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Short Communication

Offsite Construction for Emergencies: A focus on Isolation Space Creation (ISC) measures for the COVID-19 pandemic



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ABSTRACT

The outbreak of a pandemic of global concern, the Corona Virus Disease 2019 (COVID-19) has tested the capacity of healthcare facilities to the brim in many developed countries. In a minacious fashion of rapid spread and extreme transmission rate, COVID-19 has triggered a shortage of healthcare facilities such as hospital bed spaces and ventilators. Various strategies have been adopted by the worst-hit countries to slacken or halt the spread of the virus. Common Isolation Space Creation (ISC) measures for the COVID-19 pandemic containment includes self-isolation at home, isolation at regular hospitals, isolation at existing epidemic hospitals, isolation at retrofitted buildings for an emergency, isolation at Temporary Mobile Cabins (TMCs), isolation at newly constructed temporary hospitals for COVID-19. This study evaluates the ISC measures and proposes offsite and modular solutions for the construction industry and built environment to respond to emergencies. While this study has proposed a solution for creating emergency isolation spaces for effective containment of such pandemic, other critical COVID-19 challenges such as the shortage of healthcare staff and other facilities are not addressed in this study.

1. Introduction

The Corona Virus Disease 2019 (COVID-19) was reported in Wuhan City, Hubei Province, which is in the central part of China on 31 December 2019 [1]. The COVID-19 pandemic was declared a “public health emergency of internal concern” on 8 February 2020 due to its rapid spread and transmission rate between humans [2]. As of 23 March 2020, the virus has spread to 179 countries with 323,081 confirmed cases and 14,443 reported deaths [3]. Fig. 1 shows the global spread of the COVID-19 pandemic with China, Italy, USA, Spain, Germany, Iran, France, South Korea, Switzerland and the UK being the worst-hit countries after 84 days of the virus outbreak [4]. The rapid rate of spread and mode of transmission of a pandemic requires an emergency and swift approach to contain it [1]. Countries around the world are at various stages of battling the spread of COVID-19 with the cooperation of many stakeholders, including the medical, defence, transportation, aviation, logistics, manufacturing and construction industries. Hong Kong, Taiwan and Singapore were among the first movers to act swiftly through proactive travel restrictions, rigorous detection, contact tracing and strict quarantine [5]. Xu et al. [1] proposed the participation of multiple stakeholders to implement epidemic and

pandemic containment measures including virus source control, spread control and tracing.

Evidence suggests that epidemic and pandemic containment measures are not a thing of new as governments have often employed isolation measures/strategies in the past to curb pandemics [6]. For instance, during the 2009 Swine Flu Pandemic in the United States which appeared to disproportionately affect young and school-age people, self-isolation in homes was enforced on school-age people [7]. In another instance, during the outbreak of Middle East Respiratory Syndrome (MERS), patients with suspected MERS were isolated at regular hospitals to receive timely and intense care [8]. Also, in order to cope with the unprecedented outbreak of Ebola virus infection in Nigeria, NCDC took decisive action by rapidly isolating potentially infectious contacts at existing epidemic/pandemic centres/hospitals (Edem et al. [25]). Similarly, during the outbreak of MERS in 2015, Korea's healthcare system became saturated. To cater for the ever-increasing number of active cases and the uncertain possibility of relapse or reinfection, buildings were retrofitted into temporary hospitals [9]. According to Zhu and Xie [10], ISC measures, which have played crucial role during previous pandemics remains key to handling the COVID19 pandemic.

Abbreviations: COVID-19, Corona Virus Disease 2019; ECDC, European Centre for Disease Control and Prevention; HBS, Hospital Bed Spaces; ICU, Intensive Care Unit; ISC, Isolation Space Creation; NCDC, Nigerian Center for Disease control; NHS, National Health Service, UK; TMC, Temporary Mobile Cabin; WHO, World Health Organisation; WMHC, Wuhan Municipal Health Center.

