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Design of healthcare facilities with an emphasis on environmental health features

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Review Article

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ABSTRACT

This study aims to critically analyze the integration of environmental health features into the design and construction processes of healthcare facilities in Slovenia, evaluate their impact on the well-being of patients and staff, and develop more holistic and sustainable design approaches. A mixed-methods research approach was employed, beginning with a qualitative analysis of national and international legal requirements and recommendations for constructing healthcare facilities in Slovenia, focusing on environmental health. The second step involved qualitative research through a case study, including short interviews with stakeholders to gather insights on applying environmental health criteria in construction projects. In the third step, recommendations for constructing healthcare facilities were defined, synthesizing findings from previous steps. By applying the six-step engineering design methodology and evidence-based approach, we presented the most critical areas of environmental health using the example of a 400-bed hospital. Our research results have significant practical value for all phases of healthcare facility construction, effectively raising stakeholder awareness

Keywords: environmental health, indoor environmental quality, healthcare facilities, sustainable design, well-being, recommendations

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INTRODUCTION

Healthcare facilities are intricate environments that necessitate the creation of healthy, comfortable, stimulating, and healing-oriented conditions for patients, staff, and visitors [1, 2]. Consequently, designing such buildings is among the most challenging processes compared to other types and requires a transdisciplinary approach involving collaboration across various disciplines. This context's performance criteria pertain to building design and environmental health. Key determinants of environmental health include indoor environmental quality (IEQ), which encompasses optimal thermal conditions, air quality, daylight, ergonomics, universal design, sound insulation, and room acoustics. Environmental factors significantly impact human health [3, 4]. The Ministry of Health of the Republic of Slovenia [5] and the World Health Organization [6] emphasize that the most critical environmental factors of the built environment, which represent the most significant burden of disease, include air pollution, ambient noise, electromagnetic radiation, light pollution, and contaminated water and soil. This aspect is particularly crucial in the design of healthcare facilities where there are vulnerable users.

Research in environmental psychology underscores that the physical environment affects psychological well-being, directly influencing the healing process.

To broaden the academic discourse on the impact of optimal IEQ on patient treatment, a closer examination of historical and contemporary perspectives is necessary. As early as 1859, Florence Nightingale laid the foundation for understanding that IEQ is not merely an aesthetic enhancement but a crucial element of the therapeutic process [7]. Her pioneering work highlighted the importance of hygiene, ventilation, and natural light in hospital rooms, representing a revolutionary shift in medical practice. In modern times, this concept continues to evolve and deepen. An interdisciplinary approach, integrating engineers, architects, consultants, healthcare professionals, and environmental psychologists [8], facilitates a comprehensive understanding of the complex interactions between patients and their environment. Research in environmental psychology underscores that the physical environment affects psychological well-being, directly influencing the healing process.

This means that a high-quality indoor environment is not just a passive element but an active factor that enhances the effectiveness of healthcare.

Anåker et al. [9] explored the concept of healthcare facility design based on the premise that optimal physical environments can promote the health and well-being of patients and staff. The study highlights the growing demand for patient-centered, accessible, safe healthcare environments grounded in research and evaluations. The conclusions emphasize that stakeholder awareness contributes to the creation of evidence-based healthcare environments, focusing on three main themes: (i) environmental sustainability and ecological values, (ii) social and cultural interactions and values, and (iii) resilience in engineering and building construction. The Donabedian classification, cited by Fadda [10], provides a structured framework for assessing the quality of healthcare provision. The hospital environment's design, technology, and equipment are key factors in this context. This means that a high-quality indoor environment is not just a passive element but an active factor that enhances the effectiveness of healthcare. The study by Capolongo et al. [11], based on an analysis of the response of healthcare systems to the COVID-19 pandemic, proposed a decalogue to improve environmental factors, including the establishment of a territorial health network, implementation of risk control protocols, use of visual signs and other forms of orientation to improve safety, adequate ventilation, adaptability of technological systems to needs, use of high-performance, easy-to-clean materials that reduce bacterial and viral load, and use of digital technologies to support patient treatment and care, including telemedicine and remote monitoring.

Research by Gao et al. [12] also demonstrates that a proactive approach focusing on intrinsic health can significantly reduce the risk of adverse health outcomes as early as the building design phase.

In today's rapidly evolving healthcare landscape, the design of healthcare facilities is becoming increasingly crucial for ensuring high-quality and efficient healthcare delivery. Beyond functionality and aesthetic appeal, the role of environmental health in designing these spaces is gaining prominence. This aspect impacts not only the well-being of patients and staff but also the sustainability and efficiency of the entire facility. Environmental health aspects related to IEQ are often overlooked in the construction of healthcare buildings, leading to discomfort and other adverse health outcomes. Key findings from research on sick building syndrome (SBS) in hospital environments highlight the significant connection between environmental factors and SBS symptoms among hospital staff. Studies demonstrate an etiological correlation between the prevalence of SBS symptoms and environmental factors such as air quality and ventilation (volatile organic compounds - VOCs, microbes, odors), thermal comfort, and daylight [13-15]. The prevalence of SBS in hospitals varies widely, ranging from 21% to 86%, according to different studies worldwide [13, 16-21].

