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Future Hospital Building Design Strategies Post COVID-19 Pandemic

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ABSTRACT

The COVID-19 pandemic is regarded as a pivotal point in human history. The goal of architecture is to solve problems like the novel COVID-19 pandemic. As a result, new future methods to designing buildings and create environments emerged, with hospital design and infection control being prioritized as a key pillar of health care. Hospitals, like battlegrounds, require a future design that prioritizes speed and safety, not just during treatment but also during testing and follow-up care. The research aims to create an appealing, humane, and optimal therapeutic environment for dealing with the pandemic in order to raise the degree of safety that aids in the prevention of infection and illness spread. The research employs a deductive methodology, with the goal of discussing the evolution of the design of the future hospital environment through a set of design strategies based on social distancing policy, adaptability, flexibility, and engineering control of new preventive measures to deal with the current and potential future pandemics, while also considering humanistic aspects. The questionnaire was conducted to test the goals and strategies of this research through a group of specialists in order to reach the graphic results of the importance of these strategies in helping to design the hospital of the future, paving the way for future studies and research to develop building design and create environments of future hospitals.

1. INTRODUCTION

During the past two centuries, architecture and urbanism witnessed many developments. It has been environmentally shaped upon the emergence of diseases to reduce the risks of infectious environments and to re-do interior designs and architecture. Therefore, during COVID-19 pandemic, the built environment must be developed to increase the level of safety in order to prevent the spread of infection and disease [1].

The new type of Corona virus COVID-19, which appeared at the end of December 2019, has spread, and the World Health Organization declared the outbreak of COVID-19 as a pandemic on March 11, 2020, stating that the epidemic, which affects the entire world and kills people, has necessitated precautions in all areas [2], and the structural capabilities of health care facilities must be assessed and monitored, as the epidemiological situation necessitates more adjustments and rethinking [3].

According to Jonathan Flannery, MHSA, CHFM, FASHE, FACHE, Senior Associate Director of Advocacy for the American Society For Healthcare Engineering (ASHE), " Due to the influx of long lines of patients, overcrowded emergency departments, and the transformation of different spaces to triage areas, among others, in addition to the unprecedented stresses and rates of infection and the arrival of patients with unprecedented serious diseases caused by the virus [4], hospitals have a lot of design and engineering issues after COVID-19." This will reshape hospitals and healthcare systems to better respond to the crisis [5].

The global COVID-19 pandemic has shed light on the importance of the management of the built environment through design, construction and operation processes. Being one of the major pillars of health care since the worldwide spread of COVID-19, the importance of hospitals has grown not only for treatment but also for testing and aftercare as well. Thus, hospitals and healthcare systems are reshaped to better respond to the crisis.

Therefore, radical changes must take place in the design of the future hospitals to create high-quality environments that support the well-being and safety of users and create an ideal environment to deal with the pandemic. The present research applies 3 strategies to deal with the problem:

- A strategy of social distancing, separation and distribution, with consideration given to the user and human design
- Flexibility strategy and the hospital's ability to be adjusted, reshaped and expanded
- Engineering controls strategy to combat viruses

These strategies help in designing the future hospital that takes into account social distancing and safe distance policies to limit, through separation and distribution, the risks of communication, reduce infection rate and prevent cross infection. In addition, the importance of the humanistic aspects by following a natural approach for physical and mental health while taking into account social support from the social network of the users of health care buildings to avoid negative psychological impacts.

These strategies provide many engineering controls to combat the virus and allow increasing the capacity of hospitals to meet the peak of demand by using a modular design in addition to the ease of adaptation and flexibility of hospital designs which are necessary to add future functions without hindering the progress of work. The strategies were tested through a questionnaire for different samples of users and designers of health buildings to reach the necessary results for the design of the future hospital.

2. STRATEGIES FOR DESIGNING THE FUTURE HOSPITAL POST COVID-19 PANDEMIC

2.1 Strategies for social distancing, spacing and separation - Taking the user and human design into account

The strategy of social distancing, which is called physical distancing, focuses on maintaining a safe distance between the people who are not from the same residence [6].

Social distancing is designed to contain the highly contagious coronavirus. Spreading infection is known as "virus shedding," but time frames differ among diseases, that means social distancing includes keeping adequate space between you and others, at work and elsewhere. It's meant to protect not only you, but the greater public as well, by eliminating transmission routes of the virus (Figure 1).

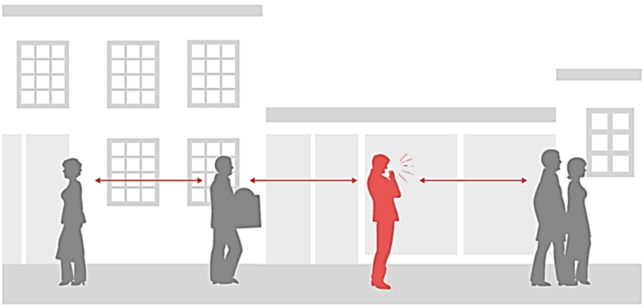


Figure 1. Social distancing, annuals of internal medicine [7]

The policy of separation and distribution of facilities aims to reduce the number of users for a single building. It is one of the important factors to avoid potential infection while providing gathering (and taking into account safe distances) in public places and parks to encourage conversations and social relations to take into account the importance of social support and positive social interaction. Social support, whether parental, family or social, plays an important role in helping the disease recover and avoiding harmful behaviors for better health and well-being [8].

2.1.1 Selection of the hospital's location

The choice of the hospital's location is a significant element in the planning decision process which has an environmental, social and economic effect on health care structures as well as the efficiency of the service. As hospitals receive a large number of users, visitors and resources, there was a tendency to localize hospitals in the central areas of the city. Nonetheless, after the spread of that contagious pandemic, the tendency to localize hospitals outside these spaces increased in order to avoid potential infection in these centers of high density. In addition to the ease and flexibility of extension [4].

Hospitals in the area outside the city are characterized by having natural surfaces that allow continuous and repeated interaction with nature as health is linked with the nature of the built environment. However, the central areas include regional facilities to provide the best health services to enhance health at the local level.

