

Emergency Healthcare Facilities: Managing Design in a Post Covid-19 World

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Abstract—During the COVID-19 pandemic, which has caused an unprecedented health and economic crisis around the globe, several countries, such as China and U.K., developed makeshift hospitals by converting public venues of other intended use (e.g., stadiums, convention centers, exhibition centers, gymnasiums, factories, and warehouses) to medical facilities, aiming to achieve in very little time a substantial upgrade of the health system's capacity. This change management capability is among the fundamental elements of infrastructure futureproofing, i.e., the process of making provision for future developments, needs or events that impact on particular infrastructure through its current planning, design, construction, or asset management processes. This article utilizes the limited available experience from these makeshift hospitals to shed light on the critical design parameters efficiently enabling the infrastructure to adapt to required changes in structure and/or operations. However, futureproofing should not be a standalone component but should be efficiently embedded in asset management practice. For this purpose, this article also proposes an appropriate associated delivery paradigm encompassing value management and building information modeling to allow the asset owners and designers to efficiently incorporate flexibility in their design planning. The structured approach of value management can be used to ensure that the project's characteristics are aligned to the public client's requirements for futureproofing while a BIM-based design management paradigm is particularly appropriate, as it allows for design changes to be shared, visualized, estimated, and resolved without the use of time-consuming paper transactions.

Key words: BIM, change management, China, coronavirus, Covid-19, design, emergency, flexibility, futureproofing, healthcare, hospitals, makeshift hospitals, pandemic, U.K., value management

INTRODUCTION

ON December 31, 2019, the World Health Organization (WHO) was alerted to a cluster of pneumonia patients in Wuhan City, Hubei Province of China. One week later, on January 7, 2020, Chinese authorities confirmed that they had identified a novel (new) coronavirus, named 2019-nCoV, as the cause of the pneumonia and few days later, on January 11, 2020, the first fatality was reported. On January 30, 2020, the

Director-General of WHO declared the 2019-nCoV outbreak a public health emergency of international concern under the International Health Regulations, following advice from the Emergency Committee [WHO 2020a]. On July 26, 2020, 15 785 641 cases of infections and 640 016 deaths had been reported worldwide as a result of COVID-19, the acute respiratory disease caused by the new coronavirus, with more than half of the deaths being recorded in Europe. The hardest hit European

countries were the U.K., Italy, France, and Spain [WHO, 2020b].

The statistics published by the UN's Committee for the Coordination of Statistical Activities [CCSA, 2020] reveal that COVID-19 and the almost global lockdown it caused, has brought dramatic changes in all aspects of public and private life and unprecedented disruptions to economies and labor markets. The data points and inflections in trends would have been unimaginable only a few months ago: 9% year-on-year fall in global production and manufacturing output, predicted fall of the value of global merchandise trade by almost 27% in Q2 2020 and the largest fall in global commodity prices on record (-20.4% between February and March 2020). On the social side, there is a shocking loss of employment—a decline of almost 10.5% in total working hours or 305 million full-time workers, some 1.6 billion students have been affected by school closures and the crisis will push an additional 40–60 million people into extreme poverty [CCSA 2020].

In the context of the COVID-19 pandemic, the world also witnessed China building a new 645 000-square-foot emergency medical facility with a capacity of 1000 patients in just 10 days [BBC, 2020a] as well as the conversion of public venues such as stadiums and exhibition centers into temporary healthcare facilities in several countries, including China, U.S., and U.K. 16 such facilities, also called Fangcang shelter hospitals, were opened in Wuhan city in February 2020 for the isolation and care of patients with mild to moderate COVID-19 symptoms. These emergency facilities were created over a period of three weeks in less than two days each, contained 13 000 hospital beds and played a major role to the successful control of the COVID-19 pandemic in China [Chen *et al.*, 2020].

Similarly, in the U.S. the army corps of engineers (USACE) built 17 alternate care sites in eight states [USACE, 2020] while in the U.K., the NHS created eight makeshift hospitals in England, one in Scotland and one in Wales, utilizing available infrastructure including Conference and Exhibition Centers, Sport and Leisure Centers, School buildings and Stadiums ([BBC, 2020b]; [Wikipedia, 2020]). The largest of these makeshift hospitals is the London NHS “Nightingale” facility, made up of two wards each with space for 2000 people, created within the ExCel conference center of east London, in just nine days.

