International review for spatial planning and sustainable development, Vol 10 No.4 (2022), 29-54
ISSN: 2187-3666 (online)

DOI: http://dx.doi.org/10.14246/irspsd.10.4_29

Spatial Adaptation for Alternative Care Facilities during the Covid-19 Pandemic:

Siting Field Hospitals for Abu Dhabi City

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Received: *April 15, 2021;* Accepted: *July 24, 2022.*

Keywords: Spatial Adaptation, COVID-19, Field Hospital, Resilience, Abu Dhabi

Abstract: During the ongoing COVID-19 pandemic, healthcare systems around the world have had their limited surge capacity rapidly overwhelmed. In such a situation, pandemic risk reduction necessitates the employment of one or more alternative care sites (ACSs). This paper aims to investigate the siting of deployable field hospitals to reduce pandemic risk and support the staff involved in direct patient care. The present study used multiple case studies of space conversions and field hospitals in several countries. Informed by the existing literature, these cases shed light on their healthcare system responses to COVID-19 and allowed for a comparative analysis. Based on the case studies, the authors propose two ACSs in Abu Dhabi City: one in an urban setting and another in a suburban area. The authors identified expansive spaces and adaptable buildings according to a set of primary criteria, including the required level of structural alterations, budget, and time. The selected sites/buildings could be transformed into field hospitals to respond to the pandemic and/or disaster risk reduction whilst boosting critical care surge capacity. Devising such measures in siting field hospitals as ACSs would eventually enable Abu Dhabi's (and the United Arab Emirates') healthcare system and institutions to become more resilient in adequately responding to unprecedented demand and/or sudden disruptions to healthcare operations in the future.

1. INTRODUCTION

The coronavirus 2019 (COVID-19) has wreaked havoc throughout much of the world, bringing into question the resilience of healthcare facilities and critical care systems. In their attempt to explain the term "resilient city", Pickett, Parker et al. (1992) and Pickett, Cadenasso et al. (2004) approached the "metaphor" of resilience by presenting two opposing definitions: one group described it as the ability of systems to return to their stable equilibrium point after a disruption, whereas the other viewed resilience as the capacity of a system to adapt and adjust to changing internal or external processes. Thus, both definitions tackle resilience from the perspective of regaining control, whether adapting or returning to a stable state. Resilience is an issue of increasing importance not only to city managers and policymakers but also to their constituents and other stakeholders operating in urban areas. They all play a vital role in urban resilience "through their capacity for active learning, robustness, ability to innovate and adaptability to change" (Mehmood, 2016).

Due to the sudden outbreak of COVID-19, cities lacking resilience were woefully unprepared for the pandemic response and thus at a considerable disadvantage. This inadequacy is due to medical supply shortages and overflow in hospitals (OCHA, 2021). One of the most apparent reasons for COVID-19 posing a substantial health threat on a global scale, especially before lockdown measures were implemented, was the highly disproportionate number of infected patients to cities' hospital bed capacities (Sagan, Webb et al., 2021). This situation became more pronounced in terms of the infected population's need for intensive care unit (ICU) admission. Therefore, field hospitals were created to help manage emergency room overflow by setting up medical tents, adapting existing buildings (e.g., hotels, stadiums, and gymnasiums) to medical standards, or by transforming non-sanitary facilities that could be geared up via low-budget outfitting (e.g., converted underground parking area of a hospital). Nevertheless, these examples may carry some limitations due to their distance from the main hospital facilities (Capolongo, Gola et al., 2020).

Modular construction and prefabricated systems (e.g., shipping containers) have also been used to build temporary hospitals and provide space for post-catastrophe recovery in a short span of time and within budget (Smolova and Smolova, 2021). However, when space is lacking, the possibility of transforming an existing building into a field or temporary hospital should be considered to provide adequate comfort to patients. According to (Megahed and Ghoneim, 2020), adaptive reuse is a sustainable approach that could become advantageous if combined with other advanced technologies in the construction sector.

Nonetheless, the COVID-19 outbreak was a wake-up call for the world. The pandemic has exposed how ill-equipped health sectors are and has laid bare weaknesses in many countries' emergency response systems. This has caused dissonance with the United Nations Sustainable Development Goals, resulting in calls for their accelerated implementation (OCHA, 2021). The present study considers requirements that would enable cities to evade medical disasters as significant as COVID-19 without interruptions to basic services—in essence, the making of resilient cities.

This paper aims to investigate the siting of deployable field hospitals to respond to a pandemic and/or disaster, risk reduction and the boosting of critical care surge capacity based on structure and design considerations. Ultimately, this paper endeavours to promote the development of resilient hospitals and public facilities to reduce pandemic risk and support the staff involved in direct patient care by addressing capacity, safety, and risk challenges for a resilient health sector in Abu Dhabi.

2. METHODOLOGY

First, to comprehend the nuance of a rapidly evolving topic, the methodology consisted of a broad review of published, peer-reviewed investigations and essays that referred to healthcare physical built environment factors such as field hospital design and layout as well as patient and staff needs, including infection and disease control, stress, privacy, and COVID-19.

Second, four case studies from cities worldwide are presented, which offer a useful model for controlling infectious disease through the employment of field hospitals following adaptive reuse approaches. The selected case studies originated from the United States, Singapore, China, and the United Arab Emirates (UAE). All four cases were analysed and compared according to the leading cause of virus transmission. Moreover, we identified the strengths and weaknesses of both community- and government-related spaces that were transformed for COVID-19 treatment.

Third, based on the case studies, the authors conducted a thorough analysis of the field hospital conversion criteria, which includes the primary considerations for planning and the physical requirements of field hospitals.

Fourth, the authors proposed and assessed two sites in the city of Abu Dhabi that could be spatially adapted to serve as field hospitals and provide emergency solutions. The established criteria were applied to the Al Muroor (urban district) and Al Ma'ared (suburban district) neighbourhoods. The authors chose facilities that were within a 2.5-km radius of a hospital. A multi-type selection of buildings was assessed based on their capacity, distance and the availability of vital facilities for a field hospital or alternative care site (ACS).

Finally, one optimal facility from each area was chosen to compare the selections by applying the primary considerations for planning and the physical requirements of field hospitals. The analysis will examine the availability of the requirements based on the Preparedness Assessment Tool and supplement them with necessary modifications.