2.1.2 Distribution of areas and zones by division and separation technique

Healthier and safer hospital buildings must be built during this crisis by designing the layout of the hospital based on dividing some hospital functions and distributing them on other facilities to reduce the number of users for a single building [9]. Furthermore, using hybrid typological technique that is characterized by a main embodiment connected to the support ward helps separate the various functional areas that provide internal units away from the rest of the hospital system without interruption of normal activities. Therefore, in emergency situations, the possibility of organizing spaces without obstructing the whole flow and road system is ensured with dedicated access to emergency and logistical vehicles in case of contagious emergencies [4]. This leads to separate service flows to provide emergency entrances for patients with infectious diseases, since they form the greatest risk of infection for the hospital system. Therefore, people should be examined at the point of entry as infected persons remain far from main doors [10]. It also takes into account some organizational aspects of both low and high care spaces in contagious emergencies, such as the intensive care as one of the most affected departments. Thus, there is a need to separate work spaces from main care spaces to reduce employee exposure to infection.

Thus, the separation of buildings or separate internal units provide the design of the hospital building mainly with horizontal formations that enables the distribution and separation of areas and circulation in a clear manner that guarantees the control of contamination and transient infection to avoid the use of horizontal and vertical connections for multiple spaces [4]. This provides effective emergency management and treatment areas for infected patients. In addition, the method of separation, distribution, horizontal formations, separate different functions, and separation of circulation allow for more natural lighting, natural ventilation and communication with nature for each functional block to achieve the necessary human requirements for users in health care buildings (Figure 2).

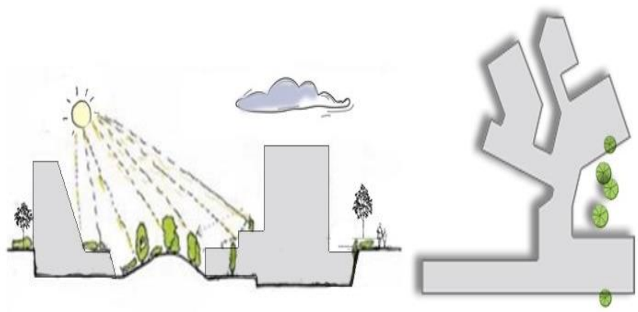


Figure 2. The benefit of nature oriented functional blocks in healthcare buildings

2.1.3 Social distancing and safe distance in light of the psychological and social aspects

During the Corona crisis, people's conception of the acceptable number of people for a given area could change, making it easier to use a decentralized network based on creating more room for individual use [11]. To practice social or physical distancing, individuals who are not from the same family should be separated by at least 6 feet in both indoor and outdoor spaces [6]. Fears of indoor infection may increase the demand for dividing spaces into parts to reduce the risk of cross-contamination at any time [12].

More outdoor spaces, more green areas and more ventilation are required to build healthier and safer hospitals during this crisis in addition to designing separate external spaces in the gardens for families to communicate without the need to pass through the main building (Figure 3). Moreover, it is necessary to provide small green spaces for practicing sports so that patients and workers can fulfill their everyday needs of nature through having a visual access to it. Rules for a safe distance relieve stress and allows for relaxation [13] while preserving familiar and vibrant sociality. According to environmental psychology, social environment has a stimulus effect for the human psyche. Social network is the structure through which social support is provided and received [14].

The principle of focusing on the patient in the design of health-care buildings has the greatest impact on the quality of the health system. Thus, the patient's experience is remarkably significant for the comprehensive health care, i.e. integrative medicine, by generating non-stressful environments.

2.1.4 Expanding outpatient areas

Outpatient clinic entry areas are extended to become screening points to separate infectious patients from the rest of the patients to minimize the risk of infection while increasing the area for diagnosis and treatment, allowing more room for beds, and creating separate areas for patients. Consequently, infection can be controlled maintaining the rest of the hospital continues to function normally [15].

It is better to use smaller waiting rooms rather than wide areas where people are seated side by side [9]. As a result, the number of patients waiting in outpatient waiting rooms is limited in order to create safer reception areas [16].

Figure 3. Outdoor spaces, green areas are required to build healthier and safer hospitals [8]

An ambulance bay was refashioned into a triage area [17]

Patient room in the emergency department [18]

A corridor that is part of the lobby can accommodate beds [18]

Figure 4. Dealing with the mass epidemic by expanding the capacity of the Hospitals

3. STRATEGIES FOR RAPID ALTERATION (FLEXIBILITY)

Flexibility is one of the most important points for hospital structures to handle emergency health care needs that arise or disappear at a very rapid rate. It is also an essential aspect that must be taken into account in hospital design, from building systems to functional and environmental units, in order to adapt to the emerging procedures that overlap within the building. Rush University Medical Center in Chicago is a relevant example during the COVID-19 pandemic.

To deal with the mass epidemic, the hospital increased the capacity of the emergency department (Figure 4), the number of isolation rooms, and minor operations to deal with the huge pandemic. Additionally, the number of negative pressure rooms connected to the outside hallway should be increased to facilitate air flow from the corridor to the room. This helps prevent the spread of infectious diseases [4]. Thus, the hospital's flexibility will be divided into two parts, namely, flexibility of use and flexibility of size.

3.1 First approach: Use flexibility and adaptability

It is the sufficient internal flexibility in the hospital's interior design to constantly adapt to the new requirements or to be used in the long term for alternative purposes to respond to future situations. Modular design contributes to achieving a higher level of flexibility by preparing the area program on the basis of a modular system.

Hospitals should be built based on the principle of modular units to design spaces, areas and the overall hospital plan. Moreover, it is completely significant to equip the hospital with easy to link and adjust modular mechanical and electrical systems. This approach can be accomplished by following a universal design method (Figure 5).

