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Interior Design Aspects Affecting Infection Rate: A Systematic Review of Possible Interventions

Yaman Sokienah[1]
Ph.D, Yarmouk University, Department of Design And Applied Arts, Faculty of Fine Arts, Yarmouk University, Irbid, Jordan
*Corresponding author: Yaman Sokienah, Ph.D, Yarmouk University, Department of Design And Applied Arts, Faculty of Fine Arts, Yarmouk University, Irbid, Jordan, Email: Yaman.s@yu.edu.jo

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ABSTRACT

In light of the COVID-19 pandemic, getting infected through the built environment is being studied. The measures that should be taken to reduce infection through the built environment are essential; not only for COVID-19, but this idea is present at all times of widespread diseases.

The purpose of this research is to systematically review the relationship between the built environment and the spread of infection to create a potential guideline to reduce the transmission rate. Articles and studies on the relationship between infectious disease and the built environment were reviewed.

Articles matching the selection criteria were identified. Most articles described peer reviews, consensus statements, and reports. The articles have provided data that can be used as guidance for reducing the transmission of infection within the built environment. It was found that evidence has been created such as ventilation, buffer spaces, flooring, and surfaces that can reduce the infection of COVID-19.

Keywords: *COVID-19, Infection Transmission, Built Environment, Interior Design.*

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INTRODUCTION

The world faces a new predator called coronavirus (COVID-19). The problematic part of the virus and its variants is the speed of infection around the world. This pandemic has had a high impact on the world and the lifestyle we are living in. One of the parts of our lifestyle that will be changing due to the coronavirus pandemic is understanding the design aspects that might reduce infection within the space (Noble, 2004).

In light of the international pandemic with the COVID-19, getting infected through the built environment is a solid idea being studied and circulating in the scientific and medical sectors. Many efforts are being undertaken to reduce and slow down the infection rates of COVID-19. However, the interaction with the built environment still poses a risk, especially in healthcare facilities and home isolation spaces where patients are being treated (Codinhoto et al., 2009).

Measures that should be taken to reduce infection through the built environment are essential in these times, not only COVID-19, but this idea is present at all times of widespread diseases like the Zika Virus (Lindsay et al., 2017). Those measures should be considered in hospitals and in homes, schools, and workplaces where airborne diseases are difficult to control (Xu & Liu, 2018).

The built environment and its role in reducing and increasing infection rates have been focused on finding guidelines that may reduce infection during such a pandemic through the built environment (Kembel et al., 2014; Lax et al., 2015; Noskin et al., 2000). The focus on this issue should be undertaken more thoroughly to avoid putting healthcare staff and patients at risk during and after the pandemic.

Several guidelines have been published with recommendations for reducing COVID-19 infections, such as the Centers for Disease Control and Prevention (CDC) guidance in the United States. (Coronavirus Disease 2019 (COVID-19) | CDC, n.d.). However, these guidelines do not provide a specific strategy for the arrangement and type of furniture, the design aspects of the built environment, and the potential for reducing infection.

The study presented here aimed to systematically review the literature and evidence on the relationship between the built environment and the spread of infection to provide a possible guideline for the design type and arrangement of furniture to reduce the spread of COVID-19 and prevent it. Accordingly, some of the different design methods and concepts for built environments are discussed, and their applications and potential for reducing infection and transmission are presented.

Hospital Environment as a Risk for Infection

It is well known that the hospital environment is one of most places where a person can contract an infection. As a piece of evidence for this, the high rate of COVID-19 victims is healthcare workers who spend many hours within hospitals and healthcare facilities (Bahl et al., 2020).

The risk of the increased infection rate in healthcare facilities during the COVID-19 pandemic can be done to the time people spend within the space of a hospital, especially in full waiting rooms where people wait for testing or treatment (Herwaldt et al., 1998). Therefore, the design process of hospitals and other healthcare facilities should pay more attention to their design to minimize infection possibilities, especially in events similar to the COVID-19 pandemic.

The focus should be given, especially to spaces where immunocompromised patients are treated, where the design can change and reduce the possibilities of infection (Noskin & Peterson, 2001).

METHODS

Search Strategy

PRISMA protocols were followed to conduct the review. Articles dealing with infection outbreaks and their relationship with the built environment and epidemiological- or experimental laboratory studies were reviewed, along with a search of the following electronic databases was undertaken: Medline, Google Scholar, EBSCO, ResearchGate, Academia, Ulrich. There was also an extensive search of the web. All data used in the review were extracted from published papers.

The search was performed using the following subject headings or a combination of abbreviated terms: construction environment, floor, medical facility, infection control, surface, spatial planning, COVID-19, coronavirus. All articles, reports, and textbook references reviewed were manually searched.

