Adaptive Architecture and Infection Prevention in Hospitals

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Abstract: In healthcare facility design, especially in hospitals, infection control is paramount due to the vulnerability of patients to nosocomial or healthcare-associated infections (HAIs). Despite advancements in medical practices and infection control measures, HAIs remain a significant challenge to patient safety and public health, particularly within hospital settings. Integrating adaptive architecture principles into hospital design and infrastructure presents a promising approach to addressing this issue. This paper examines the intersection of adaptive architecture and infection prevention in hospitals, with a focus on designing and constructing healthcare facilities to effectively curb the spread of infections.

By incorporating adaptive architecture, hospitals can create environments that are responsive to the dynamic needs of patients, staff, and infection control protocols. Design elements such as flexible room layouts, easily adaptable ventilation systems, and antimicrobial surfaces can help minimize the risk of HAIs by reducing pathogen transmission and promoting cleanliness. Additionally, strategic placement of hand hygiene stations, isolation rooms, and patient flow pathways can optimize infection control practices and enhance patient safety.

Strategically locating hand hygiene stations, isolation rooms, and patient flow pathways optimizes infection control practices and improves patient safety. By combining innovative design strategies and advanced technology, hospitals can better combat HAIs, fostering safer environments for patients and healthcare staff. This paper investigates how the collaboration of adaptive architecture and infection prevention can yield more robust and efficient healthcare facilities in the fight against HAIs.

Keywords - HAIs, Adaptive Architecture, Infection, adaptable ventilation, flexible layouts**,** antimicrobial surfaces.

I. INTRODUCTION

The covid -19 pandemic has refocused attention on the critical role of built environment in infection control, particularly in hospital setting. Hospitals globally have faced significant challenges concerning spatial limitations, ventilation infrastructure, and the management of patient flow during infectious disease outbreaks. Despite notable advancements in medical treatments and infection control protocols, healthcare-associated infections (HAIs) persist as a substantial and persistent menace to patient safety and public health.

Nosocomial infections affect a substantial number of patients globally, leading to increased mortality and financial impact on healthcare systems. In our study, we observed a higher incidence of nosocomial infections In India, research on nosocomial infections in ICUs has shown variability, with reported rates ranging from 11% to 60%. Intensive care units (ICU) remain the primary site for HAI, contributing to a quarter of all hospital infections. In a clinical setup, *Staphylococcus aureus* is the most common cause. Poor hygiene practices and conditions, plus the increased hospital patient load, significantly contribute to the same

Traditional hospital design has often been rooted in static architectural models, which may not fully accommodate the dynamic and evolving nature of infectious diseases. However, the emergence of adaptive architecture presents a promising shift in this paradigm. Adaptive architecture prioritizes flexibility, responsiveness, and adaptability to changing needs and conditions. This approach not only enhances the functionality and usability of healthcare facilities but also offers unique opportunities to optimize infection prevention measures.

Adaptive modeling, such as entropy evolution, offers a sustainable design alternative. It embraces complexity and dynamism in natural systems, fostering forward-thinking and innovative design practices. Evolutionary architecture aims to mimic the symbiotic behavior and metabolic balance found in natural environments within the built environment.

In the context of hospitals, adaptive solutions involve designs that evolve based on climatic and ecological elements, as well as advancements in science and technology. By integrating these principles, hospitals can better respond to changing infectious disease dynamics, optimize resource utilization, and promote sustainable development practices.

II. CLIMATE CHANGE AND MODES OF TRANSMISSION

Climate change refers to the prolonged modifications in Earth's climate patterns resulting from both human activities and natural processes.

The World Health Organization (WHO) identifies infectious diseases and undernutrition as the primary health impacts of climate change. A review published in Nature Climate Change in 2022 found that out of 375 infectious diseases studied, 218 (58%) have been exacerbated by climate change.

Floods can foster various health risks due to disease transmission. Contaminated floodwaters, carrying human or animal waste, can elevate the spread of faecal-oral diseases, leading to diarrheal disease and other bacterial and viral illnesses. Regions like South Asia face heightened risks due to limited access to clean water and sanitation, making faecal-oral transmission a significant concern.

To address the risk of transmitting infectious diseases to new hosts, it's essential to examine the modes of infection transmission.

1. Contact Transmission

1.1 Direct contact infection: It occur when disease-causing microorganisms are transferred from an infected individual to a healthy person through physical contact. This transmission route involves contact with contaminated hands or gloves of healthcare workers, leading to transmission via the skin or mucous membranes of the recipient. Examples include wound and skin infections or the spread of multi-drug resistant bacteria like methicillin-resistant Staphylococcus aureus.

