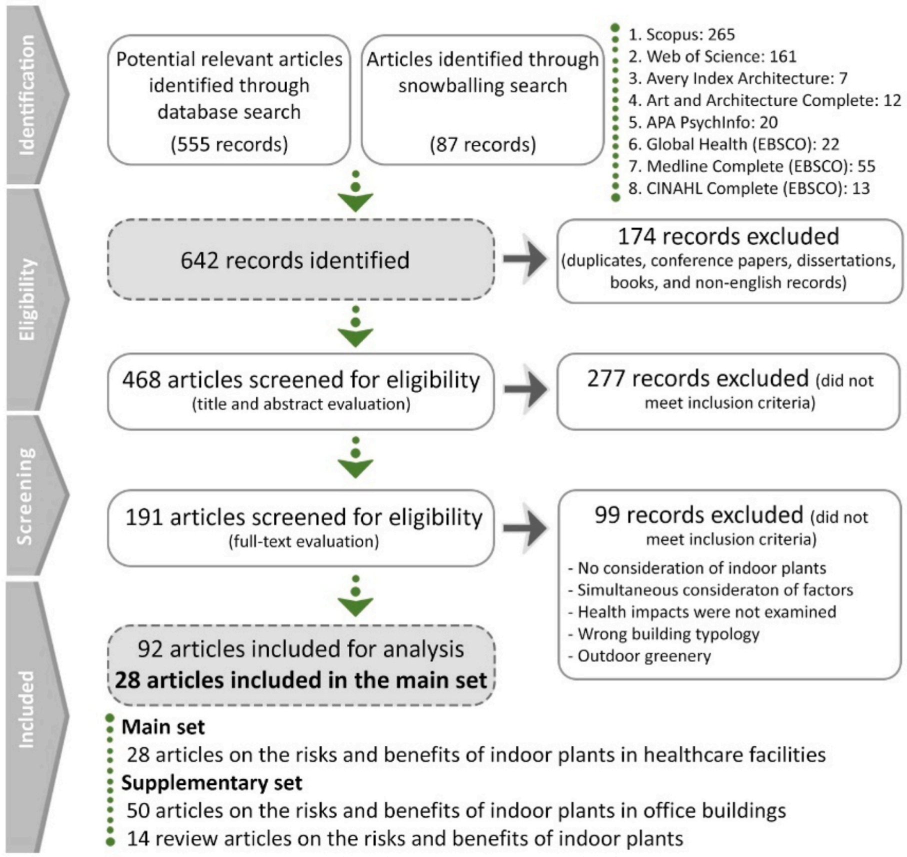

Fig. 1. Literature flow diagram.

on research context or publication date. Given the broad scope of this review, we included studies that examined natural and/or artificial indoor plants in all types of healthcare facilities (including general and specialty hospitals, mental healthcare facilities, outpatient clinics, and rehabilitation centres). However, studies focusing on nature views and images, and those examining the simultaneous consideration of different factors were excluded. To address potential bias in the application of inclusion criteria, two reviewers conducted the review at both stages, and a consensus concerning any disagreements was reached through discussions and validated by the other authors.

Twenty-eight articles met the selection criteria for the analysis. Further, given the paucity of credible research in this context, we extended our search to include studies that examined the risks and benefits of natural indoor plants in workplace settings. The rationale here was that not all spaces of healthcare facilities require complying with clinical requirements, and there is considerable similarity between the design of non-clinical spaces (particularly, in outpatient settings and mental care facilities) and typical workplace settings, such as waiting areas, reception, meeting rooms, and private/semi-private rooms. This paper posits that evidence created in workplace settings might therefore be employed to address the existing gap in the health literature and suggest novel reformulations of research questions for future research. Thus, we included 64 more articles (including 14 reviews and 50 research articles) as highly relevant to the studied area. This supplementary dataset was synthesised to provide support for information provided by the main healthcare dataset, and represent new knowledge missing in the healthcare context. In total, the team reviewed 92 articles.

The data from the total sample was tabulated according to nine fields: study (title, authors, year), country of study, aim, methodology, sampled cohorts, building typology and experiment setting (type and number of plants, type of soil, and arrangement), potential risks, linked IEQ factors, and health and wellbeing impacts (refer to *supplementary file*). Extracted data from the main set of 28 articles were synthesised and compared across publications to identify recurring patterns. Via thematic analysis, articles were first sorted into two categories: 1) potential risks of indoor plants; and 2) benefits of indoor plants. For each, we highlighted the type of healthcare setting that studies were conducted in, and then separated the studies that explicitly investigated the impacts of indoor plants on the health and wellbeing of occupants from those that discussed the risks/benefits in the built environment without exploring the health impacts. Then, the examined risks and benefits were classified for further analysis in relation to the physical and psychological health impacts linked to different IEQ factors. As for the data extracted from the supplementary dataset, while a detailed review of those records was beyond the scope of this paper, we provided a precise explanation of the existing evidence in workplace settings at the end of the associated IEQ factors, supporting the main analysis.

3. Results

3.1. Primary and supplementary datasets

As discussed above, the main dataset of 28 articles was supplemented with an auxiliary dataset concerning workplace settings. The purpose of this supplementary dataset was to address the research question and provide additional information regarding the effects of indoor plants in healthcare settings. In the following subsections, we provide an overview of the 28 articles that explored the potential risks and benefits of using indoor plants in different healthcare settings. This analysis provides an explanation of physical and psychological health impacts linked to different IEQ factors. A precise overview is also represented of the 64 articles on workplace settings, which were included as a supplementary dataset highly relevant to the studied area. This sub-analysis is added at the end of each subsection that investigates the health benefits/risks in relation to the examined IEQ factor. Given the considerable number of studies in the workplace context, these explanations supported the main analysis and helped us identify knowledge gaps accurately within the wider literature.

3.2. Experiment settings and sampled cohorts

The main set of 28 articles was classified into two groups: 1) studies that examined the risks associated with the presence of indoor plants (16 articles), and 2) studies that examined the beneficial impacts (12 articles). Here, only 30% of the first group, and 45% of the second group provided brief explanations of the types and number of plants in the experiment settings. Studies largely excluded information identifying the dimensions and environmental conditions of the room/building where the impacts of potted plants were examined. Further, nearly one-third of the studies examining the risks were related to the bacterial infections associated with flower vase water [59–63].

Regarding the healthcare settings, most studies of both groups were conducted in general hospital environments. Except for three studies conducted in laboratory conditions [64–66], the rest of the studies on the risks of infection were in different wards of acute general hospitals (with environmental details of the spaces missing). The research articles on benefits, however, were examined in a wider range of healthcare settings. Here, eight studies were carried out in general hospitals, two in oncology clinics, one in a rehabilitation centre, and one in a radiology department. Studies in outpatient facilities mainly focused on benefits related to emotional stress/anxiety and subjective wellbeing [67–69].

A summary of the cohorts sampled in the studies reviewed is presented in Table 2. Thirty percent of the first group articles assessed the infection risks for immunocompromised patients, and ninety percent of the second group evaluated the beneficial risks of plants on patients, with three articles showing benefits for care providers. Turning to the countries where studies were conducted, four, three, and three articles from the first group were carried out in the USA, the UK, and Germany respectively. Further, half of the papers that studied the benefits were conducted in the USA and the Netherlands.

3.2.1. Type of methodologies

Most articles (approximately four-fifth) used quantitative methods, three mixed methods, and two literature review (see Table 2). The quantitative studies employed a wide range of research strategies with different data collection and statistical analysis methods. Here, studies reporting on the risks commonly analysed data from different soil and air samples (collected from potting soil, vase water, or the immediate environment of plants) via various techniques, including randomly amplified polymorphic DNA patterns, molecular characterization, colonial morphology, gram staining, motility, and biochemical tests. The second group of studies mainly collected data from different types of questionnaires and medical reports and statistically analysed them. Nearly half of these studies used more than one research strategy, mostly a combination of self-reported mental health and medical measures [68, 70–73]. Further, three studies of the second group evaluated the beneficial impacts based on randomised controlled evidence [72–74]. Two mixed methods studies assessing the potential risks used surveys and soil sampling [61,64], and the one evaluating the benefits used hospital records and interviews [70]. The three review articles on the risks did not use a systematic approach in data collection [60,61,75].

3.3. Health risks of indoor plants

3.3.1. Poor indoor air quality (and direct contact with pathogens)

Health risks associated with the presence of natural plants in healthcare indoor spaces are largely discussed in relation to potential microbial infections and allergic issues. Direct contact with soil organisms (e.g., Gram-negative bacteria) and/or the inhalation of pathogenic fungal/bacterial components (e.g., Gram-positive bacteria or conidia-forming fungi) released from potting mix may have negative impacts on human physical health, ranging from nonspecific symptoms such as headaches and fatigue to allergies and respiratory diseases, to severe toxic effects, to mortality [64]. The incidence of airborne nosocomial infections, however, is highly dependent upon several factors, such as “local respiratory pathogens, susceptibility of patients, climatic conditions, construction work, ventilation equipment and organisation of the individual hospital” [76]. Indeed, environmental sources of potentially pathogenic microbes include the soil, decomposing plant material, and ornamental plants, but also building materials, construction works, contaminated shoes, inadequate filtration of outside air, accumulation of spores in dust in air ducts, vacuum cleaning, carpeting, fresh fruits, and contaminated water and surfaces [64,76,77]. The following subsections provide evidence about the potential risks of using plants in healthcare interior design.

3.3.1.1. Physical health. Physical health issues were discussed in 16 papers. Within the area of physical health, two main concerns were highlighted: hospital-acquired microbial infections (in 16 articles), and allergies (identified in one article).

