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An Appraisal of Infection Control in the Built Environment: The Architect's Perspective

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Abstract The physical living and work spaces (open spaces, healthcare facilities, schools, residential buildings, streets, and road networks) constitute the built environment. Epidemiologically, the built environment connotes the extrinsic factors that affect the agent and the opportunity for exposure. Though the relationship between the built environment and infectious disease prevention and control is gaining recognition, evolving the knowledge of efficiently adopting design strategies for infectious disease control remains a huge task in developing countries. Thus, the paper aims to appraise the nexus between infection transmission, control, and the built environment from the architect's perspective, with the view of identifying the architect's role in a pandemic. The objectives are, to identify the effects of the built environment on infection control from the historic perspective, built environment metrics associated with disease transmission, the mode of disease transmission in the built environment, and the duty of urban planners/architects in infection mitigation within the built environment. The paper relied on the existing literature, interviews, and interactions with public health officers. Five key built environment metrics that are critical for infection control were identified and the case for adopting the concepts of architectural and urban designs in infection prevention and control was established.

Keywords Architect, Building, Environment, Infection, Control

1. Introduction

Infection prevention and control describe the measures, actions, and policies that focus on preventing or reducing the danger of the spread of infectious diseases in the environment [1]. On the other hand, the term 'built environment' describes the man-made environments which afford the space for diverse human creations such as neighborhoods/cities, buildings, public parks or green spaces with their supportive facilities, e.g., water supply, energy, and road networks, etc. [2]. All the physical spaces where we reside and work (e.g., Healthcare facilities, schools, homes, buildings, streets, open spaces, and infrastructure) make up the built environment. Epidemiologically, the built environment denotes the extrinsic factors that affect the agent and the opportunity for exposure.

According to Tomcyk, Twyman, de Kraker, Rehse, Tartari … Allegranzi [3], the built environment is regularly the opening point or breeding zone for communicable disease epidemics, perhaps contributing to added spread in the municipality. In the past few years, the built environments have been trying to deal with the numerous effects of coronavirus and other communicable viruses across the world. Unarguably, the built environment, especially the healthcare environment and the space we live is desperately in need of strategies to support the level of resistance to pathogen threats. According to Carr [4], despite the advances in medicine, decontamination procedures, construction techniques/materials, and environmental systems, the built environment still presents the risk of infections. The built environment's effect on health and healing is gaining recognition, but the knowledge and understanding of how to efficiently employ design strategies to support infectious disease mitigation and occupants' wellbeing have become even more significant. Zimring, Jesse, Denham, Kamerow, Hall ... Steinberg [5] added that evidence connecting transmission of pathogens and the built environment caught across disciplines but has not recently been thoroughly appraised. The advent of the recent pandemics (SARS, And Coronavirus) has in many ways thought some lessons concerning how design strategies can be fused into the war against the spread of communicable diseases [6] Notwithstanding the increase in the knowledge and understanding of the part played by the built environment, infection control and human well-being in general, there is still no international approach that integrates the built environment into the strategies for curbing the pandemics [7]. Therefore, the paper aims to appraise the nexus between infection control and the built environment from the architect's perspective, with the view of identifying the part architect's responsibility in a pandemic. The objectives are to identify the effects of the built environment on infection control, built environment metrics associated with disease transmission, the mode of disease transmission, and the architect's responsibility in infection control within the built environment.