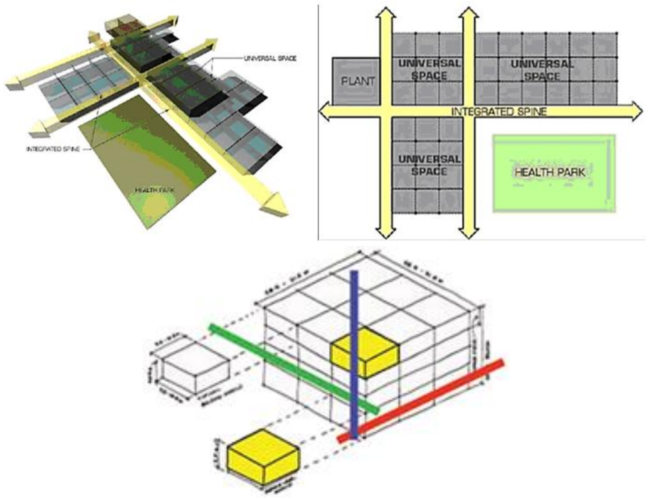


Figure 5. Following the principle of the modular unit for the design of spaces and flats and the overall hospital plan [8]

Figure 6. Redesign increases isolation space for COVID-19 patients [19]

This method is characterized by the use of large public rooms or varying sizes of rooms to provide a wider field of use, regardless of being smaller or bigger than required, while achieving direct routing of services such as medical gas supplies, electrical sockets, and electronic connections (such as communication systems, computers, radiology devices, and other equipment) [20]. This allows functional spaces to be easily re-converted and equipped with an appropriate amount of technical installations which helps in converting the usual patient rooms or a complete unit to isolation rooms and isolation zones (Figure 6). This supports the control of the infection so that the germs do not transfer from an infectious patient to the rest of the unit [10]. To minimize the risk of spreading any infectious agent in hospitals, the number of single rooms in the hospital must be increased, with individual rooms fully-equipped to be converted into double rooms in the event of an excessive influx of patients [4].

3.2 The second approach: Size flexibility

It refers to the ability of the building to extend horizontally or vertically to increase its size and the areas of its design program in response to the future requirements with the ability of the infrastructure to expand. It is a long-term flexibility [21]. In light of this concept, the extension will not be limited to the borders of any department, but will naturally extend to include the entire hospital zones. The designer shall form the plans in a manner that facilitates the changes with the passage of time, by designing circulation in shallow planes, and relying on the open-ended design by providing corridors with open ends and avoiding closing them to increase the chances of extension [20]. Therefore, it is necessary to take into account the presence of empty spaces and supportive areas between departments which are considered as a space lung to accommodate areas of expansion. In addition, unhealthy spaces, e.g. parking lots and sports spaces are to be prepared with reduced investments that allow converting them during crises such as Rambam Hospital in Haifa, Israel (Figure 7). It has been converted into a hospital with a capacity of 2000 Beds in wartime. These areas can be supported by direct internal communication with the rest of the hospital and externally with first aid, as well as providing more outdoor spaces around the hospital area to host potential temporary structures [4].

Figure 7. Flexibility in turning the underground parking into an intensive care facility [22]

4. ENGINEERING CONTROLS STRATEGY

Hospitals are battle fields where design is focused to reach the most efficient and safe methods. One of the main mechanisms for disease spread is person to person which can occur through direct contact or volatile microbes. As a result, hospital design requires more engineering controls appropriate to augment air technology systems. Good hand hygiene programs, disinfection of environmental services as well as changing building specifications [9]. are to be taken into account. Greater ventilation and more natural light are needed to control moisture and bacteria accumulation, as central air conditioning facilitates the spread of infection [12].

4.1 Ideal natural ventilation system

To design an ideal natural ventilation system, designers need to understand the main driving forces of natural ventilation - wind pressure, stack (or buoyancy) pressure. These forces control how air moves in and through the building. In addition, they can be combined, as needed, to design an ideal natural ventilation system. As a general rule, the rate of ventilation flow is measured by calculating the rate of natural ventilation by the wind through a room with two opposite openings (such as window and door) as follows: (Eq 1).

$$ACH = \frac{0.65 \times wind\ speed(m/s) \times smallest\ opening\ area(m^2) \times 3600s/h}{room\ volume(m^3)} \quad (1)$$

Eq. (1) provides estimates of the ACH and ventilation rate due to wind alone [23].

Provides estimates of the ACH and ventilation rate due to wind alone at a wind speed of 1 m/s, assuming a ward of size 7 m (length) × 6 m (width) × 3 m (height), with a window of 1.5 × 2 m^2 and a door of 1 m^2 × 2 m^2 (smallest opening) (Table 1).

Table 1. Estimated air changes per hour and ventilation rate for a 7 m × 6 m × 3 m ward [23]

Openings	ACH	Ventilation rate (I/S)
Open window (100%) + open door	37	1300
Open window (50%) + open door	28	975
Open window (100%) + closed door	4.2	150

Individual directional flow is preferred in natural ventilation systems to prevent the transmission of infection, by using the corridor for the patients' wards from one side only, with the design of the windows on the same line with the room door to create an intersecting ventilation path to the outside. Furthermore, the central corridor is avoided because it contributes to the transfer of the polluted air from one ward to the other. Also, the use of the large courtyards is sufficiently preferable with the type of external corridor, the type of atrium, chimney and hybrid ventilation systems, with the combination of natural and mechanical ventilation in a dual-mode system. The operating mode varies according to the season and sometimes according to the days [23]. Thus, closed halls, waiting rooms, double corridors, and other areas designed with little or no airflow are avoided in the design [24]. Corridors must be open-ended to avoid closed ends. In addition, there should be openings in the upper wall in halls, corridors and above doors to increase the rate of ventilation.

Natural ventilation can provide a higher ventilation rate than energy-efficient ventilation. Studies revealed that; in Chinese hospitals, isolation wards with a high percentage of openings were found to act better in preventing the spread of SARS epidemic among health workers than other designs. In other words, increasing the rate of ventilation greatly minimizes the risk of infection [24].

4.2 Selection of materials and design features:

The technique of non-spreading of infection across surfaces can be carried out by using and selecting washable materials for all internal and many external surfaces that have the ability to stop the spread of germs and infection. Thus, nanotechnology is required as a weapon to combat diseases in the field of architecture [12]. The use of solid non-porous surfaces along with smooth curved rather than corner surfaces reduce the ratio of microbes [9].

Reducing manual communication through the use of automatic doors and other systems where resources are delivered and collected automatically as a main work system in the future is significantly required [16]. In addition, it is advisable to use the special non-touch tools that can be activated by sound such as automatic doors, bells, switches ... etc. Hence, digital transformation in all activities, augmentation of engineering control and virtual technology are necessarily required in building systems [12].