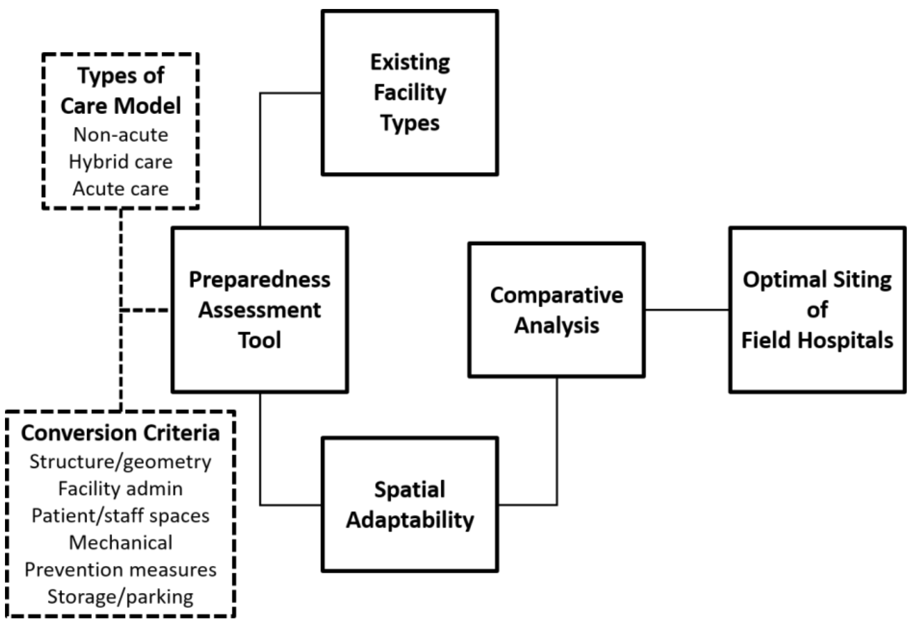

Figure 1. Conceptual framework

Assessing the feasibility of adapting existing facilities to field hospitals by applying a set of criteria creates a framework (*Figure 1*), which can lead to the selection of optimal sites in the included areas. The criteria were developed by the American Institute of Architects' COVID-19 Task Force 1 in the Coronavirus Disease (COVID-19) Alternative Care Sites Preparedness

Assessment Tool V2.0—hereafter referred to as the "Preparedness Assessment Tool", or "ACS-PAT" (AIA COVID-19 Task Force 1, 2020a).

3. CASE STUDIES

This section presents the analysis of case studies from various parts of the world representing different geographical locations (North America, Asia and the Middle East), namely New York City, Singapore, Wuhan and Sharjah. These locations were selected based on their history and experience in dealing with pandemics (e.g., Wuhan, China), the variety of field hospitals and space transformations during the COVID-19 pandemic (e.g., the use of a Navy ship in New York City), and their positive experiences in the deployment of field hospitals while considering the varying levels of risk confronting each city (e.g., logistics, technology, community response, culture, economy, government response, etc.). A comparative study is provided at the end.

3.1 New York City, USA

The United States suffered a huge toll from the pandemic. It still has the highest mortality figure due to COVID-19 of anywhere in the world. In addition to its failure to respond in a "sustained, proactive way" nationwide, "much of the responsibility has fallen on the individuals". The rate of vaccination and booster have been quite low despite warnings (Schreiber, 2022).

New York City has been the epicentre of the COVID-19 outbreak in the U.S. Earlier in the pandemic, the reported cases exceeded 38,000, with 914 fatalities (Lorenzo, 2020). At that time, a total of around 53,000 hospital beds with 3,000 ICU beds were available across the state of New York. At that point, the governor authorised hospitals to increase their capacities by 50%, while hospitals with the ability to increase capacity by 100% could add 5,000 more beds (Lardieri, 2020). However, adding more beds to hospitals was not the only solution to accommodate patients. Four temporary facilities were established in downstate New York that would accommodate approximately 4,000 beds. Those four field hospitals were to be added in Bronx, Queens, Brooklyn, and Staten Island, centralised in the heart of New York City, which was mainly due to the high number of cases in those areas (Lardieri, 2020)

Figure 2. City College dorms-top four, (City University of New York (CUNY)) and Queens College dorms-bottom two (Queens College (n.d.))

The choice of ACSs focused on large open spaces that would decrease the load on hospitals (Queens College (n.d.)). Therefore, they concentrated on transforming dorms in universities such as City University of New York's (CUNY) City College (City College (n.d.)) and Queens College (Queens College (n.d.)) into temporary field hospitals (*Figure 2*). Moreover, hotels and convalescent care facilities were considered transformable sites, with examples including the Marriott Brooklyn Bridge Hotel and the Brooklyn Nursing Home.

The city attempted to transform every available type of large space to the extent of having a Navy medical ship, the USNS Comfort (with 1000 beds) dock in Manhattan (Lorenzo, 2020). The vessel also carried on board 1,200 medical staff along with 12 operating rooms, a pharmacy, and several labs. Other temporary medical facilities (*Figure 3*) were constructed in both the Brooklyn and Javits Convention Centres (Lardieri, 2020).

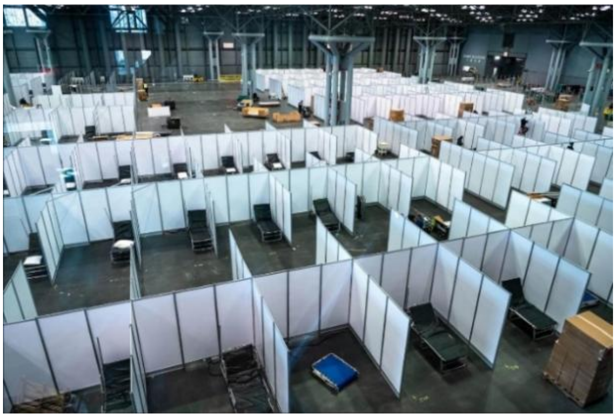

Figure 3. Javits Convention Centre (Lopez, 2020)

In March 2020, the international relief organisation known as Samaritan's Purse set up an emergency field hospital in Central Park in consultation with Mount Sinai Hospital (*Figure 4*). It was equipped with 68 patient beds and 72 health care staff that assisted in operating the facility

(Lorenzo, 2020). This customisable hospital has been designed to respond to the unique situation and needs of residents of the pandemic-stricken area. At full capacity, the field hospital would span almost half a hectare and include elements including an emergency room, lab, ultrasound imaging and digital x-ray capabilities, two operation rooms, a surgical sterilisation tent, critical care unit and over 50 inpatient beds (Samaritan's Purse, 2020).

Figure 4. Samaritan's Purse emergency field hospital- site (Samaritan's Purse, 2020)

Another field hospital was erected on the campus of Stony Brook University to gear up for another coronavirus wave (Sisak, 2020). It offered students who needed to quarantine for 14 days a housing unit before moving into their assigned on-campus accommodation (*Figure 5*). The utilisation of campus grounds turned out to be an excellent opportunity and a wise decision since some of the spaces were already in lockdown mode. Furthermore, the university offered drive-through COVID-19 testing located at the university's south parking, which is accessible not only to students but also to the community at large (Stony Brook University, 2020).

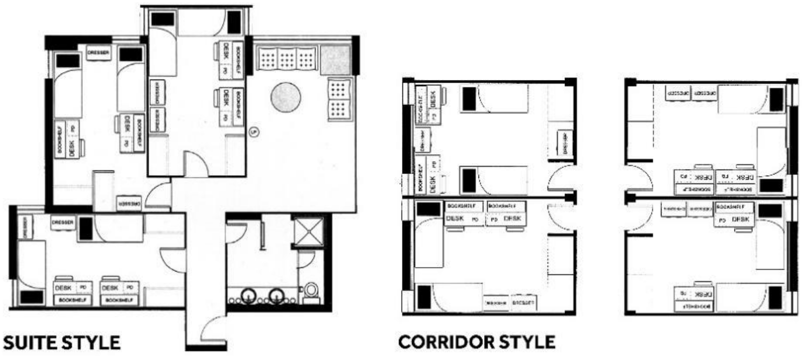

Figure 5. Stony Brook dorm styles (Housing: Campus residences (n.d.))