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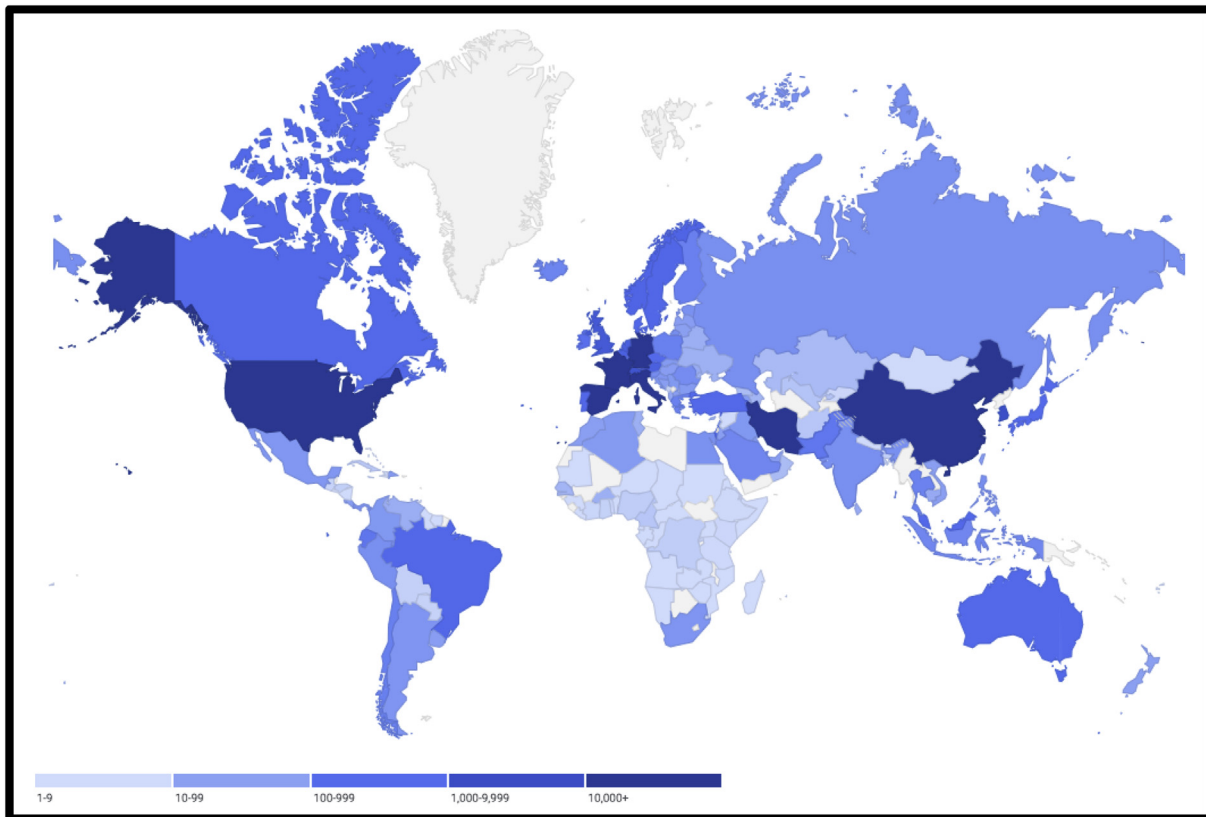


Fig. 1. Confirmed cases of coronavirus disease (Covid-19).
Source: Google Coronavirus map; 23 March 2020.

From the construction and built environment perspective, this study aims to propose an effective and sustainable solution for battling the shortage of isolation spaces in emergencies through offsite and modular construction.

Due to the complexity of COVID-19 and rate of spreading, many countries have failed to prevent the entry of the virus into their territories (BBC [26]). International containment strategies such as travel restrictions and on-arrival quarantine have come a bit too late for most countries. Therefore, most countries have initiated territorial containment strategies such as social-distancing and banning of public gatherings (White and White [27]). However, there is a need to race against time to increase capacity for the effective isolation of affected individuals.

2. Method

This study takes a classical pragmatist's stance with a mixed-method approach to propose emergency measures to increase healthcare bed-space capacity for effective isolation of individuals rapidly. The mixed-method approach involves the analysis of secondary quantitative data and the qualitative review of literature on COVID-19 built environment research. The sources of quantitative data included the European Centre for Disease Prevention and Control (ECDC), World Health Organisation (WHO), Google Coronavirus Map and Channel News Asia (CNA). The ECDC data on the daily number of reported cases of COVID-19 by country worldwide was selected because Europe was the epicentre of the pandemic as of 23 March 2020, with Italy, Spain, Germany, France, Switzerland and the UK among the 10 worst hit countries. The ECDC was a reliable source of information about the daily rate of COVID-19 infections especially for the European countries due to the fact that it is a disease management centre the entire EU. The secondary data informed the evaluation of the current trend of COVID-19 spread concerning the isolation measures used in various countries. The systematic review of available literature enabled the appraisal

of the effectiveness of current isolation measures and other key factors that affect the containment of infectious diseases.

3. An evaluation of Isolation Space Creation (ISC) measures

In response to the coronavirus outbreak, most countries, including China, have initiated various levels of travel restriction and social distancing measures [11]. It is essential to note that the global spread of the COVID-19 has continued to rise despite the existing travel restrictions by most countries [12]. The slow rate of patients' identification, the rapid spread of the disease, risk of nosocomial transmission, the unpredictability of size impacted and the lack of backup resource are among the barriers to the effective containment of COVID-19 [13]. A projection by the Imperial College COVID-19 Response Team shows the current measures taken in the UK can only slow down the spread, and there would be an urgent need to rapidly increase healthcare capacity (Elsland et al. [28]). Currently, the worst-hit countries by the COVID-19 pandemic are experiencing a severe shortage of healthcare workers, medical materials, and beds with isolation facilities [13]. The most critical challenge for the built environment and the construction industry is to rapidly provide healthcare isolation spaces for treatment of mild, moderate and severe coronavirus cases and to contain the spread of the pandemic effectively. Six main possibilities for Isolation Space Creation (ISC) measures for the treatment of COVID-19 patients include: (i) self-isolation at home; (ii) isolation at regular hospitals (public and private); (iii) isolation at epidemic control hospitals; (iv) isolation at emergency retrofitted temporary hospitals; (v) isolation at temporary mobile cabin hospitals; (vi) isolation at emergency newbuild COVID-19 hospitals.