Key findings from research on sick building syndrome (SBS) in hospital environments highlight the significant connection between environmental factors and SBS symptoms among hospital staff.

The design of healthcare facilities presents a complex challenge that necessitates an interdisciplinary approach and the consideration of numerous factors, including environmental health aspects. Despite the growing recognition of the importance of a high-quality indoor environment for the health and well-being of users, these aspects are frequently overlooked in the construction of healthcare buildings. This study investigates how these aspects are integrated into current practices and regulatory frameworks and evaluates the potential for enhancing these practices. The research question posed is: To what extent are environmental health aspects incorporated into the planning and construction processes of healthcare facilities in Slovenia, and how does this integration impact the well-being of patients and staff? The goal is to contribute to developing more holistic and sustainable approaches to healthcare facility design that will positively influence the health and well-being of users.

MATERIALS AND METHODS

A mixed-methods research approach was employed, comprising three distinct steps. The first step involved a qualitative analysis of the legal requirements and recommendations for constructing healthcare facilities in Slovenia, with a particular focus on environmental health. National legal requirements were sourced from the legislation of the Ministry of Health of the Republic of Slovenia, the Ministry of Natural Resources and Spatial Planning of the Republic of Slovenia, the Official Gazette of the Republic of Slovenia, and the Register of Regulations. International legal requirements and recommendations were examined through resources such as the Official Journal of the EU, EUR-Lex, the European Commission (EC), and websites of organizations including the World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA).

Despite the growing recognition of the importance of a high-quality indoor environment for the health and well-being of users, these aspects are frequently overlooked in the construction of healthcare buildings.

The second step entailed qualitative research through a case study to gain preliminary insights.

Short interviews were conducted with selected stakeholders involved in the construction process to understand their perspectives and needs better (professional planners, internal hygienists specialized in healthcare facilities, and experts). The interviews aimed to gather information on the application of recommendations in the construction sector that also consider environmental health criteria. The following questions were posed to the selected stakeholders: i. To what extent have you considered the requirements and recommendations for environmental health in the construction projects for healthcare facilities in which you have been involved? Was the technical guideline for constructing healthcare buildings [22] requested or recommended by the project client? If you did not use the TSG-12640-002:2021 [22], what relevant guidelines did you use besides existing legislation? ii. Were the current requirements and recommendations for constructing healthcare facilities sufficient, or did you need to use other sources of information and additional expertise? iii. To what extent was environmental health considered in this project? Which areas were well-considered, less considered, or not considered? iv. Who was involved in the expert team for the project, and who do you think would still be needed if the project were undertaken again?

In the third step, we developed guidelines for constructing healthcare facilities, emphasizing the importance of considering environmental health criteria. This step synthesizes the findings from the previous two steps, resulting in concrete guidelines formulated based on the analysis and interviews.

RESULTS AND DISCUSSION

Asimow [23], in his work "Introduction to Design," emphasized that the engineering design of a product necessitates a synthesis of human, technical, and economic factors alongside social, political, and other considerations. The process of building design morphology, as outlined by Krainer [24], progresses from abstract concepts to concrete implementations and comprises six steps: 1) defining the purpose; 2) assessing geomorphological, climatic, and site conditions; 3) determining geometry and orientation; 4) defining active areas (spaces with specific purposes) and their required conditions; 5) specifying functional areas (structural assemblies, building envelope), composition, and intersections; and 6) establishing technical systems for building operations (e.g., heating, ventilation, and air conditioning, HVAC). The design of healthcare buildings is particularly complex, requiring stakeholders to be well-versed in the functioning of individual hospital services, medical technologies, hygiene requirements, and materials suitable for hospital environments.

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The following outlines the key design recommendations of the Technical construction guideline for healthcare buildings [22] using a step-by-step approach to building design [24]. A hospital with up to 400 beds serves as an example. A similar methodology would be applied when summarizing the recommendations for a health center or emergency center. The quality of implementing these steps significantly impacts all components of environmental health within a healthcare facility, as evidenced by various studies.

1. Defining the Purpose

Healthcare facilities, particularly hospitals, are highly demanding buildings, and their construction process differs significantly from that of buildings with other purposes, as highlighted by numerous studies [25-27].

This complexity is primarily due to strict hygiene requirements, specific usage patterns, and the characteristics of users who spend up to 100% of their time indoors [28].

The classification of buildings according to their purpose [29, 30] includes healthcare buildings (1264) and (12640). Classifying a building based on its surface area is demanding (surface area over 2,000 m², height over 10 m). According to the Healthcare Activities Act [31], hospitals can be general or specialized. Specialized hospital activities encompass in-depth diagnostics, treatment, medical rehabilitation, health care, and nursing (accommodation, nutrition) in general or specialized hospitals. The definition of a building's purpose and its characteristics dictates general and specific legal requirements and recommendations, which must be meticulously specified during the project documentation preparation phase.