Inclusion Criteria

The author independently reviewed the article. The literature was selected based on its novelty, a discussion of essential topics related to the constructed environment, and the relationship between transmission within the interior space, which serves the purpose of this study. In addition, this study primarily includes studies from peer-reviewed journals, conferences, dissertations and dissertations, and medical guidelines.

It included studies published in English that included a section on accurate research methods for experimental or observational approaches to investigating the effects of architecture, interior spaces, or furniture. Table I provides insights into the categories of inclusion criteria used in the study. Also, Figure 1 provides a visual of the PRISMA protocol that was followed in the study.

TABLE 1: Criteria for Assessing evidence

Level	Criteria
I	Evidence was obtained from at least one properly randomized, controlled trial.
II	Evidence was obtained from well-designed controlled trials without randomization.
IIIa	Evidence is obtained from well-designed cohort or case-control analytic studies, preferably from more than one center or research group.
IIIb	Evidence obtained from multiple time series with or without the intervention
IV	Case series without control
V	Expert judgment, consensus statements, and reports
*Adapted from (Harris et al., 2001)	

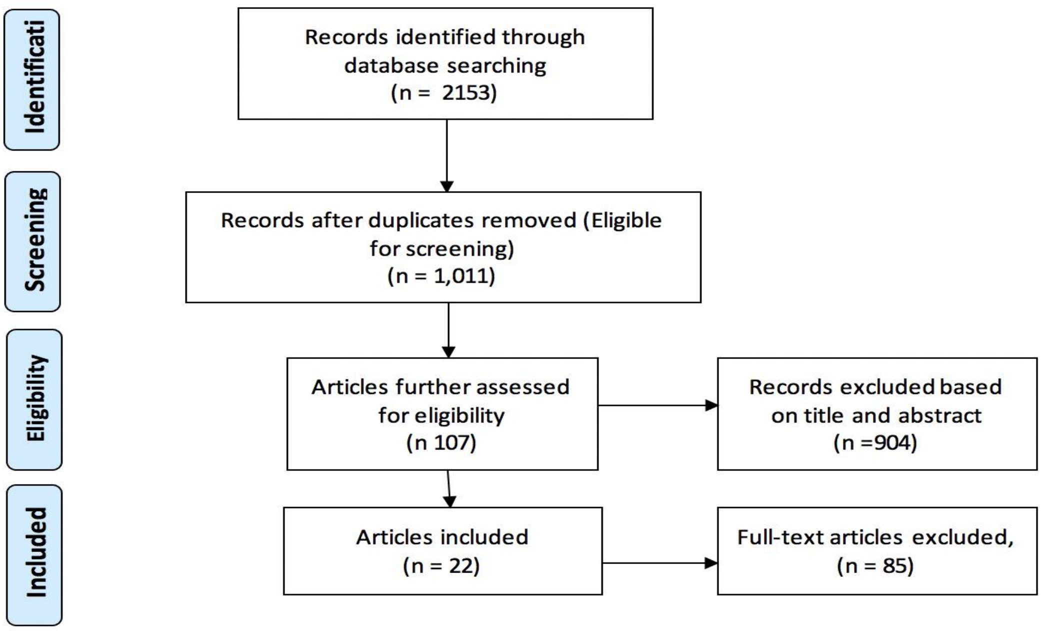

FIGURE 1: PRISMA flow diagram.

RESULTS

Two hundred research articles were identified in the database search; However, none included a meta-analysis of a randomized controlled trial. Most of the articles identified in the lowest level of evidence are classified as expert judgments by the following (Dettenkofer et al., 2004); Only 22 concurrent or historical studies that met the inclusion criteria were described. Therefore, the selected studies were classified as having the lowest level of Evidence (Level V; Table I).

The topics generally were about the HVAC systems and ventilation in the interior space, the surface materials used within the spaces, and the cleaning and disinfecting process. However, this finding cannot be generalized due to confounding variables and small study populations. The articles have provided meaningful data and information that can be used as a potential guideline and recommendations to reduce infection transmission within the built environment's interior.

Healthcare facilities, buildings, and interior spaces are the most complicated spaces people interact (Curtis, 2008). It is impossible to implement a single strategy to reduce infection rates within a space, and it is always needed to combine several strategies to reach an acceptable level of protection for the healthcare staff, patients, and families. Following are the most critical aspects of design that can be bundled to reduce infection rates within the space of healthcare facilities.

After reviewing the 22 studies, their main focus was established in Table II. There were four main elements of the interior space emphasized in the studies: Buffer Space and Anteroom, Interior Ventilation, Walls and Dividers, and Surfaces.