3.1. Self-isolation at home

In less than three months of the COVID-19 outbreak, not less than 70 countries have initiated travel restriction and self-isolation instruction to

slow down the rate of spread of the disease [14]. Governments recommend self-isolation at home for people with mild symptoms or people returning from high-risk countries to prevent the spread of COVID-19 in public gatherings [15]. This form of isolation is readily available and accessible for the treatment of people with mild symptoms with reduced risk of spreading to the public. However, there is a higher household risk for vulnerable living in shared accommodations [12]. Also, it is practically impossible to ensure compliance with self-isolation directives and the public can only rely on the discretion of people with mild symptoms for safety from the disease [16]. Self-isolation at home can be impactful in reducing the rate of spread, but it is not adequate for containing the spread of coronavirus (Hogan et al. [29]). To achieve effective containment of the virus, it is vital to ensure a closed isolation system with controlled delivery of essentials and disposal of waste.

3.2. Isolation at regular hospitals

The surge in the number of infected people in Wuhan City resulted in a 44.8% constrain of regular hospital beds with 8498 of 18,961 beds in 27 hospitals opened for treatment of COVID-19 infections (Wu et al. [30]). Majority of hospitals in Bergamo and Codogno cities in Italy are forced to turn away patients due to constrained capacity caused by the rapid surge in the number of daily COVID-19 cases (survival' [31]). In the UK, the NHS has struck a significant deal with the Nation's independent hospitals for access to 8000 hospital beds, among other provisions [12]. The use of regular hospitals for COVID-19 isolation is advantageous because it provides controlled access and medical waste disposal. However, isolation at regular hospitals portends risks to other patients and health care workers through nosocomial transmission [10]. Isolation at regular hospitals also threatens other healthcare services due to constrained spaces leading to increased risk to public health.

3.3. Isolation at existing epidemic hospitals

The use of existing disease control hospitals is very effective for early-stage containment of epidemic outbreaks (Pepple and Akpan, 2017). Countries such as Nigeria have relied on early-stage case identification, rigorous contact tracing and effective isolation at emergency disease control centre [15]. The activation of the Emergency Operation Centre, Lagos shortly after recording the first case has helped Nigeria in slowing down the spread of the virus despite its population. Despite the effectiveness of epidemic hospitals in containing the spread of diseases at the source, it is challenging to stay ahead of the COVID-19 pandemic through rigorous tracing and isolation of all contacts [1]. From the analysis of the trend of the coronavirus spread in ten of the worst-hit countries, it is crucial to prepare for an exponential surge in the number of infected people [4]. Therefore, the use of existing epidemic hospitals comes with the challenge of low capacity and the need to expand capacity for more cases rapidly.

3.4. Isolation at retrofitted temporary Covid-19 hospitals

The rapid need to expand capacity for containing the COVID-19 pandemic has led to the emergency conversion of other building facilities to meet up with the demand. For example, the Wuhan International Conference and Exhibition Centre and Hongshan Stadium were converted into temporary COVID-19 hospitals with a joined capacity of 2600 beds (Wuhan Municipal Health Centre, 2020). The UK has also moved to convert up to 10 other facilities, including the London ExCel centre into temporary hospitals to deal with the coronavirus exponential surge in number (Sky News [32]). Despite the advantages of retrofitted makeshift hospitals such as increased capacity and controlled isolation, it is essential to consider possible demerits such as its functional adequacy and fitness for purpose. Xu et al. [1] pointed out the dangers of cross-infection when using public buildings with central HVAC and the need to ensure adequate fresh air, individual thermal comfort and efficient filtering of recirculated air in vents. Also, considering the poor scalability and location constraints,

many objectives limit the effectiveness of retrofitted buildings for the containment of COVID-19.

3.5. Isolation at Temporary Mobile Cabin hospitals

The use of Temporary Mobile Cabin (TMC) hospital mitigates the functional and location constraints of creating emergency isolation spaces. Mobile cabin hospitals also improve mobility, scalability and access to remote areas for swift intervention. Though having a significant initial cost implication, the use of temporary mobile cabin hospital is sustainable and gives the opportunity of post-pandemic recovery of materials. TMCs can provide effective disease containment measure through quick set up for efficient contact tracing, testing and isolation at remote locations where infection sources have been identified. As the function of TMCs should not be confused with ambulance or patient's vehicles, the high logistic cost for material delivery and medical waste disposal of TMCs is a major demerit. Fig. 2 shows the trend of daily new cases of COVID-19 in China, where TMCs were used to expand healthcare space capacity.