The overarching international legal act is Regulation 305/2022 [32], which mandates that buildings must be designed and constructed to ensure they do not endanger people's or property's safety and not harm the environment. This requirement applies to the entire life cycle of a building, encompassing the successive and interconnected phases of a construction product's life, from raw material procurement and extraction from natural resources to final disposal. According to Regulation 305/2011 [32], a construction product is any product or group of products manufactured and placed on the market for permanent incorporation into construction works or parts thereof, where the characteristics of the construction products influence the characteristics of the construction works concerning the basic requirements.

The essential requirements according to Regulation 305/2011 [32] and the Construction Act [33], which apply to all installed construction products (i.e., building materials, HVAC equipment, etc.), include mechanical strength and stability, fire safety, hygiene and health protection, environmental protection, safety in use, noise protection, energy saving and thermal insulation, universal construction and use of buildings, and sustainable use of natural resources. In addition to the eight basic requirements, specific requirements are also considered, such as special functional, environmental, and other characteristics that individual types of buildings must meet depending on their intended use and building classification [29].

The Technical construction guideline for healthcare buildings, TSG-12640-002:2021 [22], issued by the Ministry of Health in agreement with the Ministry of Environment and Spatial Planning, is a document that provides a more precise definition of the essential requirements, design conditions, selected levels or classes of construction products and materials that may be incorporated, and the construction method to ensure the reliability of the building throughout its service life. If necessary, it also outlines the procedures to determine whether these requirements are met.

2. Assessing geomorphological, climatic, and site conditions

The primary factors in the design of buildings, including healthcare facilities, are the site conditions and associated challenges or burdens. These include insolation, which we aim to leverage by incorporating elements of passive solar architecture, essential for both the energy efficiency of the building and the provision of natural daylight.

During the non-heating season, it is crucial to ensure optimal building shading to prevent overheating. An example of a geomorphological challenge is constructing a building in a radon-risk area. In such cases, the parts of the building envelope in contact with the soil must be meticulously designed, and additional radon mitigation measures [34, 35] must be implemented to prevent radon ingress into the building. Another important site-related factor is air quality, which is the basis for designing effective ventilation systems with air purification capabilities. Noise maps are also vital for planning the building's acoustic protection elements.

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In addition to the aforementioned factors, TSG-12640-002:2021 [22] outlines additional locational and urban planning requirements that must be considered at the outset of the planning process. These include compliance with municipal spatial plans, building typology and dimensions, transport strategy with parking arrangements for employees, patients, and visitors, connection to public transport infrastructure, integration of the building with accessibility to central activities, adaptation of the design to local bioclimatic conditions—such as solar exposure, orientation, and ventilation—adaptation of the design to fire safety requirements, energy and utility provisions, proximity to and integration of green areas with trees, and allocation of space for the long-term development of the public health institution's activities.

When dimensioning a hospital [22], it is essential to consider the gravity area and its population size, the characteristics of the population served by the hospital (health status, age, and social structure), the annual number of hospital admissions, accounting for the average length of stay, the annual number of examinations, procedures, or treatments, the content of the programs and the corresponding structure and number of staff required for their implementation. This includes the structure and number of medical, paramedical, service, administrative, and technical staff, as well as the operational schedule of the individual services. Incorrect baselines or inadequate information will impact all subsequent construction and use phases.

3. Determining geometry and orientation

The geometric design of a hospital, including its floor layout and room size, significantly impacts the control and prevention of hospital-acquired infections (HAIs) [36] and airborne transmission, which has become a particularly relevant area of research in the COVID-19 era [37]. Optimal orientation of the facility and rooms is crucial to ensure both qualitative and quantitative aspects of daylighting [38] while also considering other indoor environmental quality (IEQ) factors such as air quality and soundproofing. Research indicates that optimal daylighting in a room is associated with improved performance of complex visual tasks and regulation of the body's circadian system. In hospitals, daylighting notably affects healthcare outcomes by reducing depression among patients, shortening hospital stays, and improving sleep and circadian rhythms [39]. A study by Ulrich [40] compared the recovery times of surgical patients who viewed a brick wall through a window with those who viewed green surfaces. Patients who viewed green surfaces experienced fewer post-operative complications, required less pain medication, and had hospital stays that were nearly 9% shorter than those who viewed a brick wall.

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TSG-12640-002:2021 [22] emphasizes that the functional design of a general hospital, including the floor plans of individual service areas and common and communication areas, must account for technological requirements and the needs of users (patients, visitors, and staff). The characteristics of individual services (clean, unclean, sterile) must be consistently considered, with routes separated according to priority to avoid crossing paths. Access, parking, entrances, doors, and communication areas must comply fully with the Rules on the universal construction and use of buildings [41] and universal construction standards. To prevent hospital-acquired infections and ensure the smooth operation of various services, special attention must be given to limiting encounters between hospitalized and outside patients, controlling visitor movement within the hospital, transporting materials that pose a potential risk of hospital-acquired infections in a controlled manner, and implementing all necessary protective measures.