New York City has been experiencing difficulties in handling the spread of COVID-19; however, there is an ostensible effort to secure as much space as possible to help mitigate the harm. To ensure the safety of citizens, the authorities have been taking advantage of vacant areas around the city to help control the outbreak and identify locations for establishing field hospitals. Moreover, New York Domino Park implemented social distance circles for people to enjoy public spaces. The individuals can sit in circles drawn on the grass to help maintain social distancing (Eltarabily and Elghezanwy, 2020).

In New York City, Mount Sinai Hospital is a prime example of successfully implementing an impromptu spatial redesign. They managed to absorb the overflow of patients during the outbreak, enforced infection control practices and enacted safety and protection measures. Also, several actions were taken to repurpose the spaces for COVID-19. The transformation occurred across three units, including an adult ICU, an adult medical-surgical unit, and a paediatric unit. Designers recorded active COVID-19 units through GoPro action cameras attached to clinicians and conducted Zoom video conferencing with the staff. In this manner, practitioners, designers, and researchers were able to understand the limitations they faced, analysed spaces and devised design recommendations (MASS Design Group, 2020).

Mount Sinai Hospital implemented changes aiming to protect healthcare workers while accommodating all patients. For instance, the hospital developed a new shift system that reduced the amount of risk healthcare workers were exposed to during shift changes. In addition to setting up personal protective equipment (PPE) circulation and reuse frameworks, proper donning/doffing rehearsals and executing telehealth services were used. Telehealth services include holding virtual meetings with doctors via video conferencing, online communication through texting, email and secure file exchange, and remote monitoring in which doctors can virtually check on their patients at home (HRSA, 2022). Furthermore, the hospital converted the atrium space into a step-down unit consisting of 100 beds (*6*) and repurposed the outdoor space to assemble a temporary tent facility consisting of 68 beds (MASS Design Group, 2020).

Figure 6. Mount Sinai Hospital's 100-bed step-down care unit in the atrium (MASS Design Group, 2020)

Other spatial modifications were also made, such as transforming 260 existing patient rooms into negative air pressure rooms (Heffernan, 2020). The negative air pressure system was achieved by enclosing formerly open ICU bays by using walls and doors and installing tightly sealed high-efficiency particulate air (HEPA) filters (*Figure 7*) known to efficiently control airborne contaminants and even capture COVID-19 viruses found in droplets of saliva or mucus (American Society of Heating, 2021; Heffernan, 2020). Additionally, patient monitors, intravenous (IV) fluids, medical equipment and dustbins were placed in hallways to reduce unnecessary exposure to workers while enabling more secure and simple observation.

Furthermore, each unit contained exclusive spaces for PPE and medical waste. Plans were made to bring the waste to dedicated service elevators to reduce cross-contamination (MASS Design Group, 2020).

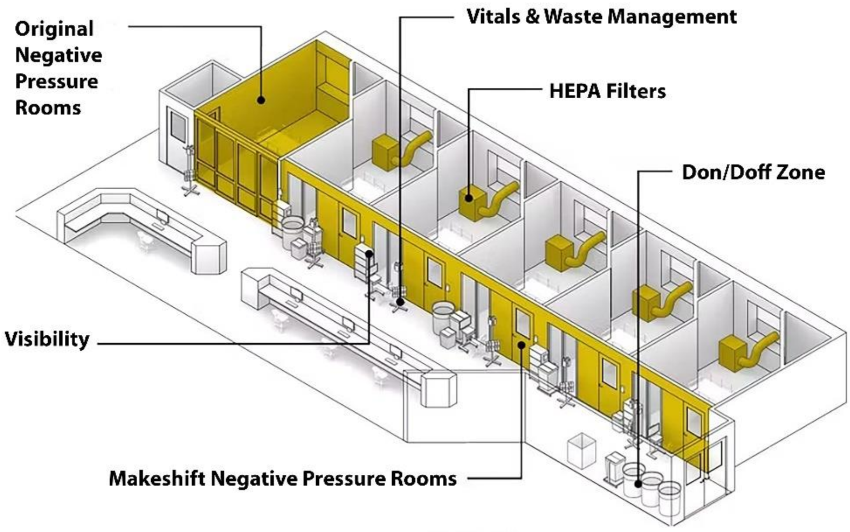

Figure 7. Alterations made to Mount Sinai Hospital's Guggenheim Pavilion rooms (MASS Design Group, 2020)

3.2 Singapore

Singapore has experienced two major COVID-19 outbreaks. The first outbreak occurred in migrant workers' dormitories, in which more than 55,000 workers tested positive. However, a recent study confirmed that more than 150,000 workers contracted the virus (Willis, 2021). Remarkably, when the second wave hit the country, the number of cases was much lower than those recorded during the first wave that affected the labour quarters (Willis, 2021).

During the COVID-19 outbreak, many hospitals around the world were overflowing with COVID-19 cases and could not admit any more patients. As a result, many countries used a variety of large spaces to treat these patients. In the case of Singapore, the government dedicated four expo halls for COVID-19 patients. Moreover, six other halls were converted into temporary spaces to deal with incoming patients. Notably, two of the halls were combined to accommodate 950 patients (Eber, 2020). Additionally, the Changi Exhibition Centre (*Figure 8*) can facilitate 2,800 occupants and the Tanjong Pagar Terminal can be occupied by 15,000 patients, according to the Prime Minister office. Moreover, the Changi Exhibition Centre is ideal because it is located near the Singapore airport and is a reasonable distance from the city (Eber, 2020).

Figure 8. Singapore Expo Convention Hall and Exhibition Centre in Changi (Eber, 2020)

As of August 2021, Singapore has dedicated more hotels to quarantining people, resulting in the country having over 90 hotels that could accommodate people from other countries, as well as individuals who have been in contact with a positive case. Moreover, other spaces such as government training facilities, schools and holiday homes were used for people to quarantine (Chua, 2021).

In 2020, the "COVID-zero" strategy was adopted by Singapore to thwart the pandemic. The government issued travel restrictions, lockdowns, and quarantine measures to help decrease the number of cases (Willis, 2021). A year later, Singapore is gradually reopening as the number of vaccinated citizens is getting higher. Singapore strove to end all restrictions and reopen for normal business once 80% of the country's population is vaccinated. However, citizens can only travel to two countries with low COVID-19 cases: Brunei and Germany. Restaurants also have to close by 10:30 pm, wearing masks is mandatory and tracking applications are still used during travel (Willis, 2021). Despite these strict rules and restrictions, Singapore is likely to overcome the pandemic faster than most Asian countries.

The country struggled with reopening since the new Delta variant spread much faster in comparison with other variants. By July 2021, 76% of the population in Singapore was vaccinated, which was enough for cancelled events to be rescheduled later in the year (Willis, 2021).

3.3 Sharjah, UAE

Since the beginning of the COVID-19 crisis, the UAE has shown resilience through its pandemic management and risk reduction, thereby becoming exemplary in readiness and adaptability. Health authorities continue to ensure the safety and wellbeing of the nation by inaugurating field hospitals throughout the seven emirates, one of them being the Sheikh Mohamed Bin Zayed field hospital in Sharjah. The hospital was built within 10 days and spans over 7000 sqm. It has a total of 204 beds, with 48 reserved for intensive care patients and 156 for those in moderate condition (Godinho, 2021).