***Hospital-Acquired Microbial Infections*:** Bacterial/fungal infection was the prime health issue noted in all studies. Five studies investigated the risk of hospital-acquired infections associated with potting soil [75, 76,78–80]. Here, exposure to airborne nosocomial pathogens (mostly different types of *Aspergillus*) isolated from the soil of ornamental plants (including Palm tree, Epiphyllum, Orange tree, Alpine rose, and Christmas flower) has been discussed to cause severe infections in immunocompromised patients; yet, this link has never been scientifically reported. For instance Ref. [78], examined the impacts of potted plants placed in the vicinity of a haematology ward on nine haematological patients, and found that four patients showed infection with *Aspergillus. terreus* strains similar to those cultured from the potting soil, whereas the rest of them showed *Aspergillus* infection with different strains from those of potting soil. Although the authors highlighted that the infection might not be hospital-acquired, potted plants were discussed as “the most probable source of infection in four out of nine patients”. Similarly [79], studied the links between fungal isolates came from 20 *Aspergillosis* patients and potting soil of ornamental plants that were kept dry for 2 weeks, a condition that is known to strongly favour spore release from fungal taxa. Although the research failed to show that *Aspergillus fumigatus* and *Aspergillus niger* isolates of potting soil caused infection in patients, the authors suggested avoiding potted plants in the immediate environment of patients under antibiotic or immunosuppressive therapy. Two other studies investigated the infection risks associated with Gram-negative bacteria in the soil of potted plants [75, 80]. [80] obtained 79 isolates of Gram-negative bacteria from 29 plants in six surgical wards, but found no relationship between these and the 235 isolates obtained from nearby patients throughout the study period. As Gram-negative bacteria can be transferred via direct contact with potting soil, it is evident that potted plants commonly do not appear to constitute a bacteriological hazard in hospitals [75].

Five articles explored the incidence of bacterial infection associated with flower vase water in hospital wards [59–63]. The literature revealed that high concentrations of Gram-negative bacteria, such as *Erwinia* spp. and *Pseudomonas aeruginosa*, were often present if the vase water was not changed frequently; reaching enormous numbers within a day or two. Here, one study tested the relationship between the bacteriology of 46 postoperative wound infections and the culture of 60 flower vase water (carnations, chrysanthemums, freesias, lilies of the valley, marguerites, roses and tulips – water was changed at the sink daily by the ward orderlies) [59]. The authors found “no definite correlation” between the types of bacteria isolated from flower vase water and those responsible for wound infections. While scholars could not

Table 2
Summary of experiment settings and types of methodologies.

	Author (s)	Country	Methodological Choice	Research Strategies	Experiment Setting (type and number of plants, type of soil, and arrangement)	Sampled Cohort	Physical/Psychological Health Impacts
1. Risks associated with the presence of indoor plants							
With the incidence of risk investigated							
1	[60]	UK	Mono method qualitative	Literature Review	General hospital; Vase water and soil of potted plants	–	- No links between flowers and potential health issues, except to severely immunocompromised patients - Banning flowers from general wards is unnecessary
2	[61]	UK	Mixed methods	Literature review, and conducting questionnaires (with descriptive analysis)	General hospital; Vase water and soil of potted plants	39 senior infection control nurses and chief executives	Contact with Gram-negative pathogens associated with flower vase water may cause healthcare-associated infection
3	[75]	USA	Multi method qualitative	Literature review and survey on hospital policies	General hospital; Potted plants and flowers	Acute care units	No solid association between the bacterial organisms present in the soil of potted plants or the water from cut flowers and hospital infections
4	[78]	Germany	Mono method quantitative	Air sampling and soil sampling (analysing randomly amplified polymorphic DNA patterns)	General hospital - Haematology ward; Potted plants placed in the vicinity of the haematology ward (Gum tree and Palm tree)	9 patients with haematological disease following myeloablative chemotherapy	- Potted plants contaminated with A. terreus and found in the vicinity of patients were the most probable source of infection in <u>four out of nine</u> patients - Potted plants are a recognised source of fungal infection and should not be permitted in wards housing *high risk patients*
5	[76]	Germany	Mono method quantitative	Air sampling and analysis	General hospital - Liver Transplant unit; Indoor plants cultivated in the hall connected to the corridor of a liver transplant unit	Liver transplant patients	- Found a link between pulmonary aspergillosis in liver transplant patients to the occurrence of large amounts of (aspergillus) spores in the mould of indoor plants - These pathogens have a low virulence for healthy individuals, but may cause severe infections in immunocompromised patients
6	[80]	Israel	Mono method quantitative	Soil sampling and analysis	General hospital - Surgical wards (general, vascular, urological, orthopaedic, neurosurgical and thoracic wards); 29 large potted plants (plants were in close proximity to areas of major activity)	235 immunocompetent surgical patients	No link between isolates of Gram-negative bacteria and those from nearby patients (wound infection)
7	[79]	Germany	Mono method quantitative	Soil sampling and analysis	General hospital – Central room; Soil of four different ornamental plants (epiphyllum, orange tree, Alpine rose, and Christmas flower) in the central room and lounge of a hospital ward (for lung diseases)	20 aspergillosis patients	- The necessity of preventing A. fumigatus infections from habitats of this fungus in the immediate environment of man in the patients with chronic lung diseases, especially those under antibiotic or immunosuppressive therapy
8	[59]	UK	Mono method quantitative	Vase water sampling and analysis	General hospital - Different general wards; 60 vases in 9 general wards at this hospital (carnations, chrysanthemums, freesias, lilies of the valley, marguerites, roses and tulips; changed daily)	46 postoperative wound infections out of a total of 880 operations	- The incidence of wound infections during the period of study was low despite the regular overgrowth of bacteria in flower vases - No definite correlation between the types of bacteria isolated from flower vase water and those responsible for wound infections
Without the incidence of risk investigated							
9	[81]	China	Mono method quantitative	Soil sampling and analysis	Tertiary care hospital - Different wards; 58 soil samples from different flowerpots in 18 departments	–	- A. fumigatus could be isolated from a majority of flowerpots - Suggested that flowerpots might pose a risk of causing as azole-resistant A. fumigatus infection in patients and recommended

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Table 2 (*continued*)

	Author (s)	Country	Methodological Choice	Research Strategies	Experiment Setting (type and number of plants, type of soil, and arrangement)	Sampled Cohort	Physical/Psychological Health Impacts
							that plants should not be kept in hospitals, especially in wards with high-risk patients
10	[82]	Iran	Mono method quantitative	Soil sampling and analysis	General hospital; 23 soil samples from a depth of 0–10 cm of the pots in four hospitals	–	presence of fungi in potted plants in hospitals represents a potential source of nosocomial infection
11	[62]	USA	Mono method quantitative	Sampling and analysis	General hospital; 24 samples of vase water from hospitals	–	- Neither gram-negative bacteria nor staphylococci were isolated from sterilised flowers. Non-sterilised flowers, however, grew bacteria similar to those cultured from the hospitals and restaurants, even when handled in an aseptic fashion - The normal immunocompetent person is at no more risk of infection from vase water than from many other sources of bacteria in the environment
12	[83]	Canada	Mono method quantitative	Soil sampling and analysis (calculated as colony-forming units per gram dry soil)	General hospital –Corridor; 5 potted plants (Dieffenbachia amoena, and Ficus benjamina, Chlorophyton comosum, and Brassaia actinophylla)	–	- Indoor plant soils constitute a serious mycotic hazard to the immunosuppressed patient - This is true not only when the plants are maintained near heat sources but even under the most moderate, controlled indoor conditions
13	[63]	USA	Multi method quantitative	Sampling and analysis (Colonial morphology, gram staining, motility, odour, and biochemical tests)	General hospital – Surgical and Burn wards; Gram-negative bacteria in vase water	–	- Flower vases may be a means of introducing potential pathogens into the hospital, and form an intermediate reservoir of hospital strains. - Suggested that flowers should not be introduced into hospital areas occupied by susceptible or debilitated patients
Without the incidence of risk investigated (laboratory experiments)							
14	[65]	Pakistan	Mono method quantitative	Soil sampling and analysis (molecular characterization)	Laboratory experiment; Ornamental palms C. seifrizii, C. cataractarum and R. excels cultivated indoor building landscape of 15 different locations	–	- Confirmed the association of A. sclerotigenum with soils and roots of potted plants with varying frequency. - Dissemination of fungal propagule may cause serious infections in immunosuppressed individuals
15	[64]	Austria	Mixed Methods	Soil sampling with qualitative and quantitative analyses	Laboratory experiment; Commercial soils, compost and soils from potted plants (surface and sub-surface)	–	- Immunocompromised individuals should avoid handling soils or potted plants in their immediate vicinity. - Persons suffering from allergies to fungi should avoid potted plants in their immediate environment and refrain from working with compost and potting soil
16	[66]	USA	Mono method quantitative	Soil sampling and analysis	Laboratory experiment; 12 commercial potting soils were investigated	–	- The soil of potted indoor plants has the potential to serve as a reservoir of aspergillus spores - No cases have been reported in the United States of pulmonary aspergillosis where spores from the soil of potted indoor plants were implicated as the source of infection for patients who contracted the disease
2. Benefits associated with the presence of indoor plants							
With health impacts investigated							
17	[71]	Netherlands	Multi method quantitative	Patient and staff survey (data from admission to discharge in the KATZ-ADL6 and physician assessments at	General hospital - Geriatric ward; Two large green walls with living plants and two moss walls in the corridors, and the	54 hospitalised geriatric patients and 15 staff	- Reduced functional decline - Increased attractiveness of the place for patients and staff

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Table 2 (*continued*)