1.2 Indirect contact transmission: - It occur when an infected person expels infectious droplets into the air through sneezing or coughing. If healthy individuals inhale these droplets or if they come into direct contact with their eyes, nose, or mouth, they may become ill. Transmission can also occur if individuals touch surfaces contaminated with these droplets and then touch their mouth, nose, or eyes before properly washing their hands.

1.3 Droplet transmission: Infections can be transmitted through air droplets expelled by coughing, sneezing, talking, and close contact with an infected individual's breathing. These droplets typically range in size from 30 to 50 micrometres

2. Bloodborne Transmission

Blood-borne transmission of pathogens primarily occurs through percutaneous injuries, which can be mitigated through changes in technique, experience, and the use of safety devices. Germs can also spread through blood products and medical supplies contaminated with viruses or bacteria.

HIV, hepatitis B and C, malaria, measles, herpes, chickenpox, and various bacterial infections are among the diseases known to be transmitted through blood-containing fluids and products.

Blood-borne precautions involve wearing gloves, a face mask, protective eyewear or goggles, and ensuring proper handling of sharp objects with appropriate disposal methods.

3. Airborne Transmission

Airborne transmission occurs when organisms from the respiratory tract, typically in small droplets less than 5 microns in size, travel over long distances. Pathogens like the chickenpox virus, tuberculosis, measles, and the novel SARS-CoV-2 virus can be transmitted through this route.

Disturbances in environmental reservoirs, including soil, water, dust, and decaying organic matter, can result in the release of clinically significant microorganisms into the air. These microorganisms can be brought indoors into healthcare facilities by people, air currents, water, construction materials, and equipment. Once indoors, they can proliferate in various ecological niches and serve as sources for airborne healthcare-associated infections.

While airborne pathogen transmission has long been recognized, effective solutions have been lacking. Some hospitals have been pioneers in adopting new technologies, including advanced Heating, Ventilation, and Air Conditioning

(HVAC) systems. While sterile filtration is practical, complete reliance on such systems may not fully address the challenges posed by airborne transmission in the era of sustainable architecture. Each technological system has its application range and limitations within the context of sustainability. Thus, a comprehensive approach that considers various factors, including architectural design, ventilation systems, and infection control measures, is necessary to effectively mitigate airborne transmission of pathogens in healthcare facilities

Indeed, technological systems can sometimes present unexpected challenges if not adequately adapted to evolving environmental conditions. Therefore, it's crucial to complement advanced technology with environmentally friendly solutions.

Natural light, for instance, serves as a potential germicidal factor and can help prevent airborne infections. Incorporating natural light into architectural designs can contribute to creating healthier indoor environments by harnessing its germicidal properties. By integrating both advanced technology and nature-inspired solutions, healthcare facilities can enhance their resilience against airborne infections while promoting sustainability and environmental stewardship.

4. Waterborne Transmission

The hospital environment is susceptible to contamination by waterborne pathogens due to factors such as suitable water temperatures for bacterial growth and the intricate structure of hospital water systems, which can lead to stagnation, corrosion, and biofilm formation. Various water reservoirs within hospitals, including potable water sources, sinks, faucets, showers, toilets, dialysis water, ice machines, water baths, flower vases, eyewash stations, and dental-unit water stations, have been associated with nosocomial outbreaks

Biofilms that develop within water distribution systems and at points of use provide a fertile environment for the proliferation of pathogens such as Legionella, mycobacteria, and Pseudomonas. Waterborne diseases pose a significant public health concern in India, with an estimated 37.7 million people affected annually. Diarrhoea alone is responsible for approximately 1.5 million child deaths each year, and waterborne illnesses result in the loss of around 73 million working days annually.

III. APPROPRIATE DESIGN STRATEGIES FOR INFECTION PREVENTION AND CONTROL

Architectural spaces, when thoughtfully designed with a specific objective, have the potential to mitigate the spread of infectious diseases. Florence Nightingale pioneered this concept with her hospital ward model, emphasizing the importance of natural daylight and cross ventilation in disinfection and reducing infection rates in hospitals. Here are several design strategies to adapt domestic, commercial, residential, and hospital spaces for infection prevention and control:

- Maximize Natural daylight and ventilation
- Enhance indoor air quality
- Promote hygiene facilities
- Facilitate physical distancing
- Utilize antimicrobial materials
- Optimize cleaning protocols
- Encourage outdoor spaces

1. Flexibility

Flexibility is characterized by the capacity to adapt and modify with minimal effort or intervention.

For a healthcare facility, such changes may occur in re-using existing functions – upgrading an existing space for better performance; creating new functions or changing for different functions – altering the space for different functions to apply. This spatial transformation will allow the space to adapt to different circumstances.

It is clear that the hospital project, often unsuitable to meet the needs of the organizational complexity of a healthcare facility, thus it is subjected to changes during the time.