The facility is managed by 75 doctors, 231 nurses, 44 technicians and health care workers. The hospital is also equipped with its own laboratory, pharmacy, and radiology department, all of which use the latest technological advancements. The Emergency Crisis and Disasters Committee was sure to provide exceptional medical equipment for health care workers, such as the latest devices to prepare injections, antibiotics and any treatment that may be required for treating COVID-19 patients (SGMB, 2021). The hospital provides treatment 24/7, with patients being situated in a comprehensive healthcare unit until they are fully recovered.

3.4 Wuhan, China

Huoshenshan Hospital was built as an initiative to combat the COVID-19 crisis. This is an emergency field hospital that spans an area of 60,000 sqm with 30 intensive care units. It was built within 10 days (January 23rd to February 2nd) to mitigate the outbreak of the virus. According to Yunfei and Liwen (2021), the 1,000-bed treatment centre houses a crew of 1,400 doctors and nurses. Huoshenshan hospital based its blueprints on Xiaotangshan Hospital in Beijing, which was built within the duration of the 2003 SARS outbreak. Although there were many similarities in the plans of the hospitals, Huoshenshan Hospital has unique features to accommodate the specifics of the coronavirus and the local conditions of the city (Yunfei and Liwen, 2021).

Also, to prevent any further spread of COVID-19, the ventilation system had to be carefully designed (*Figure 9-left*) to allow the airflow from the wards to be collected and disposed of appropriately (Yunfei and Liwen, 2021). Ventilation can help improve indoor air quality by reducing any potentially infectious COVID-19 droplets.

Figure 9. Huoshenshan Field Hospital ventilation system-*left (*Mcdonald, 2020*)* and blue anti-seepage membrane-*right* (Zhang, 2020)

Furthermore, the air pressure differences between the wards and the nurses' stations had to be carefully considered to eliminate the risk of infecting the medical staff (Yunfei and Liwen, 2021). Moreover, the location of the hospital posed a new issue since it was built near Lake Zhiyin. Since the designers had to ensure that no medical waste would contaminate the lake or land, the construction team installed an anti-seepage membrane (*Figure 9-right*) to separate the hospital from its surrounding environment (Yunfei and Liwen, 2021).

3.5 Comparative analysis of case studies

Cities that acted swiftly and managed to assess their capacity with the infection rate were able to build their ACSs in a short span of time. This allowed for risk mitigation and the control of potential pandemic threats to public health. Therefore, understanding the criteria needed for ACSs will facilitate feasibility assessments to convert facilities into ACSs and ensure that cities are better poised to adopt an effective pandemic preparedness strategy.

Having conducted a comparative analysis across the four case studies (*Table 1*), we realise how each city offered a unique approach to dealing with the critical care surge caused by the pandemic; however, certain *challenges* abound, which expose varying degrees of resiliency. For example, New York City (the epicentre of the pandemic in the USA) lacked adequate accommodation and forced many minimum wage workers to attend work amidst the pandemic while risking their health—and the health of those around them—for fear of homelessness. Also, large numbers of Sharjah's migrant workers—especially those in the construction sector—recorded the highest reported number of cases due to the nature of their work and poorly ventilated accommodation (Alsuwaidi, Al Hosani et al., 2021). In Singapore, widespread panic swelled at the beginning of the pandemic, which led to people with the mildest of symptoms being admitted to hospitals, resulting in patient overflow (Shorey, Ang et al., 2020). Additionally, dorm-style housing in the COVID ground-zero city of Wuhan led to the increased spread of the pandemic in the region and made it difficult for the occupants to properly practice social distancing (Kumar, Singh et al., 2021).

Notably, the *coping strategies* used in different countries also varied. The government of the state of New York transformed open spaces into field hospitals. While ICU beds were imported due to patient overflow, medical equipment was in short supply. In Singapore, the government issued many rules (e.g., curfews and travel restrictions) and a "COVID-zero" strategy was introduced to see an end to the pandemic. The citizens observed the rules by wearing masks and observing curfews, while the city-state also had one of the highest vaccination rates in the world (Ray, 2021).

Meanwhile, in Sharjah, several policies were introduced, such as curfews, remote working, and sterilisation programmes to reduce the spread of the disease. Other precautionary measures include drive-through testing, vaccination centres, imposing harsh fines for violators, quarantining, and the implementation of safe distancing rules. Additionally, the government suspended prayers in all places of worship. The UAE has also devised a comprehensive nationwide testing strategy that identifies new cases early on and minimises the spread of the virus through the Al Hosn app (Reynolds, 2021). The UAE population has generally been extremely compliant with the COVID-19 rules and regulations. However, the government of Wuhan focused on tracking down the source rather than trying to limit the spread of the virus (Liu and Saltman, 2020). The immediate response came in the form of setting up field hospitals. However, people were unaware of the virus, which causes a pneumonia-like illness. Eventually, the government was criticised for concealing information about the outbreak in its early stages and downplaying its severity, which led to the population being less vigilant (BBC, 2020).

While some cities chose to place their field hospitals in suburban areas (e.g., Singapore), other cities (e.g., New York) established them in urban areas. However, all the case studies demonstrated the same types of spaces being transformed and converted into field hospitals, such as exhibition halls at convention centres, stadiums, terminals, schools, training facilities and large-capacity buildings with or without bedding facilities (e.g., university dorms, nursing homes, hotels, etc.). The conversion of a Navy ship in New York City potentially represents a novel case.

Table 1. Comparative analysis across the case studies

City	Challenges (response rate, capacity/pop. density)	Governance initiatives	Types of spaces converted for COVID-19 purposes
New York, New York	Lack of accommodation for minimum wage workers forced them to attend work, which posed a health risk.	Transforming spaces into field hospitals. Exported ICU beds due to patient overflow. Lack of medical equipment.	University dorms Hotels Nursing homes Navy ship
Singapore	Panic at the outset led to cases with the mildest of symptoms being admitted to hospitals. Patient overflow.	Rules issued and observed (e.g., curfews and travel restrictions). The “COVID-zero” strategy was used to end the pandemic. Highest vaccinated population.	Hotels Expo halls Schools Holiday homes Training facilities Community centres Terminals
Sharjah, UAE	Highest number of cases was amongst migrant workers.	COVID-19 rules and regulations. Comprehensive, nationwide testing using the Al Hosn app. Population was extremely compliant. Drive-through testing, vaccination centres.	World Trade Centre Exhibition halls Stadiums
Wuhan, China	Dorm-style housing made it difficult to practice social distancing, which led to the spread of disease.	Focus on tracking down the source rather than limiting the spread of the virus. Immediate deployment of field hospitals. People were unaware of the virus. Government was criticised for not being transparent.	Sport stadiums Exhibition halls Exhibition centres Cultural complexes

4. FIELD HOSPITAL PLANNING

With the spiralling number of COVID-19 patients, the available medical supply has been outstripped and spaces are being considered to be repurposed as temporary hospitals or field hospitals. Modern hospitals lack the flexibility to accommodate a sudden surge of patients. Thus, many hospitals struggled to meet the unexpected and abrupt demand for emergency treatment and ICU beds for infectious illnesses in a short period of time (Capolongo, Gola et al., 2020). However, spaces such as schools, hotels, convention centres, arenas and exhibition halls can be converted into field hospitals to accommodate patients after some modification to meet certain medical standards and achieve high hygiene performance.