	Author (s)	Country	Methodological Choice	Research Strategies	Experiment Setting (type and number of plants, type of soil, and arrangement)	Sampled Cohort	Physical/Psychological Health Impacts
				discharge; statistical analysis)	addition of small and large potted plants		
18	[74]	Australia	Mono method quantitative	Questionnaires - randomised controlled trial (data from hospital anxiety and depression scale; statistical analysis)	General hospital - Coronary care ward; Four artificial flowering pots	122 patients	Reduced depressive symptoms in a per-protocol analysis but no significant impact on anxiety symptoms
19	[69]	USA	Mono method quantitative	Questionnaires (statistical analysis)	Cancer centre; Eleven wellness features including views of nature, art and murals, and indoor plants	62 patients and 76 staff	Significant differences between the two groups were found for indoor plants: - Patients may simply observe the presence of plants as a decorative element that brings some delight or beauty into the space. - Staff recognise the benefits of indoor plants, but they also associate plants with the chore of having to water them or with pathogenic fungi that pose a threat to patients
20	[67]	Australia	Mono method quantitative	Questionnaires (descriptive analysis)	Oncology clinic -Waiting room; Two movable green walls covered in plants, six hanging plant displays, one movable rock garden, and 12 tabletop plant arrangements	73 cancer patients, 13 staff, 52 carers, and 5 others	No significant differences between patients', staff, and carers' reactions - Artificial nature was acceptable and chosen over having no nature features at all - Promoted relaxation; added a peaceful and welcoming quality; reflected a caring hospital culture
21	Ali Khan et al. [70]	Pakistan	Mixed methods	Hospital records, personal discussion & interviews, small group debates, and focal interviews with ward doctors (statistical analysis)	General hospital – Surgical wards; Ward decorated with green plants and flower arrangements: Cycus Revoluta, Chlorophytum comosum, Syngonium podophyllum, Dracaena deremensis, Brassaia actinophylla, Araucaria beterophylla, Ficus macleilandii, etc.	270 patients	- More stable physiologic status - Improved vital signs - Less stress and anxiety level and thus reduced analgesic intake for pain relief - Reduced overall patients' stay in hospitals
22	[91]	Taiwan	Mono method quantitative	Questionnaire (statistical analysis)	General hospital; Indoor plants	737 hospital medical directors	- Having a moderating effect on physician-patient relationship stresses - Only indoor plants were found to have moderating effects on their short-term health status and health complaints
23	[90]	Netherlands	Mono method quantitative	Questionnaire – Randomised (statistical analysis)	General hospital - Waiting rooms at the radiology department; Real foliage plants (Zamioculcas, Spathacea), posters of plants, or no nature (control)	457 patients	- Lower levels of experienced stress - Pleasant atmosphere that positively influences wellbeing - Direct and indirect effects of perceived attractiveness for both real plants and the posters of plants were significant
24	[68]	Norway	Multi method quantitative	Quasi-experiment (self-report measures of health, subjective wellbeing, and emotion on arrival; statistical analysis)	Rehabilitation centre; Potted plants - placed in the reception area, the four TV rooms, and close to sitting areas in the corridor	282 patients	- Physical and mental health improved during the program, but the addition of plants did not increase the degree of improvement - Enhanced subjective wellbeing - Increased satisfaction with indoor plants
25	[73]	USA	Multi method quantitative	Medical and psychological measurements and questionnaires - randomised controlled trial (statistical analysis)	General hospital – Inpatient room (recovering from a hemorrhoidectomy); Flowering and Foliage Plants (dendrobium, peace lily, golden pothos, kentia palm, arrowhead vine, cretan brake	90 patients	- Lower ratings of pain, anxiety, and fatigue - Positive feelings and higher satisfaction about their hospital room - Providing meaningful therapeutic contact while recovering from painful surgery

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Table 2 (*continued*)

	Author (s)	Country	Methodological Choice	Research Strategies	Experiment Setting (type and number of plants, type of soil, and arrangement)	Sampled Cohort	Physical/Psychological Health Impacts
					fern, variegated vinca, and yellow star jasmine)		- Significantly enhanced physiologic responses evidenced by lower systolic blood pressure
26	[89]	Netherlands	Mono method quantitative	Questionnaires (statistical analysis)	General hospital – Photo of an inpatient room; A photo of a hospital room with and without indoor plants, participants were also presented with a scenario describing hospitalisation with a possible legionella diagnosis	77 students	Reduced feelings of stress through the perceived attractiveness of the room
27	[72]	USA	Multi method quantitative	Medical and psychological measurements and questionnaires - randomised controlled trial (statistical analysis)	General hospital – Inpatient room (recovering from abdominal surgery); Flowering and Foliage Plants (dendrobium, peace lily, golden pothos, kentia palm, arrowhead vine, cretan brake fern, variegated vinca, and yellow star jasmine)	90 patients	- Lower ratings of pain, anxiety, and fatigue, and more positive feelings and higher satisfaction about their rooms - Significantly fewer intakes of postoperative analgesics, more positive physiological responses evidenced by lower systolic blood pressure and heart rate
Without health impacts investigated							
28	[118]	India	Mono method quantitative	Air sampling and analysis	General hospital – Inpatient room; Apicra deltoidea, Sedum pachyphyllum, Bryophyllum pinnata, and B. calycinum	–	- Apicra deltoidea seems to be a very useful succulent plant in removing almost 80% of the accumulated CO2. - Mixed succulent plants like Apicra deltoidea, Sedum pachyphyllum and Bryophyllum pinnata in a hospital room were observed to remove considerable amounts of CO2

observe any correlation between bacteria presented in the vase water and the incidence of healthcare-associated infections [59–61,63], it is suggested that flowers and vase water should be avoided in areas providing care to *medically at-risk patients* and supported the addition of *antibacterial agents* such as *hydrogen peroxide* to vase water to prevent the growth of harmful organisms [63]. [61] posited that this attitude may be related to the amount of work generated, “with infection and other risks used to justify it”. Moreover, the literature could not show the differences in the diversity/abundance of bacteria observed in samples isolated from hospital flowers compared with those in restaurants/homes [62]. It is evident that the normal immunocompetent person is at no more risk of infection from vase water than from many other sources of bacteria in the environment.

Three studies explored the pathogenic fungi in soil samples of potted plants in hospitals without considering the incidence of infection [81]. identified a total of 106 isolates of *Aspergillus fumigatus* from 58 flowerpots placed in different departments of a tertiary care hospital [82]; isolated 13 different species of *Penicillium, Acremonium, Paecilomyces, Cladosporium,* and *Aspergillus* in the soil of indoor plant in four hospitals; and [83] identified a total of 16 potentially pathogenic species, including *Aspergillus fumigatus, Scedosporium Apiospermum, Phialophora Verrucosa* and *Fusarium Solani* from the soil of 5 potted plants. Although never examined, the authors argued that potting soil may constitute a serious mycotic hazard to immunosuppressed patients and haematopoietic stem cell transplant recipients. Moreover, a few other studies examined the spectrum and incidence of fungi in different potting soils via laboratory experiments [64–66]. However, none of these studies investigated how and in what quantity these spores were released into indoor airspaces from potted plants. Although some discussions about the implication of the findings in hospital environments are provided, the relation to health risks is vanishingly scarce.

Regarding the differences between potting soils [64], evaluated samples of commercial soils, compost and soils from potted plants (both surface and sub-surface). The comparison demonstrated that garden compost and commercial plant soils were composed of materials with differing degrees of maturity, whereby the spore concentration in garden compost was ten times lower than the spore concentration in commercial plant soils. While the commercial soil included the largest variety of species, compost showed the narrowest spectrum of fungi (with the largest proportion of *Aspergillus*). Further, the direct comparison of surface and subsurface soils of potted plants showed that the frequency of detected species reduced in the subsurface soil. The authors argued that to healthy persons who, except for occasional diseases, are essentially immunocompetent, “potting soil does not present an increased risk” [64].

***Allergic Rhinitis*:** Only one study conducted in a laboratory setting mentioned the possibility of allergic reactions when exposed to fungal spores eliminated from the potting soil [64]. It is suggested that possible allergy is likely, and individuals suffering from allergies to fungi, should avoid potted plants in their immediate environment and refrain from working with compost and potting soil [64,84].

3.3.1.1.1. Within workplace settings. Six research articles investigated the possible negative impacts of indoor plants on indoor air quality in workplace settings. The literature argued that the presence of bacterial/fungal pathogens in potting soil cannot necessarily be correlated with the increased taxa in airborne spore loads and/or diversity. Recent field studies in realistic office conditions showed that the presence of indoor plants did not make any significant difference to either indoor mould spore counts or species composition [85]. Similarly, the concentration of pathogenic fungi released from indoor green walls (with and without active airflow) was shown to remain well below WHO safety guidelines - even during irrigation cycles [86–88]. “Conservative numbers of indoor plants” and green walls were widely seen not to emit harmful levels of fungal propagules, and thereby it was suggested that they did not pose any significant health risks [85,87,88]. Further, while two recently published reviews mentioned the possibility of attracting pests, no health impacts were discussed [13,40,44]. Read together, the presence of natural indoor plants may not lead to harmful levels of pathogenic airborne spores with substantial health risks for occupants.

3.4. Benefits of indoor plants

3.4.1. Non-light visual comfort via physical and/or visual access to plants

3.4.1.1. Psychological health. The beneficial impacts of indoor plants were discussed in 12 articles, with 11 studies focusing on the psychological health of occupants. Three main aspects of mental health identified were: emotional stress/anxiety (identified in eight articles), subjective wellbeing (identified in five articles), and cognitive performance (identified in one article).

Emotional Stress/Anxiety: The significantly positive impacts of natural and artificial indoor plants in healthcare facilities have been highlighted on the perceived stress and anxiety level of patients and care providers. In one of the early studies in this area [89], used two pictures of a hospital room with natural potted plants and views of an urban environment. While the participants were provided with a scenario describing hospitalisation with a possible *Legionella* diagnosis, the results of the mediation analysis showed that indoor plants in a hospital room reduced feelings of stress through the increased perceived attractiveness of the room. In another study on the impacts of the real foliage plants in a hospital waiting room, patients demonstrated lower levels of experienced stress, influencing their general wellbeing [90]. It is notable that the direct and indirect effects of perceived attractiveness for both natural indoor plants and the posters of plants were significant [90]. Similarly [67,74], examined the impacts of artificial flowering pots and green walls in an oncology clinic and a general hospital respectively, and confirmed the role of artificial plants as psychological therapy in medical interventions. It was argued that artificial plants in a coronary care ward could significantly reduce depressive symptoms in patients [74]. Further, while about one-third of the respondents showed their preference for living plants in an oncology clinic waiting room, they agreed that "lifelike plants are better than no plants" due to the added relaxing, peaceful, and welcoming quality [67].

Another study focusing on hospital medical directors indicated that among several hospital interior amenities, only indoor plants had a moderating effect on physician-patient relationship stresses [91]. Natural indoor plants were seen to produce buffering effects on work stress to some extent, which considerably impacted the medical directors' self-rated health status and health complaints.

Subjective Wellbeing: While five studies mentioned improvements in the general wellbeing of participants [70,72,73], two of them focused only on wellbeing and discussed indoor plants as a wellness feature [68,69]. Potted plants placed in different sitting areas of a rehabilitation centre resulted in an increase in the subjective wellbeing of patients during a four-week program, and the patients reported more satisfaction with indoor plants and the interior generally [68]. Further [69], showed that natural potted plants in a cancer centre were associated with improved wellbeing of patients, as they brought delight and beauty into the space. It is, though, interesting that staff perceived the benefits of indoor plants, but ranked this feature as the lowest item. The authors argued that staff may associate plants with "the chore of having to water them" or with the risk of fungal infections for patients [69], which is in line with [61].

Cognitive Performance: One study examined the impacts of greening a geriatric ward of a general hospital on patients' functional decline [71]. The addition of two green walls with living plants, two moss walls, and some potted plants in the corridors and waiting areas significantly increased the attractiveness of space for patients and staff, and reduced functional decline in elderly patients.