TABLE 2: Summary of the Included Studies

Study	Title	Design Element
Andersen et al. (2009)	Floor cleaning: effect on bacteria and organic materials in hospital rooms	Surfaces
Ayliffe et al. (1967)	Ward floors and other surfaces as reservoirs of hospital infection	Surfaces
Bartley (2000)	APIC State-of-the-Art Report: The role of infection control during construction in health care facilities	Walls and Dividers/ Interior Ventilation
Chen & Poon (2009)	Photocatalytic construction and building materials: From fundamentals to applications	Surfaces
Ching et al. (2008)	Reducing Risk of Airborne Transmitted Infection in Hospitals by Use of Hospital Curtains	Buffer Space and Anteroom
Chung et al. (2008)	An antimicrobial TiO2 coating for reducing hospital-acquired infection	Surfaces
Dancer (1999)	Mopping up hospital infection	Surfaces
Hyttinen et al.(2011)	Airborne Infection Isolation Rooms – A Review of Experimental Studies	Buffer Space and Anteroom
Joseph et al. (2018)	The architecture of safety: An emerging priority for improving patient safety	Interior Ventilation/ Surfaces
Lenfestey et al. (2013)	Expert Opinions on the Role of Facility Design in the Acquisition and Prevention of Healthcare-Associated Infections	Interior Ventilation
Li et al. (2008)	Antimicrobial nanomaterials for water disinfection and microbial control: Potential applications and implications	Surfaces
Page et al. (2009)	Antimicrobial surfaces and their potential to reduce the role of the inanimate environment in the incidence of hospital-acquired infections	Surfaces
Ranney et al. (2020)	Critical supply shortages - The need for ventilators and personal protective equipment during the Covid-19 pandemic	Interior Ventilation
Schaal (1991)	Medical and microbiological problems arising from airborne infection in hospitals	Buffer Space and Anteroom
Sommerstein et al. (2016)	Cardiac surgery, nosocomial infection, and the built environment	Buffer Space and Anteroom
Stockwell et al. (2019)	Indoor hospital air and the impact of ventilation on bioaerosols: a systematic review	Interior Ventilation

Sun et al. (2015)	Antimicrobial materials with medical applications	Surfaces
Tang, Li, Eames, Chan, and Ridgway (2006)	Factors involved in the aerosol transmission of infection and control of ventilation in healthcare premises	Walls and Dividers
Walker et al. (2007)	Hospital and community-acquired infection and the built environment - design and testing of infection control rooms	Buffer Space and Anteroom
Wang (2012)	Symbol: Antibacterial properties and mechanism of nano-zinc oxide	Surfaces
Weinstein and Hota (2004)	Contamination, Disinfection, and Cross-Colonization: Are Hospital Surfaces Reservoirs for Nosocomial Infection?	Surfaces
Wyszogrodzka et al. (2016)	Metal-organic frameworks: Mechanisms of antibacterial action and potential applications	Surfaces

Buffer Space and Anteroom

It should be noted that the droplets of an initial size between 60 and 100 mm can be carried over 6m through sneezing, 2m through coughing, and 1m through breathing (Hyttinen et al., 2011b; Schaal, 1991; Walker et al., 2007). A negative pressure isolation room contributes as protection or barrier that isolates the patient from the healthcare facility's public pathway through the use of an anteroom (Herwaldt et al., 1998).

Unfavorable pressure isolation rooms are provided in infection isolation rooms that use the concept of negative air pressure to keep the space well ventilated and reduce the airborne transmission from the outside of the room. Anteroom or similar design elements such as portiere curtain should be used in traditional hospital or healthcare facility rooms where COVID-19 is being isolated or treated where it is not possible to hold all of the patients in an airborne infection isolation room (Ching et al., 2008; Sommerstein et al., 2016).

Having a positive or negative anteroom can protect from the microbes located in the corridor leading to the room. Therefore, providing a buffer space between the public way and the isolation or treatment room can provide extra protection for the patient and the spaces outside of the room from spreading the infection.

Walls and Dividers

Walls are what make an interior space. Without walls, it would be almost impossible to create an isolated environment. Walls, partitions, and dividers can be used in healthcare facilities to separate patients from each other. However, in pandemic times, such as the COVID-19 pandemic, it is hard to find much space or the time to divide all the available healthcare facilities within the timeframe provided to establish emergency isolation and treatment space.

It is highly recommended that the isolation treatment facilities' walls have smooth surface paint (Bartley, 2000). In addition, if the isolation and treatment space is only constructed for an emergency, such as COVID-19, dividers, and curtains can reduce transitions between beds.