When planning for the deployment of field hospitals, several aspects must be considered, including site selection, physical structure and mobility, infection prevention and control measures, selection and training of staff, adequate capacity, and management of information sharing (Bar-On, Peleg et al., 2020).

4.1 Primary considerations

When searching for a potential site for a field hospital, a city must first determine the hospital setting and type of field hospital model to follow. Based on the Preparedness Assessment Tool, three types of field hospital models exist. These include non-acute care, hybrid care and acute care models. These models will be selected based on several variables (see *Table 2*).

Table 2. Types of care models for field hospitals

Model	Purpose	Structural change	Budget	Timeline	Treatment type
Non-acute care model	Increase beds	Minimal alterations	Low cost	Few days	General/low-level care
Hybrid care model	Increase beds and ventilators	Moderate changes	Moderate cost	Few days	Mid-level care
Acute care model	Increase ventilators	Significant modifications	High cost	Days/weeks	ICU care

4.2 Physical requirements for field hospitals

Any field hospital requires sufficient services and resources that are designed to meet immediate medical needs. These would help in reducing cross-contamination, performing all types of surgery, maintaining a high-quality environment, and providing continuous patient and intensive care. Health services would include patient wards, an ICU, operating room, radiology services, laboratory, examination rooms and pharmacies. Alternatively, supporting services should comprise a power generator and distribution systems, standalone HVAC systems, a kitchen, clean water storage and wastewater treatment, medical and general waste disposal, a thermal camera, closed-circuit cameras, self-disinfection gates, as well as water closets (WCs) and break rooms exclusively for medical staff (Bricknell, 2001; Reed and Lushniak, 2020).

4.3 Converting existing structures into a field hospital

Transforming existing buildings into field hospitals would typically require 10–14 days (Brady, 2020; Mcdonald, 2020). A study conducted by the international design firm HKS (2020), concluded that hotels and schools can be quickly converted into hospitals. Given the proper resources and crew, the aforementioned conversion timeline would be feasible (Brady, 2020). According to Chrisman, Kazenberger et al. (2020), the following types of structures ensure the successful conversion of existing buildings into COVID-19 hospitals.

4.3.1 Large-capacity venues

Large-capacity venues (e.g., convention centres, arenas, and auditoriums) are good candidates for conversion to field hospitals. For instance, convention centres, are, by definition, designed to provide flexible multipurpose spaces; therefore, they are suitable to house temporary healthcare facilities. Moreover, convention centres typically have multiple entry points. These entry points could be converted for specific and limited uses. For instance, one entry point could be for emergency responders and staff, another could be for family access and registration, and another could serve as a screening or triage station.

Restrooms at convention centres also offer the capacity needed if isolation is not required. However, if isolation is a requirement, additional restrooms should be provided (Chrisman, Kazenberger et al., 2020).

Convention centres also offer fully equipped kitchens and commissaries, which are required in order to provide nutrition and meals to patients, staff/caregivers and families.

Structured and isolated deliveries can be achieved since these kitchens usually have service corridors and vertical transportation to the exhibit hall and meeting rooms/ballrooms. Although most convention centres have an efficient emergency generator, more studies may need to be conducted depending on the chosen convention centre (Chrisman, Kazenberger et al., 2020).

4.3.2 Hotel and dormitory rooms

Hotels are deemed suitable locations for temporary hospitals since they offer private rooms with bathrooms that can be used as isolation rooms. They also have existing technology that can allow patients to connect with their family and friends who cannot accompany them. Available food services would provide for patients and staff. Likewise, the aforementioned features would also apply to dorm rooms.

Notably, airflow and exhaust systems require consideration and modifications. To maintain negative pressure in the space, the exhaust systems of these facilities need to be upgraded. However, if this is not possible due to infrastructure challenges, an exhaust system with a HEPA filter could be installed and extended out of a window to ensure negative pressure in the room (Chrisman, Kazenberger et al., 2020). Concerning medical gas, a pipe system can be installed in the corridor and provided to each space. However, if this is not feasible, a bottled oxygen system may be installed.

Lastly, as previously mentioned, it is important to check whether any building used has an emergency generator. This system needs to be provided since it is crucial for patient care areas to have a continuous power supply for at least 24 hours in case of an emergency (Chrisman, Kazenberger et al., 2020).

4.4 Criteria for transforming existing buildings into field hospitals

Indeed, there are important aspects to consider when selecting adaptable structures. According to the ACS-PAT (AIA COVID-19 Task Force 1, 2020a), several criteria should be referred to when converting existing buildings to ACSs.

In terms of *basic components for the candidate structure*, building age, safety, floor area, municipal water supply and power generation are some of the most important considerations. Therefore, a building should be less than 20 years old and built according to contemporary codes. The structure should not be composed of a wood framing system since it is inappropriate for temporary healthcare operations. Moreover, the floor area must be sufficient to accommodate all necessary functions. Clinical procedures should also be capable of being safely performed with existing water conditions and pressures. An adequate number of grounded outlets should also be available.

Regarding *structure and geometry*, the existing structure must allow for additional live loads (i.e., the number of patients and staff in addition to medical equipment and furniture). Additionally, staff must be guaranteed ease in moving patients and medical equipment by assessing the layout (walls, doors, corridors, etc.). Staff must also be able to easily monitor patients. This would be accomplished by assessing visibility in mainlining sightlines in patient care areas.

There are also issues related to *facility-specific administration*, which should enable facility operators to maintain, monitor and manage the facility. These issues may include potential hazards, permanent/portable HVAC equipment, medical gas supplies and protocols to prevent contamination and bio-hazardous waste exposure. *Patient spaces* must also accommodate direct or remote patient monitoring (DPM/RPM). They must also provide patient seclusion and allow daylight to penetrate the patient space. Other considerations include the provision of toilets for patients, handwashing sinks for staff, connections for ventilators, IV poles, monitors, biohazard disposal, etc. Moreover, *nurse station spaces* must accommodate a documentation area for physicians and nurses, including a nurse's area, a cardiopulmonary resuscitation cart and a handwashing sink. In such facilities, *floor materials* such as carpets and rugs should be avoided and replaced with protective tape or non-porous flooring to decrease the risk of contamination and ease the cleaning process.

On the *mechanical* side, major considerations should include isolation and negative pressure, which can be achieved through maintaining negative pressure by using/creating airborne infection isolation rooms (AIIRs), locating exhaust near patients' beds when possible, ensuring that spaces are protected from cross-contamination and evaluating existing exhaust capacity, filtration, and air change rates. It may also be necessary to upgrade the exhaust system to maintain negative pressure. Other considerations include air changes and filtration allowing 10 air changes per hour (ACH), minimum efficiency reporting value (MERV-14) filters and the provision of HEPA filters. Furthermore, *power generators* must support life-sustaining medical equipment, the nurse call system, egress lighting, the fire alarm system, elevators, IT infrastructure and an automatic transfer switch. It is also important to install *Emergency Medical Service* (*EMS) communication* and secure a nurse call system to support patient care.