3.4.1.2. Physical health. The beneficial impacts of indoor plants on general health, vital signs, and analgesic intake were identified in four articles.

General Health/Analgesic Intake: The literature showed that the presence of flowering and foliage plants (such as Dendrobium, Peace Lily, Golden Potho, Cycas Revoluta, Ficus Benjamin, Kentia Palm, Arrowhead Vine, and Jasmine) in wards and patient rooms could be an inexpensive, non-pharmacological and non-invasive medicine beneficial to the wellbeing of hospital patients. Ali Khan et al. [70] showed ward decorated with green plants and flower arrangements provided a "satisfying, relaxing, comfortable, colourful, calm, and attractive" atmosphere for patients, resulting in improved patients' vital signs (including blood pressure, respiration rate, heart rate, and temperature), and reduced analgesic intake for pain relief. It is argued that indoor plants act as a strong positive distraction for patients leading to less stress and anxiety level, and thereby, minimising overall patients' stay in hospitals. Similarly [72,73], found that the use of natural plants in the design of patient rooms recovering from painful surgery could help lessen ratings of pain, anxiety, and fatigue, and increase positive feelings and higher satisfaction about their room. The physical impacts were reported as fewer intakes of postoperative analgesics, lower systolic blood pressure and heart rate, and decreased length of hospitalisation. Another study also highlighted the impacts of reduced anxiety and stress levels on general health [91]. Indoor plants were found to have a moderating effect on physician-patient relationship stresses, resulting in improvements in hospital medical directors' self-rated general health status.

3.4.1.2.1. Within workplace settings. Similar to studies on healthcare facility design, the literature on the visual comfort and psychological benefits of indoor plants in workplace settings is more comprehensive than the other IEQ factors. In total, this review found 23 research articles and eight reviews investigating this factor. Here, observing indoor ornamental plants in working environments is seen to enhance productivity/performance and work efficiency [92–101], levels of concentration and work attention [99,101–103], mood and emotions [94,98,104–106], levels of perceived fascination of the setting [107,108], and satisfaction [99,109]; as well as reduce mental stress and anxiety level [95,100,102,110–113], mental fatigue [104–106,114], and sick building symptoms (SBS) and sick leave [100,115,116].

A few studies also investigated the effects of plant removal and found that the absence of plants elicited significant negative effects on perceived attention, productivity, stress and efficiency [92,99,112]. As for the impacts of non-light visual comfort on physical health, experiments in laboratory settings showed positive effects on oxyhemoglobin (oxy-Hb) concentration [106], participants' electroencephalography (EEG) and heart rate [97,105,112,117], blood pressure [112], and Electrodermal Activity (EDA) [97]. There is therefore substantial evidence demonstrating the psychological health impacts of physical and/or visual access to natural indoor plants in both main and supplementary datasets.

3.4.2. Improved indoor air quality

Although the impacts of indoor plants in improving indoor air quality have been widely examined, to the knowledge of authors, only one study investigated this relationship in the healthcare building typology [118]. showed that indoor plants (such as Apicra deltoidea, Sedum pachyphyllum, Bryophyllum pinnata, and B. calycinum) could enhance the air quality and increase the comfort of the hospital environments by removing CO_2 and other unknown gases. Here, Apicra deltoidea seemed to be a very useful succulent plant in removing almost 80% of the accumulated CO_2, in the dark, a simulating condition of the night. Mixed succulent plants, like Apicra deltoidea, Sedum pachyphyllum and Bryophyllum pinnata, were also observed to remove considerable amounts of CO_2 in a hospital room.

3.4.2.1. Within workplace settings. Nineteen research articles and ten reviews discussed the ability of indoor plants in ameliorating indoor air pollution - via direct (absorption) and indirect (biotransformation by microorganisms) mechanisms, thirteen of which highlighted the significant positive effects on the health of office workers. The literature has shown that indoor potted plants and green walls can significantly decrease the concentration of air contaminants, such as Co_2, No_2, PM_{10}, $PM_{2.5}$, and VOCs (specifically, formaldehyde, benzene, and toluene) [119–130]. Further, five systematic reviews highlighted the beneficial effects of plants on indoor air quality [33,38–41]. A few studies aimed to advance the discussion to examine the health impacts, such as the incidence of sick building syndrome [45,131–134] and skin issues [135]. However, these studies failed to demonstrate the links between indoor plants, improved air quality, and health impacts – missing is the links between indoor plants and purifying impacts or improved air quality and health impacts (e.g., respiratory and allergic health implications). Moreover, a few recent studies investigated the impacts of indoor plants on enriching indoor microbiome [136–139]. While the presence of indoor plants was seen to create a specific structural and functional core microbiome - leading to a proportional reduction of human-source taxa, it is still unclear if they can contribute to microbial diversity and limit the spread of opportunistic pathogens in the built environment.

3.4.3. Humidity and thermal comfort

There was no study in the main dataset examining the benefits of indoor plants in healthcare settings in relation to improved thermal comfort and its health impacts.

3.4.3.1. Within workplace settings. A few studies explored the influences of a *considerable* number of indoor plants on the thermal comfort of office workers [129,130,140–142]. Three systematic reviews also noted the impacts on relative humidity and temperature, leading to enhanced human comfort levels in the working environment [31,44,45]. However, no physical or psychological health impacts have been investigated.

3.5. Risk mitigation strategies

The literature also highlighted some strategies to reduce the risks associated with the use of indoor plants. First, indoor plant maintenance regimes must comply with certain considerations and standards of cleanliness and safety. Here, it is highly suggested that healthcare facilities employ expert companies for maintenance services, schedule services out of hours (e.g., weekends or late afternoon when departments are not operational), use separate access (not through clinical treatment or patient areas), limit flower and plant care to staff with no direct patient contact, and clean and disinfect vases after use outside the immediate patient environment [27,85]. Second, options for reducing soil disruption are necessary, including growing plants where they are accessible without contacting the soil, using subsurface or drip irrigation (known as sub-irrigation), and using containing plants to allow replacement without disturbing soil [143]. Another strategy is the use of self-watering pots to reduce watering frequency and risk of under/-overwatering, which is the most common cause of plant deterioration [73]. Further, soil or substrate can be further protected by the addition of a top layer of sterilised material such as woodchips or pebbles, so that spores would not have been easily released from the soil surface.

Third, the addition of antibacterial agents such as *hydrogen peroxide* to vase water was proved as a successful strategy to prevent the growth of harmful organisms [63,65]. Fourth, using soil-less growing media is seen to allow plants to thrive in a sterilised, soil-less mixture, free of organic materials which could attract pests or mould. However, it is important to note that this strategy decreases the rate of air purification, as soil microorganisms play an important role in pollutant degradation [33]. Last, choosing the right type and number of indoor plants is necessary to achieve beneficial impacts. For further information on the differences between plants in enhancing indoor air quality, refer to studies conducted by Refs. [31,144]; and [40].

4. Discussion

Via a systematic process, this review describes the current state of research into the positive and negative impacts of indoor plants on the health and wellbeing of occupants in healthcare settings. Due to the limited credible evidence in this context and diverse functional and clinical requirements of spaces within healthcare facilities, we posited that the extensive evidence of the influences of indoor plants in workplace settings could be adopted in support of design and research in the health context. Here, we provide a brief overview of the findings and knowledge gaps identified from this review before moving to recommendations for future research.

4.1. Overview of findings

While microbial risk assessment associated with the presence of indoor plants in healthcare facilities has been discussed in the literature since the mid-1970s, recent studies, published in the past two decades, focusing on the possibility of healthcare-associated infections through the presence of indoor plants are vanishingly rare. The literature discussed that there might be negative health implications caused by direct contact with potting soils (or flower vase water) and/or the inhalation of pathogenic fungal/bacterial components released from potting soil in certain conditions (dry soil, disturbed soil); yet, there is no evidence supporting this assertion. Given the reported limitations of the studies, the literature to date has not been able to scientifically examine how and in what quantity indoor plants might lead to hospital-acquired infections [64,76,78,145]. Similarly, the architectural features and environmental conditions of the wards, patient rooms, and waiting areas with potted plants and their influences on the rate of nosocomial infections have not been discussed accurately. Here, research carried out in workplace settings has shown that potting soil of natural indoor plants and green walls may not necessarily increase the diversity/load of pathogenic airborne spores, beyond the WHO safety guidelines. While nearly two-thirds of studies in healthcare settings discussed the risks of indoor plants, only ten percent of the literature in workplace settings examined the potential risks. As a few editorial letters noted [84,145–147], we believe that research has been limited in demonstrating a solid association between the bacterial and fungal organisms present in the soil of potted plants or flower vase water and the incidence of hospital-acquired infections.

Despite the acknowledged psychological benefits, the presence of indoor plants in the design of healthcare buildings has been banned, as a precautionary measure [60,75,84]. The lack of credible and reliable research establishing the causal links (with findings limited to the descriptions of potential risks) has resulted in repeating similar shortcomings [17,148,149]. This paper, in line with [150]; argues that decision-makers need to embrace and prioritise biophilic-based opportunities in design thinking, while considering the clinical functionality, efficiency, cost restrictions, or habitual practice in designing healthcare facilities, resulting in enhanced quality of patients and care providers experiences. We also suggest that stakeholders explain their clinical needs and ideas within the multidisciplinary teams when developing design briefs rather than prescribing the specifications of spaces.

As shown in the evidence map (see Table 3), while the literature on the impacts of natural indoor plants in healthcare buildings is scant, the benefits and evidence in office buildings are promising, particularly in enhancing air quality and non-light visual comfort with about forty studies. This review provides a significant stepping-stone by mapping both risks and beneficial influences of indoor plants helping healthcare researchers and designers reformulate research questions for greater impact. Providing reliable and credible evidence about the risks of microbial infections can open up a vast sea of opportunities in this area, resulting in enhanced healing processes and patient experience, care provider performance, as well as organisational efficiency and economic benefits.

This review also found that there is emerging evidence linking the

Table 3
Evidence map.