Health applications make independent living possible for the elderly and patients with serious health conditions. Currently, the Internet of Things (IoT) sensors are being used to continuously monitor and record their health conditions and transmit warnings in case any abnormal indicators are found. If there is a minor problem, the IoT application itself may suggest a prescription to the patient (Figure 8).

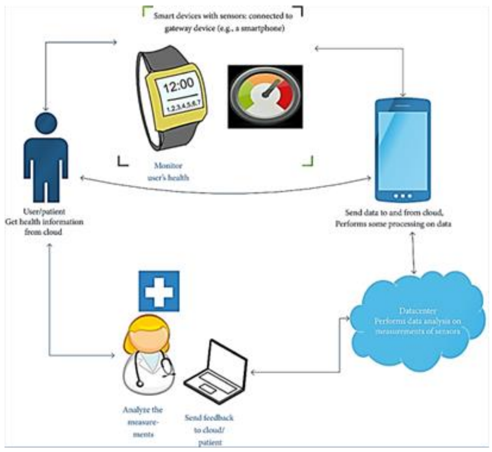


Figure 8. Block diagram of a smart healthcare system [25]

4.3 HVAC and building services systems provide security

The quality of indoor air is significantly critical to the health and safety of people, especially in hospitals, clinics, and health care facilities to protect patients, staff, and visitors from the transmission of infection. Therefore, ventilation and filtration through heating, ventilation and air conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of infection transmission through the air [26]. When the relative humidity of the room is maintained between 40% and 60%, it generally does not allow the survival of microorganisms [27].

The overall effectiveness of reducing particulate concentrations depends on the efficiency of the filtration and the rate of air flow through the particle size filter with the filter location in the HVAC system or room air cleaner.

Infection control and air sanitization units are used in hospitals, especially in isolation rooms for infectious diseases, intensive care rooms, waiting rooms and halls of hospitals, clinics, banks, offices and other vital places to reduce the risk of spreading infectious diseases from one person to another. First, air passes through a group of ULTRAVIOLET C BAND (UVC) lamps that kill the majority of viruses and microbes. Then, it passes through the HEPA filter with an efficiency of

99.999% to hold it and prevent its return in the atmosphere or push it to the outside air.

A 6-inch round duct connection (additional option) can be made on a part of the air outlet to expel part of the air to the outside as an exhaust. This contributes to increasing the negative pressure ratio inside isolation rooms to ensure that no air escapes from the room without passing through the UV bulbs and the HEPA filter 99.999 % to eliminate the scape and spread of viruses to the outside air [28].

Portable HEPA Filter System with UV feature is a device located in the room to sanitize air. It is an air sanitization unit with an air handling system to improve the quality of the indoor air. The recycled air is filtered to remove particulate matter and microorganisms through the HEPA filter system with ultraviolet rays to reduce the possibility of infection by making the area free of pollutants [26].

5. STUDY DESIGN AND PARTICIPANTS

A special questionnaire about Future Hospital Building Design Post COVID-19 Pandemic is conducted to inquire about the development of the design of the future hospital environment through a set of strategies that are based on the policy of social distancing, adaptability, flexibility and engineering control of the new preventive measures to deal with the current and potential future pandemic, taking into account the humanistic aspects.

A total of (154) specialists participated in the questionnaire. The demographic characteristics of the respondents are presented in (Table 2).

5.1 Measurement scales

The questionnaire consisted of two main sections; Current status of Hospital Design Building and Future hospital design success indicators.

In the first section (Current status of Hospital Design Building) participants are asked which of the following Strategies and indicators have been practiced by the planners and designers to combat future infection in design health care buildings ranging from (Always) to (Never). Additionally, they are asked to indicate the level of practice and importance for each Strategy and indicator ranging from (Extremely Important) to (Least Importance): Distribution of areas and zones, Build healthier and Safer hospitals to promote healing both psychologically and physiologically, Strategies for rapid alteration (Flexibility) to easily re-converted, extended and equipped in response to the future requirements, Engineering controls strategy, Selection of materials and design features to reduce the ratio of microbes, HVAC and Building Services Systems provide security (Table 3), In the second section (Future hospital design success indicators) participants are asked about the level of influence the following indicators on the hospital future design success ranging from (Very low) to (Very high): avoid potential infection, enhance Wellbeing and healing, and adapt to the emerging procedures (Table 4).

Table 2. Results of demographic characteristics of the respondents (N = 154)

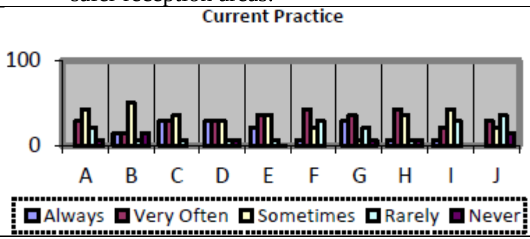
Demographic characteristics	N	Percentage (%)
Gender:		
Male	50	32.47
Female	104	67.53
Years of experience in design hospital building or working in hospital building		
Less than 5 years	64	41.7
5 to 10 years	12	7.8
10 to 15 years	20	12.9
15 to20 years	24	15.6
More than 20 years	34	22
Your profession field in your organizatio		
Architecture	72	46.8
Hospital manager	12	7.8
Hospital worker Engineer	22	14.3
Medical staff	40	25.9
HVAC Engineer	0	0
Others	8	5.2
Highest level of education qualification		
Bachelor's degree	8	5.2
Diploma	16	10.4
Master's degree	40	25.9
PhD	90	58.5
Organization function		
Client/Developer	21	13.6
Consultant	90	58.5
Contractor	25	16.2
Others	18	11.7
The extent you would describe your level knowledge on Hospital Design or Infectio control		
Very Good	80	52
Good	56	36.4
Fair	18	11.6
Poor	0	0
Very Poor	0	0
Whether you have attended any formal training on Infection control in hospital building		
Yes	92	59.7
No	62	40.3