3.6. Isolation at newbuild Covid-19 hospitals

Due to the vastness in the number of factors that affect the containment of COVID-19 spread, it is difficult to measure the impact that the swift delivery of the newbuild Wuhan Huoshenshan and Leishenshan COVID-19 hospitals in containing the spread of pandemic outbreak (Xinhuanet.com [33]). However, it is essential to acknowledge that the timely delivery of the two newbuild COVID-19 hospital projects positively affected the curve of the pandemic spread, as shown in Fig. 2. South Korea is another country among the ten worst-hit within the first three months of the outbreak that is currently recording a downward trend in the number of new cases, as shown in Fig. 3. The current success in South Korea is attributed to its preparedness due to lessons from the Middle East respiratory syndrome (MERS) outbreak in 2015, which enabled more swiftness in conducting tests, enforcing strict self-isolation and tracing contacts (Normile [34]). As much as it is essential to expand the capacity for disease identification, it is crucial to expand the capacity of effective isolation of cases to contain the spread of COVID-19. The construction Wuhan Huoshenshan COVID-19 Hospital took only ten days (from 23 January 2020 to 2 February 2020), while the development of the Leishenshan COVID-19 Hospital took 14 days (from 25 January 2020 to 8 February 2020). The timely delivery of newbuild COVID-19 hospitals can effectively mitigate the limitations of other ISC measures.

4. Findings and discussion

The review of literature and data analysis revealed three main factors that influence the containment of COVID-19 spread. The factors include: (i) daily testing capacity for detecting COVID-19 infection; (ii) capacity for effective isolation infectious persons to prevent further spread, and; (iii) treatment of isolated individuals [1,13,17]. combination of trend analysis and review of academic and news media literature was combined to

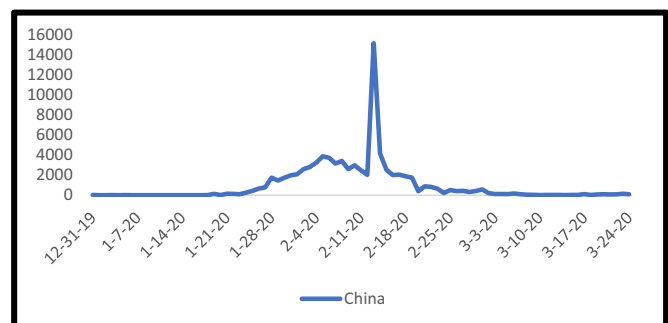


Fig. 2. Trend of Covid-19 spread in China [4].

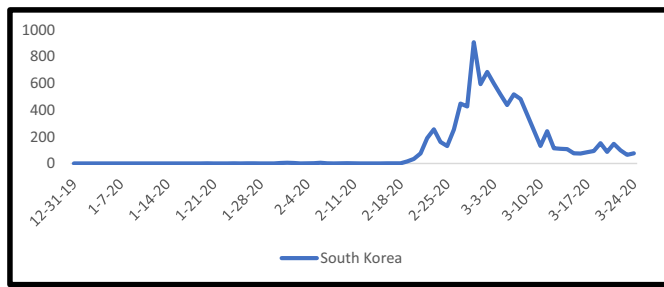


Fig. 3. Trend of Covid-19 spread in South Korea [4].

juxtapose the COVID-19 trend with the isolation measures being used in the worst hit countries. Fig. 4 shows a subjective curve for COVID-19 containment, where the turning point (A) at a point in time (t^*) when all the new cases of COVID-19 are confirmed, and there is the certainty that there are no untested new cases.

Point A shows the importance of closing the gap of the uncertainty of the actual number of infected people through adequate testing capacity. As of 24th of March 2020, only China and South Korea had reached the turning point out of the ten worst-hit countries. Many countries are yet to close the gap of uncertainty and still between the point ($t = 0$) and (t^*), which requires the combined efforts of increasing the capacity to test people and the ability to isolate all infected individuals effectively. The required capacity for effective isolation (X^*) at the turning is the number of hospital bed spaces required for treating all confirmed cases of COVID-19 until they are no longer infectious. At a point in time (t_1), the capacity for effective isolation should be (X_1) rather than (X_0) because of the challenge of meeting the demand for more effective isolation spaces in ample time. However, it is difficult to determine the required capacity for untested people infected with the virus due to the high dependence on “COVID-19 daily testing capacity” of various countries. It is therefore vital to propose sustainable strategies for the built environment to meet up with the current demand for enhanced capacity for effective isolation.

4.1. Value of construction and the built environment in the fight against Covid-19

The lockdown of cities to non-essential services is now a standard measure in many countries, including the UK, USA and Nigeria. It is, however, essential to be able to classify “essential services” correctly in the fight against the COVID-19 pandemic. Considering the urgent need of expanding

healthcare capacity for ISC and the importance of a resilient built environment, the construction industry at various levels in various countries needs to rise to the current challenges. The construction industry is required to carry out primary activities including material logistics, emergency construction, delivery of modular components to the site, emergency retrofitting of existing buildings to makeshift hospitals, maintenance and facilities services. Fig. 5 shows the essential activities of the construction industry, which will add value to the fight against COVID-19.

Also, construction workers must provide efficient infrastructures to improve the productivity of frontline healthcare workers. Occupational health and safety measures for construction workers should be urgently revisited to ensure strict compliance, minimise the risk of viral infection and enforce COVID-19-specific safety measures. Workers must be aware of the purpose and risks of working in the kind of conditions, which are necessary to win the fight against coronavirus. Lastly, support services such as technology development and emergency procurement guidelines can help to eliminate the bottlenecks that could hinder the required progress rate required in construction. It is important carefully derive value from emergency construction approaches the rapidly boost capacity for effective isolation and ensure resilience of the built-environment in responding to the current challenges of COVID-19.