#Studies	Direct contact with soil/vase water	Air Quality	Thermal comfort and humidity	Acoustic comfort	Non-light Visual comfort	Psychological Health Impacts	Physical Health Impacts
Risks associated with the presence of indoor plants in healthcare settings							
With the incidence of risk investigated (#9)	06	03	-	-	-	-	09
Without the incidence of risk investigated (#4)	02	02	-	-	-	-	-
Without the incidence of risk investigated (laboratory experiments) (#3)	02	02	-	-	-	-	-
Benefits associated with the presence of indoor plants in healthcare settings							
With health impacts investigated (#9)	-	-	-	-	11	11	05
Without health impacts investigated (#1)	01	-	-	-	-	-	-
Risks associated with the presence of indoor plants in workplace settings							
With health impacts investigated (#6)	01	06	-	-	-	-	03
Benefits associated with the presence of indoor plants in workplace settings							
With health impacts investigated (#40)	06	13	07	02	31	35	12
Without health impacts investigated (#17)	17	16	03	01	-	-	-

use of indoor plants in the design of healthcare facilities to create restorative and healing environments, resulting in health-promoting buildings for individuals, society, and the environment. However, only a few studies have demonstrated a solid relationship between indoor plants and improved physical health of patients and care providers; mostly limited to assumptions about the healing process. Further, despite the widely acknowledged air-purifying capacity of plants, particularly in laboratory and workplace settings, there is only one study investigating the role of indoor plants in improving the air quality of hospital inpatient rooms and no research on the associated health impacts (such as fatigue, headache, respiratory diseases, etc.). This paper, in line with [33]; posits that the existing literature is limited to examining the physiological manifestations of the psychological effects prompted by indoor plants (see Table 4).

There is a paucity of research exploring the links between the presence of indoor plants (and/or human-plant interactions) and occupants' physical health/comfort associated with indoor air quality, thermal and humidity comfort, as well as acoustic comfort in different types of healthcare facilities. A similar gap has been discussed in a recent study on the health impacts of green buildings and the rate of SBS,

Table 4
The benefits of indoor plants associated with biophilic design patterns.

Biophilic Category	Biophilic Design Patterns	Setting	Improved Physiological Response	Emotions and Mood and Preference	Improved Cognitive Functioning
NATURE IN THE SPACE	1. Visual & Direct Connection with Nature A view and direct access to elements of nature, living systems and natural processes	Green plants and flower arrangements [68,70,72,73,90,91] Green walls with living plants, moss walls, and potted plants [71] Artificial flowering pots [74]; Artificial green walls, hanging plant displays, rock garden, and tabletop plant arrangements [67] Views of nature, art and murals, and indoor plants [69]	Improved vital signs, lower systolic blood pressure, lower ratings of pain, anxiety and fatigue, and thus reduced analgesic intake for pain relief, and reduced overall stay [70,72,73] Short-term health status and health complaints [91] Enhanced subjective wellbeing [68,90]	Increased attractiveness of the place for patients and staff [71,89]; bringing delight and beauty into the space [69]; added a peaceful and welcoming quality; reflected a caring hospital culture [67] Reduced levels of experienced stress and depressive symptoms [74,89,90]; Promoted relaxation [67] Having a moderating effect on physician-patient relationship stresses [91] Positive feelings and higher satisfaction about their hospital room [68,72,73]	Reduced functional decline [71]
	2. Connection with Natural Systems Awareness of natural processes, especially seasonal and temporal changes characteristic of a healthy ecosystem	Green plants and flower arrangements [68,70,72,73,90,91] Green walls with living plants, moss walls, and potted plants [71] Views of nature, art and murals, and indoor plants [69]	Improved vital signs, lower systolic blood pressure, lower ratings of pain, anxiety and fatigue, and thus reduced analgesic intake for pain relief, and reduced overall stay [70,72,73] Short-term health status and health complaints [91] Enhanced subjective wellbeing [68,90]	Increased attractiveness of the place for patients and staff [71,89]; bringing delight and beauty into the space [69] Reduced levels of experienced stress and depressive symptoms [89,90] Having a moderating effect on physician-patient relationship stresses [91] Positive feelings and higher satisfaction about their hospital room [68,72,73]	Reduced functional decline [71]

highlighting the importance of evaluating occupant comfort and health [151]. Further, research has been rare in investigating the combined beneficial impacts of indoor plants, addressing two prime biophilic design patterns, in relation to other patterns on the physical and mental health of patients, care providers, and visitors. As [22] pointed out, healing is a complex constellation of experiences, requiring links between multiple aspects of the built environment and a complex constellation of emotions, cognitions, and behaviours. Thus, healthcare designers and researchers should adopt a holistic approach considering all influential factors, when developing design solutions for creating healing spaces.

4.2. Recommendations for future research

This review revealed some key knowledge gaps in the literature. To better understand the potential risks in the design of healthcare buildings and to best benefit from the key properties and qualities associated with the presence of plants, future research may examine.

1. Healthcare-associated infection rates for different quantities/types of indoor plants and potting soils, plant conditions and maintenance regimes, distance and proximity to patients, as well as dimensions, architectural features and environmental conditions of the space. It is essential to understand what is considered conservative in relation to the space.
2. If and how fungal spore concentrations and variety of species in potting soils are affected/can be mitigated by factors such as the type of plants cultivated, planting densities, age of plants, growth substrates, maintenance regimes, ambient temperatures and airflow, or watering habits [13].
3. Whether indoor plants growing in soil-less media pose microbial infection or allergic issues for occupants.
4. Impacts of indoor plants on air quality and physical health (such as the incidence of respiratory illnesses, allergies, etc.), and the processes affecting this relationship [44,152].
5. Methods and strategies to combine indoor plants and mechanical air conditioning equipment to regulate the indoor thermal environment and enhance acoustic comfort, and explore subsequent health impacts.
6. Influencing mechanisms of exposure to/interaction with indoor plants on human health and wellbeing in relation to the biophilia hypothesis [11].
7. Differences between the impacts of using natural and artificial indoor plants on health and wellbeing.
8. Indoor plants as effective environmental cues in the wayfinding process for patients.
9. The psychological and social impacts of indoor plants on occupants. It might be interesting to explore the correlation between the presence of indoor plants and social interactions between people as a strategy to alleviate depression issues.

Given the vast range of knowledge, the scientific world has a hierarchy of evidence with meta-analysis of randomised controlled trials as the strongest evidence, and opinions of recognised experts, or case studies, as the weakest evidence [153,154]. As it is typically challenging to have two identical buildings for testing different conditions, exploring the aforementioned causal relationships in the built environment is not straightforward [155]. There are also significant challenges in generalising the research outcomes and transforming raw scientific data into well-defined, “tangible and meaningful design concepts” that are practical in making design decisions [20,156,157].

To address existing issues in the transition of, and translation from, research findings to healthcare design innovations, Sal Moslehian et al. [158] suggested researchers, hospital designers, healthcare developers, policy makers, and stakeholders to “re-formulate research questions” through “transdisciplinary approaches”. Developing a meaningful interaction between architectural, service and organisational design of healthcare facilities is vital for creating impacts on healthcare policies and generating new healthcare models, resulting in value creation and building design innovations. Scholars need to develop multidisciplinary teams (including architectural and environmental design researchers, biologists, and medical microbiologists), whereby members feel responsible to understand other discipline needs and ideas, for innovation and greater impact. Future research might adopt a holistic approach addressing interconnected variables to reach a balance between the clinical and functional requirements of healthcare facilities and psychological needs of occupants in the environmental and spatial design of areas.

4.3. Strength and limitations

A wide-ranging exploration was conducted of the literature on the benefits and risks of indoor plants and health, through a systematic approach of literature searching and selection. While the aim was to focus on peer-reviewed articles, we considered the *letters to editor* that reported a link between healthcare-associated infections and indoor plants. However, papers published in conferences or in a language other than English were missed by our selection criteria. Furthermore, by its nature, a scoping review does not attempt to assess the quality of the evidence, so conclusions on the relationships between indoor plants and health must remain tentative. The observation that three fourth of the studies did not identify any limitations in their research is indicative of the need for further scrutiny of the quality of the current evidence and the need for further research on this topic.

5. Conclusion

Biophilic healthcare design has been widely recognised to promote healing and restorative environments. However, integrating natural indoor plants in healthcare facilities, as one of the crucial elements of biophilic design, is an under-researched field. Given the dearth and diversity of the literature in this context, we scoped a wide range of studies via a cross-disciplinary and systematic approach. In the context of modern healthcare environments, there is still a noticeable tension between essential emotional/psychological healing factors and the cost/efficiency factors of physical treatments, whereby the provision of indoor plants is commonly limited in favour of the latter set of factors. Although there is minimal or no evidence showing links between increased indoor microbial loads/diversity induced by indoor plants and the incidence of healthcare-associated infections, policies and regulations are commonly against the use of natural indoor plants, shadowing the building design innovation of care spaces. The lack of convincing and definitive evidence, fragmented literature, and studies exclusive of diverse influential design features and elements commonly lead to overlooking the significant values of incorporating natural indoor plants, such as decreasing emotional stress/anxiety, and enhancing general health, subjective wellbeing, and cognitive performance.

It is widely acknowledged that ageing populations, the emergence of infectious diseases, growing lifestyle-related chronic diseases, and exponential advances in innovative but costly digital therapeutics and care pathways continue to increase healthcare demand and expenditure. Thus, exploring efficient, low-cost, and sustainable strategies to create healing and therapeutic environments - such as the use of natural indoor plants – warrants further research using a holistic and multidisciplinary approach to address the existing complex issues and disconnections. This research area and identified knowledge gaps may be in the interest of global health sector, due to the significant impacts of building design on the health and wellbeing of occupants in healthcare facilities.