4. Defining active areas and their required conditions

Research consistently demonstrates a significant association between overcrowding in hospital wards and rooms and an increased risk of infections, particularly hospital-acquired infections (HAIs) or nosocomial infections. Overcrowded wards have been linked to a higher prevalence of nosocomial infections than non-crowded wards [42]. Kaier [43] reports that most studies (75%) indicate hospital bed occupancy rates and staff shortages directly impact nosocomial infections. Studies investigating infrastructure factors, such as the use of hospital beds and staff shortages, have shown that the prevalence of nosocomial infections is higher in these contexts. Research on infrastructure (e.g., the age of the unit) and organizational risk factors (e.g., corridor bed utilization) for Clostridioides difficile infection (CDI) and methicillin-resistant Staphylococcus aureus (MRSA) in hospitals found that older units were associated with higher rates of infection risk factors [44, 45]. Sartini et al. [45] also highlight that overcrowding in emergency centers contributes to numerous negative consequences affecting the quality of care. Among these consequences is an increased risk of nosocomial infections, as overcrowding can lead to reduced staff attention to infection prevention protocols, longer waiting times for patients in crowded areas—thereby increasing potential exposure to pathogens—and difficulties adequately isolating patients with infectious diseases. Borg [46] also found a significant positive correlation between new cases of MRSA infections and overall bed occupancy rates, suggesting that overcrowding may be an essential factor in the spread of MRSA within hospitals, even in non-ICU settings. Lowe et al. [47] state that inadequate hospital infrastructure, lack of resources and staff, insufficient in-service training and supervision on infection prevention and control, and high visitor numbers are barriers to effective infection prevention programs in hospitals.

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TSG-12640-002:2021 [22] highlights that inpatient wards are typically situated in a separate building within a general hospital. The number of inpatient wards should reflect annual patient admission rates, the duration of inpatient stays, local needs, and future developments, particularly as the number of day patients (post-intervention day patients) increases. The functional design of the inpatient building should accommodate one or more inpatient wards per floor, designated as active zones. Connections between the inpatient ward and other wards should be facilitated through internal, heated corridors directly linked to services for the supply of medicines, sterile and medical supplies, food, linen, clean beds, and other necessities, as well as services for cleanliness, hygiene, and maintenance.

The functional design of the inpatient building should accommodate one or more inpatient wards per floor, designated as active zones.

A sick ward's most commonly used organizational unit comprises 24-30 beds. Inpatient wards can be designed as single, double, or multi-corridor units.

Patient rooms are classified as active spaces. The ratio of patients to rooms has shifted significantly in recent years within the EU, favoring single rooms due to their superior effectiveness in infection control, reduction of infection transmission, alleviation of patient stress, enhancement of patient-staff communication, and assurance of patient privacy [48]. The TSG-12640-002:2021 [22] recommends a ratio of 70% single rooms and 30% double rooms. Multi-bedded rooms are designated for day hospitals, short-term observation up to 24 hours, and intensive care units. Each ward should include at least one room for isolation (ventilation regime). The number of isolation rooms should be determined according to professional requirements. For calculating the size of patient rooms, 19 m^2 per bed in single rooms, 17.5 m^2 per bed in double rooms, and 16 m^2 per bed in multi-bed rooms should be considered. Patient rooms should be designed to allow a supine patient to be wheeled in without moving or obstructing other patients. For access, hygiene, infection prevention, and patient privacy, the distance between beds should be at least 150 cm.

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The indoor room conditions are defined according to the specifics of the user (health condition, activities) and support the treatment. For instance, the recommended air temperature for a burn patient with extensive burns is 32 °C (optimally also a sensible temperature of 32 °C) with a relative humidity of 80% [1, 49, 50]. A room for newborns also requires a different temperature. Certain specific medical procedures necessitate their air temperature settings. Scientific knowledge is employed through the evidence-based design (EBD) approach to determine the optimal requirements. In addition to legislative requirements, the designer must also consider the client's needs. It is emphasized that conditions should be defined to meet the highest indoor environmental quality category [2].

5. Specifying functional areas, composition, and intersections

Designing buildings, spaces, and materials is crucial for preventing infections in healthcare settings. These infections include catheter-associated urinary tract infections, central venous catheter-associated bloodstream infections, surgical wound infections, ventilator-associated pneumonia, hospital-acquired pneumonia, and Clostridium difficile infections [51]. In the European Union and the European Economic Area (EU/EEA), more than 3.5 million cases of HAIs occur each year, resulting in over 90,000 deaths and approximately 2.5 million disability-adjusted life years (DALYs). Additionally, HAIs account for 71% of cases of antibiotic-resistant bacterial infections [52]. Raoofi et al. [53] state in a systematic review and meta-analysis that the rate of universal HAIs was 0.14 percent, with the rate of HAIs increasing by 0.06 percent annually. The rate of HAIs and the most common microorganisms vary across different settings. A multifaceted approach addressing various modes of pathogen spread is essential, as airborne transmission can be mitigated through appropriately designed strategies.

In the European Union and the European Economic Area (EU/EEA), more than 3.5 million cases of HAIs occur each year, resulting in over 90,000 deaths and approximately 2.5 million disability-adjusted life years (DALYs).