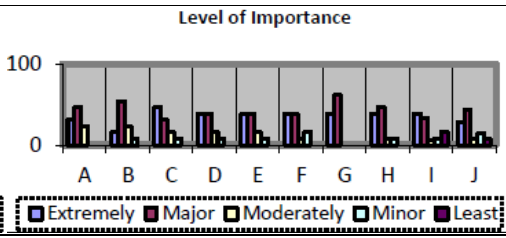
First Section: Current status of Hospital Design Building

Table 3. Results of the current status of hospital design building

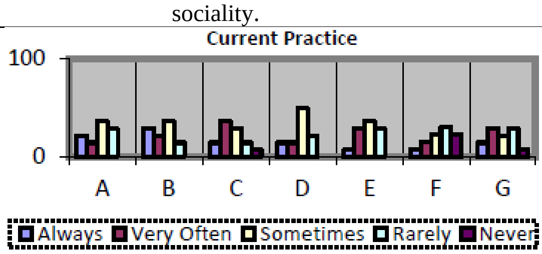
Design Indicators	Current Practice					Level of Importance				
	Always	Very Often	Sometimes	Rarely	Never	Extremely	Major	Moderately	Minor	Least
Distribution of areas and zones										
A. Localize hospitals outside the centers of the city high density.	0	28.6	42.9	21.4	7.1	30.7	46.2	23.1	0	0

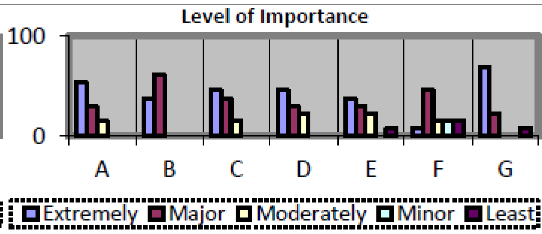
B. Reduce the number of users for varies zones.	14.3	14.3	50	7.1	14.3	15.4	53.8	23.1	7.7	0
C. Separate internal units and separate the various functional areas.	28.6	28.6	35.7	7.1	0	46.1	30.8	15.4	7.7	0
D. Separate service flow patients as emergency and Outpatient clinic entry.	28.6	28.6	28.6	7.1	7.1	38.4	38.5	15.4	7.7	0
E. Outpatient clinic entry areas are extended to become screening points.	21.4	35.7	35.7	7.1	0.1	38.5	38.5	15.4	7.6	0
F. Increase the area for diagnosis and treatment, creating more room for beds.	7.1	42.9	21.4	28.6	0	38.5	38.5	7.6	15.4	0
G. Separate work spaces from main care spaces.	28.6	35.7	7.2	21.4	7.1	38.5	61.5	0	0	0
H. Dividing spaces into parts to reduce the risk of cross-contamination at any time.	7.1	42.9	35.7	7.2	7.1	38.5	46.2	7.6	7.7	0
I. Separation of visitors' circulation from the hospital's internal.	7.1	21.4	42.9	28.6	0	38.5	33.0	5.5	7.6	15.4
J. Use smaller waiting rooms rather than wide areas to create safer reception areas.	0	28.6	21.4	35.7	14.3	28.6	42.9	7.1	14.3	7.1



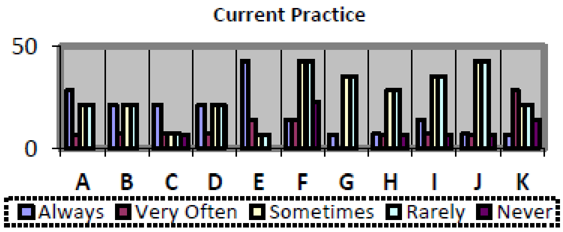


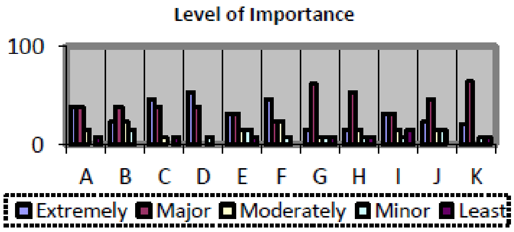
Build healthier and Safer hospitals to promote healing both psychologically and physiologically.										
A. Access to Nature: more outdoor spaces, more green areas.	21.4	14.3	35.7	28.6	0	53.8	30.8	15.4	0	0
B. Communication with nature for each functional block (more natural lighting, natural ventilation).	28.6	21.4	35.7	14.3	0	38.5	61.5	0	0	0
C. Incorporates several courtyards to increase the daylight zone.	14.3	35.7	28.6	14.3	7.1	46.1	38.5	15.4	0	0
D. Utilizes natural and aesthetic factors.	14.3	14.3	50	21.4	0	46.2	30.7	23.1	0	0
E. Separate external spaces in the gardens for families are located directly outside.	7.1	28.6	35.7	28.6	0	38.4	30.8	23.1	0	7.7
F. Provide small green spaces for practicing sports so for patients and workers.	7.7	15.4	23.1	30.8	23.1	7.7	46.2	15.4	15.4	15.3
G. Rules for a safe distance while preserving familiar and vibrant sociality.	14.3	28.6	21.4	28.6	7.1	69.2	23.1	0	0	7.7