4.2. Benefits and limitations of the ISC measures

The identified ISC measures are beneficial in various ways. Although ISC-1 (self-isolation at home) was found not to be effective for containing COVID-19 spread, ISC-1 is the most resourceful for slowing down the spread of unidentified COVID-19 cases. Among others, ISC-2 (isolation at regular hospitals) is commonly used due to the availability of healthcare professionals. However, it portends risks to the healthcare workers and other patients because of the design for regular hospital services. ISC-3 (isolation at existing disease control hospitals) was found to be very effective for COVID-19 containment, but it is limited by capacity, location and lack of scalability. Table 1 shows a comparison of the ISC measures in terms of some benefits and limitations. Considering the need for enhanced capacity for effective containment, ISC-4, ISC-5 and ISC-6 are very critical for the fight against COVID-19 in the eventuality of a high surge in the number of confirmed new cases. However, these measures (ISC-4 to 6) are cost-intensive, not readily available and depends on each country's capacity for rapid development.

Hence, it is crucial to consider the efficient combination of all ISC measures for containing COVID-19 by discussing the benefits and shortfalls of each ISC measure during strategic planning. Multiple factors affect the

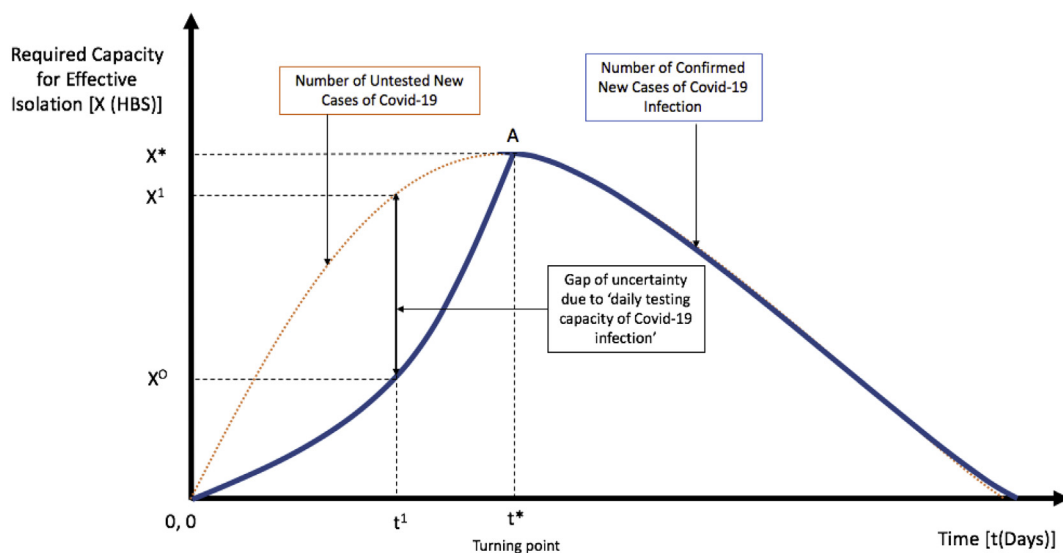


Fig. 4. Subjective curve for Covid-19 containment.

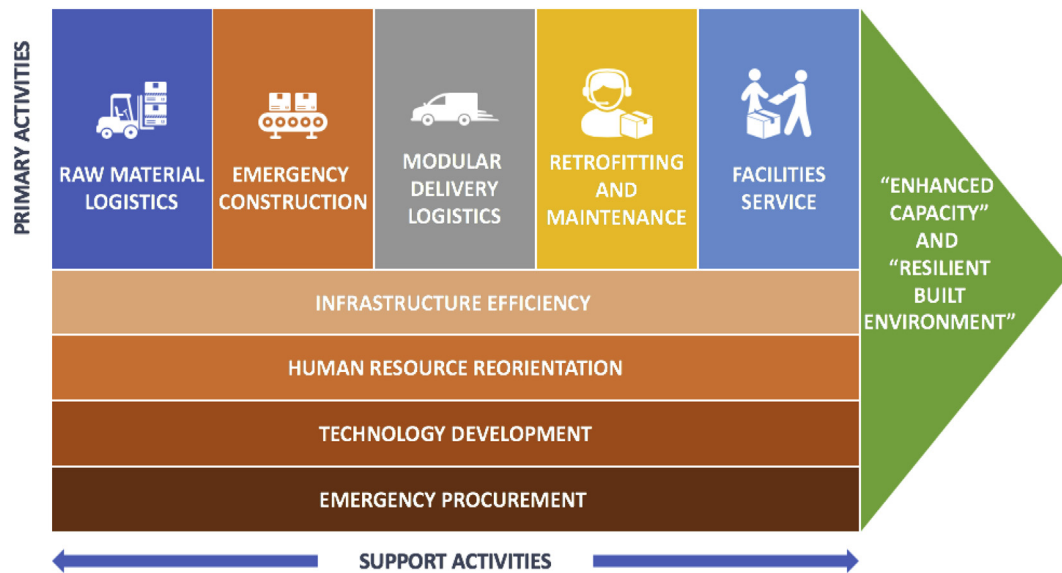


Fig. 5. Value of the construction industry in combating Covid-19 spread.

ability to deliver (ISC-4 to 6), which are the best ISC measures for rapidly expanding capacity for effective isolation of COVID-19 infectious people and containment of the disease. It is also essential to consider factors such as location, building efficiency, scalability and flexibility, during the creation of effective isolation spaces for COVID-19 treatment and containment.