Based on a systematic literature review, Chair et al. [53] determined that most studies advocate for controlled airflow without recirculation, 12 air changes per hour, and high-efficiency particulate air (HEPA) filters to remove contaminated air from isolation rooms. Additionally, maintaining humidity levels at or below 60% and temperatures between 18-30 °C is recommended.

The paper concludes that further interdisciplinary research is essential to quantify the optimal range of HVAC system parameters, considering door types, vestibules, and bed management, to mitigate infection transmission in isolation rooms effectively. Ashe [54] emphasizes that properly designing materials, buildings, and rooms, particularly concerning HVAC systems, is crucial for controlling the spread of infections in healthcare settings. A thorough understanding of these design principles enables clinical staff to optimize the use of spaces and systems, thereby reducing the risk of infection transmission to patients and healthcare workers.

Ashe emphasizes that properly designing materials, buildings, and rooms, particularly concerning HVAC systems, is crucial for controlling the spread of infections in healthcare settings.

TSG-12640-002:2021 [22] stipulates that the design must adhere to the treatment criteria of the room based on the following requirements: cleanliness classification concerning the process (rooms with no special requirements, clean, unclean, sterile), air cleanliness classification, level of risk of nosocomial infections (no/low/medium/high risk), and user requirements (patients, employees, visitors, service workers, etc.). The selection of materials and the construction of structural units, including their composition and design, must be tailored to the specific requirements of the space, such as indoor conditions, sound insulation between rooms, fire separation between rooms or fire sectors, water resistance in wet rooms, protection against ionizing radiation, and resistance to mechanical influences. The procedure for determining the final treatment concerning hygiene requirements is summarized in Table 1.

Table 1: Finishing of walls, floors, and ceilings based on the function of the rooms, categorized according to hygiene requirements (adapted from TSG-12640-002:2021 [22])

Type of Active Space	Level of Infection Risk	Example	Materials	Cleaning
Spaces with special hygiene requirements	Very high	Operating rooms, transplantation rooms, burn units, neonatology units, isolation rooms, cytostatic preparation areas, and similar spaces.	The materials used for final finishes in these spaces must ensure bacteriostasis. Surfaces must be smooth and resistant to the required type and frequency of cleaning and disinfection. Wall and floor ceramics are not permissible in these areas. The quality of materials must allow cleaning and disinfection procedures to be carried out for a minimum of 5 years.	Ability to prevent bacterial growth, thorough cleaning and disinfection, and high-pressure cleaning.
	High	Intensive care units, recovery rooms, delivery rooms, neonatal units, hemodialysis units, endoscopy rooms, sterile areas of sterilization, autopsy rooms, and similar spaces, as well as spaces where procedures producing harmful substances are conducted (such as laboratories).	The final surfaces of the spaces must be completely smooth, resistant to mechanical damage, and capable of withstanding the demanding type and frequency of cleaning.	Regular, thorough cleaning with detergents and disinfectants.

Spaces with general hygiene requirements	Average	Waiting rooms, examination rooms, non-sterile areas of central sterilization, pharmacies without medication preparation, laundries, restrooms, corridors, elevators, staircases, and similar spaces.	The final surfaces of the spaces must facilitate the required cleaning and disinfection.	Occasional wet cleaning and disinfection.
Spaces without special hygiene requirements	Low	Lobbies, administrative offices and services, technical rooms, and similar spaces.	The final surfaces of the spaces must facilitate the required type and frequency of cleaning.	Basic hygiene maintenance and easy cleaning. Cleaning and hygiene maintenance in the spaces must be carried out under the guidance and constant supervision of the hospital infection control service.

In addition to hygiene, the finish and color of walls, floors, and ceilings significantly impact the illuminance of rooms. It is essential to ensure that the recommended values for the reflectance coefficients of surfaces in rooms are met, following SIST EN 12464-1:2015 [55], and to achieve the minimum class of reaction to fire for the cladding. Another critical aspect in the design of structural assemblies is providing acoustic protection for buildings and spaces through room acoustics, as stipulated by the Rules on protection against noise in buildings [56, 57]. This aspect is often overlooked in design practice despite the necessity for full compliance with legislative requirements.

From the perspective of preventing HAIs, advanced materials and technologies are also being developed, which include: a. Antimicrobial coatings, b. "Skin shark" surface structure prevents microbial attachment and allows self-cleaning, and c. Multifunctional coatings, which combine "skin shark" and antimicrobial agents. Antimicrobial agents are characterized by their selectivity [58].

6. Establishing technical systems for building operations

Another critical aspect in the design of structural assemblies is providing acoustic protection for buildings and spaces through room acoustics, as stipulated by the Rules on protection against noise in buildings.

Tecnical systems such as HVAC are paramount in designing healthcare facilities, as they influence environmental health characteristics for several key reasons related to achieving optimal IEQ for all user groups (patients, employees, visitors). The diversity of thermal requirements (parameters: air temperature, relative humidity, operative temperature, mean radiant temperature, air velocity, metabolic rate, clothing insulation level), depending on activity and health status, has been highlighted by numerous studies [1, 2]. Therefore, it is essential to pay special attention to the design, selection, and proper functioning of HVAC systems when planning healthcare facilities, as they have a direct impact on the health, safety, and well-being of all occupants, as well as on the environmental sustainability of the facility itself [59].