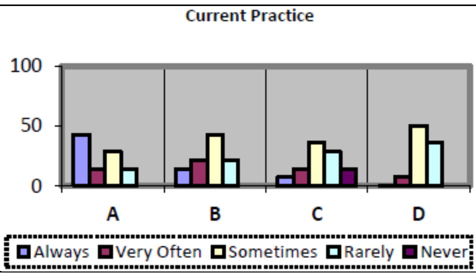


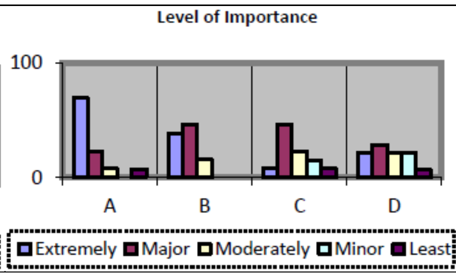
Strategies for rapid alteration (Flexibility): to easily re-converted, extended and equipped in response to the future requirements										
A. The principle of modular units to design hospital areas to equip it with easy.	28.6	7.1	42.9	21.4	0	38.5	38.5	15.4	0	7.6
B. Use of large public rooms while achieving direct routing of services.	21.4	7.2	50	21.4	0	23.1	38.5	23	15.4	0
C. Possibility to convert the usual patient rooms or a complete unit to isolation rooms or zones.	21.4	7.2	57.1	7.2	7.1	46.2	38.5	7.6	0	7.7
D. The number of single rooms in the hospital must be increased.	21.4	7.2	50	21.4	0	53.8	38.5	0	7.7	0
E. Possibility of equipping individual rooms fully- to be converted into double.	42.9	14.3	35.7	7.1	0	30.8	30.8	15.4	15.4	7.6
F. The ability of the building and infrastructure to extend.	14.3	14.3	28.6	42.8	0	46.1	23.1	23.1	7.7	0
G. The plans form in a manner that facilitates changes with the passage of time.	7.1	0.3	57.1	35.5	0	15.4	61.5	7.7	7.7	7.7
H. The corridors with open ends to increase the chances of extension	7.2	7.1	50	28.6	7.1	15.4	53.8	15.4	7.7	7.7
I. The presence of supportive areas between departments to expansion.	14.3	7.2	35.7	35.7	7.1	30.8	30.8	15.4	7.6	15.4
J. Preparing the unhealthy spaces, e.g. parking lots that allow converting them during crises	7.2	7.1	35.7	42.9	7.1	23.1	46.1	15.4	15.4	0
K. Providing more outdoor spaces to host potential temporary structures	7.1	28.6	28.6	21.4	14.3	21.4	64.2	0.2	7.1	7.1



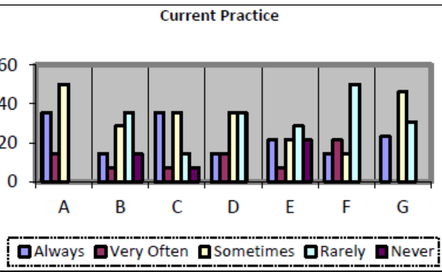


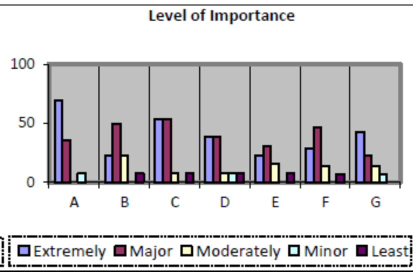
Engineering controls strategy										
A. Increasing the rate of ventilation greatly minimizes the risk of infection.	42.8	14.3	28.6	14.3	0	69.2	23.1	7.7	0	0
B. Closed halls, waiting rooms, double corridors and others with little or no airflow are avoided	14.3	21.4	42.9	21.4	0	38.4	46.2	15.4	0	0
C. Using the corridor for the patients' wards from one side only, with the windows on the same line with the room door to create ventilation path.	7.1	14.3	35.7	28.6	14.3	7.7	46.2	23.1	15.3	7.7
D. There should be openings in the upper wall in halls, corridors and above doors to ventilation.	0.1	7.1	50	35.7	7.1	21.4	28.6	21.4	21.4	7.1



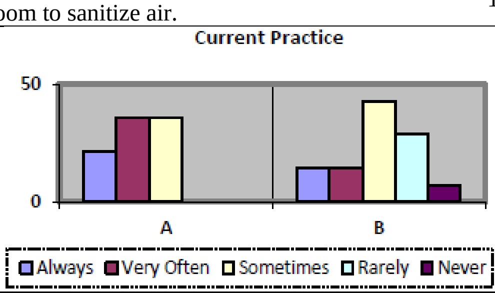


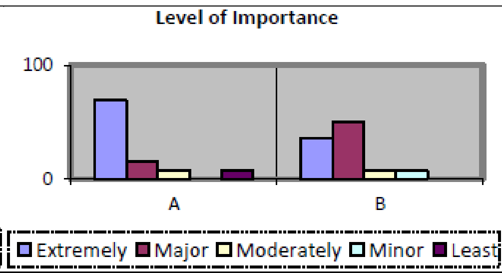
Selection of materials and design features to reduce the ratio of microbes:										
A. Using and selecting washable materials for all internal and many external surfaces.	35.7	14.3	50	0	0	69.2	23.1	0	7.7	0
B. Nanotechnology is required as a weapon to combat diseases in the field of architecture.	14.3	7.1	28.6	35.7	14.3	23.1	46.2	23.1	0	7.7
C. The use of solid non-porous surfaces along with smooth curved corners reduce the microbes.	35.7	7.2	35.7	14.3	7.1	53.8	30.8	7.7	0	7.7
D. Reducing manual communication through the use of automatic doors.	14.3	14.3	35.7	35.7	0	38.5	38.5	7.7	7.7	7.7
E. Resources are delivered and collected automatically as a main work system.	21.4	7.2	21.4	28.6	21.4	23.1	53.8	15.4	0	7.7
F. It is advisable to use the special non-touch tools such as automatic doors, bells, switches ... etc.	14.3	21.4	14.3	50	0	28.6	50	14.3	0	7.1
G. Digital transformation in all activities and virtual technology are necessarily required.	23.1	0	46.1	30.8	0	42.9	35.7	14.3	7.1	0





HVAC and Building Services Systems provide security										
A. Infection control and air sanitization units are used to reduce the risk of spreading infectious diseases.	21.4	35.7	35.7	0	7.1	69.2	15.4	7.7	0	7.7
B. Portable HEPA Filter System with UV feature is a device located in the room to sanitize air.	14.3	14.3	42.8	28.6	0	35.8	50	7.1	7.1	0

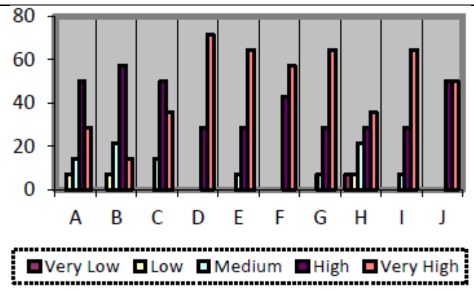




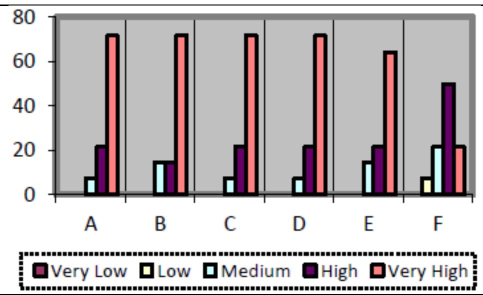
Second Section: Future hospital design success indicators