CRediT authorship contribution statement

Anahita Sal Moslehian: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Phillip B. Roös:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Jason S. Gaekwad:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Lana Van Galen:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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References

[1] S.R. Kellert, J. Heerwagen, M. Mador, Biophilic Design: the Theory, Science and Practice of Bringing Buildings to Life, John Wiley & Sons, Chichester, 2007.
[2] S. Kellert, E. Calabrese, The Practice of Biophilic Design, 3, Terrapin Bright LLC, London, 2015, p. 21.
[3] K. Gillis, B. Gatersleben, A review of psychological literature on the health and wellbeing benefits of biophilic design, Buildings 5 (2015) 948–963.
[4] N.A. Salingaros, Biophilia and Healing Environments, Terrapin Bright Green, 2015, pp. 1–44.
[5] W.D. Browning, C.O. Ryan, Nature inside: a Biophilic Design Guide, Routledge, 2020.
[6] R.S. Ulrich, R.F. Simons, B.D. Losito, E. Fiorito, M.A. Miles, M. Zelson, Stress recovery during exposure to natural and urban environments, J. Environ. Psychol. 11 (1991) 201–230.
[7] R. Kaplan, S. Kaplan, The Experience of Nature: A Psychological Perspective, Cambridge University Press, 1989.
[8] K.-T. Han, A review: theories of restorative environments, J. Therapeut. Hortic. (2001) 30–43.
[9] B.-Y. Yang, T. Zhao, L.-X. Hu, M.H. Browning, J. Heinrich, S.C. Dharmage, B. Jalaludin, L.D. Knibbs, X.-X. Liu, Y.-N. Luo, Greenspace and human health: an umbrella review, Innovation 2 (2021), 100164.
[10] K.-T. Han, L.-W. Ruan, Effects of indoor plants on self-reported perceptions: a systemic review, Sustainability 11 (2022) 4506.
[11] J.S. Gaekwad, A.S. Moslehian, P.B. Roös, A. Walker, A meta-analysis of emotional evidence for the biophilia hypothesis and implications for biophilic design, Front. Psychol. 13 (2022).
[12] S. Totaforti, Applying the benefits of biophilic theory to hospital design, City, Territ. Architect. 5 (2018) 1–9.
[13] S.G. Persiani, Benefits of using plants in indoor environments: exploring common research gaps, Architecture 1 (2021) 83–98.
[14] M.S. Abdelaal, V. Soebarto, Biophilia and Salutogenesis as restorative design approaches in healthcare architecture, Architect. Sci. Rev. 62 (2019) 195–205.
[15] N.A. Sachs, Research on Nature in Healthcare: what Do We Still Need? SAGE Publications Sage CA, Los Angeles, CA, 2019.
[16] A. Sal Moslehian, T. Kocaturk, F. Andrews, R. Tucker, The nature of innovation in hospital building design: a mixed grounded theory study, Construct. Innovat. (2022) ahead-of-print.
[17] B.H. Tekin, R. Corcoran, R.U. Gutiérrez, A systematic review and conceptual framework of biophilic design parameters in clinical environments, HERD: Health Environ. Res. Des. J. 19375867221118675 (2022).
[18] Y. Zhao, Q. Zhan, T. Xu, Biophilic design as an important bridge for sustainable interaction between humans and the environment: based on practice in Chinese healthcare space, Comput. Math. Methods Med. (2022). PMID: 35818624.
[19] S. Singha, Future Healthcare Design, Routledge, 2020.
[20] C. Wagenaar, N. Mens, G. Manja, C. Niemeijer, T. Guthknecht, Hospitals: A Design Manual, Birkhäuser, 2018.
[21] R. Guenther, G. Vittori, Sustainable Healthcare Architecture, John Wiley & Sons, 2013.
[22] J. Dubose, L. Macallister, K. Hadi, B. Sakallaris, Exploring the concept of healing spaces, HERD: Health Environ. Res. Des. J. 11 (2018) 43–56.
[23] P.B. Roös, Regenerative-Adaptive Design for Sustainable Development: A Pattern Language Approach, Springer, 2021.
[24] P. Roös, L. Van Galen, S. Kilbane, D. Jones, E. Duncan, Hobsons Bay Wetlands Centre: Architecture and Landscape Brief, 2020.
[25] Ahia, Australasian Health Facility Guidelines (AusHFG) - Part D: Infection Prevention and Control, Australasian Health Infrastructure Alliance, Sydney, Australia, 2016.
[26] NHMRC, Australian Guidelines for the Prevention and Control of Infection in Healthcare, National Health and Medical Research Council and Australian Commission on Safety and Quality in Health Care, Canberra, Australia, 2020.
[27] CDC AND HICPAC, Guidelines for Environmental Infection Control in Health-Care Facilities; Recommendations of CDC and HICPAC, Centers for Disease Control (CDC) and Prevention and Healthcare Infection Control Practices Advisory Committee (HICPAC), Atlanta, Georgia, 2003.
[28] I.S.F.I.D. Isid, in: G.M.L. Bearman, M. Stevens, M.B. Edmond, R.P. Wenzel (Eds.), A Guide to Infection Control in the Hospital, fifth ed., 2014 (Boston, MA. USA).
[29] Clinical Excellence Commission, Infection Prevention and Control Practice Handbook, Clinical Excellence Commission, Sydney, Australia, 2020.
[30] Queensland Health, Capital Infrastructure Requirements - Volume 3 Architecture and Health Facility Design – Section 2: Manual and Specifications, 2020.
[31] L. Deng, Q. Deng, The basic roles of indoor plants in human health and comfort, Environ. Sci. Pollut. Control Ser. 25 (2018) 36087–36101.
[32] T. Bringslimark, T. Hartig, G.G. Patil, The psychological benefits of indoor plants: a critical review of the experimental literature, J. Environ. Psychol. 29 (2009) 422–433.
[33] A. Aydogan, R. Cerone, Review of the effects of plants on indoor environments, Indoor Built Environ. 30 (2021) 442–460.
[34] V.I. Lohr, What are the benefits of plants indoors and why do we respond positively to them? II Int. Conf. Landscape Urban Hortic. 881 (2009) 675–682.
[35] K.-T. Han, L.-W. Ruan, Effects of indoor plants on self-reported perceptions: a systemic review, Sustainability 11 (2019) 4506.
[36] K.-T. Han, L.-W. Ruan, L.-S. Liao, Effects of indoor plants on human functions: a systematic review with meta-analyses, Int. J. Environ. Res. Publ. Health 19 (2022) 7454.
[37] T. Zhao, I. Markevych, D. Buczyłowska, M. Romanos, J. Heinrich, When green enters a room: a scoping review of epidemiological studies on indoor plants and mental health, Environ. Res. (2022), 114715.
[38] S. Bandehali, T. Miri, H. Onyeaka, P. Kumar, Current state of indoor air phytoremediation using potted plants and green walls, Atmosphere 12 (2021) 473.
[39] M. Dela Cruz, J.H. Christensen, J.D. Thomsen, R. Müller, Can ornamental potted plants remove volatile organic compounds from indoor air?—a review, Environ. Sci. Pollut. Control Ser. 21 (2014) 13909–13928.
[40] K.-T. Han, L.-W. Ruan, Effects of indoor plants on air quality: a systematic review, Environ. Sci. Pollut. Control Ser. 27 (2020) 16019–16051.
[41] K.J. Kim, M. Khalekuzzaman, J.N. Suh, H.J. Kim, C. Shagol, H.-H. Kim, H.J. Kim, Phytoremediation of volatile organic compounds by indoor plants: a review, Hortic. Environ. Biotechnol. 59 (2018) 143–157.
[42] T. Pettit, P. Irga, F. Torpy, Towards practical indoor air phytoremediation: a review, Chemosphere 208 (2018) 960–974.
[43] P. Irga, T. Pettit, F. Torpy, The phytoremediation of indoor air pollution: a review on the technology development from the potted plant through to functional green wall biofilters, Rev. Environ. Sci. Biotechnol. 17 (2018) 395–415.
[44] F. Liu, L. Yan, X. Meng, C. Zhang, A review on indoor green plants employed to improve indoor environment, J. Build. Eng. 53 (2022), 104542.
[45] T.A. Moya, A. Van Den Dobbelsteen, M. Ottele, P.M. Bluyssen, A review of green systems within the indoor environment, Indoor Built Environ. 28 (2019) 298–309.
[46] R.S. Ulrich, C. Zimring, X. Zhu, J. Dubose, H.-B. Seo, Y.-S. Choi, X. Quan, A. Joseph, A review of the research literature on evidence-based healthcare design, HERD: Health Environ. Res. Des. J. 1 (2008).
[47] R. Weerasuriya, C. Henderson-Wilson, M. Townsend, Accessing green spaces within a healthcare setting: a mixed studies review of barriers and facilitators, HERD: Health Environ. Res. Des. J. 12 (2019) 119–140.
[48] E.R. Huisman, E. Morales, J. Van Hoof, H. Kort, Healing environment: a review of the impact of physical environmental factors on users, J. Build. environ. 58 (2012) 70–80.
[49] A. Drahota, D. Ward, H. Mackenzie, R. Stores, B. Higgins, D. Gal, T.P. Dean, Sensory environment on health-related outcomes of hospital patients, Cochrane Database, Syst. Rev. (3) (2012). Art. No.: CD005315.
[50] A. Eijkelenboom, P.M. Bluyssen, Comfort and health of patients and staff, related to the physical environment of different departments in hospitals: a literature review, Intell. Build. Int. 14 (2022) 95–113.
[51] K. Dijkstra, M. Pieterse, A. Pruyn, Physical environmental stimuli that turn healthcare facilities into healing environments through psychologically mediated effects: systematic review, J. Adv. Nurs. 56 (2006) 166–181.