As highlighted by interviewees in continuation, innovative cyber-physical systems for heating, cooling, and ventilation simultaneously ensure an optimal thermal environment and efficient energy use. In a study by Dovjak et al. [1, 2], a user-centered integrated cyber-physical system (UCCPS) was developed for a room dedicated to burn patients.

The UCCPS system creates optimal thermal conditions that support treating burn patients while providing thermally comfortable conditions for healthcare workers and visitors. Adequate ventilation in hospitals has become a significant area of research, especially following the COVID-19 pandemic. The primary objective has been to define qualitative and quantitative ventilation criteria to prevent microbiological risks and ensure optimal air quality. Wu et al. [37] modeled the transmission of COVID-19 in an isolation room at the Royal Brompton Hospital in London, UK. They aimed to investigate the optimal room layout to reduce the risk of infection for healthcare staff.

Their findings play a crucial role in determining the location of the air extractor, filtration rates, and the placement of the patient bed while also considering the health and safety of the staff working in the area. Research indicates that an appropriate ventilation system with suitable filters helps remove pathogens such as bacteria and viruses from the air, thereby reducing the risk of infection transmission among patients, visitors, and healthcare personnel. Emphasis is placed on adhering to recommendations defined by ASHRAE, REHVA, and WELL Building Standard [60-62]. Understanding and considering various parameters related to the efficiency of new and existing HVAC systems are essential for ensuring healthy, energy-efficient, and economical options for different types of buildings [63].

Research indicates that an appropriate ventilation system with suitable filters helps remove pathogens such as bacteria and viruses from the air, thereby reducing the risk of infection transmission among patients, visitors, and healthcare personnel.

Opinions

In the interviews, the selected stakeholders indicated that their role in the healthcare facility renovation project was primarily to ensure the hygiene regime, representing a specific but limited aspect of environmental health. Comprehensive adherence to the requirements and recommendations in the field of environmental health, as outlined in current guidelines (e.g., IEQ), was entrusted mainly to the external project office chosen for its expertise in this area. No information is available on whether the investor requested or recommended using TSG-12640-002:2021 [22]. Consequently, it is impossible to determine whether TSG-12640-002:2021 [22] was utilized as a key reference document in the design and implementation of the renovation. The external expert emphasizes that if TSG-12640-002:2021 [22] was not employed, it is essential to identify and analyze alternative sources of information used by the external office to accurately assess the environmental health aspects. These sources could include an analysis of the project's compliance with relevant national and international environmental health regulations, expert guidelines, and standards [e.g., 25, 36, 60-62] in the field of IEQ, an analysis of the application of scientific research and findings in the field of environmental health to the design and implementation of the project, an analysis of project documents, and a detailed analysis of the conceptual design and final project to evaluate the integration of environmental health principles. It was also noted that environmental health is not comprehensively considered in the legislation and implementation of healthcare facility construction. The need to address the working environment following the cyber-physical system (CPS), which includes the external and internal environment, building architecture, HVAC systems, and their management and control, was emphasized. The composition of the expert team should be regulated to ensure adherence to CPS principles.

It was also noted that environmental health is not comprehensively considered in the legislation and implementation of healthcare facility construction.

The Certified Engineering Technologist involved in healthcare facility projects emphasizes that the introduction of the Technical guidelines for construction (TSG) under section 0.1.2 describes the circumstances in which these guidelines are applied to facilitate the preparation of documentation for the construction of healthcare facilities and the construction process itself. These guidelines have been adhered to in all previous projects. Simultaneously, all changes in European legislation have been taken into account. The most significant changes occurred during the COVID-19 pandemic, primarily concerning stricter conditions in spaces (entry and exit filters, air filtration, air pressure, number of air exchanges per room, monitoring conditions in the room, and remote monitoring of patients with infectious diseases). There have also been some changes regarding the preparation of medications in hospital wards.

The most significant changes occurred during the COVID-19 pandemic, primarily concerning stricter conditions in spaces (entry and exit filters, air filtration, air pressure, number of air exchanges per room, monitoring conditions in the room, and remote monitoring of patients with infectious diseases).