It goes without saying that the abovementioned makeshift hospitals make one of the most powerful examples of a futureproof infrastructure, i.e., an infrastructure with the ability to adapt to required changes in structure and/or operations in the future, e.g., expansion of capacity, change in usage mode or volumes [Masood *et al.*, 2014]. The experience of the ongoing COVID-19 pandemic particularly highlights the crucial role of adaptive design strategies, which allow for public venues such as the aforementioned ones to be rapidly converted into hospitals and achieve in very little time a substantial upgrade of the health system's capacity. This article aims to shed light on the critical design parameters of makeshift hospitals and outline the required design delivery paradigm for effectively futureproofing design development in the context of emergency healthcare needs.

BACKGROUND

The delivery of healthcare services remains largely site based, requiring significant physical space for medical personnel to conduct all of the activities associated with the provision of medical care and attention. However, large hospital construction projects are planned from 10 to 20 years in advance,

and hospitals are typically designed to have a lifespan of more than 40 years. Furthermore, all hospitals must respond over their life cycles to changing demands imposed by shifting demographics, increasingly sophisticated medical technologies, workforce capacity, and capability issues, pressured public and private sector health budgets, and changing epidemiological patterns ([Carthey *et al.*, 2011]; [Olsson and Hansen, 2010]).

In the above context, the concept of design flexibility as a means of responding to the uncertainty is no stranger at all to the healthcare sector. Flexibility changes the goal from optimizing designs to a set of deterministic point forecasts to finding designs that will affect favorably the entire distribution of possible outcomes [Cardin, 2014]. Besides, an optimal design is one that inhibits change of function least, rather than one that fits a specific function best [Healy and McKee, 2002]. According to Olsson and Hansen [2010], the three aspects of flexibility are adaptability, convertibility, and expandability. Adaptability can be defined as the ability of a building to meet shifting demands without physical changes. Convertibility can be defined as the possibility for construction and technical changes with minimum cost and disturbance. Finally, expandability can be defined as the ability to increase (or reduce) the size of a building. Examples of flexible design in hospital buildings can include structural foundations that allow additional floors to be added on top of existing buildings or areas that are built but not fitted out with medical equipment or functional rooms that may be refitted for medical purposes other than their original use [De Neufville and Scholtes, 2011].

However, all the literature around design flexibility concerns nontemporary facilities, designed and intended from the beginning to be used as medical care premises. The

case of makeshift hospitals is totally different, in the sense that the selected venues (exhibition centers, stadiums, leisure centers, etc.) had never been designed to be used for medical care purposes. Therefore, their primary feature is this of adaptability, i.e., the ability to be readily adapted or reconfigured in response to changing needs, uses, capacities, risks, or requirements [Masood *et al.*, 2014]. This change management capability is among the fundamental elements of infrastructure futureproofing, which can be defined as “the process of making provision for future developments, needs or events that impact on particular infrastructure through its current planning, design, construction or asset management processes” [Masood *et al.*, 2014].

DESIGN AND CHANGE MANAGEMENT EXPERIENCE FROM THE COVID-19 MAKESHIFT HOSPITALS

In the context of futureproofing and the associated design flexibility management, it is beneficial to identify the critical parts of projects where flexibility is needed and choose appropriate strategies for its implementation [Olsson, 2006]. The ongoing COVID-19 pandemic, unavoidably shifts the focus of futureproofing toward large public venues (e.g., stadiums, convention centers, exhibition centers, gymnasiums, factories, and warehouses), which have the potential to be used as makeshift hospitals in case of emergency.

Although there currently are very limited sources available, some preliminary points of guidance can be drawn. Specifically, Chen *et al.*, [2020] stressed that future design and construction of large public venues with such a potential, should integrate features facilitating the required conversion like interior equipment that

can be rapidly removed, entrances that are large enough for hospital beds and ventilation systems that reduce the risk of cross infection. Furthermore, the London Nightingale hospital’s contractor, BDP, highlighted that the Exhibition Center was selected because of its large flat floor hall spaces with flexible mechanical, electrical, and plumbing (MEP) infrastructure that could easily be adapted to meet the needs of the temporary hospital. Also, minimal building intervention was essential to ensure rapid project delivery, so the building assets were used to the maximum; the bed heads and service corridors were constructed utilizing a component system usually used to construct exhibition stands while simple reinforcement allowed for services to be fitted to the walls ([BDP, 2020a]; [Architect’s Journal, 2020]).