Several scholars aim to identify strategies that can provide different levels of flexibility, sub-divided into hospital systems, buildings, functional and environmental units; in particular for inpatient wards, out-patient clinics, emergency and urgent care spaces.

2. Spatial planning

Spatial planning plays a crucial role in infection prevention and control within healthcare facilities.

- **Zone segregation:** Divide the facility into distinct zones, based on infection risk levels, patient conditions, and treatment needs. This segregation helps in containing potential outbreaks and minimizing cross-contamination
- **Traffic flow management:** Design layouts that facilitate efficient traffic flow, with separate pathways for patients, staff, and visitors to reduce congestion and limit opportunities for disease transmission.
- **Buffer zones**: Create buffer zones between different functional areas, such as patient rooms, treatment areas, and public spaces, to provide an additional barrier against the spread of infections.
- Special attention must be paid to zones such as the ICU. and the surgical zone that must be isolated from the main traffic routes, in particular the axis vertical traffic such as elevators shafts and staircases in order to reduce travelling intensity and avoid infected airflow from stack effect to minimize the effect of airborne transmission.

3. Enhanced natural light and ventilation

There is evidence indicating that the presence of fresh air and sunlight penetrating buildings can impact the transmission of airborne pathogens. Before the discovery of antibiotics, both ventilation and sunlight were considered vital safeguards against infection. Natural ventilation, driven by these forces, can typically provide a high ventilation rate more economically compared to mechanical ventilation systems. This is because it utilizes natural forces and large openings, making it an efficient option for maintaining indoor air quality and reducing the risk of airborne pathogen transmission.

For natural ventilation, the following minimum hourly averaged ventilation rates are recommended:

- 160 liters per second per patient (hourly average ventilation rate) for airborne precaution rooms, with a minimum of 80 liters per second per patient. Note that this requirement applies only to new healthcare facilities and major renovations
- 60 liters per second per patient for general wards and outpatient departments
- 2.5 liters per second per cubic meter for corridors and other transient spaces without a fixed number of patients. However, if patient care is conducted in corridors during emergencies or other situations, the same ventilation rate requirements for airborne precaution rooms or general wards should be applied.
- When natural ventilation alone cannot meet the recommended ventilation requirements, alternative ventilation systems, such as hybrid (mixed-mode) natural ventilation systems, should be considered. If these alternatives are insufficient, mechanical ventilation systems should be employed.

4. Harnessing sunlight: Natural disinfectant

In 1877, Downes and Blunt observed that sunlight hindered the growth of bacteria when transmitted through glass. Subsequent research demonstrated sunlight's ability to eliminate various bacteria, including those responsible for tetanus, typhoid, anthrax, and tuberculosis.
Direct sunlight has been found effective in killing M. tuberculosis, although diffuse light is less so. A study conducted in 1942 at a Californian sanatorium explored tuberculosis infection risk among patients and staff. Patients treated under the 'open air' regimen, exposed to elements day and night, showed negative environmental cultures from hand-touch sites, dust, and air samples within the ward. Investigations indicated that tubercle bacilli exposed through an unglazed north window perished within four or five days. In contrast, bacilli survived for months in enclosed spaces.
Exposure to direct sunlight can potentially improve well-being and resistance to infection. Bright-light therapy, utilized in treating psychiatric conditions such as seasonal and major depression, underscores sunlight's therapeutic benefits. Patients in sunlit hospital wards exhibit better recovery outcomes, including reduced length of stay, mortality rates, perceived stress, and pain.

5. Adaptive finishing materials

Florence Nightingale emphasized the importance of selecting construction materials wisely, particularly plaster, which was believed to transmit pathogens due to its tiny voids. She recommended using solid plaster or covering materials like special paints to mitigate this risk. In operating rooms and other critical areas, ceilings made of monolithic concrete fixed with hidden light bulbs were advised to prevent workers from entering the room to replace bulbs, thus minimizing contamination.

Recent studies on COVID-19 have shown variations in virus lifespan on different surfaces. For infection prevention, the following materials and design considerations are recommended:

- Utilize copper-infused or plated materials for frequently touched surfaces such as handrails to reduce viral transmission.
- Design sinks for easy cleaning and to prevent waste spillage into sensitive areas

Choose plaster with a mixture of de-coagulant in cement screed or high solidity, or apply smooth POP screed after cement plastering to eliminate surface voids. Avoid textured paints with fine sand

- Install entrance doors and curtains with sensors for automatic opening and closing to minimize contact with doorknobs.
- Minimize multiple entrances into public spaces to facilitate monitoring and compliance with health regulations.
- Equip sinks with motion sensors to reduce transmission risks, and specify controls and equipment with minimal flat surfaces and crevices.
- Reduce the number of horizontal surfaces like ledges to minimize areas where pathogens can accumulate and spread.