Infection and prevention control measures must be developed to include designated areas to store and dispose of PPE while placing sanitisation stations in the access points of the temporary hospital. Moreover, disinfectant and cleaning supplies should be available throughout the hospital for regular use. As a requirement for sanitised *storage rooms*, the facility should have an allowance for cooling rooms that offer refrigeration for medication and room-temperature spaces for supplies and other types of medication.

Finally, as per most health care facilities, emergency and supply truck *parking* spots need to be located near the selected site's entrances for immediate access.

5. ALTERNATIVE CARE SITE PLAN FOR ABU DHABI CITY

In the following sections, we propose an ACS work plan for assessing existing facilities and adapting them to offer emergency solutions in times of crisis. Analysing the preparedness of a city to withstand another pandemic requires locating potential healthcare sites that fit the aforementioned criteria. The analysis involves identifying two areas in the city: one urban, the other suburban. An investigation of potential sites for conversion ensues, which leads to choosing the optimal site for future consideration.

It is generally understood that suburban and urban areas may vary according to the types of facilities they offer and their residential capacity. In the case of urban areas, it is important to locate field hospitals in high-density areas that would help reduce the spread of disease since dense city centres are the most vulnerable (Capolongo, Gola et al., 2020). On the other hand, erecting field hospitals in suburban areas, which are known for their low density, would facilitate residents' access to medication and treatment. Acknowledging this difference will facilitate the decision to locate and select suitable and responsive ACSs that can meet shifting community needs.

Since each area type offers an array of facilities, it is important to focus on spaces that can be easily transformed and utilised (e.g., community and convention centres, fairgrounds, hotels, schools, stadiums, etc.).

This section discusses the selection process of candidate sites in the city of Abu Dhabi that could be spatially adapted to serve as ACSs. This process involves evaluating the feasibility of spatially adapting the existing facilities into field hospitals and then determining the optimal choice against a set of criteria, as illustrated in the "ACS-PAT". What follows is an exploration of design considerations to reduce risk and offer support to staff engaged in direct patient care by addressing capacity, safety, and risk challenges for a resilient health sector in Abu Dhabi.

5.1 Proposed alternative care sites

Upon investigation of suitable ACS locations for the city of Abu Dhabi, two sample areas were identified—each 5 km in diameter (*Figure 10*). Nicholl, West et al. (2007) conducted an observational study to assess the relationship between distance to hospital and patient mortality during emergencies. According to the study, patients with respiratory emergencies had the most significant association between distance and mortality—the greater the distance, the greater the risk of death. Given that COVID-19 primarily attacks the respiratory system, the study's findings were implemented. A distance of 0–10 km proved to have the lowest number of deaths in comparison to the rest of the studied distances. The urban site is located in Al Muroor District, which is highlighted by the landmark Sheikh Khalifa Medical City Hospital. The suburban site is in Al Ma'ared (exhibition) District, which is marked by Zayed Military Hospital.

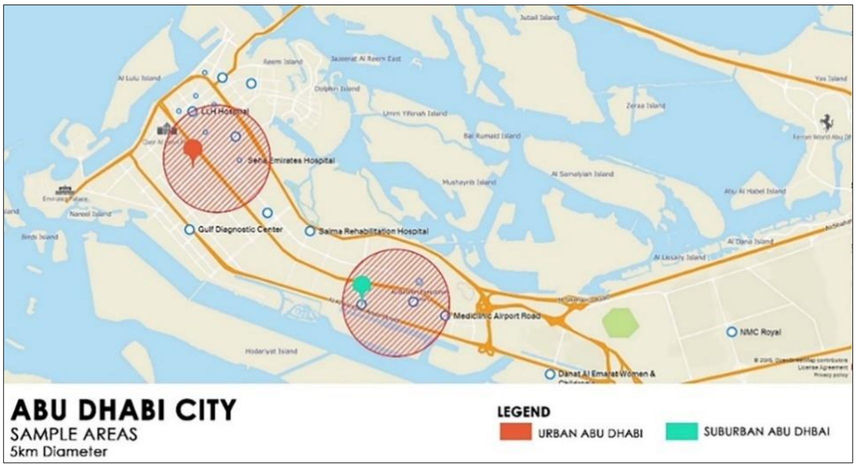

Figure 10. ACS area location map (based on Google Maps)

5.2 ACS in urban Abu Dhabi

The map below shows the urban-focused sample chosen for this project (*Figure 11*), with the main hospital (Sheikh Khalifa Medical City Hospital) clearly marked. First, a circle with a radius of 2.5 km was drawn to demarcate the area. Based on the literature review and case study analysis, candidate sites within this area were identified. These could serve as ACSs and would include, for example, stadiums, full-service hotels, universities, and schools. The information was later arranged into a table according to its proximity, space, and ease of access.

Figure 11. Al Muroor urban ACS location map (based on Google Maps)

The Al Muroor area is located near the heart of the city and houses a mixture of commercial and residential properties. This area is close to life's necessities, making it a highly dense place. Additionally, the site has the advantage of being located near Sheik Khalifa Medical City, which consists of a 586-bed acute care hospital. Based on the authors' observations, since

COVID-19 cases are expected to be high in this location, the need for ACSs will be vital.

The map also locates many full-service hotels, universities, stadiums, etc. The selected buildings will be subject to the proposed Criteria of Transforming Existing Buildings into Field Hospitals. The criteria are adopted based on the aforementioned Preparedness Assessment Tool.

To identify the optimal ACS, a comparative analysis across candidate facilities was based on several considerations (*Table 3*).

Table 3. Al Muroor candidate ACS

Building name	**Dusit Thani Hotel**	**Centro By Rotana Hotel**	**Khalifa University**	**Al Jazira Stadium**	**Al Nahyan Stadium**
Building type	High-rise hotel	High-rise hotel	University	Sports stadium	Sports stadium
Building age	8 years Built in 2013	10 years Built in 2011	14 years Built in 2007	41 years Built in 1980	16 years Built in 1995
Structural material	Concrete/steel structure	Concrete/steel structure	Concrete/steel structure	Concrete/ steel structure	Concrete/ steel structure
Number of floors	37	20	6	2	1
Floor area	Approx. 1,595 sqm	Approx. 538 sqm	Approx. 13,735 sqm	Approx. 34,250 sqm	Approx. 33,165 sqm
Municipal water supply	Existing	Existing	Existing	Existing	Existing
Power outlets	Existing	Existing	Existing	Existing	Existing

As *Table 3* demonstrates, the most suitable location for the ACS is Dusit Thani Hotel, which is due to its full-service capabilities. It offers a large number of private rooms with enough space for patient treatment. The hotel also offers a variety of different open spaces that can easily be partitioned for acute care treatment models. The hotel itself is equipped with the necessary facilities for a field hospital and offers a certain amount of flexibility in its use.

5.2.1 Hotel modification analysis

The above comparative analysis has identified Dusit Thani Hotel (a full-service hotel) as the leading candidate for a potential ACS, thus making it worthy of further investigation. Therefore, the following is a discussion of the modifications that Dusit Thani Hotel may undergo based on the existing and required features and set of criteria (discussed earlier) to guarantee the structure's adaptability and resiliency.