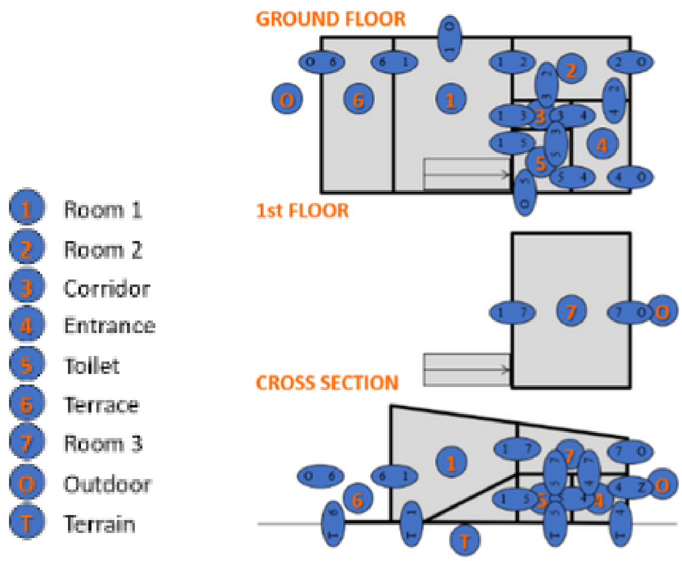
It is crucial to consider the requirements for neutralization and disinfection of sewage from infectious disease wards in all healthcare facilities (which is already mandated by legislation but is not always adhered to in the construction of new facilities).

Recommendations

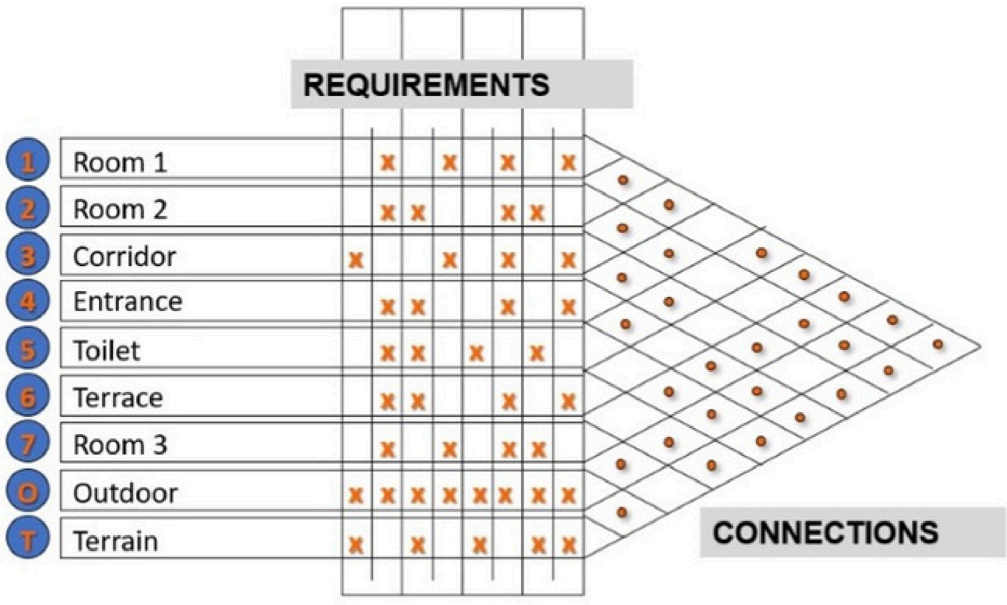
»The engineering design of a hospital building is a purposeful activity directed toward fulfilling human needs, particularly those that can be met by the technological factors of our culture« [23].

In the following, we have outlined recommendations applicable to the design phase of new buildings or renovations. When determining the composition of structural assemblies (Step 5), adhering to the procedure presented in Scheme 1 is crucial. Initially, we define the active spaces and functional zones, representing our concerns. In their horizontal and vertical distribution, we consider zoning criteria following the requirements detailed in planning morphology. We specify the requirements and recommendations for each space for all IEQ parameters. Based on this, we establish a set of desired characteristics for the composition of structural assemblies by function (load-bearing and protective structures). Special attention should be given to the final finishes, joints, and connections.

Determination of active spaces.



Requirements and recommendations by areas of indoor environmental quality.



A set of desired characteristics for the composition of structural assemblies by function (load-bearing and protective structures). Special attention should be given to those vertical and horizontal assemblies that separate spaces with higher levels of risk.