2. Related Studies on Built Environment and Infectious Disease Control

Even though there are quite a few factors that possibly enhance the spread of pathogens within the built environment, architectural decisions are still critical in the transmission chain [8]. Current investigations from quite a few countries throughout the coronavirus plague reveal that appropriate hospital design that reduces the chance of infection spread can encourage health care workers [4]. An earlier study by Urich [9] revealed that single rooms are better than multi-bed rooms in terms of infection control. A recent study by Cohen, Liu, Cohen, & Larson [10] showed that examining some environmental features within healthcare facilities, for instance, room occupancy, more patients in a single room, and activity level inside the room, have possibly helped the healthcare staff in decreasing the level of disease spread. Urich &Wilson [11] opined that ensuite toilets in single rooms are regarded to be more effective in restraining outbreaks when compared to shared or common bathrooms. Interestingly, some studies focus on or highlight the built environment layout and its effects on healthiness. A study by Jiang & Verderber [12], on the effects of circulation zones in the healthcare environment on occupants' sensitivities and experiences, posited that these spaces might influence the positive perceptions of sick persons in the direction of their inclusive satisfaction with healthcare amenities. The study found that within the healthcare environment setting, spaces significantly influence the positive perceptions of patients in the direction of their overall satisfaction. Moreover, visuals, openings, and designs that allow a window view of nature can enhance the rate of patient recovery and can decrease the tension levels among workers [13]. An earlier study by Boyce, Potter-Bynoe, Chenevert, & King [14] shows that design that allows more daylight into space provides a natural disinfectant and an excellent bactericidal factor [6]. Ulrich, Zimring, Quan, Joseph, & Choudhary [11] added that ventilation in hospitals is affected by factors such as the airflow direction/pressure, room air changes per hour, and the category of air filter, ventilation system maintenance, and the humidity. Another research by Joshi, Kaur, Kaur, & Mishra [15], highlighted the relevance of the design and the construction of the environmental surfaces in the direction of mitigating the contamination spread chain hence, suggested that architectural design, material specification, and surface textures should be well-thought-out in the light of administrative policies and maintenance measures. Studies by Renalds, Smith, & Hale [16] posited that the built environment factors as a crucial domain of socioecological framework suggestively affect lasting occupants' wellness or health outcomes, and such outcomes have been recognized in diverse social and urban settings. Nevertheless, numerous built environments feature that impact health has been acknowledged in previous reviews [17]. This underscores the imperatives of inspiring deliberate and thorough research awareness of researchers across disciplines including architecture in infection transmission factors and pathways in the built environment.

3. Methods and Materials

The study relied on data from secondary sources, which were largely obtained from the extensive review of the existing literature within the scope of the study and other subjects correlated to infection control within the built environment. These include; books, articles, journals, web information, official statistics of the government, and interviews.

3.1. An Overview of the Built Environment and Infection Control

Restraining contact between individuals by seclusion, quarantine and lockdown were the foremost historical methods against bacterial pandemics [7], while, urban and architectural procedures regarding daylight or sunlight and air quality came into the limelight in the 19th century. Around the middle of the 15Th century, the outbreak referred to as the 'Black Death' or the 'Bubonic Plague, accounted for numerous epidemics which overwhelmed the European Community resulting in the death of millions of people [18]. This led to measures to limit contact amongst persons: quarantine, isolation, and dedicated constructions, such as the 27 km stretch, 1.8m tall Plague Wall in the French Vaucluse highlands found in 1721 [19]. Other measures were shorting down Port, communal baths rooms, and counselling people to limit contact with wildlife [20]. Urban dwellers became more conscious of environmental sanitation, and architects were engaged to help with the planning of cities and designing better planned public spaces [20]. Pinheiro & Luís [21] added that the 'Black Death' resulted in the implementation of key alterations in the planning of European cities.

During the Classical period (480–323 BC), about two-thirds of the inhabitants of Athens were lost to a devastating plague, so much so that it provoked Hippocrates and his groups to move to Athens to assist. In his investigation, he discovered that the dry-hot working environment was likely responsible for the few that survived [22]. Further analyses of the street pattern of Athens during the outbreak, revealed that their working environment allowed slight solar radiation to pass through, as, against the street layout, this is because the Greeks adopted the labyrinthine street layout for defence against enemy incursion [23].

Worthy of mention is the emergence of the Hygiene movement in 1820 in France. Murray [24] stated that the movement later metamorphosed into the "Hygiene Commissions (1848) and the Commission for Unhealthy Housing (1950). Murray [24] added that the movement was in response to an outbreak of tuberculosis also referred to as "the white plague", with the highest mortality rate in Western Europe. The concept was meant to make public health scientifically provide a direction for architecture, urbanism, and political decisions, as it concerns the epidemics in 1800. Following the 19th-century Hygiene Movement and the demand for urban renewal after the First World War, the pioneering 'Modernist Architects' in Europe were birthed to formulate broad-minded design solutions [25]. The deep-seated design thinker and Swiss-French modernist architect Charles Edouard Jeanneret, who was also known as Le Corbusier (1887–1965), agreed with the fact that the rapid progression of urbanization was responsible for social deterioration. Hence propounded the 'Five Points of a New Architecture' as a derivative of the Hygiene movement theories [7]. These points of 'New Architecture' are; House on pilotis, a golden roof, a free plan, horizontal windows, and a free façade. He demonstrated his deep-seated philosophies on city planning and house design to encourage good health and sound morality [26]. Before the invention of antibiotics, the Hygiene Movement ideologies were adopted stressing indoor air circulation and between buildings, lighting and sunlight, and sun-oriented buildings.