Firstly, in terms of *structure and geometry*, Dusit Thani Hotel meets all current local, state, and national building codes. The building type does accommodate a high live load. On the other hand, the required modifications would allow the hotel to ensure ease in the conveyance of patients and medical equipment as well as patient monitoring.

Available features related to *facility-specific administration* include smoke detectors, a sprinkler system in all rooms and hallways, smoke detectors in all rooms, and hallways equipped with fire extinguishers. The hotel has emergency lighting and complies with national, emirate and local fire laws. Additionally, there are emergency exits provided for each floor and central air conditioning. Regarding the *required* modifications, there should be provisions for medical gas supplies and protocols to prevent contamination by bio-hazardous waste.

Considering *patient spaces*, each guestroom is equipped with private toilets, windows, and multiple electrical sockets, which will make it easy to add medical equipment. Modifications here will entail direct or remote patient monitoring (DPM/RPM) and connections for ventilators, IV poles, monitors, biohazard disposal, etc.

The *nurse station spaces* can be accommodated through the availability of a reception area, staff lounge and 24/7 video surveillance of entrances, the hotel lobby, and hallways. What may be needed is a documentation area for physicians and nurses, a nurse's area and a cardiopulmonary resuscitation cart.

Regarding *mechanical* provisions, centralised air conditioning is available in all guest rooms and an HVAC system exists in ballrooms, exhibitions halls and the lobby. However, several modifications would be required to meet the mechanical criteria, which include isolation and negative pressure, the maintenance of negative pressure, creating AIIRs, placing exhaust near patients' beds when possible and ensuring spaces are protected from cross-contamination. *Power* is maintained through emergency backup generators that can support elevators, escalators, indoor and outdoor lighting, parking areas, fire alarms and smoke detectors.
Nevertheless, power must also support life-sustaining medical equipment, the nurse call system and egress lighting.

A nurse call system is already available in guest room toilets. However, EMS communication must be installed along with a secure nurse call system to support patient care.

In terms of *infection and prevention control measures*, sanitisation stations are placed at the access points of the hotel. There are also disinfectants and cleaning supplies throughout the hotel for regular use. However, there should be areas designated for the storage and disposal of PPE.

In addition to a parking garage, hotel surface parking is also available. There is direct access to the lobby and basement parking. Also, offloading areas exist along the back side of the building. However, the parking lot must be secured, and emergency and supply truck parking spaces should be located near the hotel's entrances for immediate access.

In addition to the large storage rooms, pre-existing medical services are an advantage. Having identified these features, storage areas must be freed up for medical equipment and sterilised before use.

While the marble tile *flooring* of the hotel is a plus, its curtains must be removed or replaced with easy-to-clean shutters. Carpets, where they may exist, should be covered with PPE material, and replaced with protective tape or non-porous flooring to decrease the risk of contamination and ease the cleaning process.

As illustrated in the analysis, Dusit Thani Hotel is an excellent choice as an ACS. However, the hotel still requires many modifications to make it suitable for medical use, which costs both time and money. This setback means the possibility of it operating as a full treatment facility is very slim. It is a high-rise building embellished with interior materials that facilitate the spread of infection. Notably, the idea of utilising it as a quarantine facility is being contemplated. Also, this hotel has a large capacity and includes facilities that are mandatory for any field hospital.

5.3 ACS in suburban Abu Dhabi

Al Ma'ared District is considered a hub for exhibitions and mixed-service hotels (*Figure 12*). Additionally, this area currently offers two COVID-19 testing centres: Abu Dhabi National Exhibition Centre (ADNEC) and Zayed Sports City Stadium. These venues reaffirm its suitability as a field hospital site.

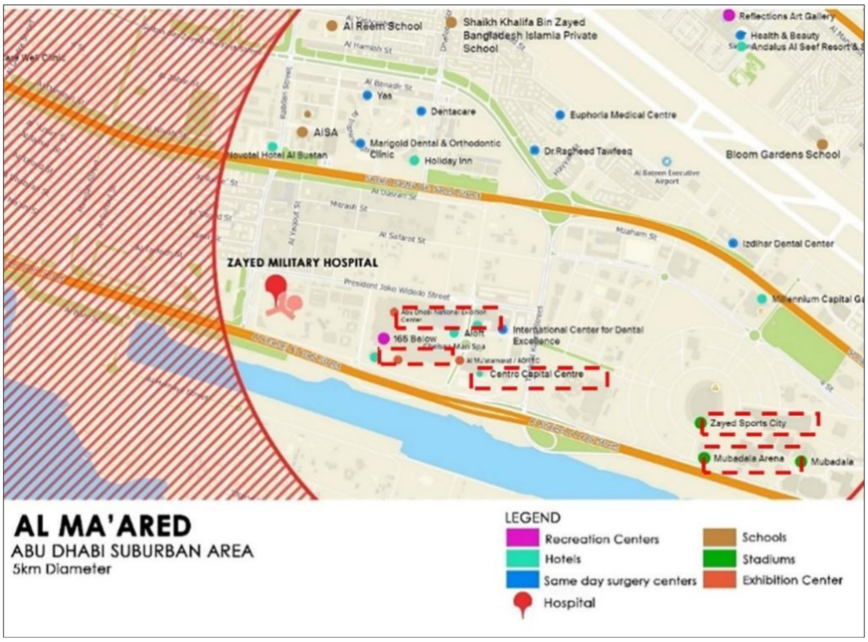

Figure 12. Al Ma'ared Suburban ACS location map (based on Google Maps)

The buildings in this area were selected and then compared according to the basic criteria of building type, age, structural material, number of floors, floor area, municipal water supply and power outlets (*Table 4*). These criteria were adopted from the Preparedness Assessment Tool.

The selected buildings included hotels such as Capital Centre Arjaan by Rotana Hotel and Andaz Capital Gate Hotel. In addition to various exhibition centres and stadiums, the ADNEC, Zayed Sports City Stadium and Mubadala Arena—mainly event halls—are flexible and can accommodate a multitude of events.

Table 4. Al Ma'ared candidate ACSs

Building name	**Abu Dhabi National Exhibition Centre (ADNEC)**	**Mubadala Arena**	**Zayed Sports Stadium**	**Andaz Capital Gate Hotel**	**Capital Centre Arjaan by Rotana Hotel**
Building type	Exhibition centre	Sports arena	Sports stadium	High-rise hotel	High-rise hotel
Building age	14 years Built in 2007	8 years Built in 2013	41 years Built in 1980	10 years Built in 2011	6 years Built in 2015

Building name	**Abu Dhabi National Exhibition Centre (ADNEC)**	**Mubadala Arena**	**Zayed Sports Stadium**	**Andaz Capital Gate Hotel**	**Capital Centre Arjaan by Rotana Hotel**
Structural material	Concrete/steel structure	Concrete/steel structure	Concrete/ steel structure	Concrete/ steel structure	Concrete/ steel structure
Number of floors	3	3	3	35	26
Floor area	73,000 sqm	Approx. 6,920 sqm	Approx. 88,500 sqm	53,100 sqm	Approx. 6200 sqm
Municipal water supply	Existing	Existing	Existing	Existing	Existing
Power outlets	Existing	Existing	Existing	Existing	Existing

Once the collected data was catalogued for the suburban area and a comparative analysis was made across the selected buildings, it is safe to say that the ADNEC showed the most promise as a potential ACS candidate due to its vastness, proximity to the city centre and desirable facilities. ADNEC already has several departments that would make the conversion to a field hospital swift and economical. Additionally, it meets many of the criteria listed in the Preparedness Assessment Tool.