Table 4. Results of the Future hospital design success indicators

Indicators leading to design success	Very low	Low	Medium	High	Very high
Avoid potential infection					
A. localize hospitals outside the centers of the city high density	0	7.1	14.3	50	28.6
B. Reduce the number of users for a single building	0	7.1	21.4	57.1	14.3
C. Separate the various functional areas	0	0	14.3	50	35.7
D. Reduce the risk of cross-contamination at any time	0	0	0	28.6	71.4
E. Separation of visitors' circulation from the hospital's internal circulation	0	0	7.1	28.6	64.3
F. Separation of infection patient's circulation from the hospital's internal circulation	0	0	0	42.9	57.1
G. Maximizing users and patient's exposure to fresh air and daylight	0	0	7.1	28.6	64.3
H. Increase waiting areas and gatherings spaces which their smaller size	7.1	7.1	21.4	28.6	35.7
I. Using washable, self-cleaning, air-purifying and antibacterial materials for all internal and many external surfaces	0	0	7.1	28.6	64.3
J. HVAC and Building Services Systems provide security	0	0	0	50	50

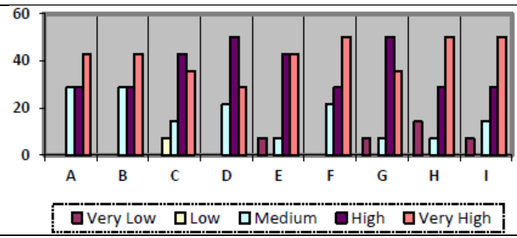


Indicators leading to design success	Very low	Low	Medium	High	Very high
Enhance Wellbeing and healing					
A. Achieve the necessary human requirements for users	0	0	7.1	21.4	71.5
B. Location with external views: green space and good natural views	0	0	14.3	14.3	71.4
C. The orientation and shape of the building blocks are designed to maximize rooms facing daylight and natural ventilation	0	0	7.1	21.4	71.5
D. Physical access to nature to help recovery through accessible gardens	0	0	7.1	21.4	71.5
E. Generate non-stressful environments	0	0	14.3	21.4	64.3
F. Building cluster social interaction spaces	0	7.2	21.4	50	21.4



Indicators leading to design success	Very low	Low	Medium	High	Very high
Adapt to the emerging procedures					
A. Achieve a higher level of flexibility	0	0	28.6	28.6	42.9
B. Availability a wider field of reuse of more rooms, areas and units	0	0	28.6	28.6	42.9
C. Easy to link and adjust modular mechanical and electrical systems	0	7.1	14.3	42.9	35.7
D. Allows functional spaces to be easily re-converted and equipped	0	0	21.4	50	28.6

E. Converting the usual patient rooms or a complete unit to isolation rooms and isolation zones	7.1	0	7.1	42.9	42.9
F. Individual rooms fully-equipped to be converted into double rooms	0	0	21.4	28.6	50
G. The ability of the design building form to help easy for the extension	7.1	0	7.1	50	35.7
H. the unhealthy spaces are to be prepared to allow converting them during crisis	14.3	0	7.1	28.6	50
I. Providing more outdoor spaces to host potential temporary structures	7.1	0	14.3	28.6	50



6. CONCLUSIONS

In the early 2020, Corona pandemic began to spread worldwide. This highlighted the importance of providing a suitable built environment to limit the spread of infection. Thus, infection control inside hospitals became a priority.

The researcher conducted a set of questionnaires and questions divided into two sections. The first section discusses the extent of the presence of design indicators in the current situation of the hospital building, as well as the importance of their presence in focusing on current problems during the crisis. The second section discusses the indicators of hospital design success in the future.

The findings of the surveys proved the significance of the strategies. The research focuses on the design of a future hospital following Corona pandemic which it is stated as follows:

- The first strategy is based on indicators of spacing, separation and distribution and also achieve human aspects through a natural approach to physical and mental health, taking into account the social network support for users of health care buildings. To avoid negative psychological effects.
- The second strategy is based on adaptation and reshaping indicators in the hospital design process, from building systems to functional and environmental units, to adapt to the new procedures that overlap with the building, or to be used in the long term for alternative purposes to immediately respond to the emerging situations.
- The third strategy is based on engineering controls indicators in design to increase air technology systems, change the specifications of buildings, provide an ideal natural ventilation system and more natural light, control humidity and bacteria accumulation, and use infection control units to sanitize the air.

In the end, this crisis has contributed to highlighting the importance of the presence of several newly developed design measures to combat infection in health care buildings. This study presented the strategies expected in the design of hospitals as a result of the dynamics of the pandemic while preserving the humanitarian aspects of reducing tension, stimulation and response to treatment. This leads the way to developing an integrated approach for evaluation and action which helps to apply more of these strategies.

REFERENCES

[1] Megahed, N.A., Ghoneim, E.M. (2020). Antivirus-built environment: Lessons learned from COVID-19 pandemic. Sustainable Cities and Society, 61: 102350, https://doi.org/10.1016/j.scs.2020.102350

[2] World Health Organization. (2020). Coronavirus disease 2019 (COVID-19): Situation report, 51. https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200311-sitrep-51-covid-19.pdf?sfvrsn=1ba62e57_10, accessed on Aug. 30, 2020.

[3] World Health Organization. (2020). Ensuring a safe environment for patients and staff in COVID-19 health-care facilities: A module from the suite of health service capacity assessments in the context of the COVID-19 pandemic: Interim guidance, 20 October 2020 (No. WHO/2019-nCoV/HCF_assessment/Safe_environment/2020.1). World Health Organization.