Moreover, in medieval Europe, leprosy inhibition resulted in the advent of a novel devoted architectural program known as the leprosarium [26]. The last decade has witnessed a surge in infectious diseases, dominated by zoonosis. Jones, Patel, Levy, Storeygard, Balk, Gittleman & Daszak [27] earlier reported that between 1940 and 2004, health agencies reported the emergence of 335 infectious diseases manifesting a huge quantity of drug-resistant microbes. Jones, Grace, Kock, Alonso, Rushton …. Pfeiffer [28] stated that environmental influences like overlapping habitats owing to the agricultural disturbance in the ecosystems, urban heat islands [29] and global warming are often cited reasons. Recently, there was a pandemic known as a severe acute respiratory syndrome (SARS), part of the coronavirus family (SARS-CoV-1) [30] and this was followed by the Covid-19 outbreak. The existing inhibition procedures that were used were social distancing and isolation. Wilder-Smith, Chiew, & Lee [30] reported that in a few locations, monitoring of a person's temperature was made compulsory, especially at the entrance of the airport, train stations, schools, and supermarkets.

3.2. Disease Transmission in the Built Environment

According to McQueen & Ehnes [31] and Schettler [32], several pathogens persevere in the environment and endure for a long period. However, for good infection control, it is important to understand how microbes and diseases-causing pathogens are transmitted within the built environment. Also, the mode of transmission, varied environments, and indications significantly influence the choice or type of infection control approach in the built environments. According to the World Health Organisation-WHO [33], contamination through viruses in the built environments is primarily spread through three methods, these are; airborne respiratory droplets and contact as described in Figure 1.

Droplet spread occurs when someone is exposed to respiratory droplets (5 μm-7 μm) containing the virus. Droplets are produced by symptomatic patients and asymptomatic people during speaking, coughing, and sneezing [34], this often takes place in corridors, lobbies, room spaces, and outdoor settings. The danger of airborne cross-infection is determined by the quantity of air mass breathe out by the infected person which is then breathed in by the unprotected person. Notably, conversational and direct (face-to-face) exposure spread is the main characteristic of short-range airborne paths in spaces [35].

Aerosols are less than >5 μm airborne micro-particles that can be suspended in the air over long distances and are often conveyed by the airflow current, at a substantial distance [36]. Airborne transmission can also take place in corridors, lobbies, rooms, and outdoor spaces.

Contact transmission is spread through direct contact with a sick person or indirectly by leaving droplets comprising the virus on any person (greeting, handshake, hug) [36] and surfaces such as door handles, handrails, worktops, sink taps, and wall surfaces [6].