Additionally, BDP [2020b] drew up an instruction manual to share with other countries taking on similar emergency projects, which provides very useful insights on the fit-out strategies and processes adopted. The notes and sketches reveal that space is the most crucial factor with requirements encompassing clear span, large flexible space for the patients wards and additionally, space for medical gases, space for general parking, space for ambulance parking, space for temporary generators, space for staff changing and showers, and space to accommodate CTs (at least two for resilience) and temporary mortuaries. Other space related considerations include air ambulance access, the proximity of the venue to appropriate staff accommodation and the ability of the existing venue’s fire strategy to align with the new function, considering different risks in the form of increased oxygen and evacuation of patients.

Additionally, the recent experience confirms how efficient ventilation is of paramount importance along with determining clean and dirty routes and specifying the permissible flows of

equipment, medical staff and patients through the ward’s clean and dirty areas. BDP’s instructions (2020) for the ventilation suggest the use of existing systems and modification of controls to maximize fan duty, ensure full fresh air with no recirculation and introduce a pressure regime to push air from clean areas to dirty areas and out of the building. Chen and Zhao [2020] confirm the primary role of ventilation in infection control highlighting the fact that the insufficient ventilation in makeshift hospitals may increase infection risk of opportunistic airborne transmission. They urge for the ventilation rates to increase to as high as the system can support and additionally suggest the use of air purifiers to reduce the possible virus-laden aerosols. The critical contribution of ventilation systems has also been noted by Chen *et al.*, [2020] and Her [2020] drawing on China’s and South Korea’s experience from emergency medical facilities.

Furthermore, mechanical ventilation systems are also crucial for the creation of negative pressure rooms, i.e., rooms where the pressure of the air is at a slightly lower level than the pressure of the entry area, so that contaminated air cannot escape from the isolation room, as air naturally flows from areas with higher pressure to areas with lower pressure [Agarwal *et al.*, 2020].

Apart from ventilation, the fundamental role of the venue’s mechanical systems is also evidenced by the crucial need for reliable electrical infrastructure to support the function of ICU’s life-saving ventilators and equipments as well as the absolute requirement for an efficient network able to supply medical gases (e.g., oxygen) to each of the beds. London Nightingale project’s experience shows that extensive upgrading modifications were necessary to ensure that the power supply can cope with demand while a bespoke gas installation was

constructed with two distribution ring mains running around the basement car park at high level, rising up to feed each bed head through the services floor boxes ([Architect's Journal, 2020]; [BBC, 2020b]). The medical gases system was located at a space adjacent to the ward block to facilitate the installation of the gas circuits required to connect the oxygen evaporators and the air compressors with the ward [BDP, 2020b].

The infrastructure system also needs to be able to support the operation of video and audio devices. Video surveillance is crucial in safeguarding equipment, medicines, personal protective equipment, and other supplies while also being necessary for access control and to restrict public access for contagion mitigation. Furthermore, video and audio surveillance solutions can be used for the communication between patients and healthcare professionals, minimizing unnecessary patient contact, and aiding them in prioritizing resources where they are needed most [Axis communications, 2020]. The utilization of popular and easy to use information and technology solutions like smart phone apps and cloud during the COVID-19 pandemic for efficient patient monitoring by doctors and nurses has been indicatively reported by [Xu *et al.*, 2020], [Bae *et al.*, 2020], and [Hillrom, 2020].

Apart from the staff's and patients' well being and safety discussed above, another essential aspect highlighted by the recent experience from makeshift hospitals is that of biosecurity. Given the dependence of virus stability on temperature, hot water of at least 70 °C should be made available for cleaning purposes [Agarwal *et al.*, 2020]. For the decontamination and sterilization of equipment, steam can be used as a simple, cost-effective sterilization technique (de Man, 2020). However, a central steam supply for this purpose

seems not to be essential as the majority of published protocols rely on specialized commercial steam bags which in case of limited supply can be efficiently replaced by microwave-generated steam [Zulauf *et al.*, 2020].

Regarding the environmental safety, the use of relevant disposal protocols is mandatory. As far as wastewater treatment is concerned, Wang *et al.*, [2020] explained that the kind of disinfectant used largely determines the engineering characteristics of the hospital system, e.g., the pipes location, length, height, and material. Zhang *et al.*, [2020] described the disinfection system applied to the first makeshift hospital in Wuhan. Regarding the centralized disposal of COVID-19 medical waste, this is preferentially treated by high temperature incineration which is the most common and effective way to kill infectious pathogens [Peng *et al.*, 2020]. Detailed protocols for the packaging and pretreatment of waste are provided by [Wang *et al.*, 2020], [Duan *et al.*, 2020], and [Peng *et al.*, 2020].