5. Modular and offsite construction for the Covid-19 emergency

Using the evidence gathered in this study, the use of modular and offsite approaches has suddenly become essential to deliver efficient buildings for containing COVID-19 rapidly. While offsite construction involves the pre-fabrication of complete components or elements at factories located away from the project site, modular construction (also commonly referred to as offsite construction) consists of the production of “repeatable sections” or “containers” at offsite location and installation on-site [23]. In the development of isolation units for emergencies, it is vital to consider the specific building requirements, the available approaches for the quickest delivery and the potential environmental impacts. According to the Department of Health, Estates and Facilities [22], the design of isolation rooms should meet basic requirements including an enclosed space for infectious individuals, controlled access and supply, controlled management of contaminated waste, availability of nursing essentials and a conducive enclosure conditions (temperature, ventilation, humidity etc.). Fig. 6 shows a typical negative pressure isolation room for managing infectious individuals. (See Figs. 7–10.)

The focus of this study is not to evaluate the effect of inferior isolation methods on either the recovery rate of COVID-19 papers or to the risk of further spread of the contagious disease. However, it is essential to note that by February 11, 2020, 1716 medical personnel have been infected by COVID-19 in China due to the exposure to patients that were not correctly isolated [16]. Therefore, isolation rooms must meet the requirements to ensure effectiveness despite the COVID-19 emergency. Existing and novel approaches of modular and offsite construction will help to mitigate the challenge of “delivery urgency of isolation spaces” and the “need for the rapid expansion of effective isolation capacity”. The benefits of modular and approach approaches can be classified into three phases viz. construction phase, pandemic management phase and post-pandemic phase. These three phases will be discussed concerning emergency construction, building engineering for efficiency and post-pandemic environmental impact, respectively.

5.1. Emergency construction

Emergency construction is the process of using available resources to produce facilities that meet specific functional requirements rapidly. The most important benefits of the modular or offsite construction approach for emergency construction is the rapid turnaround time, scalability, flexibility, reduced interdependencies and mobility. Both methods are advantageous for enabling a “Simple-to-Complex” design system for developing emergency facilities. The Simple-to-Complex system enables the design and development of simple components or modules that can be configured or reconfigured into complex facilities depending on demand dynamics. These two approaches for emergency construction also leverage on the number of available resources to enable a distributed small factories system, which works independently towards a common goal. The adoption of offsite construction for emergency construction of isolation facilities requires many vital considerations, which will help decision-makers in developing the strategy and system of implementation. The following are essential factors to be considered when considering the deployment of offsite approaches:

- 1. Functional requirements for isolation facilities:** Typically, isolation facilities differ from quarantine and requires enclosed space for infectious individuals. Other requirements include controlled access, controlled supply of essentials, controlled management of contaminated waste, availability of nursing essentials and a conducive enclosure conditions for a patient (temperature, lighting, ventilation, humidity etc.).
- 2. Availability and accessibility of material resources:** The characteristics, quantity and readiness of material resources for construction will determine how fast the materials are converted to finished products. There are many building materials that are resources for emergency construction including steel, timber, aluminium, precast concrete etc. Resourceful materials for emergency construction of isolation facilities for COVID-19 can also include finished products that used for other purposes such as shipping containers and caravans. For example, there are about 555,000 caravans in the UK, which can meet the requirements for conversion to effective isolation units for infected individuals.
- 3. Skill level of construction and management workers:** The skill level of construction workers affects the ability to adapt to new systems and working conditions. The expertise of construction management workers will determine the efficiency with, which new systems are set up and utilised for agile production processes. Therefore, it is important to consider a viable means of upskilling construction workers through training and on-the-job skill development to meet up with the growing needs.

Table 1
Benefits of the identified ISC measures for Covid-19 containment.