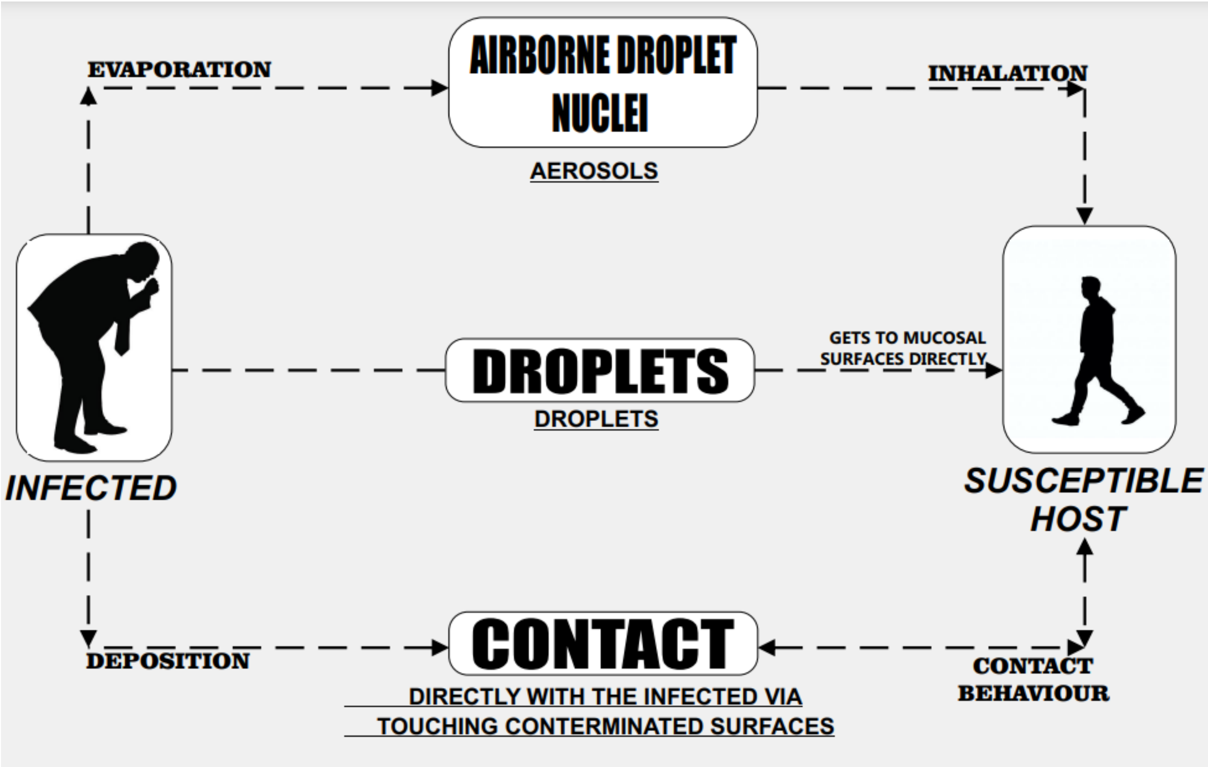

Figure 1. Mode of infectious disease transmission in the built environment

4. Discussions

The study highlighted the nexus between the built environment and infection control with a focus on the role of the architect. Reviewed studies have shown the characteristics of the built environment that directly and significantly influence health outcomes, these include; urban density, air quality diversity, accessibility, design, airflow, lighting, and other elements of exterior and interior design, such as surface finishes or materials.

The reviewed studies presented several measuring procedures for identifying compound indexes for disease infection control in built environments. In summary, five built environment metrics concerning disease transmission and control were evaluated in the study, and the selection was based on their frequency in the literature. From the historical perspective, disease outbreaks such as the Black Death, cholera, tuberculosis, SARS, and the current Covid-19 [18] have influenced the varied designs introduced as a protective procedure to buildings and urban settings. Specifically, infectious diseases and the built environment response could be summarized in Table 1. Also, studies reviewed identified built environment factors that influence health outcomes and connect architectural decisions, these built environment metrics can be concise in a five-dimensional outline.

Table 1. Historical perspective of infectious diseases and the built environment

No	Period	Disease	Built Environment response
1	2nd Century	Infectious diseases	Separation of Water and Sanitation System
2	14th Century	Black death	Urban planning with large space between buildings, large public spaces with a better design/layouts
3	19th Century	Cholera Tuberculosis	Sanitation of sewage systems Design with balconies, terraces, and flat roofs to integrate daylight and enough air. Redesign of furniture
4	20th Century	Spanish Flu	Social distancing
5	21st Century	SARS-CoV-1	Temperature taking, and enhanced ventilation and drainage systems

4.1. Built Environment Metrics Associated with Infectious Disease Control

In the literature reviewed, some key built environment metrics were identified, these are urban population density, diversity (Land Use Mixture), design, and destination accessibility (public transit and transit distance)

i) Urban Density

Population densities describe continuous close interaction with each other per unit square meter, especially in Cities, this makes them superlative centres for the quick transmission of infectious diseases [37]. Studies have tried to identify the relationship between population and the pandemic. A Nigerian study reported that population concentration seemed to remain a reasonable risk factor for COVID-19 CMR per million population [38]. A study in India indicated that in the 1918 influenza pandemic, regions with a lesser density had a lesser death rate [39]. Although more research is still needed to investigate the relationship, an Italian study by Perone [40] including additional variables posited that population density was not substantial nonetheless, in its place, cars and higher death rates were positively linked with firm density. However, further categorization of urban density and pandemics was carried out by Wang, Wu, Wang, He ……. Lu, [41]. Wang et al [41] classify urban density into; Commercial facility density, school density, and road density. The study reported that a more robust indication was found in the link between SARS-CoV-2 infection risk and commercial facilities. Further explanation was given by Frank, Iroz-Elardo, MacLeod, & Hong [42] to the effect that persons who reside in neighbourhoods with more commercial destinations and services are probably going to use these amenities. Li, Zhou, Jia, Peng, Fu, & Zou [43], added that most commercial buildings and centres are designed as interior spaces with insufficient airflow since the virus often intensifies in confined spaces, and the buildings can easily become high-risk areas.