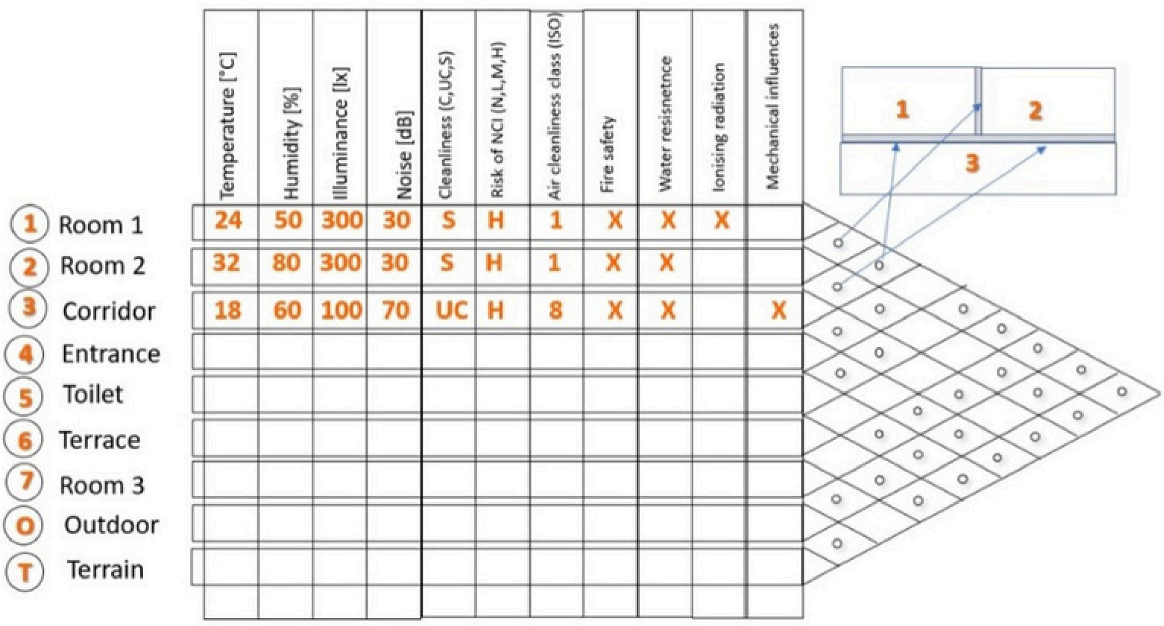


Figure 1: Illustration of the process for determining the characteristics of structural assemblies (adapted from [24, 64])

When determining the desired characteristics for structural assemblies that adhere to the presented scheme, the probability of errors in the final material selection is significantly reduced. This methodology is particularly advantageous in public procurement contexts where specific characteristics are mandated.

To realize the objectives of sustainable and healthy healthcare facilities, further educating the stakeholders involved in their construction is imperative. Enhancing awareness of the importance of environmental health among all stakeholders—architects, civil engineers, sanitary engineers, acousticians, electricians, healthcare professionals, investors, and others—is crucial. Additionally, promoting the adoption of innovative and sustainable solutions that ensure an optimal indoor environment is essential. In this regard, models such as the Integrated Healthcare Architecture Framework (IHAF) by Jaušovec and Garbrovec [65] are of substantial value. This comprehensive model encapsulates the multifaceted aspects of healthcare architecture, including critical categories such as architectural and design guidelines, user experience and satisfaction, and sustainability and environmental impact.

Enhancing awareness of the importance of environmental health among all stakeholders—architects, civil engineers, sanitary engineers, acousticians, electricians, healthcare professionals, investors, and others—is crucial.

In conclusion, historical evidence supports the validity of the correct planning approach, which is grounded in basic needs [23], locational givens, and burdens. The first health center in Slovenia was established in Lukovica in 1926. This health station was named after Ms. Jelka Reven Komotar, a nurse who worked there. Regrettably, it was the first health facility named after a nurse and remains the only one [66]. The construction of this building adhered to the morphology of the design process, beginning with both the site conditions and the burdens [24].

Specifically, the village surroundings had unregulated hygienic conditions, a high incidence of typhoid and other infectious diseases, and a high infant mortality rate. The preventive work of Ms. Jelka Reven Komotar's social-health treatment was reflected in the purpose of the newly constructed health building. The health center offered a wide range of services to improve public health. In addition to general healthcare, the center included maternal and child consultation centers, children's dispensaries, school polyclinics, a dairy kitchen, and public bathing facilities [67]. The institution's entire focus was on prevention, encompassing sanitation measures such as the construction of water and sewage systems, which contributed to eradicating typhoid fever. Statistics indicate that from 1926 to 1935, infant mortality rates were halved [68]. Hygiene courses on infant care and nutrition, along with exhibitions and lectures, significantly elevated the health culture of the population. Ms. Jelka Reven Komotar was an indispensable link between families and the health center [67-70]. Contemporary health facilities must revive the philosophy of prevention and strengthen the bond between patients and the healthcare environment.

CONCLUSIONS

Designing healthcare facilities focusing on environmental health is crucial to ensuring a safe, healthy, and sustainable environment for patients, staff, and visitors. This article has emphasized the importance of integrating environmental health features into the planning process, focusing on key areas of environmental health that are directly related to the quality of healthcare facility design.

Thoughtful design can significantly impact the well-being and health of healthcare facility users. Ensuring optimal air quality, thermal environment, natural lighting, and appropriate acoustic conditions improves comfort. These factors also contribute to faster patient recovery and reduce staff stress.

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Choosing sustainable materials and including natural elements in the design underscore a commitment to environmental protection. These choices also promote biophilic design principles, fostering a sense of connection to nature [62].

Future research and development of innovative solutions in environmentally responsible healthcare facility design will be essential. Raising awareness of the importance of these environmental health features among planners, investors, and users is also necessary. Only through collective efforts can we create healthcare facilities that provide top-quality healthcare and contribute to a better environment and health for all. Integrating environmental health features into the design of healthcare facilities is an ethical and socially responsible practice and a key strategy for improving the quality of healthcare services and promoting sustainable development.

Only through collective efforts can we create healthcare facilities that provide top-quality healthcare and contribute to a better environment and health for all.

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CONFLICT OF INTEREST

The authors report no conflicts of interest. The manuscript has not been published and is not being considered for publication elsewhere.

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