DESIGN DELIVERY PARADIGM FOR EFFICIENT FUTUREPROOFING

[Masood *et al.*, 2016] note that futureproofing should not be a standalone component, but should be efficiently embedded in asset management practice. This requires addressing stakeholder requirements at an early stage, adopting standardized approaches, establishing, and implementing criteria to help assess the current state of futureproofing and take necessary actions to keep on future-proofing agenda [Masood *et al.*, 2016].

The above requirements point directly toward the structured approach of value management, which can be used to ensure that the project's characteristics are aligned to the public client's requirements for

futureproofing or any other aspect of interest. The process incorporates a series of workshops involving key representatives from both the public client and the designer where the stakeholders are expected to reach consensus on what constitutes "value" for them, how this translates into specific criteria and how they rank in terms of relative importance [Connaughton and Green, 1996].

By incorporating the above-mentioned design aspects in the criteria used for the evaluation of design alternatives, the public client is bound to comparatively score them against these criteria and ultimately identify the one presenting the best futureproofing performance. Detailed examples of the process can be found in ICE [1996]. A point of caution in the above process concerns the workshops' attendees who should collectively have the necessary experience to make informed decisions. Especially in the context of healthcare facilities' design, the multidisciplinary needs require many different disciplines to be brought together under a unified umbrella with the aim to make a streamlined plan for establishing the unit [Agarwal *et al.*, 2020]. The Nightingale hospital's contractor has specifically highlighted that the experience of the healthcare architecture team and their understanding of clinical flows allowed logical repurposing spaces with minimal new construction [Architect's Journal, 2020].

Additionally, given the uncertainty involved and in line with the view that the constantly changing futureproofing requirements require a radical shift of construction toward the "digital era" [Love *et al.*, 2018], the most appropriate design management paradigm is one based on a Building Information model (BIM). BIM is a digital representation of all physical and functional characteristics of a facility or site, serving as a knowledge database, which enables

reliable information exchange and decisions during the asset's life cycle from inception onwards [Krystallis *et al.*, 2015]. In case of an urgent need for conversion of the facility the use of BIM is particularly appropriate, as it allows for design changes to be shared, visualized, estimated, and resolved without the use of time-consuming paper transactions [Sacks *et al.*, 2018].

Furthermore, it provides opportunities for facility managers to effectively manage health and safety issues for facility users by inputting into BIM data from on-site sensors monitoring the infrastructure condition [Fanning *et al.*, 2014]. The latter is of critical importance in the context of a potential need for transformation and upgrade of ventilation and other mechanical and electrical systems as seen in the recently converted makeshift hospitals in the UK. A relevant ontology of building monitoring data and building performance indicators has recently been proposed by [Mahdavi and Wolosiuk, 2019].

The aforementioned design delivery paradigm encompassing value management and BIM will allow for

the asset owners and designers to efficiently incorporate flexibility in their design planning, in contrast to the usual practice of flexibility being frequently used but rarely prepared for [Olsson, 2006].

CONCLUSION

The COVID-19 pandemic has caused an unprecedented health and economic crisis with unpredictably deep and multifaceted consequences, already felt around the globe. Securing the operation of health facilities able to cope with the outbreak of such a highly contagious as well as lethal disease, has been the top priority for many governments. In fears that the capacity of traditional hospitals would be overwhelmed, makeshift hospitals were developed in several countries, by converting public venues of other intended use to medical facilities.

The so far very limited literature around these emergency hospitals' design features reveals several critical aspects including the existence of large flat space for the patient ward, availability of large space for fundamental and auxiliary medical and nonmedical operations,

a ventilation system able to adapt as per the required standards for infection control, an equally adaptable MEP infrastructure, air ambulance access, proximity of the venue to appropriate staff accommodation, and fire safety features able to align with the new function.

Awareness of these features enables the decision makers to proactively identify suitable venues for use as makeshift hospitals so as to better plan their response in case of a second spike of the COVID-19 pandemic or a similar public health emergency. Furthermore, the aforementioned features can be used as a futureproofing checklist for owners and designers planning new public venues, as they are best placed to timely ensure that the new facilities can potentially be utilized as emergency medical facilities if needed, either immediately or following limited upgrade. Finally, the use of Value Management approach and BIM, form the most appropriate design delivery paradigm, able to significantly increase the futureproofing value and performance of new facilities in the context of emergency accommodation of urgent healthcare needs.

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