Most studies on school density indicated a positive association. A study in China by Jin, Leng, Gong, Xiong, Yao …. Yan [44] showed that having more educational institutions was linked with suggestively more chances of having COVID-19 cases in a neighbourhood. Concerning road density, few studies posited that road density as an element of the built environment was found to have a positive connection with virus infection. For instance, Ma, Li, & Zhang [45] reported that the spread of COVID-19 had obvious spatial agglomerations all across China. This underscores the relevance of control measures for traffic flow and pedestrian activities. Public transport could be a high-risk environment for the transmission of infectious diseases, as a result of a large number of people grouped in a confined environment. However, to what extent road density influences infections within the built environment requires further study. Fezi [7] concluded that architecture and urbanism could be the panacea to resolve the issue of a highly populated urban environmental model having a low density of population as recommended by epidemiological research.

ii) Diversity- Land Use Mixture

Land-use forms likewise affect the well-being of urban communities [46], especially infectious disease transmission. The mixture is a result of attention to, the built environment, land use, and physical activity. According to Powell [47] the plans of our neighbourhood impact how we get to work or go to the supermarket, and the accessibility of parks and commercial facilities that we may be interested to visit. Public health can be described as a group activity. Thus, added to its shared essence, there are three key characteristics of community health activities: prevention, population, and professional diversity. Fezi [8] added that access to urban facilities and reducing transportation distance while upholding social interactions is a crucial aspect of averting and mitigating epidemics. The risks are characterized by travelling, tourists, and commercial or business people. An analysis by Yang, Li, Kral, Hupert, & Dogan [48] reveals substantial spatial discrepancies and in what way they disproportionately influence the pandemic risk of the exposed public. Views from the reviewed studies demonstrated that occupants in the walkable built environment (connected streets, higher population density, and mixed land use) engage more in taking a walk and less in driving than those who reside in out-of-town communities. The finding establishes the relationship between land use planning and public health and makes the case for infection control input into land-use design procedures.

iii) Urban Design

The design of the built environment plays a significant part as a determining factor in health outcomes and infectious disease mitigations. However, Brizuela, Garcí-Chan, Pulido, & Chowell [50] argued that urban factors of health outcomes often differ within spatial scales smaller than the resolution of epidemiological datasets. Historically, it was observed that apart from the protective role provided using urban design strategies, characterized in isolating infected areas, during the pandemic urban design played an additional new role. According to AbdelHakam [51], instead of the protection role, it provided a direction to understanding the origins of the Cholera epidemic. Thus, it contributes to effectively managing the spread. Moreover, the built environment morphology was found to be significant during the outbreak. For instance, AbouKorin, Han, & Mahran [52] found that Cities with radial and grid design concepts were linked to higher rates of infectious disease transmission when compare to Cities with the linear design concept. This of course raises some questions; should we now redesign our cities? Should our roads, streets, and parks be redesigned? Some scholars opined that COVID -19 pandemic provides an opening for architects and urban planners to set free more street space for cyclists and pedestrians. Suggestively, redesigning streets might be necessary because of other growing needs apart from social distancing.

iv) Accessibility-Public Transit and Destination

This metric describes public access to the hospital, school, commercial facilities, transit distance, and destination. Some studies identified positive links between accessibility to public transit and infectious disease transmission infection [44]. However, before the pandemic, strong evidence previously existed of aerosol transmission over long distances [53]. In a Nigerian study, Oleribe, Oladipo, Ezieme, Crossey, & Taylor-Robinson [54] advocated for the decentralization of healthcare facilities, while, Mogaji [55] posited that public transport, operatives, and other stakeholders need to review or adjust the timetables to deal with the increased demands of transport and the scarcity of options as a result of social distancing. Moreover, the result from a USA study demonstrated that public transit employed in US metropolitan areas during the pandemic was linked to the scale of outbreaks [56]. Shen, Duan, Zhang, Wang, Ji, Wang ... Shi [57] added that the danger of virus transmission in public destinations is extensive, given the possibility of virus exposure among public transit passengers. The main issue arising from the nexus between infectious disease and a sustainable built environment is the interrogation or question of the movement of persons. The present case of covid -19 underscored the need to travel in private vehicles as against public transport, this is because public transport is regarded as a probable vector of virus-related spread in the community.