IV. CASE STUDY

TATA Medical Centre
Location : Kolkata , India
Architects : Cannon design , Carambiah &George
Year of completion : 2019
Capacity : 437 beds
Site area : 13 acres (52609 sq.mt)

The Tata Medical Center (TMC) in Kolkata has emerged as a pivotal institution in addressing the rising burden of cancer in India. Over the years, cancer cases and deaths have doubled from 1900 to 2016, highlighting the urgent need for accessible and high-quality cancer treatment.

Figure 1. TATA Medical Centre

TMC was established with a mission to transform this reality, serving as a beacon of hope for patients not only in India but also across Southeast Asia. By offering comprehensive cancer care services, including diagnosis, treatment, research, and supportive care, TMC strives to improve outcomes and enhance the quality of life for cancer patients.
In first stage the hospital had a capacity of 150 bed hospital and outpatient facility. immediately after the center opened the demand rose and due to space constraints, the Tata Medical Center (TMC) faced the difficult decision of turning away approximately 30 percent of patients seeking treatment. Additionally, the high demand for services led to significant waiting times, with some patients waiting up to two months to undergo surgery.
And thus phase two of the hospital was made which had a capacity of 240 beds and a education block for students and faculties.

Figure 2. TATA Medical Centre courtyards and pathways between two blocks connecting spaces

In TMC's campus courtyards and outdoor spaces promotes not only well-being of patient and fast recovery but also helps in natural ventilation, allowing fresh air to circulate throughout the facility.
Outdoor spaces also provide ample room for physical distancing, allowing patients, visitors, and staff to maintain a safe distance from each other.
Sunlight exposure in outdoor areas can serve as a natural disinfectant, diminishing the viability of pathogens present on surfaces and in the air.

The waiting rooms are made bigger to not only cater the patient but also the family members and also for safe distancing between people and not to create crowding in the main block.

TMC prioritizes sustainable and resilient building practices, understanding their crucial role in environmental conservation and operational efficiency. Through the integration of energy-efficient systems, utilization of renewable energy sources, and implementation of water conservation measures, the hospital minimizes its ecological impact while optimizing resource management and reducing operational costs

The Centre is designed to create a calming and healing environment for patients. By incorporating abundant natural light, tranquil indoor gardens, and serene spaces, the atmosphere encourages relaxation and supports the healing journey. Additionally, patient rooms are carefully crafted to prioritize privacy, dignity, and independence, fostering a sense of respect and empowerment throughout their time at the facility.

TMC Kolkata establishes a standard of excellence in sustainable healthcare design and operations, showcasing a dedicated commitment to environmental responsibility and community welfare. Serving as a pioneering example, the facility inspires future healthcare projects to embrace adaptive architecture principles, thereby promoting innovation and fostering a more sustainable and resilient healthcare landscape.

V. CONCLUSION

In conclusion, this research underscores the critical significance of adaptive architecture in augmenting infection prevention measures within hospital environments. By incorporating flexible spatial layouts, advanced ventilation systems, and antimicrobial materials, adaptive architecture presents innovative solutions to mitigate the transmission of infections and uphold the health and well-being of both patients and healthcare professionals. The dynamic nature of adaptive architecture enables hospitals to effectively navigate evolving infectious challenges, including pandemics, by swiftly adapting their infrastructure to accommodate surges in patient volume and enforce infection control protocols with efficiency and agility.
Despite the undeniable benefits of adaptive architecture, its full potential is hindered by several challenges, most notably the upfront costs associated with implementation and resource allocation. However, it is imperative to acknowledge that the long-term advantages of adaptive architecture in bolstering infection prevention efforts far outweigh these initial obstacles.
the implementation of adaptive architecture in hospital design not only enhances infection prevention measures but also fosters a conducive environment for patient healing and healthcare delivery.
The adaptability of adaptive architecture enables hospitals to respond promptly to emerging infectious threats, ensuring the continuity of healthcare services even during crises. By swiftly adapting their infrastructure to accommodate evolving needs, hospitals can effectively manage patient influxes, enforce infection control protocols, and maintain the highest standards of patient care.

REFERENCES

[1] Roles of sunlight and natural ventilation for controlling infection: historical and current perspectives - PMC (nih.gov)
[2] https://www.nature.com/articles/s41558-022-01426
[3] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8331240/
[4]https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10801286/#:~:text=Infection%20control%20programs%20that%20include,variability%20in%20patient%20conditions%20persist
[5] https://www.archdaily.com/957631/tata-medical-center-cannondesign
[6] Epidemiology and characteristics of nosocomial infections in critically ill patients in a tertiary care Intensive Care Unit of Northern India - PMC (nih.gov)