[52] H. Salonen, M. Lahtinen, S. Lappalainen, N. Nevala, L.D. Knibbs, L. Morawska, K. Reijula, Physical characteristics of the indoor environment that affect health and wellbeing in healthcare facilities: a review, Intell. Build. Int. 5 (2013) 3–25.
[53] Z. Munn, M.D. Peters, C. Stern, C. Tufanaru, A. Mcarthur, E. Aromataris, Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach, BMC Med. Res. Methodol. 18 (2018) 1–7.
[54] R. Armstrong, B.J. Hall, J. Doyle, E. Waters, Scoping the scope of a cochrane review, J. Public Health 33 (2011) 147–150.
[55] A.C. Tricco, E. Lillie, W. Zarin, K.K. O'brien, H. Colquhoun, D. Levac, D. Moher, M.D. Peters, T. Horsley, L. Weeks, PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation, Ann. Intern. Med. 169 (2018) 467–473.
[56] C. Wohlin, Guidelines for snowballing in systematic literature studies and a replication in software engineering, in: Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering, Citeseer, 2014, pp. 38–48.
[57] T. Greenhalgh, R. Peacock, Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources, BMJ 331 (2005) 1064–1065.
[58] Covidence Systematic Review Software, Veritas Health Innovation, Melbourne, Australia, 2020. https://www.covidence.org/.
[59] C. Bartzokas, M.P. Holley, C.A. Sharp, Bacteria in flower vase water: incidence and significance in general ward practice, J. Br. Surg. 62 (1975) 295–297.
[60] D. Gould, J. Chudleigh, J. Gammon, R. Ben Salem, The evidence base and infection risks from flowers in the clinical setting, Br. J. Infect. Control 6 (2005) 18–20.
[61] D. Gould, J. Gammon, R.B. Salem, J. Chudleigh, M. Fontenla, Flowers in the clinical setting: infection risk or workload issue? NT Res. 9 (2004) 366–377.
[62] S. Kates, K. Mcginley, E. Larson, J. Leyden, Indigenous multiresistant bacteria from flowers in hospital and nonhospital environments, Am. J. Infect. Control 19 (1991) 156–161.
[63] D. Taplin, P. Mertz, Flower vases in hospitals as reservoirs of pathogens, Lancet 302 (1973) 1279–1281.
[64] D. Haas, S. Lesch, W. Buzina, H. Galler, A.M. Gutschi, J. Habib, B. Pfeifer, J. Luxner, F.F. Reinthaler, Culturable fungi in potting soils and compost, Sabouraudia 54 (2016) 825–834.
[65] I.U. Haq, S. Ijaz, A. Faraz, N.A. Khan, Potted ornamental Chamaedorea seifrizii, Chamaedorea cataractarum and Rhapis excels palm species: hosts for the opportunistic fungal pathogen, Pakistan J. Agric. Sci. 57 (2020) 433–437.
[66] E.M. Kenyon, L.H. Russell, D.N. Mcmurray, Isolation of pathogenic Aspergillus species from commercially-prepared potting media, Mycopathologia 87 (1984) 171–173.
[67] S. Blaschke, C.C. O'callaghan, P. Schofield, "Artificial but better than nothing" the greening of an oncology clinic waiting room, HERD: Health Environ. Res. Des. J. 10 (2017) 51–60.
[68] R.K. Raanaas, G.G. Patil, T. Hartig, Effects of an indoor foliage plant intervention on patient well-being during a residential rehabilitation program, Hortscience 45 (2010) 387–392.
[69] M. Tinner, P. Crovella, P.F. Rosenbaum, Perceived importance of wellness features at a cancer center: patient and staff perspectives, HERD: Health Environ. Res. Des. J. 11 (2018) 80–93.
[70] M. Ali Khan, N. Amin, A. Khan, M. Imtiaz, F. Khan, I. Ahmad, A. Ali, B. Islam, Plant therapy: a nonpharmacological and noninvasive treatment approach medically beneficial to the wellbeing of hospital patients, Gesunde Pflanz. 68 (2016) 191–200.
[71] A.E.V.D. Berg, J. Maas, L.V.D. Hoven, K. Tanja-Dijkstra, Greening a geriatric ward reduces functional decline in elderly patients and is positively evaluated by hospital staff, J. Aging Environ. 35 (2021) 125–144.
[72] S.-H. Park, R.H. Mattson, Effects of flowering and foliage plants in hospital rooms on patients recovering from abdominal surgery, HortTechnology 18 (2008) 563–568.
[73] S.-H. Park, R.H. Mattson, Ornamental indoor plants in hospital rooms enhanced health outcomes of patients recovering from surgery, Alternative Compl. Med. 15 (2009) 975–980.
[74] Y. Koh, H. Rashid, S. Khaw, A. Nasis, Artificial FLOwering plants in Reducing Anxiety and depressive symptoms following Acute Coronary Syndromes (A-FLORA-ACS): a randomised controlled trial, Heart Ves. 34 (2019) 888–897.
[75] L.A. Lacharity, E.R. Mcclure, Are plants vectors for transmission of infection in acute care? Critical Care Nursing Clinics 15 (2003) 119–124.
[76] K. Schaal, Medical and microbiological problems arising from airborne infection in hospitals, J. Hosp. Infect. 18 (1991) 451–459.
[77] A. Sepahvand, M. Shams-Ghahfarokhi, A. Allameh, Z. Jahanshiri, M. Jamali, M. Razzaghi-Abyaneh, A survey on distribution and toxigenicity of Aspergillus flavus from indoor and outdoor hospital environments, Folia Microbiol. 56 (2011) 527–534.
[78] C. Lass-Flörl, P.-M. Rath, D. Niederwieser, G. Kofler, R. Würzner, A. Krezy, M. Dierich, Aspergillus terreus infections in haematological malignancies: molecular epidemiology suggests association with in-hospital plants, J. Hosp. Infect. 46 (2000) 31–35.
[79] F. Staib, U. Folkens, B. Tompak, T. Abel, D. Thiel, A comparative study of antigens of Aspergillus fumigatus isolates from patients and soil of ornamental plants in the immunodiffusion test, Zentralbl Bakteriol Orig A 242 (1978) 93–99.
[80] Y. Siegman-Igra, A. Shalem, S.A. Berger, S. Livio, D. Michaeli, Should potted plants be removed from hospital wards? J. Hosp. Infect. 7 (1986) 82–85.
[81] H. Fan, Y. Chen, L. Duan, J. Zhao, C. Qin, H. Li, J. Sun, L. Han, Comparison of two typing methods for characterization of azole resistance in Aspergillus fumigatus from potting soil samples in a Chinese Hospital, Antimicrob. Agents Chemother. 64 (2020), 1578-19.
[82] M. Hedayati, A. Mohseni-Bandpi, S. Moradi, A survey on the pathogenic fungi in soil samples of potted plants from Sari hospitals, Iran, J. Hosp. Infect. 58 (2004) 59–62.
[83] R.C. Summerbell, S. Krajden, J. Kane, Potted plants in hospitals as reservoirs of pathogenic fungi, Mycopathologia 106 (1989) 13–22.
[84] H. Humphreys, On the wrong scent: banning fresh flowers from hospitals, J. Hosp. Infect. 4 (2006) 527–528.
[85] F.R. Torpy, P.J. Irga, J. Brennan, M.D. Burchett, Do indoor plants contribute to the aeromycota in city buildings? Aerobiologia 29 (2013) 321–331.
[86] A. Darlington, M. Chan, D. Malloch, C. Pilger, M. Dixon, The biofiltration of indoor air: implications for air quality, Indoor Air 10 (2000) 39–46.
[87] R. Fleck, R. Gill, T. Pettit, P. Irga, N. Williams, J. Seymour, F. Torpy, Characterisation of fungal and bacterial dynamics in an active green wall used for indoor air pollutant removal, Build. Environ. 179 (2020), 106987.
[88] P. Irga, P. Abdo, M. Zavattaro, F. Torpy, An assessment of the potential fungal bioaerosol production from an active living wall, Build. Environ. 111 (2017) 140–146.
[89] K. Dijkstra, M.E. Pieterse, A. Pruyn, Stress-reducing effects of indoor plants in the built healthcare environment: the mediating role of perceived attractiveness, Prev. Med. 47 (2008) 279–283.
[90] C.J. Beukeboom, D. Langeveld, K. Tanja-Dijkstra, Stress-reducing effects of real and artificial nature in a hospital waiting room, J. Alternative Compl. Med. 18 (2012) 329–333.
[91] B.Y.-J. Lin, Y.-K. Lin, C.W. Juan, S. Lee, C.-C. Lin, Moderating role of interior amenities on hospital medical directors' patient-related work stresses, HERD: Health Environ. Res. Des. J. 6 (2013) 77–92.
[92] A. Smith, M. Pitt, Sustainable workplaces: improving staff health and well-being using plants, J. Corp. R. Estate. 11 (2009) 52–63.
[93] R.K. Raanaas, K.H. Evensen, D. Rich, G. Sjøstrøm, G. Patil, Benefits of indoor plants on attention capacity in an office setting, J. Environ. Psychol. 31 (2011) 99–105.
[94] S. Shibata, N. Suzuki, Effects of an indoor plant on creative task performance and mood, Scand. J. Psychol. 45 (2004) 373–381.
[95] V.I. Lohr, C.H. Pearson-Mims, G.K. Goodwin, Interior plants may improve worker productivity and reduce stress in a windowless environment, J. Environ. Hortic. 14 (1996) 97–100.
[96] A. Smith, M. Tucker, M. Pitt, Healthy, productive workplaces: towards a case for interior plantscaping, Facilities 29 (2011) 209–223.
[97] Q. Lei, C. Yuan, S.S.Y. Lau, A quantitative study for indoor workplace biophilic design to improve health and productivity performance, J. Clean. Prod. 324 (2021), 129168.
[98] L. Larsen, J. Adams, B. Deal, B.S. Kweon, E. Tyler, Plants in the workplace: the effects of plant density on productivity, attitudes, and perceptions, Environ. Behav. 30 (1998) 261–281.
[99] N. Hähn, E. Essah, T. Blanusa, Biophilic design and office planting: a case study of effects on perceived health, well-being and performance metrics in the workplace, Intell. Build. Int. 13 (2021) 241–260.
[100] T. Bringslimark, T. Hartig, G.G. Patil, Psychological benefits of indoor plants in workplaces: putting experimental results into context, Hortscience 42 (2007) 581–587.
[101] M. Nieuwenhuis, C. Knight, T. Postmes, S.A. Haslam, The relative benefits of green versus lean office space: three field experiments, J. Exp. Psychol. Appl. 20 (2014) 199.
[102] P. Archary, A. Thatcher, Affective and cognitive restoration: comparing the restorative role of indoor plants and guided meditation, Ergonomics (2021) 1–10.
[103] K. Li, Y.Z. Yang Zhai, Q. Song, X. Luo, J. Liu, Effects of indoor foliage plants on college students' work attention recovery: an experiment focusing on plant characteristics, Eur. J. Hortic. Sci. 86 (2021) 642–650.
[104] J.D. Thomsen, H.K. Sønderstrup-Andersen, R. Müller, People–plant relationships in an office workplace: perceived benefits for the workplace and employees, Hortscience 46 (2011) 744–752.
[105] M. Elsadek, B. Liu, Effects of viewing flowering plants on employees' wellbeing in an office-like environment, Indoor Built Environ. 30 (2021) 1429–1440.
[106] S.-A. Park, C. Song, J.-Y. Choi, K.-C. Son, Y. Miyazaki, Foliage plants cause physiological and psychological relaxation as evidenced by measurements of prefrontal cortex activity and profile of mood states, Hortscience 51 (2016) 1308–1312.
[107] V.I. Lohr, C.H. Pearson-Mims, Physical discomfort may be reduced in the presence of interior plants, HortTechnology 10 (2000) 53–58.
[108] K.H. Evensen, R.K. Raanaas, C.M. Hagerhall, M. Johansson, G.G. Patil, Restorative elements at the computer workstation: a comparison of live plants and inanimate objects with and without window view, Environ. Behav. 47 (2015) 288–303.
[109] J. Qin, C. Sun, X. Zhou, H. Leng, Z. Lian, The effect of indoor plants on human comfort, Indoor Built Environ. 23 (2014) 709–723.
[110] M. Toyoda, Y. Yokota, M. Barnes, M. Kaneko, Potential of a small indoor plant on the desk for reducing office workers' stress, HortTechnology 30 (2020) 55–63.
[111] A. Smith, M. Pitt, Healthy workplaces: plantscaping for indoor environmental quality, Facilities 29 (2011) 169–187.
[112] A. Hassan, C. Qibing, L. Yinggao, J. Tao, G. Li, M. Jiang, L. Nian, L. Bing-Yang, L. Shiliang, Do plants affect brainwaves? Effect of indoor plants in work environment on mental stress, Eur. J. Hortic. Sci. 85 (2020) 279–283.
[113] J. Yin, J. Yuan, N. Arfaei, P.J. Catalano, J.G. Allen, J.D. Spengler, Effects of biophilic indoor environment on stress and anxiety recovery: a between-subjects experiment in virtual reality, Environ. Int. 136 (2020), 105427.