v) Green parks/areas and Public Spaces

The existing studies suggested that green spaces or parks seem to be more than just a luxury. The general health outcomes have a positive relationship with the proportion or ratio of green space in people's living environment. Accordingly, the design and development of green areas in the built environment ought to be assigned a more fundamental position in spatial planning/design strategy. A study by Kondo, Fluehr, McKeon, & Branas [58] indicated a steady negative connection between urban green space experience and death, heart rate, and viciousness, and a positive link with physical activity, devotion, and temperament. Regarding the present COVID-19 pandemic, existing studies understood and described the allocation of green areas as a key component of the environment's role in disease contamination risk. However, the varying preferences and potentials about green spaces and parks might result in fresh designs, usages, and practices in green space design/planning.

Public spaces are pivotal to social interactions. Unarguably, among many challenges resulting from the coronavirus pandemic was social interruption, thus putting public space under intense examination. According to Verreault & Moineau [59] COVID-19 droplet transmission occurs up to 11-2 meters. Social interactions in public spaces are among the utmost critical issue in the built environment concerning infectious disease control. Therefore, the space separating the sitting platforms that are ideal for greetings, talk, and play: that is, life in between buildings as a dimension of architecture, urban design, and city planning needs to be cautiously treated.

4.2. Architectural and Built Environment Procedures in Infectious Disease Control

Relying on experiences, previous scientific discoveries all through the present pandemic, and the reviewed existing studies, architecture and urbanism can offer a solution using built environment/building design concepts. In indoor spaces, air control through cross ventilation, humidifying, and filtering can be used to restrain or control virus spread. An earlier study revealed that sustaining an indoor relative humidity of less than 40% will meaningfully decrease the infection capability of the aerosolized virus [60]. With the demand for adequate space for safe distancing as required by the centre for disease control, it becomes imperative for a review of critical space dimensions. Such spaces like corridors, lobbies, entrance foyers, balconies, etc. The study also suggests a review of building setbacks to allow for more space between buildings.

As part of urban renewal and improving urban resilience, dimensions for pedestrian walkways and footbridges need to be reviewed or adjusted to suit safe distancing requirements. At present, the width for most existing walkways in Lagos and Abakaliki, Nigeria is 1.2m as shown in Figure 2, while, minimum width of 0.6m behind a barrier kerb is provided for pedestrians on both sides of a bridge. To meet the social distance requirement, the paper suggests a review of these dimensions. Moreover, with the increase in online shopping, adequate drop-off should be integrated into residential estates layout to aid the delivery of goods.

Figure 2. Ebele Jonathan Boulevard, Abakaliki, Nigeria (Source; Author, date: 03/02/22)

Restricted and not well-ventilated spaces, like stair-well or elevators, must be carefully planned as they are the most susceptible to aerosol contamination. Jones, Grace, Kock, Alonso, Rushton, Said, ... Pfeiffer [28] added that narrow and poorly ventilated spaces, such as stairs or elevators, must be well designed and avoid close-end corridors [6] since they are the utmost vulnerable space for aerosol infection. Lessons deduced from the historical perspective of the built environment and infectious disease control indicated that daylight played an active role in the pre-antibacterial age. Lateef [62] stated that daylight or sunlight is an outstanding bactericidal agent and can inhibit infection. Reducing places of contamination, high-touch areas, and the use of building materials with antibacterial effects could reduce the potential for infection, especially in public spaces. Spaces such as shopping malls, worship centres, etc should be designed with large and flexible entrances and integrating areas for hanging or keeping clothes and possibly infected items from the outdoors and could even be equipped with wash basins

5. Conclusions

The epidemiologic triad is a traditional model of disease transmission that has long recognized the environment as a key member of the triad. This ought to include both the natural environment and the built environment. The nature and mechanism of interactions that are possible within these various aspects of the environment to give rise to diseases or their prevention and control will be modified by both nature, design, and use of such spaces.

This review has shown how these interactions may have been modified due to prevailing designs of the built environment in the different contexts and times examined. The case for adopting the concepts of architectural and built environment in infection prevention and control has been established. As has been demonstrated in the COVID-19 pandemic, non-pharmaceutical measures are important in preventing and controlling emerging diseases whose dynamics are often changing rapidly. The knowledge of how the built environment infectious disease risk is critical to controlling the present pandemic. Architectural concepts and interventions that can help modify the agent-host interaction within the built environment should be considered as part of these tools. These interventions it is hoped will contribute to the overall implementation of the principles and practices of infection prevention and control of diseases.

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