Isolation space creation (ISC) measures	Ease of creation	Adequate capacity	Timeliness	Meets functional requirement	Flexibility	Controlled access	Controlled supplies	Controlled waste disposal	Mobility	Environmental sustainability	Scalability	Effective isolation	Reference
ISC-1. Self-isolation at home	✓	✓	✓			✓	✓	✓		✓			[18]; [5]; [14]
ISC-2. Isolation at regular hospitals			✓			✓	✓	✓		✓			[18]; [16]; [19]
ISC-3. Isolation at existing disease control hospitals	✓		✓	✓		✓	✓	✓		✓		✓	[15]; [20]; [17]
ISC-4. Isolation at retrofitted temporary hospitals		✓				✓	✓	✓	✓	✓			[21]; [12]
ISC-5. Isolation at temporary mobile cabin hospitals	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	[22]; [21]; [20]
ISC-6. Isolation at newbuild Covid-19 hospitals		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	[17]; [10]

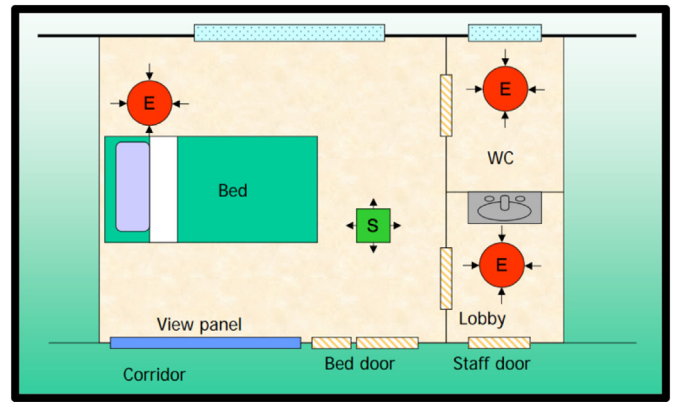


Fig. 6. Typical design of isolation room for infectious patients. Source: Department of Health, [24].

- Occupational health and safety:** With the existing COVID-19 challenges, the health and safety condition for emergency construction workers must be subject to stricter measures to protect workers and prevent the spread of coronavirus through the workers. Also, the consideration of COVID-19 safety issues should not overshadow the typical safety issues in construction.
- Technological capacity:** The availability of technologies and technology-user skill level will determine the process efficiency, communication effectiveness, information sharing and degree of collaboration. The implementation of Simple-to-Complex systems requires high coordination efficiency, which relies on technologies such as BIM, mobile and cloud computing.
- Scalability and flexibility:** The requirement for adequate isolation spaces at various locations varies rapidly with time and requires a high level of scalability and flexibility of the rapidly changing demand. The main ways of predicting COVID-19 spread include citizens engagement for symptoms (e.g. China), contact tracing (e.g. Nigeria) and location clustering (e.g. South Korea). The need for isolation spaces can change rapidly for any location. Therefore, adequate consideration should be taken to ensure the scalability and flexibility of emergency COVID-19 hospitals.
- Mobility:** Temporary mobile cabin hospitals are essential for moving ICU facilities closer to severe cases and minimise the risk of in-transit ambulance casualty. TMCs are also very flexible and scalable for varying requirements such as location and capacity. Building modules, which constitute part of a larger temporary hospital can also be transported to other places as the capacity requirements changes.
- Cost and schedule efficiency:** The outbreak of COVID-19 has caused huge economic downturn for most countries, which means that it is expedient to ensure cost efficiency as much as schedule efficiency in the delivery of construction projects for emergencies.

Offsite construction is especially pertinent for the fight against COVID-19 due to its capability for rapid delivery of projects, decentralised working system and reduced dependencies between project activities.

5.2. Building engineering for efficiency

The design and implementation of offsite construction for the delivery of isolation facilities for the containment of COVID-19 require innovative solutions to ensure the efficiency of operations for frontline health workers. An inherent benefits of modular healthcare facilities are the ability to move health workers closer to the locations in demand, and the decentralised working system, which will minimise the risk of interpersonal transmission of COVID-19 among healthcare workers. For scalable and flexible modular designs, it is vital to ensure reliable access to building services such as electricity, water, convenience and nursing supplies. Also, the risk and environmental impact of medical waste management must be taken into



Fig. 7. Examples of emergency modular isolation units.



Fig. 8. Examples of viable materials for emergency construction of isolation units.

consideration to ensure efficiency and prevent further spread of coronavirus. Therefore, there must be a strict methodology for waste storage, collection, treatment and disposal when using modular, mobile or temporary hospital facilities [19]. Aside from the challenge of medical waste management, the use of modular and temporary healthcare facilities has the problem of logistics for distributing medical essentials in a timely and appropriate fashion. Care must be taken to ensure that health workers don't run out of essentials when using decentralised healthcare facilities.

Xu et al. [1], identified a possible pathway for long-range airborne transmission of COVID-19 and emphasised the importance of minimising cross-infection even among infected individuals who are receiving treatment. COVID-19 isolation and treatment facilities should be designed for a full fresh air ventilation system for each isolation units, and efficiency filters must be used for recirculated air. Figure shows the possible transmission pathways.

It is also essential to ensure energy efficiency in consideration of thermal comfort and air safety from COVID-19 infection. Xu and Liu, [20], suggested air disinfection and cleaning methods including mechanical air filters, ultra-violet (UV) germicidal irradiation, high-efficiency particulate

air (HEPA) filters and ion generators to keep the air free of pollutants and pathogens. These should be adopted to keep modular healthcare facilities in conducive conditions and enhance the recovery process of patients. The use of efficient modular healthcare systems can improve the operational efficiency and safety of frontline healthcare workers by helping to isolate COVID-19 patients at source and freeing up regular hospitals for people having other health issues. TMCs can also reduce the number of ambulance transit mortality by deploying mobile ICU facilities and doctors to locations where critical attention is required.