5.3.1 Exhibition centre modification analysis

A worksheet was developed to consider the existing and required features for ADNEC, which are based on specific ACS criteria. Suggestions are made with regard to the modifications that must be applied to the building. The following provides a summary of these suggestions.

In terms of *structure and geometry*, the structure meets all current local, state, and national building codes. Since it is an exhibition centre, it would naturally accommodate a high live load. However, for it to be transformed into a field hospital, the existing structure would have to allow for additional live loads and ensure the easy conveyance of patients and medical equipment by evaluating the layout and visibility for monitoring patients.

Other important features include smoke detectors, sprinklers, HVAC systems, fire extinguishers, etc. ADNEC complies with national, state, and local fire laws; however, the venue should be able to maintain, monitor and manage potential hazards, in addition to other provisions mentioned in the previous candidate site.

In terms of patient spaces, this building would require direct or remote patient monitoring (DPM/RPM), patient seclusion, daylight that can penetrate patient spaces, toilets for patients, handwashing sinks for staff, connections for ventilators, IV poles, monitors, biohazard disposal, etc.

For the nurse station spaces to function properly, they would require a documentation area for physicians and nurses, a nurse’s area, a cardiopulmonary resuscitation cart and a handwashing sink.

Regarding mechanical considerations, a provision for isolation and negative pressure would be paramount to ensure that spaces are protected from cross-contamination, amongst other things.

Power must also support life-sustaining medical equipment, a nurse call system and IT infrastructure. EMS communication must also be installed. Infection and prevention control measures would call for cross-contamination prevention methods and planning out the flow of patients and health workers.

Parking availability is an advantage, and it must be secured. Emergency and supply truck parking spots must also be located near the ADNEC entrances for immediate access.

As expected, the selection of ADNEC as a candidate for ACS proved to be encouraging. However, it does require minimal changes to manage patient surge situations. Thus, when crisis strikes, this readily adaptable multipurpose venue could undergo a smooth conversion into a field hospital.

Moreover, ADNEC proves to be the most favourable location for a field hospital because of its structure and layout, which makes it easy to accommodate many visitors. It is also accessible using public transport. Furthermore, it is the fastest and most economical option. While Dusit Thani Hotel is a good option, it would require many changes for the rooms to be fully transformed for medical use, which would involve a great deal of time and money.

We must also realise that a full-service hotel would mainly be used to accommodate low- and mild-risk patients. However, it would also prove useful in reducing the surplus of low-symptom patients filling up hospitals. Ballrooms and meeting halls can also prove beneficial for treating high-risk patients. However, existing spaces may not have the capacity to accommodate the required number of beds or to store medical supplies and medicine that require refrigeration.

6. CONCLUSION

To boost the health care system capacity during the first wave of the coronavirus pandemic, many countries around the globe set up field hospitals to treat COVID-19 patients. Siting ACSs in Abu Dhabi City proved a valuable lesson regarding the need to consider future crises as part of the planning process to preserve the vitality of cities.

In this paper, the proposed ACSs and structures for Abu Dhabi are based on the analysis conducted at each site. The authors then drew a comparison between the candidate facilities—namely ADNEC and Dusit Thani Hotel—to determine which one is better suited for treating COVID-19 patients and serving as a model ACS for future emergency response. Subsequently, we can discern that ADNEC satisfies most of the criteria listed by the Preparedness Assessment Tool.

With COVID-19 taking centre stage in our lives, the world gained valuable lessons. The outbreak shed light on the challenges posed by old and outdated hospitals, including structural, organisational, and technical issues. Hospitals should be more flexible and prepared to accommodate a sudden influx of patients (Hsu, 2020). Likewise, ensuring the well-being of healthcare providers is essential since they are vulnerable to exposure and severe infection. The pandemic offers an opportunity to reimagine the design of the next generation of hospitals while planning and preparing for the next health emergency or natural catastrophe (AIA COVID-19 Task Force 1, 2020b).

More importantly, integrating health as a determining factor in city design and planning—especially with regard to pandemics—can be achieved through the design of public spaces, studying the social behaviour of people and raising awareness among citizens, among other means (Eltarabily and Elghezanwy, 2020). These arrangements must be made to provide a safe space for the citizens if a disaster strikes. Additionally, planners and designers must adhere to specific practices that make it easier for the city to reform a structure into a field hospital or shelter whenever it is required.

Open and large spaces such as stadiums and exhibition halls offer a great range of flexibility in their layout. They are also the most suitable for high-risk patient treatments due to their pre-existing facilities and services. Also, hotels of varying service levels can accommodate low- and mild-risk patients to quarantine and monitor their condition. It is imperative to have a clear layout of pre-existing facilities to reduce the overflow of patients in hospitals.

Additionally, cities should cooperate with local disaster relief agencies and prepare a master plan listing all the possible ACSs and changes they have to undergo. A pre-made programme will help reduce cost and time, control the crisis and protect the livelihoods and health of citizens. The process of transforming a structure into a field hospital could be very time- and resource-consuming amidst a pandemic; therefore, a map of potential sites that can easily be converted into field hospitals or shelters should be developed with an easy-to-follow action plan.

Finally, this paper argues for the need to consider disaster risk reduction in planning and design. It also argues that resilience is vital to limit long- and short-term damages. The more resilient a city is, the more manageable the risk.

One limitation of this study was that the authors intended to simultaneously deal with two different scales (i.e., urban, and architectural) at the outset of the study. This proved to be challenging when attempting to study the spatial adaptation of field hospitals to a site or determine the building selection criteria. Therefore, the authors opted to focus their research on building typologies within urban and suburban areas.

Notably, variations in socio-economic conditions, culture, governance initiatives and community response have played a key role in creating inequalities between cities (and countries) before, and during the COVID-19 pandemic whilst accentuating the existing ones. Therefore, comparing case studies with different conditions posed another challenge to analysing cities' positive experiences in creating field hospitals and undergoing space transformation.

The authors considered these factors and analysed several cases in ongoing research in which the UAE's strategies for combating the outbreak will be extensively discussed. Future studies could further explore the adaptive approach in risk management, facility siting and resilience planning.

AUTHOR CONTRIBUTIONS

Original idea, R.M.; conceptualization, R.M. and A.H.; paper structure, R.M. and A.H.; methodology, R.M., A.H. and A.A.; data curation, A.H., A.A. and M.W.; writing—original draft preparation, A.A., M.W., Z.H. and H.H.; revisions and editing, R.M., A.H., and A.A.; supervision and coordination, R.M.; funding acquisition, R.M. All authors have read and agreed to the published version of the manuscript.

ETHICS DECLARATION

The authors have no conflicts of interest to disclose.

ACKNOWLEDGEMENT

The authors like to acknowledge the Abu Dhabi University, in particular the office of research for giving us support.

FUNDING

This research was supported by Abu Dhabi University through the Research, Innovation and Impact Grant (Project code 19300565).

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