[114] K. Genjo, H. Matsumoto, N. Ogata, T. Nakano, Feasibility study on mental health-care effects of plant installations in office spaces, Japan Architectural Review 2 (2019) 376–388.
[115] T. Fjeld, The effect of interior planting on health and discomfort among workers and school children, HortTechnology 10 (2000) 46–52.
[116] K.H. Evensen, R.K. Raanaas, G.G. Patil, Potential health benefits of nature-based interventions in the work environment during winter. A case study, Psyecology 4 (2013) 67–88.
[117] J.-Y. Choi, S.-A. Park, S.-J. Jung, J.-Y. Lee, K.-C. Son, Y.-J. An, S.-W. Lee, Physiological and psychological responses of humans to the index of greenness of an interior space, Compl. Ther. Med. 28 (2016) 37–43.
[118] S. Raza, G. Shylaja, B. Gopal, Different abilities of certain succulent plants in removing CO2 from the indoor environment of a hospital, Environ. Int. 21 (1995) 465–469.
[119] G. Aini Jasmin, M. Noorizan, M. Suhardi, A. Murad, K. Ina, The Use of Plants to Improve Indoor Air Quality in Small Office Space, Pertanika Journal of Social Sciences & Humanities, 2012, p. 20.
[120] B. Bhargava, S. Malhotra, A. Chandel, A. Rakwal, R.R. Kashwap, S. Kumar, Mitigation of indoor air pollutants using Areca palm potted plants in real-life settings, Environ. Sci. Pollut. Control Ser. 28 (2021) 8898–8906.
[121] L.-Y. Chen, M.-W. Lin, Y.-K. Chuah, Investigation of a potted plant (Hedera helix) with photo-regulation to remove volatile formaldehyde for improving indoor air quality, Aerosol Air Qual. Res. 17 (2017) 2543–2554.
[122] C. Gubb, T. Blanusa, A. Griffiths, C. Pfrang, Interaction between plant species and substrate type in the removal of CO2 indoors, Air Quality, Atmosphere & Health 12 (2019) 1197–1206.
[123] C. Gubb, T. Blanusa, A. Griffiths, C. Pfrang, Potted plants can remove the pollutant nitrogen dioxide indoors, Air Quality, Atmosphere & Health 15 (2022) 479–490.
[124] K.J. Kim, M.I. Jeong, D.W. Lee, J.S. Song, H.D. Kim, E.H. Yoo, S.J. Jeong, S. W. Han, S.J. Kays, Y.-W. Lim, Variation in formaldehyde removal efficiency among indoor plant species, Hortscience 45 (2010) 1489–1495.
[125] H. Teiri, H. Pourzamani, Y. Hajizadeh, Phytoremediation of VOCs from indoor air by ornamental potted plants: a pilot study using a palm species under the controlled environment, Chemosphere 197 (2018) 375–381.
[126] C.K. Thomas, K.J. Kim, S.J. Kays, Phytoremediation of indoor air, Hortscience 50 (2015) 765–768.
[127] B.C. Wolverton, A. Johnson, K. Bounds, Interior Landscape Plants for Indoor Air Pollution Abatement, 1989.
[128] R.A. Wood, M.D. Burchett, R. Alquezar, R.L. Orwell, J. Tarran, F. Torpy, The potted-plant microcosm substantially reduces indoor air VOC pollution: I. Office field-study, Water Air Soil Pollut. 175 (2006) 163–180.
[129] N. Fernández-Bregón, M. Urrestarazu, D. Valera, Effects of a vertical greenery system on selected thermal and sound mitigation parameters for indoor building walls, Food, Agriculture Environment 10 (2012) 1025–1027.
[130] Y. Shao, J. Li, Z. Zhou, F. Zhang, Y. Cui, The impact of indoor living wall system on air quality: a comparative monitoring test in building corridors, Sustainability 13 (2021) 7884.
[131] T. Fjeld, B. Veiersted, L. Sandvik, G. Riise, F. Levy, The effect of indoor foliage plants on health and discomfort symptoms among office workers, Indoor Built Environ. 7 (1998) 204–209.
[132] Y. Gong, T. Zhou, P. Wang, Y. Lin, R. Zheng, Y. Zhao, B. Xu, Fundamentals of ornamental plants in removing benzene in indoor air, Atmosphere 10 (2019) 221.
[133] Z. Gou, S.S.Y. Lau, Sick building syndrome in open-plan offices: workplace design elements and perceived indoor environmental quality, J. Facil. Manag. 10 (2012) 256–265.
[134] H.-H. Kim, J.-Y. Lee, J.-Y. Yang, K.-J. Kim, Y.-J. Lee, D.-C. Shin, Y.-W. Lim, Evaluation of indoor air quality and health related parameters in office buildings with or without indoor plants, J. Jpn. Soc. Hortic. Sci. 80 (2011) 96–102.
[135] L. Soininen, M. Roslund, N. Nurminen, R. Puhakka, O. Laitinen, H. Hyöty, A. Sinkkonen, Indoor green wall affects health-associated commensal skin microbiota and enhances immune regulation: a randomized trial among urban office workers, Sci. Rep. 12 (2022) 1–9.
[136] A. Mahnert, R.A. Ortega, C. Berg, M. Grube, G. Berg, Leaves of indoor ornamentals are biodiversity and functional hotspots for fungi, Front. Microbiol. 9 (2018) 2343.
[137] W.A. Wicaksono, T. Reisenhofer-Graber, S. Erschen, P. Kusstatscher, C. Berg, R. Krause, T. Cernava, G. Berg, Phyllosphere-associated microbiota in built environment: do they have the potential to antagonize human pathogens? J. Adv. Res. 43 (2022) 109–121.
[138] Y. Dockx, M. Täubel, E.M. Bijnens, K. Witters, M. Valkonen, B. Jayaprakash, J. Hogervorst, T.S. Nawrot, L. Casas, Indoor green can modify the indoor dust microbial communities, Indoor Air 32 (2022).
[139] A. Mahnert, C. Moissl-Eichinger, G. Berg, Microbiome interplay: plants alter microbial abundance and diversity within the built environment, Front. Microbiol. 6 (2015) 887.
[140] G. Mangone, S. Kurvers, P. Luscuere, Constructing thermal comfort: investigating the effect of vegetation on indoor thermal comfort through a four season thermal comfort quasi-experiment, Build. Environ. 81 (2014) 410–426.
[141] X. Meng, L. Yan, F. Liu, A new method to improve indoor environment: combining the living wall with air-conditioning, Build. Environ. 216 (2022), 108981.
[142] A.J. Smith, A. Fsadni, G. Holt, Indoor living plants' effects on an office environment, Facilities 35 (2017) 525–542.
[143] L. Johnson, Evaluation of the potential for hospital acquired infection from live plants in a health facility atrium, Am. J. Infect. Control 41 (2013) S68.
[144] M. Franchini, P.M. Mannucci, Mitigation of air pollution by greenness: a narrative review, Eur. J. Intern. Med. 55 (2018) 1–5.
[145] B. Surial, M. Vázquez, W. Steiger, E. Rolli, S. Brand, K. Mühlethaler, J. Marschall, Assessing the infection risk of a vertical garden in a hospital setting, Infect. Control Hosp. Epidemiol. 43 (2022) 273–275.
[146] V. Smith, A. Streifel, F. Rhame, B. Juni, Potted plant fungal spore shedding, in: Abs Ann Meeting Am Soc Microbiol, 1988.
[147] K. Kerr, Flowers and healthcare-associated infection, J. Hosp. Infect. 64 (2006) 301–302.
[148] The Centre For Health Design, in: An Introduction to Evidence-Based Design: Exploring Healthcare and Design, third ed. ed, EDAC Study Guide, Concord, CA, 2009.
[149] K. Hamilton, Research informed design, best practice, and fresh perspectives: can we all get along? Health Environ. Res. Des. J. 7 (2014) 94–97.
[150] S. Blaschke, C.C. O'callaghan, P. Schofield, Nature-based care opportunities and barriers in oncology contexts: a modified international e-Delphi survey, BMJ Open 7 (2017), e017456.
[151] R. Elnaklah, I. Walker, S. Natarajan, Moving to a green building: indoor environment quality, thermal comfort and health, Build. Environ. 191 (2021), 107592.
[152] F. Brilli, S. Fares, A. Ghirardo, P. De Visser, V. Calatayud, A. Muñoz, I. Annesi-Maesano, F. Sebastiani, A. Alivernini, V. Varriale, Plants for sustainable improvement of indoor air quality, Trends Plant Sci. 23 (2018) 507–512.
[153] E. Peavey, K.B. Vander Wyst, Evidence-based design and research-informed design: what's the difference? Conceptual definitions and comparative analysis, Health Environ. Res. Design J. 10 (2017) 143–156.
[154] J.F. Stichler, Weighing the Evidence, SAGE Publications Sage CA, Los Angeles, CA, 2010.
[155] S. Hall, P. Oldfield, B.J. Mullins, B. Pollard, C. Criado-Perez, Evidence based practice for the built environment: can systematic reviews close the research - practice gap? Procedia Eng. 180 (2017) 912–924.
[156] K. Freihoefer, T. Zborowsky, Making the case for practice-based research and the imperative role of design practitioners, HERD 10 (2017) 66–82.
[157] R. Codinhoto, Evidence and Design: an Investigation of the Use of Evidence in the Design of Healthcare Environments, The University of Salford, 2013.
[158] A. Sal Moslehian, T. Kocaturk, R. Tucker, An integral view of innovation in hospital building design: understanding the context of the research/practice gap, Build. Res. Inf. (2021) 1–16.