Walls, curtains, and dividers should be easy and quick to clean. Those dividers should also be removable, and easy to readjust the layout of the space based on the capacity of the emergency where the staff might need more space to admit more patients in the cases of a pandemic. Also, (Tang, Li, Eames, Chan, & Ridgway, 2006) suggest that using sliding doors to pass through spaces instead of hinged doors can control airborne transmission while also having improved seals around doors and windows.

Furthermore, (Aliabadi, Rogak, Bartlett, & Green, 2011) suggest that the layout of the rooms at healthcare facilities refers to the placement of the beds, windows, and doors, and the space planning of the facility in a way that all the parts are connected through corridors can help to isolate the microbes that lead to spreading the infection in the space.

Interior Ventilation

Interior ventilation has been an important topic that has been discussed by many researchers and its impact on pollutants and infection transmission through airflow (Bartley, 2000). Also, ventilation is one of the essential things needed by healthcare facilities for CIVID19 patients (Ranney et al., 2020).

There are two main types of ventilation: mechanical ventilation and natural ventilation with windows in inpatient rooms. Each of these ventilation systems can be used throughout a healthcare facility. However, the focus has been on mechanical ventilation systems due to their ability to use HEPA filters to improve indoor air quality (Joseph et al., 2018; Stockwell et al., 2019).

The usage of multiple filter layers throughout the HVAC system, such as HEPA filters in the healthcare facility, is one of the major topics that can be observed that research is interested in. However, there is a shortage of research evidence that supports the claim that HEPA filter has an impact on reducing infection rates in healthcare facilities (Lenfestey et al., 2013)

Either way of the ventilation method used by the healthcare facility, ventilation should be on top of the critical aspects of preparing a healthcare facility for COVID-19 patients. Even though it was found that window ventilated patient rooms were not significantly different from mechanically ventilated rooms regarding the potential abundance of bacteria (Bartley, 2000). Isolation and treatment spaces should always be ventilated as possible and filtered to reduce the microbes' transmission, especially in the more condensed facilities.

Surfaces

In the past decade, the spread of SARS and avian influenza, along with other infectious diseases, has become an important topic worldwide. One of the topics that were widely discussed is the processes of developing and applying coating materials to surfaces in healthcare facilities that have antimicrobial properties which can reduce space-related infections, such as copper, which has such properties but it still needs more research and verification (Chung et al., 2008; Joseph et al., 2018; Page et al., 2009).

Research suggests that microbes and viruses such as COVID-19 can stay active on a surface as long as 5-8 days on countertops in the case of VRE Pathogens and up to several days in the case of SARS and COVID-19 (Weinstein & Hota, 2004). These numbers should be alarming to the people who decide the selection of surfaces and countertops materials and finishes. Therefore, the finished materials selected for healthcare facilities should be studied and analyzed before selection to reduce the chance of spreading and transmitting microbes and viruses such as COVID-19 throughout the space without even noticing.

Furthermore, Floors and the materials that cover them, such as carpeting, are surfaces where microbes settle. Therefore, it is one of the most critical areas to be taken care of when there is a fear of an infection spreading in a space (Ayliffe et al., 1967; Dancer, 1999). While regularly cleaning the floors of the space may reduce the microbes settling on the floor (Andersen et al., 2009).

Specifying the suitable flooring material can reduce the collection of microbes on the floors. Also, laminar flow air curtains can reduce the number of microbes that settle on the floor (Dancer, 1999). It is highly recommended for healthcare designers and decision-makers to specify certain finish materials for all the parts where COVID-19 patients and healthcare staff come in contact to reduce the number of infected people, especially the staff members.

(Chen & Poon, 2009) state that laboratory and fieldwork confirm the possibility of reducing infection transmission by using photocatalytic cementitious materials. Therefore, specifying self-cleaning and self-disinfecting building materials such as glass and ceramic for countertops and other parts where staff and patients come in contact might reduce the impact of the COVID-19 pandemic. Table III presents a summary of the significant antimicrobial materials that can be used within the interior space of the healthcare facilities through the fabrication of the materials on surfaces by coatings.