[4] Capolongo, S.G. (2020). A decalogue of design strategies for resilient hospitals, Acta Biomed. COVID-19 and Healthcare Facilities, 91(9): 50-60. https://doi.org/10.23750/abm.v91i9-S.10

[5] Flood, J., Shingleton, J., Bennett, E., Walker, B., Amin-Chowdhury, Z., Oligbu, G., Avis, J., Lynn, R.M., Davis, P., Bharucha, T., Pain, C.E. (2021). Paediatric multisystem inflammatory syndrome temporally associated with SARS-CoV-2 (PIMS-TS): Prospective, national surveillance, United Kingdom and Ireland, 2020. The Lancet Regional Health-Europe, 3: 100075. https://doi.org/10.1016/j.lanepe.2021.100075

[6] COVID-19. (2020). CDC Centers for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html, accessed on July 14, 2021.

[7] Social distancing, Annuals of Internal Medicine. (2020). Centers for Disease Control and Prevention; https://www.usatoday.com/in-depth/news/2020/03/16/social-distancing-coronavirus-isolation-quarantine-pandemic-virus-infection-symptoms/5019940002/, accessed on Mar. 17, 2020.

[8] Ouf, T.A., Makram, A., Abdel Razek, S.A. (2021) Design indicators based on nature and social interactions to enhance wellness for patients in healthcare facilities.

In: Trapani F., Mohareb N., Rosso F., Kolokotsa D., Maruthaveeran S., Ghoneem M. (eds) Advanced Studies in Efficient Environmental Design and City Planning. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham. https://doi.org/10.1007/978-3-030-65181-7_36

[9] Diamond, F. (2020). Q&A: Design hospitals to best fight infections like COVID-19. Infection Control Today Journal. https://www.infectioncontroltoday.com/view/qa-design-hospitals-best-fight-infections-covid-19, accessed on May 22, 2020.

[10] Eastwood, T. (2020). Pandemic preparedness: How hospitals can adapt buildings to address worst-case scenarios. Canadian Architect Magazine. https://www.canadianarchitect.com/pandemic-preparedness-how-hospitals-can-adapt-buildings-to-address-worst-case-scenarios/, accessed on Apr. 7, 2020.

[11] Honey-Roses, J.A. (2020). The impact of COVID-19 on public space: An early review of the emerging questions – design, perceptions and inequities. Cities & Health.

[12] Ahmed, Z. (2020). Architecture After the COVID-19 pandemic: Re-imagining our world. Energy & Power Magazine. https://www.academia.edu/43403039/Architecture_After_The_Covid_19_Pandemic_Re_Imagining_Our_World, accessed on June 22, 2020.

[13] Honey-Rosés, J., Anguelovski, I., Chireh, V.K., et al. (2020). The impact of COVID-19 on public space: An early review of the emerging questions–design, perceptions and inequities. Cities & Health, 1-17. https://doi.org/10.1080/23748834.2020.1780074

[14] Rantanen, A., Kaunonen, M., Åstedt-Kurki, P., Tarkka, M.T. (2004). Coronary artery bypass grafting: social support for patients and their significant others. Journal of Clinical Nursing, 13(2): 158-166. https://doi.org/10.1046/j.1365-2702.2003.00847.x

[15] Cousins, S. (2020). Rethink: How will COVID-19 affect healthcare design? The RIBA Journal, Architecture Information & Inspiration. https://www.ribaj.com/intelligence/future-of-healthcare-design-in-post-pandemic-world, accessed on June 24, 2020.

[16] Waite, R.P. (2020). How will COVID-19 change the design of health facilities? Architects Journal. https://www.architectsjournal.co.uk/news/how-will-covid-19-change-the-design-of-health-facilities, accessed on May 28, 2020.

[17] Guarino, M. (2020). A designated area is set up for coronavirus patients in the ambulance bay at Rush University Medical Center in Chicago. The Washington Post. https://www.washingtonpost.com/health/2020/04/09/rush-hospital-coronavirus, accessed on April 9, 2020.

[18] Perkins &Will. (2020). This Is What Rush Was Built For. https://perkinswill.com/news/this-is-what-rush-was-built-for/, accessed on March 11, 2020.

[19] Makram, A., Abou Ouf, T. (2010). The Future Hospital in 21st century – Sustainable Hospital. The 7th International Conference, Mansoura University, Sharm El –Sheikh.

[20] Makram, A., Abou Ouf, T. (2010). The future hospital in 21st century – sustainable hospital. The 7th International Conference, Mansoura University, Sharm El –Sheikh.

[21] Babbu, A.H. (2016). Flexibility": A key concept in hospital design. International Journal of Application or Innovation in Engineering & Management., 5(5): 24-28.

[22] El Batsh, M. (2020). As hospitals overflow, Haifa's Rambam transforms parking lot into virus ward. https://www.timesofisrael.com/as-hospitals-overflow-as-haifas-rambam-transforms-car-park-into-virus-ward/, accessed on Sept. 24, 2020.

[23] Chartier, Y., Pessoa-Silva, C.L. (2009). Natural Ventilation for Infection Control in Health-Care Settings. Geneva: Wold Organization.

[24] Emmanuel, U., Osondu, E.D., Kalu, K.C. (2020). Architectural design strategies for infection prevention and control (IPC) in health-care facilities: towards curbing the spread of COVID-19. Journal of Environmental Health Science and Engineering, 18(2): 1699-1707. https://doi.org/10.1007/s40201-020-00580-y

[25] Sethi, P., Sarangi, S.R. (2017). Internet of Things: Architectures, Protocols, and Applications. Journal of Electrical and Computer Engineering, 2017: 9324035. https://doi.org/10.1155/2017/9324035

[26] ASHRAE. (2020). Ashrae Epidemic Task Force. Filtration & Disinfection. ASHRAE. https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-filtration_disinfection-c19-guidance.pdf, accessed on Oct. 21, 2021.

[27] Arundel, A.V., Sterling, E.M., Biggin, J.H., Sterling, T.D. (1986). Indirect health effects of relative humidity in indoor environments. Environmental Health Perspectives, 65: 351-361. https://doi.org/10.1289/ehp.8665351

[28] Wargocki, P., Kuehn, T.B.B., Muller, C., Conrad, E. (2021). ASHRAE position document on filtration and air cleaning. ASHRAE, Atlanta. https://www.ashrae.org/file%20library/about/position%20documents/filtration-and-air-cleaning-pd-feb.2.2021.pdf, accessed on Feb. 2, 2021.