5.3. Post-pandemic environmental impacts

There are existing examples of modular isolation cabin and pods at University Hospital of North Tees and Dorset County Hospital to reduce the exposure of health workers as there are have been many reported cases of health workers contracting COVID-19. Makeshift coronavirus isolation



Fig. 9. Mobile health vehicle.
Source: IMeBIO: <https://www.medicalexpo.com/prod/imebio/product-128187-947967.html>.

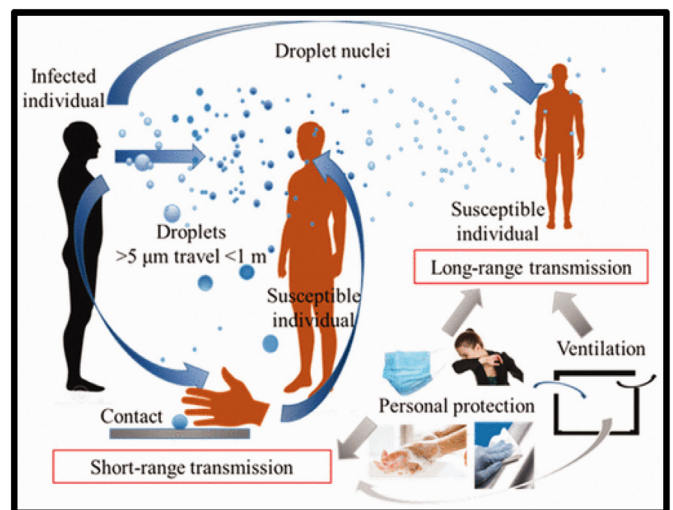


Fig. 10. Possible transmission pathway for Covid-19.
Source: Xu et al., [1].

'pods' have emerged at hospitals across England as the country is on high alert for new cases of the illness. Aside from the benefits of increased operational and safety of modular facilities during the pandemic period, there are more post-pandemic environmental benefits of modular hospitals.

The use of offsite construction for the emergency delivery of temporary and modular hospital is viable for the post-pandemic recovery of materials. The proposed emergency offsite solutions, as well as the suggested materials, are easily recoverable and restored to previous use. For example, the conversion of caravans to mobile hospitals can facilitate the easy restoration to previous use after rigorous post-pandemic disinfection [18]. Materials can also be recovered, reduced, reused or recycled for other purposes in the construction industry with the consideration of crucial circular economy principles to eliminate wastes.

6. Conclusion

This study focused on the importance of effective isolation measures for infectious people with COVID-19. The capacity for effective isolation, along with two other factors, which are the capacity for testing and the ability to treat, were found to be very important in fighting the outbreak of COVID-19. This study identified the common isolation measures and evaluated the effectiveness of these measures in containing COVID-19. Six ISC measures were identified, of which three were found to be most effective. ISC-1 (isolation at home), ISC-2 (isolation at regular hospitals) and ISC-4 (isolation at retrofitted public buildings) were found to be less effective. While ISC-1 is quite popular for slowing down the spread of COVID-19, it doesn't effectively contain the virus because of the exposure to household cross-infection and non-adherence to self-isolation guidelines. ISC-2 has also proven not to be effective for containing infectious diseases due to the dangers of nosocomial transmission to other patients, exposure of health workers and the confinement of hospital spaces against other conditions. While ISC-4 is very useful in expanding capacity for containing COVID-19 but most times the converted public buildings do not meet the functional requirement for individual isolation of patients, and most useful for mass quarantining of patients.

The most effective isolation measures, according to this study are ISC-3 (isolation at existing epidemic control hospitals), ISC-5 (isolation at temporary mobile cabin hospitals) and ISC-6 (isolation at newbuild COVID-19 hospitals). While ISC-3 is found to be very effective, the challenge of low-capacity is common due to the lack of preparedness and early intervention by many countries. Hence, ISC-5 and ISC-6 are the most recommended approaches for effectively containing COVID-19 in cases where the number surge has overwhelmed the capacity of healthcare centres. This study proposes the offsite and modular strategies to expand capacity, especially with ISC-3, ISC-5 and ISC-6 rapidly. The proposed solutions were also considered through the construction, operational and post-pandemic phases to highlight the specific benefits and challenges of using offsite construction. This paper has made an essential contribution to the use of offsite construction for emergencies such as COVID-19 outbreak. Further studies are recommended for the design and development of standardised isolation units using the simple to complex approach. This would enhance the ability to rapidly develop, configure and reconfigure simple modules to form complex facilities.

Effective isolation is among the factors that affect the containment of a massive outbreak of infectious disease. It is vital to enhance the capacity to effectively isolate infectious individuals with the consideration of patients' convenience, workers safety, the efficiency of logistics, appropriateness of waste handling, among others [19]. Although, this study proffered a solution for emergency creation of isolation hospitals for the treatment of coronavirus, other essential factors such as the availability of experienced health workers and personal protective equipment, were not considered in this study.

Declaration of Competing Interest

The authors confirm that there are no known conflicts of interest associated with this manuscript and the funding body has been duly acknowledged.

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