TABLE 3: Summary of the Major Antimicrobial Materials

Antibacterial Material	Characteristics	Prospective Applications	Resource
Copper, Silver, Metal Ion Phosphate Antibacterial Materials, Metal-Organic Framework.	Long-acting, high-efficiency, slow-release antibacterial material with high durability.	They are used in medical applications and coating.	(Page et al., 2009; Sun et al., 2015; Wyszogrodzka et al., 2016)
Hydroxyapatite, Ag-Containing Phosphate Antibacterial Materials	The double salt of phosphoric acid has a vital adsorption function, a large specific surface area, non-toxic and stable chemical properties, and a good combination of efficiency.	Surface coatings of medical devices	(Li et al., 2008; Sun et al., 2015)
Zno Materials, Tio2 Materials	Broad-spectrum antimicrobial properties, non-toxic, low cost, robust, and self-cleaning ability.	Fibre, plastic, ceramic, coating, biomedical.	(Chung et al., 2008; Sun et al., 2015; Wang;, 2012)
Antibacterial Material	**Characteristics**	**Prospective Applications**	**Resource**
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Hydroxyapatite, Ag-containing phosphate antibacterial materials	The double salt of phosphoric acid has a vital adsorption function, a large specific surface area, non-toxic and stable chemical properties, and a good combination of efficiency.	Surface coatings of medical devices	(Li et al., 2008; Sun et al., 2015)
ZnO materials, TiO2 materials	Broad-spectrum antimicrobial properties, non-toxic, low cost, robust, and self-cleaning ability.	Fibre, plastic, ceramic, coating, biomedical.	(Chung et al., 2008; Sun et al., 2015; Wang;, 2012)

DISCUSSION AND CONCLUSION

A large part of scientific research focuses on the process and the methods of infection transmission. However, not many researchers have studied the effect of the interior space components that might be a factor that contributes to infection transmission within the space. However, people spend most of their lifetime within the interior space, breathing, sleeping, exercising, and getting treatment.

This review was done to systematically review the literature and evidence on the relationship between the built environment and infections spread to create a potential guideline for the design and furniture type and layout to reduce and prevent COVID-19 from spreading more and more.

Articles dealing with infection outbreaks and their relationship to the built environment and epidemiological or experimental laboratory studies were reviewed, and the following electronic databases were searched. However, very little experimental and empirical research was found to link the design and layout of the interior space to the infection transmission. Very little research has been found linking the design and layout of the interior space to the transmission of infection.

Addressing the impact of the built environment on the healing process and well-being of COVID-19 and reducing infection rates are becoming increasingly important in healthcare design. We examined the most critical parts of the built environment that may be related to the rate of infection of COVID-19. It was found that evidence has been created in several parts, such as ventilation, buffer rooms, flooring, and surfaces, which can influence the reduction of the infection rate of such a pandemic as COVID-19.

It can be noticed that there is no one gold standard to be used in designing a healthcare facility or an interior space that would reduce the infection rate. Research has found that there should be a combination of strategies that need to be implemented in the space to reduce healthcare facility-related infection, and actions need to be taken at all levels (Curtis, 2008; Lenfestey et al., 2013).

Many topics that include interior design and healthcare space do not have much evidence-based design research that supports new strategies (Huisman et al., 2012). However, it is worth considering reducing the spread of viruses and other microorganisms in the healing space in the future. Overall, most of the studies reviewed have found that the constructed environment affects the treatment of medical conditions and reduces infection rates.

The research collection has been revised to provide the most up-to-date knowledge of the elements that influence the spread of viruses and microbes. It is hoped that this information may help public health authorities and the general public inform about the solutions and infection control that will be implemented to reduce the possibility of infection transmission through the built environment. Another concept that needs to be studied more in terms of its role in microbes transmission is proximity, which was studied in depth before. However, the coronavirus pandemic has shown that there is not enough application of the theory of proximities. One factor that needs to have more thought about is the concept of open workplaces, especially in large corporate offices. The design trends favor the open workplace, so there should be a more isolated workspace.

This paper summarizes the interior design aspects of space that might reduce the infection rate in light of the COVID-19 pandemic. Inpatient and outpatient facilities, schools, homes, and government buildings were contaminated with the virus. However, the hospital areas were significant spaces that might have a role in spreading the infection.

In this research, we argue that the interior space plays a central role in the patient experience and the caregiving activities of healthcare providers and staff, often directly. However, there are significant gaps in evidence-based research in these areas that need more focus from researchers and healthcare providers to provide safer and reduce space-related infections (Joseph et al., 2018).

While understanding the design aspects of healthcare facilities helps reduce the infection rate, the data obtained for the research were limited. Therefore, more extensive research and analysis of the design aspects of indoor hospital spaces will provide further knowledge about reducing infection rates through interior design.

This study does not cover all of the parts of the built environment that affect the transmission of microbes and viruses. However, this study provides readers with an overview of the research that has been conducted in the area of microbes and virus transmission throughout the interior space, which can emphasize the importance of rethinking interior design when designing healthier spaces.

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Institutional Review Board Statement

There was no testing on human subjects, human data or tissue, or animals.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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